

JAMSTEC

2003 Annual Report



Japan Agency for Marine-Earth Science and Technology

JAMSTEC 2003 Annual Report

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Preface

Changes in the global environment, global warming for example, are one of the great issues confronting humanity in the 21st century. It goes without saying, moreover, that the oceans which cover 70 percent of the Earth's surface are supremely important in this regard. Accurate understanding of the oceans is, thus, indispensable for grasping and understanding the Earth as a system, for predicting future events and for finding solutions to these issues. JAMSTEC has, since its inception, devoted itself to "knowing the oceans." Now our aims are broader, to understand not only the oceans but the total system we call the Earth as a whole. The scope of our research is gradually expanding to include not only the whole of the Earth's surface but also the Earth's mantle.

In pursuit of this objective, we have made significant progress in developing powerful tools. One example is the supercomputer-based Earth Simulator used for ocean and atmospheric and crust simulations. These simulations have demonstrated their effectiveness in predicting warming trends, clarifying the mechanisms of climate change, and modeling plate tectonics.

In September, a drilling derrick rising 112m above the surface of the sea was mounted on the Chikyu, a deep-sea drilling vessel now under construction in anticipation of the start of international operations in 2006. With the installation of this derrick, the Chikyu becomes one of the most impressive oceanographic research ships in the world. Analysis of cores drilled by the Chikyu and measurements taken in the holes it drills will shed new light on changes in the global environment, the mechanisms of earthquakes, and still undiscovered biospheres concealed in the oceans' depths. The Chikyu and a second deep-sea drilling vessel from the USA will play central roles in the Japan-US directed Integrated Ocean Drilling Program (IODP) to be officially launched in October, following the signing of a letter of agreement between Japan's Ministry of Education, Culture, Sports, Science and Technology and the US National Science Foundation.

This August, the eagerly awaited autonomous underwater-research vessel (AUV) Urashima successfully passed the world's first test of underwater operation powered by fuel cells. Our goal is to achieve an autonomous operating range of 300km in FY04.

In the hydrographic survey field, our oceanographic research vessel Mirai completed BEAGLE2004, a 200-day circumnavigation of the Southern Hemisphere, conducting highly precise observations of oceans in the Southern Hemisphere, for data had been said to be totally lacking. Analysis of this data clarified changes in ocean temperature and materials transport and may also help to explain global warming and other global environmental changes. In addition, the Kushiro-Tokachioki Submarine Seismic Activity Detection System set up by our center successfully provided measurements of the 2003 Tokachioki earthquake. This was the first time ever that data on a magnitude-8 class earthquake generated in a subduction zone where one oceanic plate slips under another was collected from a point near the epicenter. Detailed analysis of fault movements along the plate boundary and of tsunami generated by the earthquake provided a rare and precious body of data.

All Frontier Research Systems introduced as part of an effort to bring together experts from all around the world are proceeding smoothly with their research. These projects have helped to clarify how arctic and high-latitude winter climates affect the summer climate in Japan. An experimental model that demonstrates how global warming accelerates the downward movement of stratospheric ozone to the troposphere. Measurements of northward flowing currents southeast of Okinawa confirm the predictions of a mathematical simulation predicting their existence. Other projects have clarified how, in regions between the mantle plumes where plates emerge and subduction zones in which plates are pulled back into the Earth's interior, materials are recycled in a billion-year long process. In these and other ways, these projects provide important results that contribute to a better understanding of the Earth as a total system.

On April 1, 2004, the Japan Marine Science and Technology Center became an independent administrative institution, the Japan Agency for Marine-Earth Science and Technology. This FY03 report is, therefore, the last in our series of annual reports on Japan Marine

Science and Technology Center activities. But while we are now a new organization, our staff remains the same. We continue as before, dedicating ourselves to promoting research in marine science and technology and to creating a brighter future for all humankind. We look forward to your continued support.

November 2004



Yasuhiro Kato
Chairman

Japan Agency for Marine-Earth Science and Technology

A handwritten signature in blue ink that reads "Yasuhiro Kato". The signature is fluid and cursive, written over a light blue background that resembles water ripples.

Outline of Activities

Overview

To promote ocean development in our country, the Japan Marine Science and Technology Center (JAMSTEC) carried out a variety of activities during FY 2003 (ending March 31, 2004), in close cooperation with domestic and foreign organizations. These activities included research and development, dissemination, education and training, information services, and construction, improvement and shared use of facilities and equipment.

Details of these activities are described below.

1. Research and development activities

JAMSTEC carries out its R&D activities under categories of Research Project; Category 1, Research Project; Category 2 or Personal Research depending on the objective, content and progress status of these activities. JAMSTEC has established a flexible R&D system under which to conduct research according to the plan drawn up at the beginning of each fiscal year, that enables creative research based on researcher's own initiatives or adjustment to the situation change. In addition, JAMSTEC carries out Commissioned Research and Cooperative Research at the request from, and with the cooperation of, other domestic and foreign organizations.

The R&D activities that JAMSTEC carried out for FY2003 are summarized below:

(1) Research Project; Category 1

JAMSTEC carries out important, large-scale or comprehensive R&D projects as Research Project; Category 1 to make contributions to the economic and social development and the improvement of marine science and technology. In FY2003, JAMSTEC carried out Research Project; Category 1 as listed in Table 1.

(2) Research Project; Category 2

As Research Project; Category 2, JAMSTEC carries out R&D projects to further develop the basic results obtained from Personal Research and other researches that may possibly develop into future Research Project; Category 1. In FY2003, JAMSTEC carried out Research Project; Category 2 as listed in Table 2.

(3) Personal Research

As Personal Research, JAMSTEC carries out

research projects based upon individual researchers' spontaneous conceptions to maximize their abilities, or those that might develop into Research Project; Category 2 or Researches Project; Category 1 in the future. In FY2003, JAMSTEC carried out Personal Research as listed in Table 3.

(4) Commissioned Research and Cooperative Research

As Commissioned Research, JAMSTEC carries out research projects involving marine science and technology, which are commissioned by other organizations to JAMSTEC and whose implementation JAMSTEC considers will benefit its own interests. In FY2003, JAMSTEC carried out commissioned Research as listed in Table 4.

As Cooperative Research, JAMSTEC carries out research projects in which high-level results are likely to come, while reduction in costs and required time is expected by sharing R&D resources with other organizations. In FY2003, JAMSTEC carried out Cooperative Research as listed in Table 6.

2. Education and Training Activities

JAMSTEC provides dissemination, education and training to disseminate the results of its R&D efforts widely to the world, and to contribute to the human resources development essential to advance marine science and technology advancement in Japan. In fiscal 2003 JAMSTEC conducted training in diving skills and diving operations management, the Science Camp for high school students, the Marine Science School for primary, middle and high school students, university students and high school teachers with the support of the Japan Foundation, and Improvement of Marine

Outline of Activities

Data Utilization Ability in Countries near the Pacific Equator to improve the ability to utilize marine observation data in countries near the Pacific Equator by delegating marine science and technology researchers.

3. Activity Related to Information Services

JAMSTEC continued to collect the indispensable marine science and technology literature (e.g., books, journals, conference publications, and technical reports) published world wide, and published a broad range of reports on its research achievements for dissemination both in Japan and overseas. JAMSTEC also distributed its own publication Blue Earth to major libraries through-out Japan, and to the public on a paid subscription basis, and created the Hyper Ocean-Earth Encyclopedia web site to foster a greater interest in and understanding of marine and earth science among young people. In addition, JAMSTEC continued expanding its ocean database, and operating its supercomputer systems.

4. Operation of the JAMSTEC Fleet

JAMSTEC owns and operates the following vessels to undertake the programs and services: research vessels NATSUSHIMA and KAIYO, support vessel YOKOSUKA, deep sea research vessel KAIREI, oceanographic research vessel MIRAI, 6,500m class manned research submersible SHINKAI 6500, 3,000m class ROV HYPER-DOLPHIN, and 10,000m class Deep Sea ROV KAIKO. The operations of these vessels in fiscal 2003 are outlined below.

On May 29, 2003, during the diving of KAIKO in the sea approximately 130km SE of Muroto Cape, Kochi Prefecture, the secondary cable connecting the launcher (base vessel) and the vehicle (operation vessel) were cut. The vehicle surfaced and drifted. Despite a search of more than three weeks, it is still missing. As a countermeasure, we prepared KAIKO 7000 by connecting the remodeled UROV7K to KAIKO's secondary cable.

(1) NATSUSHIMA

In fiscal 2003 NATSUSHIMA was at sea for a total of 290 days, providing operational support for HYPER-DOLPHIN, and conducting various marine surveys and deep-sea towing missions.

(2) KAIYO

In fiscal 2003 KAIYO was at sea for a total of 279 days, conducting various marine surveys, structural surveys under the ocean bottom and deep-sea towing missions.

(3) YOKOSUKA

In fiscal 2003 YOKOSUKA was at sea for a total of 250 days, providing operational support for SHINKAI 6500, conducting various marine surveys and examining sea areas for the deep sea cruising AUV URASHIMA, etc.

(4) KAIREI

In fiscal 2003 KAIREI was at sea for a total of 273 days, providing operational support for KAIKO, and conducting various marine surveys, structural surveys under the ocean bottom and deep-sea towing missions.

(5) MIRAI

In fiscal 2003 MIRAI completed five joint-use missions and was at sea for a total of 328 days, conducting observation navigation at a latitude of approximately 30 degrees south to quantitatively investigate global warming (observation cruise around the Southern Hemisphere [BEAGLE 2003]).

(6) SHINKAI 2000

On November 11, 2002, SHINKAI 2000 completed its 1,411th dive in Sagami Bay and ceased 21 years of operation. It was debarked on November 26 to the submersible serving site at the Yokosuka main office. On March 4, 2004, its registration was deleted and SHINKAI 2000 was retired.

(7) SHINKAI 6500

SHINKAI 6500 completed a total of 68 dives in the Sea of Japan, Nankai Trough, Nansei Islands, Mariana Trench and the sea east of the Philippines.

(8) DOLPHIN-3K

On September 29, 2002, DOLPHIN-3K completed

Outline of Activities

its 576th dive in the seas surrounding the Ogasawara Islands, then ceased 16 years of operation. It was debarked on November 26 to the submersible serving site at the Yokosuka main office. On March 4, 2004, DOLPHIN-3K was retired.

(9) HYPER-DOLPHIN

HYPER-DOLPHIN completed a total of 126 dives in

offshore Kushiro and Tokachi, offshore Sanriku, Izu-Ogasawara, Sagami Bay, Suruga Bay, Kagoshima Bay, the sea west of Kagoshima and the Nansei Islands.

(10) KAIKO (KAIKO 7000)

KAIKO (KAIKO 7000) completed a total of 18 dives in Izu-Ogasawara, the Nankai Trough and the sea west of the Philippines.

Table 1 Research Project; Category 1

	Subject	Period	Department
1	Advanced technology research and development	FY2003-2007	Marine Technology Department
2	Research on ocean sensors for mounting on stratospheric platforms	FY1998-2004	Marine Technology Department
3	Research and development of autonomous underwater vehicle	FY1998-2004	Marine Technology Department
4	Wave power equipment technology research and development (Formerly: Research and development of technologies to utilize ocean energy)	FY1989-2003	Marine Technology Department
5	Comprehensive research on dynamics under the ocean bottom	FY1998-	Deep Sea Research Department
6	Development and facilitation of the multidisciplinary deep-sea real-time observation network system	FY1996-	Deep Sea Research Department
7	Clarification of the structure and roles of marine ecosystems in the Earth system	FY2003-	Marine Ecosystems Research Department
8	Research and development of coastal environments and their utilization	FY1998-2005	Marine Ecosystems Research Department
9	Tropical Ocean Climate Study	FY2001-2006	Ocean Observation and Research Department
10	Observation and research relating to Pacific Ocean heat and material transport through ocean general circulation and their changes	FY2002-2007	Ocean Observation and Research Department
11	Arctic Ocean climate studies	FY1991-	Ocean Observation and Research Department
12	Research on the chemical environment and its changes in the ocean	FY2002-	Ocean Observation and Research Department
13	Time-series observational study in the North Pacific	FY2000-2005	Mutsu Institute for Oceanography Research Group 1
14	Research on the past changes of the marine environment	FY1999-	Mutsu Institute for Oceanography Research Group 1
15	Promotion of Ocean Drilling in the 21st Century	FY1990-	OD21 Program Department
16	Frontier Research System for Global Change	FY1997-	Frontier Research Promotion Department
17	Frontier Observational Research System for Global Change	FY1999-	Frontier Research Promotion Department
18	Frontier Research System for Extremophiles	FY2001-	Frontier Research Promotion Department
19	Operation of the Bio-Venture Center	FY2001-	Frontier Research Promotion Department
20	Institute for Frontier Research on Earth Evolution	FY2001-	Frontier Research Promotion Department
21	Promotion of the Earth Simulator Project	FY1999-	Computer and Information Department, Yokohama Institute for Earth Sciences

Outline of Activities

Table 2 Research Project; Category 2

	Subject	Period	Department
1	Research on oceanic island arc structure and formation history in the Mariana Trench and Island Arc System	FY2003-2005	Deep Sea Research Department
2	Research on ROV for icy sea and deep-ocean bottom surveys	FY2003-2005	Marine Technology Department
3	Gas Hydrate: Research on the evaluation of its impact on global environmental change	FY2003-2005	Deep Sea Research Department

Table 3 Personal Research

	Subject	Period	Department
1	Development of core-log data integration for geological analysis in borehole	FY2001-2003	Deep Sea Research Department
2	Study on electrical potential mapping and monitoring on the sea floor	FY2001-2003	Deep Sea Research Department
3	Basic study on thermal and hydrological monitoring in boreholes	FY2001-2003	Deep Sea Research Department
4	Elucidation of the sedimentation system in the Oyashio-Kuroshio mixing area	FY2002-2004	Deep Sea Research Department
5	Tsunamis caused by slow earthquakes	FY2002-2004	Deep Sea Research Department
6	Development of ocean bottom electrometer	FY2002-2004	Deep Sea Research Department
7	Study for the formation of the back-arc basins	FY2002-2004	Deep Sea Research Department
8	Research on upper-mantle rock magnetism	FY2003-2005	Deep Sea Research Department
9	Research using multi-element isotopes on plumes in back-arc basins caused by the deep mantle	FY2003-2005	Deep Sea Research Department
10	Evaluation of rock deformation characteristics and mass transfers in earthquake-prone areas under dynamic conditions	FY2003-2005	Deep Sea Research Department
11	Clarification of the fore-arc upper mantle history based on the petrography and geochemistry of ocean bottom peridotite	FY2003-2005 FY2003-2005	Deep Sea Research Department Deep Sea Research Department
12	Crustal stress measurement in earthquake prone-areas and superficial subduction areas		
13	Research on electromagnetic pulse subsurface exploration systems	FY2002-2004	Marine Technology Department
14	Research on high-performance (low specific gravity, high strength) buoyancy material	FY2001-2004	Marine Technology Department
15	Underwater acoustic technology research using phase-conjugated waves	FY2003-2005	Marine Technology Department
16	Empirical experiments with a synthetic aperture sonar prototype	FY2003-2005	Marine Technology Department
17	Communication system of the deep sea cruising AUV URASHIMA using an engineering test satellite of VIII type	FY2003-2005	Marine Technology Department
18	Research on power equipment in hydrothermal vents with thermoelectric conversion technology	FY2003-2005	Marine Technology Department
19	Study on measurement of chlorofluorocarbons and its applying for oceanography	FY2001-2003	Ocean Observation and Research Department
20	Research on paths of ENSO signals from mid-latitude to tropical region in the Pacific Ocean	FY2002-2006	Ocean Observation and Research Department
21	Study on the measurement of the tropical rainfall over the ocean	FY2002-2004	Ocean Observation and Research Department

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22	Studies on the transport process of coral eggs and larvae in coral reef region	FY2001-2003	Marine Ecosystems Research Department
23	Study on the uptake of various elements using Porites corals	FY2001-2003	Marine Ecosystems Research Department
24	Preliminary study on the mass and heat distribution being associated with the ocean general circulation	FY2000-2002	Ocean Observation and Research Department
25	Research on phenotypes of dendritic demersal organisms	FY2002-2004	Marine Ecosystems Research Department
26	Research on the relationship between shape, swimming and stomach contents in jellyfish species	FY2002-2004	Marine Ecosystems Research Department
27	Establishment of methods to analyze the genomesize using fluorophotometry	FY2002-2003	Marine Ecosystems Research Department
28	Investigation of growth records and measurements of age in days in jellyfish species	FY2002-2003	Marine Ecosystems Research Department
29	Clarification of bottom feeder adaptability to the environment	FY2003-2005	Marine Ecosystems Research Department
30	Analysis of protist diversity in chemosynthetic ecosystems	FY2003-2005	Marine Ecosystems Research Department
31	Basic research on marine environmental changes and response by calcareous plankton	FY2002-2004	Mutsu Institute for Oceanography Research Group 1
32	Basic research on quantitative measurement of organic carbon particles subsiding from photic zones using Th-234	FY2003-2005	Mutsu Institute for Oceanography Research Group 1
33	Survey research on the cost effectiveness of JAMSTEC	FY2003-2005	Planning Management Division, Planning Department
34	Renovation of the ocean-bottom seismometer to improve functionality	FY2003-2005	Research Support Department
35	Domestic production of a data-processing facility in the TRITON center for the development of a next-generation ocean observation buoy	FY2003-2005	Research Support Department
36	Research on efficiency improvement and upgrading of deep sea image archives	FY2003-2005	Computer and Information Department

Table 4 Commissioned Research

	Subject	Period	Consignor	JAMSTEC Dept.
1	Imaging of vents by acoustic exploration through drilled holes	FY1999-2004	Ministry of Education, Culture, Sports, Science and Technology	Deep Sea Research Department
2	Research on temperature and flow field distributions of hydrothermal circulation systems by observing heat flow and electromagnetic fields	FY2003-2004	Ministry of Education, Culture, Sports, Science and Technology	Deep Sea Research Department
3	Development of integrated atmosphere-ocean integrated models and implementation of experimental warming prediction	FY2002-2006	Center for Climate System Research, the University of Tokyo	Frontier Research System for Global Change
4	Development of integrated Earth system models for the prediction of global environmental change	FY2002-2006	Ministry of Education, Culture, Sports, Science and Technology	Frontier Research System for Global Change
5	Clarification of the changing processes in concentration of tropospheric ozone and research on its influence on warming	FY2002-2006	School of Science, the University of Tokyo	Frontier Research System for Global Change
6	Development of an advanced 4D assimilation system of combined air-sea-land data and construction of an integrated data set for initialization and re-analysis to forecast climate change with high precision	FY2002-2006	Ministry of Education, Culture, Sports, Science and Technology	Frontier Research System for Global Change

Outline of Activities

7	Behavior of colloid particles in critical fluctuations	FY2002-2006	Japan Space Forum	Frontier Research System for Extremophiles
8	Preliminary studies of comprehensive research on climate and environment in air pollution in Asia	FY2003	Ministry of the Environment	Frontier Research System for Global Change
9	Clarification of the mechanism of fluctuating group structures of plankton crowds and investigation of functional change in ecosystems caused by such fluctuation	FY2003-2005	Tohoku National Fisheries Research Institute, Fisheries Research Agency	Frontier Research System for Global Change
10	Preliminary research with satellite data on the precision of estimates of greenhouse gas absorption and emission	FY2003	National Institute for Environmental Studies	Frontier Research System for Global Change
11	Estimation of CO ₂ absorption and emission by developing a meso scale inverse model	FY2003-2006	National Institute for Environmental Studies	Frontier Research System for Global Change
12	Elaboration of source inventory and quantitative evaluation of the impact of reductions in CH ₄ and N ₂ O in agricultural ecosystems	FY2003-2007	National Institute for Agro-Environmental Sciences	Frontier Research System for Global Change
13	Structural survey research on plate shapes in the assumed focus area of the Tonankai-Nankai earthquake	FY2003-2007	Ministry of Education, Culture, Sports, Science and Technology	Institute for Frontier Research on Earth Evolution
14	Structural survey research for the improvement of aftershock observation and precise identification of focus location in the Tokachi-oki Earthquake in 2003	FY2003	Ministry of Education, Culture, Sports, Science and Technology	Institute for Frontier Research on Earth Evolution
15	Research on construction of an underground structural model for estimating ocean bottom strong tremors around the Nankai Trough	FY2003-2004	CRC Solutions Corp.	Institute for Frontier Research on Earth Evolution
16	Research on sample arrangement of deep sea foraminifera and genetic analysis	FY2003-2004	Southampton Oceanography Centre	Institute for Frontier Research on Earth Evolution
17	Research on the generalization of geochemical analyses of pelite	FY2003-2004	Japan Oil, Gas and Metals National Corporation	Institute for Frontier Research on Earth Evolution

Table 5 Extramural Research

	Subject	Period	Consignee	JAMSTEC Dept.
1	1) Improvement and development of global wind stress data set 2) Research on arctic connection modeling	FY2002-2006	Hokkaido University	Frontier Research System for Global Change
2	Improvement, analysis and construction of a data set for global sea-surface information focused on high precision, high-resolution sea-surface temperatures by satellite observation	FY2002-2006	Tohoku University	Frontier Research System for Global Change
3	Improvement and development of a sea-surface flux data set	FY2002-2006	Tokai University	Frontier Research System for Global Change
4	Research on the high-dimensional non-linear non-Gaussian filter and its application to a 4D data assimilation system	FY2002-2006	The Institute of Statistical Mathematics	Frontier Research System for Global Change

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5	Research on progress in initialization and prediction precision of super-high resolution climate model	FY2002-2006	Kyoto University	Frontier Research System for Global Change
6	Research on data assimilation for marginal seas	FY2002-2006	Kyushu University	Frontier Research System for Global Change
7	1) Collection and quality management of re-analysis associated integrated data and creation of an international data network 2) Analysis of re-analysis data by statistical assimilation of marine data and intercomparison with a high-precision re-analysis data set 3) Improvement of a distributed shared database, system utility and control environment	FY2002-2006	Advanced Earth Science and Technology Organization	Frontier Research System for Global Change
8	Survey research on compiling a database of measurements of deep sea natural radioactivity	FY2001-2003	Advanced Earth Science and Technology Organization	Deep Sea Research Department

Table 6 Cooperative Research

	Subject	Period	Partners	JAMSTEC Dept.
1	Research of the performances of sea floor boreholes employed for seismo-geodetic observation	FY2001-2003	Earthquake Research Institute, the University of Tokyo	Deep Sea Research Department
2	Study on application of deep sea radioactivity detector and on method of data analysis	FY2001-2003	Japan Atomic Energy Research Institute and Japan Marine Science Foundation	Deep Sea Research Department
3	Research for improving low frequency responses from optical fiber seismographs	FY2001-2003	Oki Electric Industry Co., Ltd.	Deep Sea Research Department
4	Long-term ocean bottom electromagnetic observation around the Nankai subduction zone	FY2002-2004	Earthquake Research Institute, University of Tokyo	Deep Sea Research Department
5	Exploration of ocean bottom microstructures in the Nankai Trough	FY2002-2004	Earthquake Research Institute, University of Tokyo	Deep Sea Research Department
6	Basic research on massive earthquakes in the Chishima Trench -Analysis of seismic waves and tsunamis-	FY2003-2005	Faculty of Science (Hokkaido University), Active Fault Research Center (National Institute of Advanced Industrial Science and Technology), Earthquake Research Institute (the University of Tokyo)	Deep Sea Research Department
7	Study on the functional use of deep seawater for applications on industry	FY2001-2003	Kikkoman Corporation, SUNSTAR INC., Suntory Ltd. and NISSUI, Ltd.	Marine Ecosystems Research Department
8	Research on the monitoring technology for the hydro thermal plume	FY2001-2003	Central Research Institute of Electric Power Industry	Marine Technology Department
9	Development of an AUV-ROV hybrid underwater vehicle for use in shallow water The research of electric field fluctuation measurement by the submarine cable	FY2001-2004	KOWA CORPORATION	Marine Technology Department
10	Research on gas storage using nano-materials	FY2002-2004	Japan Steel Works, Ltd.	Marine Technology Department

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11	Research on a heat-resistant cultivation tank in deep-sea microbe cultivation equipment.	FY2002-2004	Mitsubishi Heavy Industries, Ltd., Kobe Shipyard and Machinery Works	Marine Technology Department
12	Research on optical fiber sensor arrays	FY2003-2005	National Defense Academy In Japan	Marine Technology Department
13	Study on estimation of basin-scale CO ₂ fluxes in the North Pacific	FY2000-2004	Meteorological Research Institute	Ocean Observation and Research Department
14	Vicarious calibration study of the ocean color sensor GLI in the East China Sea	FY2001-2003	NASDA and EORC	Ocean Observation and Research Department
15	Study on oceanic radiocarbon in the western North Pacific and adjacent seas	FY2001-2003	Mutsu Establishment, Japan Atomic Energy Research Institute	Ocean Observation and Research Department
16	Research on bottom feeders at the long-term observation station offshore Muroto	FY2003-2005	Faculty of Science, Kochi University	Marine Ecosystems Research Department
17	Analysis of gene expression of chemosynthetic symbionts in various environments	FY2003-2005	Takara Bio Inc.	Marine Ecosystems Research Department

Activities of Major Establishments

In the transformation into an independent administrative institution under the Reorganization and Rationalization Plan for Special Public Corporations, decided by the Cabinet in December 2001, the Law for an Independent Administrative Institution, Japan Agency for Marine-Earth Science and Technology was put into effect on June 18, 2003.

The Japan Marine Science and Technology Center was dissolved on April 1, 2004 and combined with a part (vessels and their operational organization) of the Ocean Research Institute, the University of Tokyo to begin as the "Independent Administrative Institution, Japan Agency for Marine-Earth Science and Technology". Fiscal 2004 is our significant turning point.

1. Yokosuka Headquarters

(1) Land and Building

(a) Land

In April 1972, the central Government invested in kind, in JAMSTEC, a piece of nationally owned land of 40,159.57 m² in Yokosuka city, Kanagawa Prefecture. An 18,391.84 m² portion of the reclamation work, which had been under way on the seaside of the JAMSTEC site since fiscal 1980, was completed in fis-

cal 1982. In fiscal 1983, JAMSTEC purchased a piece of land: 855.99 m², from the central Government, and in May 1985, the second-stage reclamation work of 4,518.93 m² was completed.

Because the level of the reclaimed land, and that of the existing ground, differed, the level of the existing site was raised, during a period from fiscal 1986 to fiscal 1987. During a period from fiscal 1988 to fiscal 2000, environmental conservation measures were taken. In fiscal 2001 JAMSTEC purchased a 1,118.99 m² plot of land, and in fiscal 2002 purchased an adjacent plot of 1,030.62 m² to bring the total land area of Yokosuka Headquarters to 66,075.92 m².

(b) Building

As may be noted from Table 7, buildings have been added since 1972, one after another. In fiscal 2000, there were 34 research buildings of various purposes, with a total floor area of 37,232.93 m². In fiscal 2001 JAMSTEC purchased the Marine Ecosystems Research Building (old Information and Power Source Building) from Fuyo General Lease Co., Ltd. In fiscal 2003, the facility maintenance building and gas bank building were dismantled so there are currently 32 research buildings with a total floor space of 36,953.63 m².

Outline of Activities

Table 7 Research Facilities of Yokosuka Headquarters

Building	Total floor area (m ²)	Year for construction
Diving Simulator Building	1,586.64	Fiscal 1972 Modified in fiscal 1975
Maintenance Building (old Sea Area Research Building)	(484.37)	Fiscal 1972 Modified in fiscal 1980 Dismantled in fiscal 2003
Marine Training Building	584.88	Fiscal 1972 Modified in fiscal 1992
Marine Engineering Experiment Building	3,000.00	Fiscal 1972-73 Modified in fiscal 1994
Diving Training Building	1,595.85	Fiscal 1973 Modified in fiscal 1995
Gas Bank Building	(309.33)	Fiscal 1973 Modified in fiscal 1978 Dismantled in fiscal 2003
Waste Treatment Building	153.90	Fiscal 1973
Marine Science and Technology Building (old Exhibition Building/ old Headquarters Building)	2,249.93	Fiscal 1974 Modified in fiscal 2000 (earthquake resistance reinforcement)
Hyperbaric Experiment Water Tank Building	622.33	Fiscal 1975
Common Use Building (old Numerical Analysis Building)	796.50	Fiscal 1976 Modified in fiscal 1995
Ecosystems Experiment Building (old Animal Experiment Building)	202.05	Fiscal 1977
	749.00	Expanded in Fiscal 1979
Maintenance Yard for Research Submersible Vessel	1,220.74	Fiscal 1983
Warehouse for Marine	112.18	Fiscal 1984
Transformer Building for the Research Submersible Vessels Maintenance Yard	72.00	Fiscal 1987
Attached Building for the Research Submersible Vessels Serving Yard	800.00	Expanded in fiscal 1991
Deep-sea Research Building	5,639.82	Fiscal 1993
Ocean Research Building	1,981.80	Fiscal 1994
Maintenance Yard for Remotely Operated Vehicles	493.51	Fiscal 1995
Marine Ecosystems Research Building (old Information and Power Source Building)	1,124.32	Fiscal 1995 Purchased in fiscal 2001
Frontier Research Building	1,980.00	Fiscal 1996
Guard House	25.11	Fiscal 1996
New Prefabricated Building	99.37	Fiscal 1996
Chemical Wastewater Temporary Storage Building	19.59	Fiscal 1997
Special High-Voltage Power Receiving Station	458.54	Fiscal 1998
Canteen (Shin-kai Tei)	484.70	Fiscal 1999
Marine Technology Research Building	2,091.23	Fiscal 1999
Headquarters Building (new Headquarters Building)	3,366.25	Fiscal 1999
Headquarters International Exchange Facility	344.18	Expanded in fiscal 2000
	19.61	Expanded in fiscal 2003

Outline of Activities

Main Building North Wing (old Annex Building)	4,858.25	Expanded in Fiscal 2000
Others (set)	221.35	
Total	36,953.63	

2. Mutsu Institute for Oceanography

(1) Outline of Activities of the Mutsu Institute for Oceanography

(a) Outline of the Mutsu Institute for Oceanography

JAMSTEC established the Mutsu Office, its first local office, in October 1995 in Sekinehama of Mutsu City, Aomori Prefecture, on a site facing the sea of the Tsugaru Strait. This is because the "MIRAI", an ocean and earth research vessel, would continue using Sekinehama Port, the home port of the Mutsu, a nuclear-powered vessel. The local office supported the research activities of the "MIRAI". Notably, the local office was engaged in operation management of the "MIRAI", analysis of samples collected by the "MIRAI", and interpretation of the analytical results. Based on the performance and expectation of roles to be played in clarifying the global environmental change, the Mutsu Office was restructured in October 2000, that was three years after creating the Mutsu Institute for Oceanography.

The Institute functions as the home port for the "MIRAI", and operates such facilities as an administration building, observation equipment and machinery maintenance shop, sample analysis facility, and a facility for promoting research exchanges. The Institute is also responsible for maintenance and repair of observation systems on TRITON buoys, collection and management of observation data, various kinds of tests on ARGO floats before deployment under the ARGO Plan, and pretreatment of seawater for determining age by radioactive carbon (^{14}C). The Institute has also installed an array of analytical instruments including the inductively coupled plasma mass spectrometer, stable isotope ratio mass spectrometer, and electron microscopes to strengthen its function as a base for marine science research.

With these facilities and equipments, the Institute is

undertaking research that will position it as the hub of earth science research centering on the northern seas such as the Northwestern Pacific Ocean, Arctic Ocean and the Sea of Okhotsk.

(b) Public Relation Activity

The understanding and cooperation of the people living in Mutsu City, the home port of the "MIRAI", is indispensable for the smooth operations of the "MIRAI", and through broad-ranging public relations activities, Mutsu Institute for Oceanography is endeavoring to bring the achievements and dreams of marine science and technology to the general public, and especially to the younger generation who represent the future of ocean research.

In fiscal 2003, as in fiscal 2002, the Mutsu Institute for Oceanography opened its facilities at the Sekinehama Port in Mutsu City to the general public on Marine Day as a special event for Science and Technology Week with the catchphrase "Let's take a look at the ocean institute" (Figure 1). A total of 602 people visited the Institute. The Institute also opened an electron microscope experience school with the support of Mutsu City's education board (Figure 2). Thirty students from middle and high schools observed their



Fig. 1 Open Public Day at Mutsu Institute

Outline of Activities



Fig. 2 The electron microscope experience school

own samples with the microscope and experienced the amazing minute structures of nature. As a part of the high school student internship (working experience), the Institute hosted six participants from two schools and provided valuable educational activities for them, such as chemical composition analysis and data analysis of sea floor sediments as well as maintenance of the ocean observation buoy system. The Institute also performed activities in dissemination/public relations, sending staff to a "Coordinated middle and high school education investigation workshop" backed by the Aomori Prefecture Government and Mutsu City's education board and coordinated the regional forum "Development of oceanic and romantic towns".

(2) Building and Facility of the Mutsu Institute for Oceanography

(a) Improvement of Facilities and Equipment at the Mutsu Institute for Oceanography.

In fiscal 2003, maintenance, management and repair of each building were performed selectively. Some noteworthy repairs in fiscal 2003 are described below.

(i) Observation Equipment and Machinery Maintenance shop

Observation Equipment and Machinery Maintenance shop is located at the Sekinehama Port facing the sea and, having no barrier, is directly exposed to wind, rain and snow. As a result, the waterproof seals were damaged more severely than expected. Repairs have been

performed on the seals of the walls since fiscal 2002. In fiscal 2003, waterproofing was performed twice to fix the rain leaking from the expansion joint between the inspection and maintenance buildings.

(ii) Sample analysis Facility

To prevent insect damage, a new vent was opened in the windshield room to minimize entrance door opening time.

(iii) Mutsu Guest House

An earthquake with a seismic intensity in the lower 5 range caused by the Tokachi-oki Earthquake on September 26, 2003, was observed in the Sekinehama area, and some cracks were found on the walls of the Observation Equipment and Machinery Maintenance shop and Mutsu Guest House. A particularly damaged wall in the research exchange building was repaired.

(iv) Others

Some repairs were performed on the site's asphalt. Parking lots were built for the sample analysis Facility and administration office buildings.

(b) Facilities

(i) Hyperbaric experiment water tank

As in fiscal 2002, the hyperbaric experiment water tank which was installed in Observation Equipment and Machinery Maintenance shop at the end of fiscal 2001, was used to adjust the buoyancy of 126 ARGO floats, to check the operation of 30 TRITON buoy releasers and to check the operation of three pieces of equipment for the North-Pacific time-series research. Pressurization was performed for hyperbaric experiments and maintenance a total of 173 times.

Among the maintenance, a new rupture plate was attached to the pressurization equipment to ensure the mechanical safety in case of abnormal rises in pressure. Also, in order to perform the maintenance inside the pressurization equipment even filled with water in the tank, valves were introduced in both the high-pressure and low-pressure sides to improve maintenance (Figure 3).

On the Mutsu Institute's open public day, guests

Outline of Activities



Fig. 3 Hyperbaric experiment water tank, Pressurization equipment

were invited to draw pictures on clean white styro-foam cups for understanding the high-pressure world in deep seas. As a souvenir for participants in open public day, the cups were pressurized in the hyperbaric experiment water tank.

(ii) Research facilities for strong acid use

Since fiscal 2003 the Mutsu Institute for Oceanography started to use strong acid for the research and a research facility dedicated to the strong acid experiments was planned. As a result of examination of various possibilities, the Institute decided to rebuild a vessel container that can be used both at the Institute and on the research vessels. The rebuilding was designed in various points to handle strong acid in a wide range of environments from the equatorial zone to cold regions, on land or on a vessel.

1) Facilities

The container was rebuilt to have two rooms inside, research room and machine room, for easy maintenance of large equipment such as air-conditioning machine and for saving enough space for the research room. Also for transportation on a trailer or a container vessel, the equipments were put in appropriate positions and the protruding parts outside the container were removed, e.g. by changing the door of the research room to a sliding door (Figures 4 and 5).

A water intake and a drain outlet were put on both sides of the container, in view of the usage under various conditions. To enhance the durability, sealing capability and ease of hose connection, a quick cou-

pling was used for the intake and the outlet.

2) Machine room

In the machine room, an air-conditioning machine, transformer, air evacuator and duct were placed to support research. The container's original door was used for the machine room, so the room can be accessed for maintenance without entering the research room (Figure 6).

3) Research room

To appropriately handle strong acid and avoid any damage to the outer environment, the room was equipped with a draft chamber made of polypropylene, an emission gas cleaner (Scrubber), a sink made of polypropylene, an experiment table, a pure water processing equipment and a chemical storage. A loading space for experimental equipment is reserved to meet various research needs.

For operation on vessels, the sink was designed to have a separate tray for waste chemical liquid, so waste liquid can be sent directly to a tank. Two waste liquid tanks were prepared and can be selected by the valve (Figure 7).

The interior wall, ceiling and floor of the container were covered with thermal insulation and boarded with 15mm plywood, which made it easier to put up a shelf and install equipment. Also for usage on a vessel, a lot of brackets were used for use on a ship.

4) Air-conditioning facilities

An air-conditioning machine, which can maintain a temperature of 30 to -10 degrees C, was installed.

Outline of Activities



Fig. 4 Exterior of the research facility for strong acid



Fig. 5 Entrance of research room and its interior

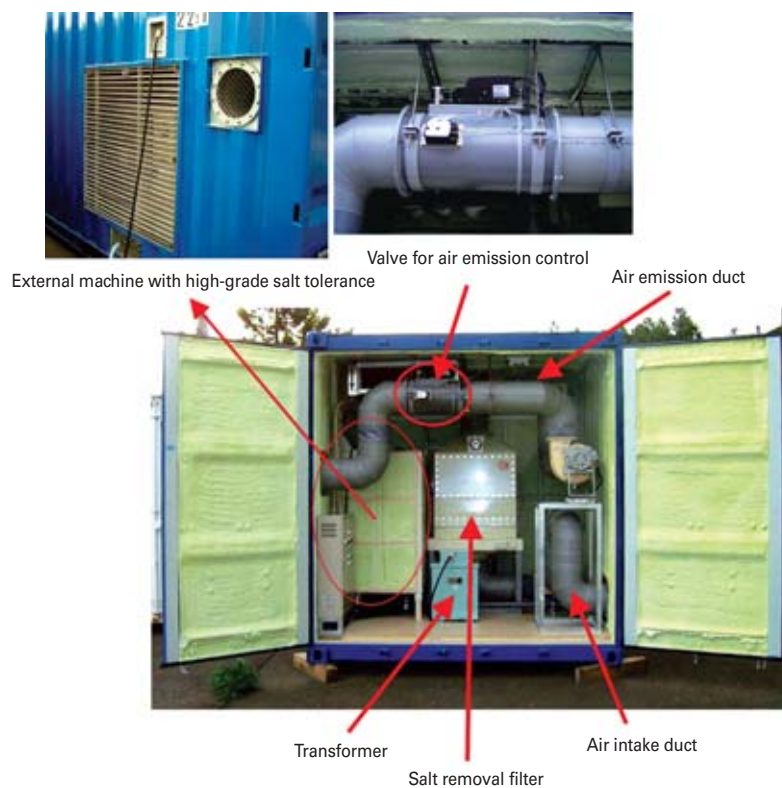


Fig. 6 Interior of machine room

Outline of Activities

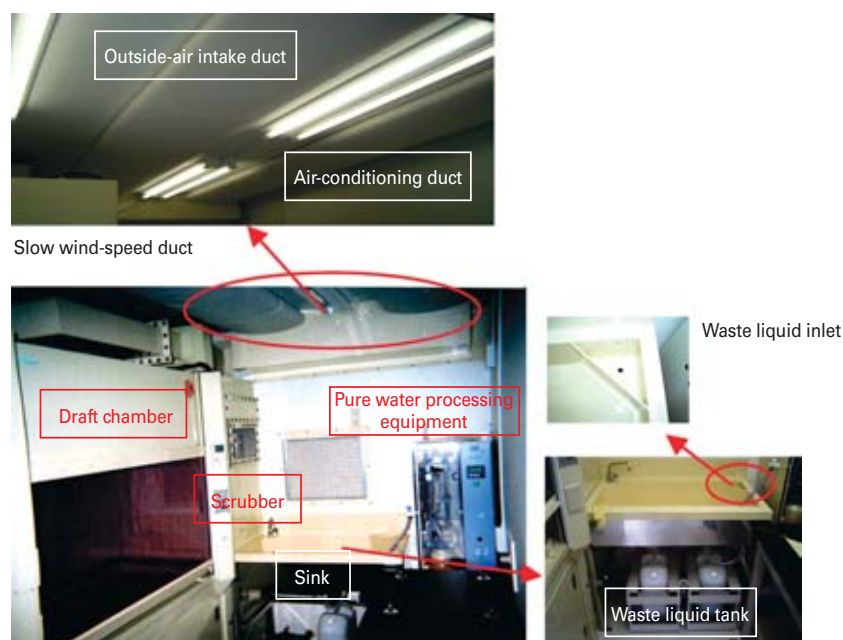


Fig. 7 Location of research room equipment

Intake air comes through a large salt-removal filter into the room, for usage in a coast area or on a vessel. The degree of opening of the draft chamber gate, to prevent backflow of gas from the draft chamber to the room while using strong acid, and to keep the room safe and comfortable, can control volume of air intake and emission (Figure 6).

Also, for outside air intake in the research room and emission of air by ventilation, a new air intake system was employed for the air-conditioner, which slowly sends air to the room through a special filter duct. This new system does not disturb airflow in the research room. Hence workability and safety of experiments in the container were increased because the airflow does not come directly to operators, experiment equipment and chemicals (Figure 7).

3. YOKOHAMA Institute for Earth Sciences

(1) Outline of activities of the Yokohama Institute for Earth Sciences.

In July 1996, the Subcommittee on Earth Science and Technology of the Council for Aeronautics, Electronics and Other Advanced Technologies, of the former Science and Technology Agency (current

Ministry of Education, Culture, Sports, Science and Technology), issued a report, entitled "Toward the Realization of Global Change Prediction." This report recommended promotion of a research and development study toward understanding and forecasting global change, incorporating three functions: observation research, model study, and simulation study.

In fiscal 1998, JAMSTEC was enabled, by the third supplementary budget for fiscal 1998, to participate in the Earth Simulator Project, led by the former Science and Technology Agency. The project had actually been promoted by the Japan Atomic Energy Research Institute (JAERI) and the National Space Development Agency of Japan (NASDA).

To promote the Earth Simulator Project, JAMSTEC intended to obtain an appropriate site to construct necessary facilities. Through mediation by the Science and Technology Promotion Division of the Planning Department of the Kanagawa Prefectural Government, JAMSTEC was able to obtain the site of former Kanagawa Prefectural Industrial Research Institute. JAMSTEC decided to build the YOKOHAMA Institute for Earth Sciences on this site, with the facili-

Outline of Activities

ties for the Earth Simulator constituting the core, equipped with functions to disseminate information on global change, and on the results of research work on the ocean and the solid earth.

Yokohama Institute for Earth Sciences covers a total area of 33,400 m², and consists of the Frontier Research Building, Conference Building, Earth Simulator Building, Chilling Equipment Building, and Super Computer Building leased from Kanagawa Prefecture. In May 2002 the Earth Science Museum, Information Technology Building and Guest House were completed, marking the end of all construction work on the planned buildings. In August 2002 the Yokohama Institute for Earth Sciences was officially declared open at an opening ceremony attended by Atsuko Toyama, Minister of Education, Culture, Sports, Science and Technology.

Prior to this, the Earth Simulator began operating in March 2002, while its application in research began in July.

With the establishment of marine and earth science information facilities, JAMSTEC's information-related functions were transferred to the Information

Technology Building, enabling the integrated analysis of marine information collected by JAMSTEC and information on global change obtained from the Earth Simulator, and management of these data. The Earth Science Museum provides open public access to marine and earth science research achievements primarily through image displays in the display facilities.

(2) Land, Building, Major Facilities of the YOKOHAMA Institute for Earth Sciences

(i) Land

JAMSTEC began buying land from the Kanagawa Prefectural Government in March 2000. In fiscal 2003, JAMSTEC completed the purchase of a total area of 33,389.94 m².

(ii) Building

JAMSTEC began constructing buildings in fiscal 1999, and in fiscal 2002 completed the marine and earth science information facilities comprising the Information Technology Building, Earth Science Museum and Guest House, and finished a series of developments.



Fig. 8 General view of Yokohama Institute for Earth Sciences

Outline of Activities

Table 12 Installation of Research Facilities of the YOKOHAMA Institute for Earth Sciences

Building	Specifications	Total floor area (m ²)	Year for construction
Earth Simulator Building	Two-story steel frame structure building	6,363	FY1999-2000
Chilling Equipment Building	One-story reinforced concrete building	525	FY1999-2000
Earth Simulator Research Building	Three-story reinforced concrete building, one-story penthouse	3,477	FY1999-2000
Frontier Research Building	Four-story steel frame structure building	4,443	FY2000
Conference Building	Two-story reinforced concrete building	1,894	FY2000
Earth Science Museum	Four-story reinforced concrete building	3,323	FY2001-2002
Guest House	Two-story reinforced concrete building	498	FY2001-2002
Information Technology Building	Six-story pre-cast concrete building of post-compressed joints	6,118	FY2001-2002
Guard House	One-story reinforced concrete building	63	FY2001-2002
Operators' room	Two-story reinforced concrete building	296	FY2001-2002
Super Computer Building	Three-story reinforced concrete building	1,420	FY1999

4. Global Oceanographic Data Center (GODAC)

(1) Outline of activities of GODAC

JAMSTEC has been commissioned to manage the Global Oceanographic Data Center (GODAC) established in Nago, and operations began in fiscal 2001. Since its opening, GODAC has undertaken the digitization of its images of deep sea survey and research achievements, and is collecting, processing and providing data on the oceans and global environment in collaboration with the Yokohama Institute for Earth Sciences. GODAC is opening its facilities and equipment such as its lecture rooms and educational image systems for

extracurricular classes like the "Comprehensive Learning Hours" and "Working Experience" classes for primary and middle schools mainly in Okinawa's northern districts, and for training researchers from the Asia-Western Pacific Ocean region. GODAC also provides tours of its facilities not only to group visitors but also to the general public, and is making a solid contribution to local tourism. GODAC functions as a pivotal dissemination center of data on the oceanographic and global environment, and is developing a rich library of educational content to help promote a deeper understanding of marine science and technology.



Fig. 9 General view of GODAC (From the side of Ginoza Village)

Outline of Activities

International cooperation

Ocean observation and research must be done on a global scale in order to tackle climate change and other global environmental issues.

To contribute to our understanding of these issues and facilitate ocean observation and research more effectively and efficiently, JAMSTEC is building and promoting a cooperative relationship with international organizations, joint international programs, and overseas research institutions.

1. International organizations

JAMSTEC is supporting the activities of IOC (Intergovernmental Oceanographic Commission) of UNESCO (United Nations Educational, Scientific and Cultural Organization) by sending experts as members of the various working groups, and assessing international trends necessary for the smooth implementation of ocean observation and research under the application of the Law of the Sea.

JAMSTEC participates in such organizations as SOPAC (South Pacific Applied Geoscience Commission), an influential body in the South Pacific, one of JAMSTEC's main observational research areas, and POGO (Partnership for Observation of the Global Oceans), an important forum for the world's major oceanographic research institutions, and sends researchers to other marine-related international organizations as required in order to contribute to and assist in their research activities.

2. Joint international programs

JAMSTEC participates in the activities of the following international programs.

- ARGO (The Array for Real Time Geostrophic Oceanography)
- CLIVAR (The Climate Variability and Predictability Programme)
- GOOS (Global Ocean Observing System)
- ICDP (International Continental Scientific Drilling Program)

- InterMARGINS (The International Margins Program)
- InterRidge (An initiative for international cooperation in ridge-crest studies)
- IODP (Integrated Ocean Drilling Program)
- PICES (North Pacific Marine Science Organization)

3. Intergovernmental cooperation

JAMSTEC participates in intergovernmental research cooperation between Japan and such countries or regions as the U.S., U.K., Australia, Canada, China, Germany, France, Russia, and EU.

The following intergovernmental committees were held in fiscal 2003.

- October 2003: 4th Meeting Japan-Canada Joint Panel on Earth Science and the Environment of the North Pacific
- January 2004 : Japan-France 20th Joint Session of Ocean Development Sub-Committee

4. Cooperation with overseas institutions

JAMSTEC is carrying out research cooperation under memoranda and agreements concluded with related organizations in the U.S., France, Germany, Canada, Indonesia, India, U.K., South Korea and Australia.

(1) Woods Hole Oceanographic Institution (WHOI)

The agreement for research cooperation was revised in June 2002. The two organizations are cooperating over a wide range of research fields, including marine geology and geophysics, polar research, biogeochemistry and the carbon cycle, marine physics and reobservation of the WOCE observation lines, geochemical evolution of the solid earth, submersible engineering and safety, and ocean bottom observation stations.

(2) Scripps Institution of Oceanography (SIO)

JAMSTEC and SIO renewed their agreement for research cooperation in December 1996, and are cooperating in research into the global ocean circulation, and the deformation of the oceanic plate in the Pacific

Outline of Activities

Ocean. In February 2002 study of thermal and material flux at ocean bottom floor was added to the memorandum as a new field of research cooperation. Also, a consensus agreement on international research collaboration using the Earth Simulator was concluded in December 2002 between the Earth Simulator Center and Scripps Institute of Oceanography.

(3) Pacific Marine Environmental Laboratory, National Oceanic and Atmospheric Administration, (NOAA/PMEL)

In December 1997 the memorandum between JAMSTEC and PMEL on observational research in the Pacific Ocean was partially amended, and under it, the two organizations are cooperating in the deployment of joint international research mooring buoys in the Tropical Pacific Ocean. When the memorandum was renewed in December 2002, a new provision on cooperation regarding loss and damage to buoys was added.

(4) Joint Oceanographic Institutions (JOI)

In July 1998 JAMSTEC signed an agreement on deep-sea scientific drilling with JOI, the ODP planning and management organization. Under this agreement, JAMSTEC and JOI concluded an agreement on technical exchanges for the ODP database in 2000. In 1999 they signed an agreement on a science and technology and operational information project connected with the IWG support office.

(5) Lamont-Doherty Earth Observatory (LDEO) of Columbia University

JAMSTEC signed a memorandum on research cooperation with LDEO in December 1997, and since then, the two organizations have exchanged research data in such fields as physical oceanography, marine science, and marine solid-earth science.

(6) Monterey Bay Aquarium Research Institute (MBARI)

In June 2001 JAMSTEC and MBARI signed a

memorandum on research cooperation, under which the two organizations are cooperating in research on chemosynthetic seep and vent communities and mid and deepwater communities, on the development of a video image database, and on ROV piloting methods.

(7) Texas A&M University (TAMU)

JAMSTEC and TAMU concluded a memorandum on research cooperation in August 2002. Under the memorandum, the two organizations will cooperate in research on plate tectonics and geophysics, global ocean circulation and climate changes, drilling and sampling technology.

(8) French Research Institute for Exploitation of the Sea (IFREMER Institut français de recherche pour l'exploitation de la mer)

Under the memorandum for research cooperation signed in July 1998, JAMSTEC and IFREMER are cooperating in research on underwater technology and deep-sea microorganisms. Conferences were held at JAMSTEC's Yokosuka Headquarters in June 2000 and September 2001. In October 2000 at a Japan-France intergovernmental conference in Paris, discussions were held on submarine technology and deep-sea observation stations, and over the same period, a seminar on deep-sea microorganisms was also held.

(9) Alfred Wegener Institute for Polar and Marine Research (AWI)

JAMSTEC and AWI concluded a research cooperation memorandum in 1995, and the cooperative ties are expected to further expand in marine research and deep-sea microorganisms.

(10) Indonesian Agency for the Assessment and Application of Technology (BPPT)

JAMSTEC has been cooperating BPPT on ocean observation in the Equatorial Pacific Ocean under a memorandum for research cooperation signed in 1997. The agreement was expanded in 2000 to a comprehen-

Outline of Activities

sive memorandum for research cooperation that also included deep-sea research. In March 2002 and March 2004, a conference on research cooperation was held at JAMSTEC's Yokosuka Headquarters.

(11) Canadian Department of Fisheries and Oceans (DFO)

JAMSTEC and DFO signed a memorandum for cooperation in ocean research in March 2000. The memorandum has facilitated discussions at symposiums and seminars and joint observation and research with a view to understanding the climate system in the Arctic sea area.

(12) Indian National Institute of Oceanography (NIO)

In May 2000 JAMSTEC and NIO signed a memorandum on cooperation on ocean observation research in the Indian Ocean. Under the memorandum, they are cooperating in the maintenance of TRITON buoys deployed in the Indian Ocean and analysis of the data they provide.

(13) Southampton Oceanography Centre (SOC)

JAMSTEC and SOC signed a memorandum on research cooperation in March 2002. Cooperation extends across the fields of geophysics, physical oceanography, chemical oceanography, marine instrumentation, and atmospheric and oceanic simulation.

(14) Korea Ocean Research & Development Institute (KORDI)

JAMSTEC and KORDI signed a memorandum on research cooperation in September 2002. Under the memorandum, the two institutions cooperate in various research fields, including marine geology and geophysics study of trench-arc-marginal sea systems, ocean engineering unmanned underwater vehicle, deep-sea biological communities, utilization of deep sea water, and microbial diversity and isolation of deep-sea microbes.

(15) Commonwealth Scientific & Industrial Research Organisation, Australia (CSIRO) Marine Research

In August 2003, a memorandum on research collaboration was concluded between JAMSTEC and CSIRO Marine Research. The collaboration covers research on heat and material transports through ocean circulation and their variability, research on fate of carbon dioxide in the Indian Ocean and research on the distribution of chlorofluorocarbons in the Southern Ocean.

JAMSTEC has signed cooperative research agreements with the following organizations for international research collaboration:

- The University of Alaska (UA), USA
- The University of Wisconsin-Madison, USA
- The University of California, Berkeley, USA
- Seismological Laboratory, California Institute of Technology (CITSL), USA
- International Research Institute for Climate Prediction (IRI), USA
- National Energy Research Scientific Computing Center (NERSC), USA
- The Center for Computational Visualization (CCV), The University of Texas, USA
- University of Hawaii (UH), USA
- Graduate School of Oceanography (GSO), The University of Rhode Island, USA
- The National Museum of Natural History, Smithsonian Institution, USA
- Italian Aerospace Research Center (CIRA), Italy
- The University of Edinburgh, UK
- Hadley Centre for Climate Prediction and Research, UK
- Recherche en Prévision Numérique, Environnement Canada, CANADA (RPN/MSC)
- Geological Survey of Canada (PGC), CANADA
- Research School of Earth Sciences (RSES), The Australian National University, AUSTRALIA
- The University of Sydney Institute of Marine Science (USIMS), AUSTRALIA
- Costa Rica National University, COSTA RICA

Outline of Activities

- Chulalongkorn University, THAILAND
- Institute of Atmospheric Physics (IAP), Chinese Academy of Science, CHINA
- Chinese Academy of Meteorological Science (CAMS), CHINA
- Belau Cares Inc. (BCI), Belau
- French National Center for Scientific Research (CNRS), FRANCE
- Institute of Geography (IG), Mongolian Academy of Science, MONGOLIA
- Institute of Meteorology and Hydrology (IMH), MONGOLIA
- Permafrost Institute (PI), Russian Academy of Sciences, RUSSIA
- Institute for Biological Problems of Cryolithozone (IBPC), Russian Academy of Sciences, RUSSIA
- Limnological Institute, Russian Academy of Sciences (LIRAS), RUSSIA
- State Hydrological Institute (SHI), RUSSIA
- Central Aerological Observatory (CAO), Russian Federal Service for Hydrometeorology and Environmental Monitoring, RUSSIA

5. Others

From August 2003 to February 2004, the oceanographic research vessel MIRAI conducted the observation cruise around the Southern Hemisphere (BEAGLE 2003). Making port calls at Brisbane, AUS-

TRALIA, Valparaiso, CHILE, Santos, BRAZIL, Cape Town, SOUTH AFRICA, Tamatave, MADAGASCAR, and Fremantle, AUSTRALIA, MIRAI held open house onboard, seminars, exhibitions to widely introduce JAMSTEC's activities and help people understand the importance of marine science research.

The fifth meeting of POGO (Partnership for Observation of the Global Oceans) was held at Miyoshi Memorial Auditorium, Yokohama Institute of Earth Sciences, from November 18 to 20, 2003. A total of 45 participants from 13 countries made presentations and actively exchanged opinions on the operation of ocean observations, achievements and future work. On the closing day, the "Yokohama Declaration" was adopted, advocating POGO's contributions to the implementation of an ocean observing system.

6. Overseas trips, dispatch of survey teams and researchers overseas, and hosting of foreign researchers

7. Acceptance of foreign researchers under the Japan Society for the Promotion of Science (JSPS) visiting researcher system, and under the Ministry of Education, Culture, Sports, Science and Technology (MEXT) personnel exchange system

Research Activities

Deep Sea Research Department

Outline of research activity

The overall objectives of Deep Sea Research Department research activity are to understand the dynamics of the solid earth, with emphasis on natural phenomena on and/or beneath ocean floors such as earthquake and tsunami, and on heat and material transfer from the subsurface to the seafloor. In general, crustal movement and deformation of oceanic plates occurs slowly, but there are rapid deformations such as earthquakes. To understand these diversity of earth's dynamics, we pursue a continuous, multi-disciplinary approach as opposed to the "snapshot image" observations. We make the best use of and improve the JAMSTEC research facilities, including research fleets and HOV/ROV as well as in-situ long-term ocean bottom observation systems to detect and monitor continuously states of oceanic plate and the sea floor.

Our department has been conducting two major projects and related studies focusing on the projects, which are 1) Integrated Research on Dynamics beneath Deep Ocean Floor, and 2) Observation Networks on Deep Sea Floor. Among several results from these projects during April 2003 through March 2004, three issues were particularly introduced here.

The most stimulating result during this period is a success in the real time observation of the 2003 Tokachi-oki Earthquake with the deep sea cabled observatory which was installed very close to the epicenter. We could continuously obtain high-resolution records of seismic waves and ocean-bottom pressures throughout the earthquake sequence. In particular, the pressure records show direct evidence for the seafloor uplift during the earthquake.

We succeeded in launching a brand-new Navigable Sampling System (NSS) which makes "pin-point" operation possible, such as core sampling. A lot of piston core samples were obtained from hanging- and foot-wall sides across a submarine active fault with the help of video images of the sea bottom surface using two cameras attached to NSS.

Aiming at the drilling through the subsurface active seismic fault of the 1999 Chi-chi Earthquake, Taiwan Chelungpu Fault Drilling Project (TCDP) started under the collaboration with National Central University and National Taiwan University, Taiwan.

Several geophysical examinations on high-resolution subsurface profile were made to better understand the marine geology and geophysical issues around the western Pacific region. A brief summary of our seafaring activities is attached at the end of this report.

New staff members at DSRD during this period are En-Chao Yeh from the Brown University, USA as a Post-Doc. researcher, Testuo No and Kaoru Takizawa from Nippon Marine Enterprise Co. as technical staff.

1. Integrated Research on Dynamics beneath Deep Ocean Floor

a) Understanding the active fault and its behavior *TCDP Project*

On September 21, 1999, the Chi-chi earthquake ($M_L 7.3$, $M_w 7.6$) took place at a depth of 10 km to the east of Nantou City, central Taiwan. It was the largest inland earthquake event of the last century in Taiwan. Unfortunately, approximately 2,500 local people died. The earthquake ruptured the out-of-sequence Chelungpu fault in the fold-and-thrust zone in the

West Central Taiwan. The rupture ran about 100 km length. The earthquake has opened tremendous research opportunities on the understanding of earthquake and active fault because of high-resolution record of surface displacement along the earthquake fault as well as speed of rupturing and propagation pattern data. A 2000 m deep drilling project, Taiwan Chelungpu Fault Drilling Project (TCDP), was designed to penetrate the fault plane deeper than 1000 m in order to promote our understanding on fault dynamics and its propagation mechanism. In particular

Deep Sea Research Department

many researchers pointed out that behavior of the northern portion of the Chelungpu Fault is likely to resemble to that of the Nankai Earthquake. We started the plan to take the whole-round core samples from the fault and its surroundings and to examine a state of stress and deformation under the collaboration with National Central University and National Taiwan University, Taiwan.

NanTroSEIZE Project

Ultra-deep drilling proposal to Nankai seismogenic zone was submitted to Integrated Ocean Drilling Program (IODP), in order to understand the nature of nucleation and propagation dynamics of M8 class subduction-zone earthquakes. It proposes to sample and instrument at the seismogenic fault at 6 km deep beneath seafloor. This year, another site survey using "Shinkai 6500" was carried out during the YK03-03 cruise in the Nankai Trough off Kumano, Kii Peninsula. We focused on core sampling, gas-tight fluid sampling, heat flow measurements, natural gamma-ray intensity measurements in and around an active splay fault. We also carried out diving observations at the very front splay fault on the Tokai Thrust, off Tokai region, under the collaboration with University of Tokyo and Hokkaido University. The region off Tokai, as well as the Sagami Bay, is believed to cause disastrous earthquakes in the near future. By using the Navigable Sampling System (NSS), owned by and developed with the close cooperation with the Ocean Research Institute, University of Tokyo, we tried to examine the amount of vertical displacement of the fault during a single earthquake event and assessed its recurrence time at the Enshu Fault, off Tokai region (Figs. 1 and 2). One-by-one correlation could be taken between one piston core sample obtained from the hanging wall side and two core samples from the foot-wall side, which tells us the amount of vertical displacement caused by the latest event. The time of the last event was obtained by the depositional age

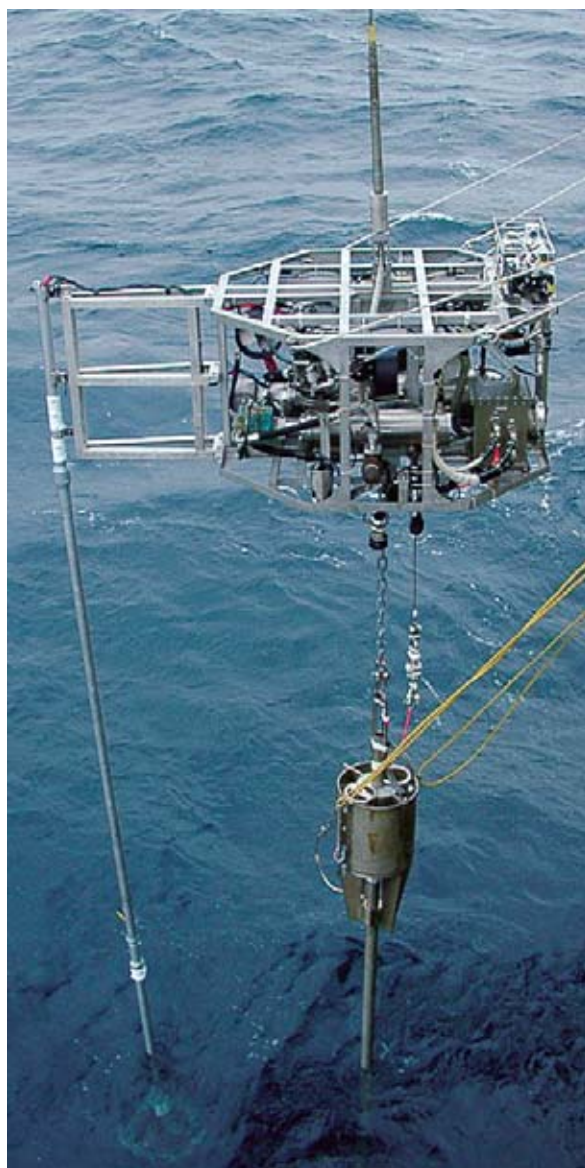


Fig. 1 The piston corer system and TV camera for observing the sea floor were attached to NSS (Navigable Sampling System) vehicle during RV KAIYO cruise.

of the disturbed layer (the event deposit; being accumulated right after the earthquake on the foot-wall side). If such event deposits can be recognized as several horizons along the core samples, it is possible to estimate the recurrence time of the active fault. We believe that the last seismic event at the Enshu Fault occurred ca. 1,300 years ago and its vertical displacement probably reached > 40 cm. We have not obtained the recurrence time yet.

Deep Sea Research Department



Fig. 2 Snap pictures by the surveillance camera of NSS.

Upper photo: The piston corer system waiting for the launch
Lower photo: The penetrating corer into the seafloor.

a) Electromagnetic structure in a Nankai Trough off Kumano

If the formation is under the high pore pressure condition, the breaking strength significantly decreases. Then fluid condition within the formation should be crucial in order to understand field condition to cause big earthquakes. We carried out electromagnetic survey in the region between off Kii Peninsula and Kumano Basin to build image of the pore fluid distribution within the formation because the resistivity can be a good proxy for the pore water distribution within the crust. Four short-period ocean bottom electromagnetic meters (OBEM) installed in a transect line across the continental slope off Kumano were recovered in 2002. The marine magnetotelluric soundings suggested that Philippine Sea plate has a relatively high electrical conductivity seaward of Nankai Trough, and it

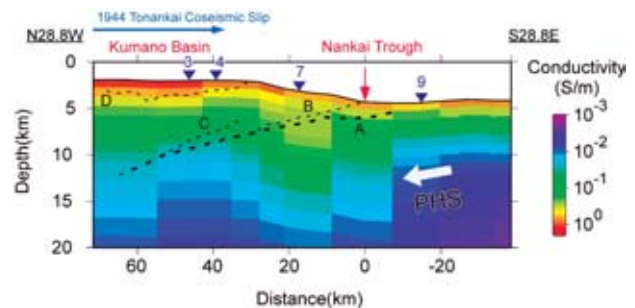


Fig. 3 Electrical conductivity structure below the Nankai Trough off Kumano. Locations of the trough axis and observation sites are indicated by a red arrow and blue triangles, respectively. Broken lines (A-D) indicates major seismic reflectors, and the reflector A corresponds to top of the subducting Philippine Sea plate. A blue line indicates a high-velocity slip area at the 1944 Tonankai earthquake.

decreases as Philippine Sea plate subducts beneath Honshu (Fig. 3). It demonstrates that the electrical conductivity is low in the horizon of 5-10 km deep, which corresponds to the upper part of rupture area in the 1944 Tonankai Earthquake. Therefore, the upper limit of seismogenic fault would be controlled mainly by the pore fluid within the crust.

b) Evolution of Oceanic Island arc in the Mariana arc-trench system

The Mariana Arc system extends over 1200 km in the southern portion of Izu-Bonin-Mariana Arc system and is an excellent example of an intra-oceanic convergent zone. We carried out detailed side-scan sonar, high resolution seismic and short-period ocean bottom electromagnetic surveys (Fig. 4). The sonar image told us the process of the back-arc spreading (Figs. 5 and 6), and seismic data indicated the P-wave structure across the arc system in detail (Fig. 7). OBEM data revealed the electrical conductivity structure in the crust and mantle (Fig. 8).

c) Paleomagnetic record in North Pacific

The objectives of this project are to prove or disprove orbital and/or paleoclimatic modulation of the geomagnetic field, and to understand the energy sources of the geodynamo. To examine these, we have

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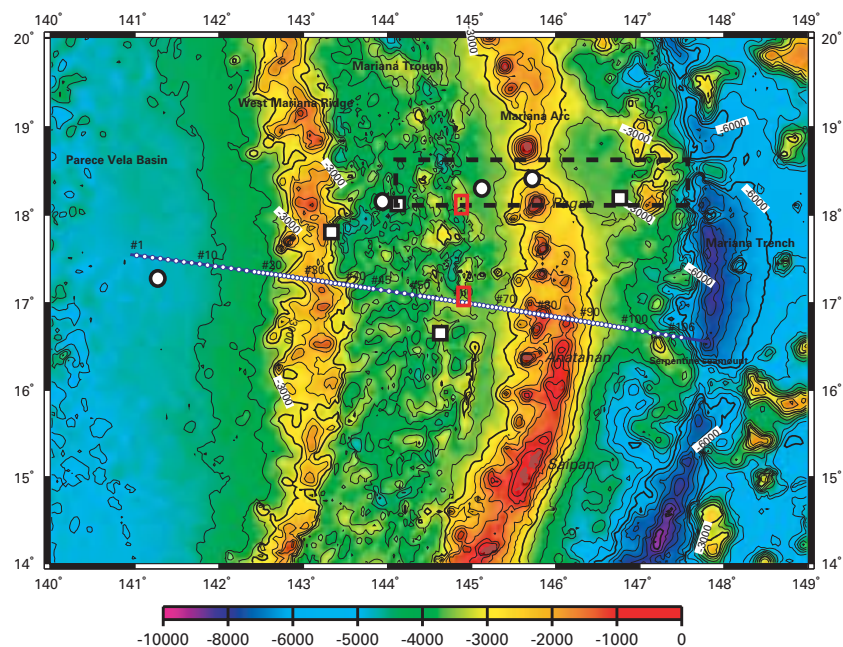


Fig. 4 Topography map of Mariana experimental area. Red rectangle, small open circles, large open circles are survey area using side-scan sonar system, ocean bottom seismographs and ocean bottom electrical magnetometers, respectively. Solid and dot lines are an active seismic line and an area of study for electrical conductivity, respectively.

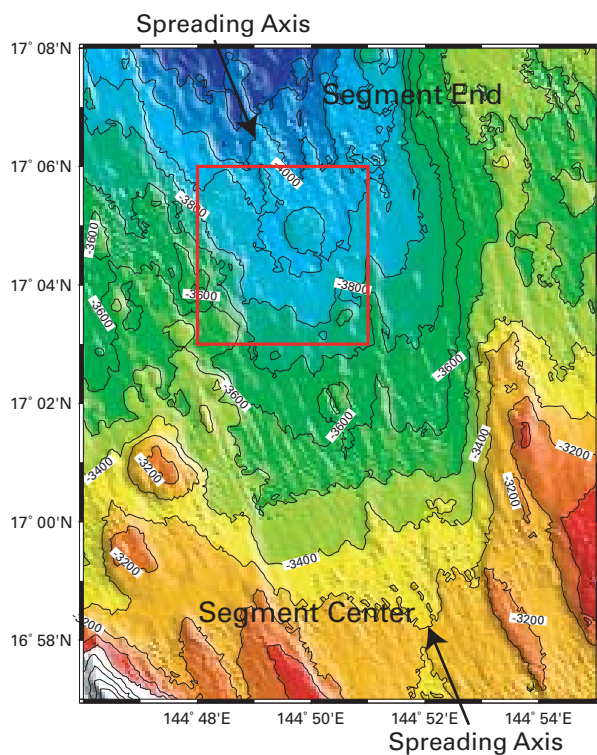


Fig. 5 Bathymetry of the central Mariana Trough in 17°N.

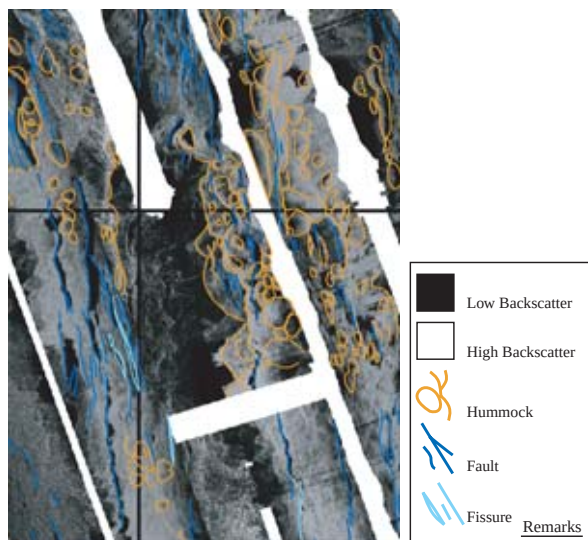


Fig. 6 Side-scan image of the back-arc spreading segment (as a unit of seafloor spreading activity). Sheet flow of lava is dominant in the segment center. On the other hand, morphological transition is found that hummock of lava is dominant in the segment end. The transition would depend on viscosity of lava, caused by temperature, and/or the inclination of the slope, and the flow rate.

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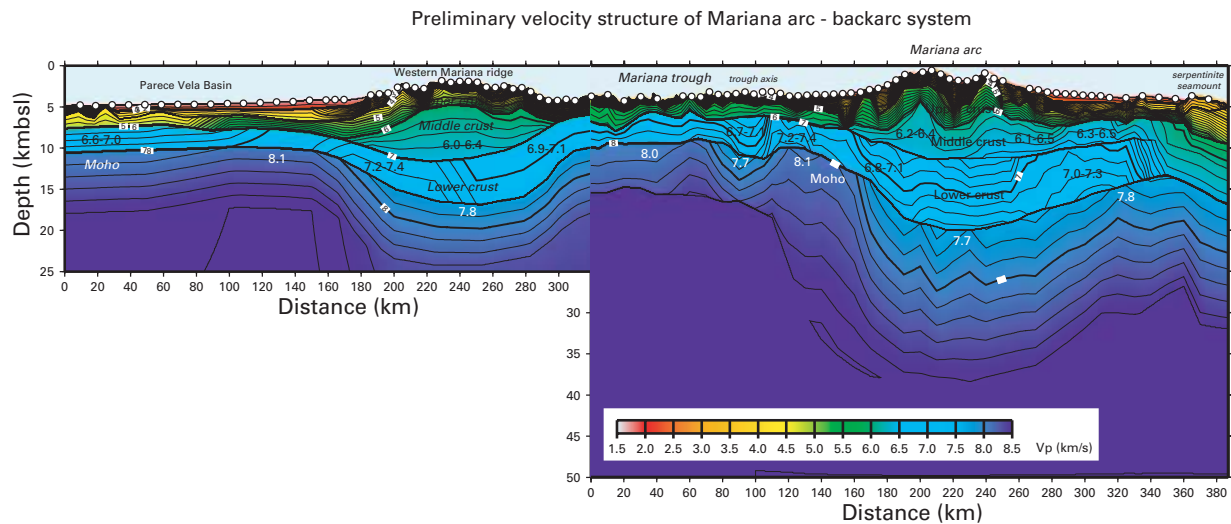


Fig. 7 Preliminary velocity model of Mariana arc - backarc system obtained by a 2-D traveltimes inversion and a tomographic inversion using first arrivals. Interval of contour lines is 0.1 km/s. The arc and trough areas have thick and thin crusts, respectively. Crustal thickness of the Mariana arc and the West Marina ridge are about 20 km and about 17 km, respectively. Crust of the Mariana trough and the Parece Vela basin are about 6 km thick. Andesitic middle crust with P-wave velocity of about 6 km/s exists beneath only arc areas. Lower crust of the Mariana arc has P-wave velocity of over 7 km/s and the thickness is over 2-3 times of that of the Mariana trough. And a lower crusts of boundary areas between an arc and a trough have abnormal P-wave velocity of 7.0-7.4 km/s.

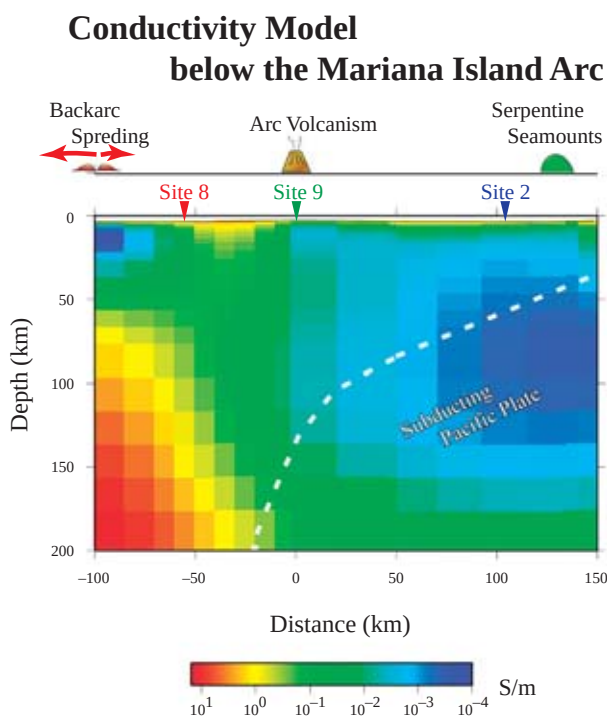


Fig. 8 Electrical conductivity structure below the Mariana island arc and trench system (along 18°N). A broken line indicates top of the subducting Pacific Plate. Both the subducting plate and the mantle wedge below the island arc show low conductivity, while the mantle below the Mariana Trough has high conductivity.

investigated a long-term fluctuation of paleomagnetic intensity, declination, and inclination in the global scale. During the KR03-10 cruise, piston cores were sampled in the northeast Pacific and in the Hess rise regions. So far, there were few paleomagnetic data in the northeast Pacific. We sampled 20-meter-long piston cores from sediment layers at six sites. We also carried out seabeam survey, backscatter imaging, and single-channel seismic profiling. Since paleomagnetic data in the Hess Rise revealed a high-quality paleomagnetic data, we expected much older sediments which are also worth investigation. The Hess Rise site is a candidate for an IODP drilling to obtain the long-term paleomagnetic data (back to ca.10 Ma).

2. Observation Networks on Deep Sea Floor

a) Development of sea floor earthquake observation systems

JAMSTEC keeps operating two cabled observatories; one located to the south off Muroto of Shikoku Island over the Nankai Trough forearc (Muroto Station), and the other to the south off Kushiro,

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Hokkaido over forearc of the Kuril Trench (Tokachi/Kushiro Station). On September 26, 2004, the Tokachi-oki Earthquake (Mw8.0) took place (Fig. 9). The Tokachi/Kushiro cabled observatory successfully obtained complete, continuous seismic and pressure records of the earthquake. They are the first near-by

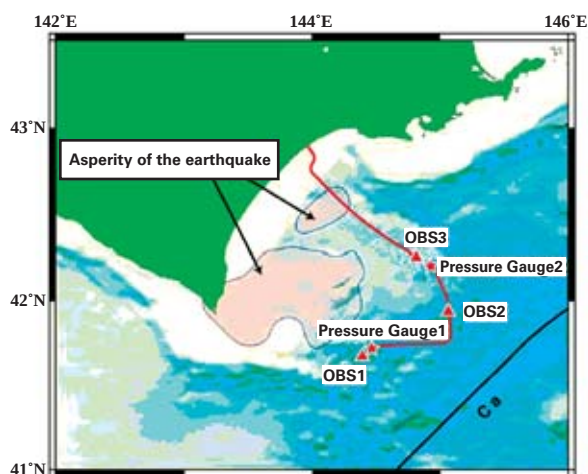


Fig. 9 Map showing the slip distribution of the 2003 Tokachi-oki earthquake and the off Kushiro-Tokachi cabled observatory. Red line represents the submarine cable, in which triangles and stars indicate ocean-bottom seismometers and pressure gauges, respectively. Coseismic vertical deformation of the sea-floor could be detected by the pressure gauges (PG1 and PG2).

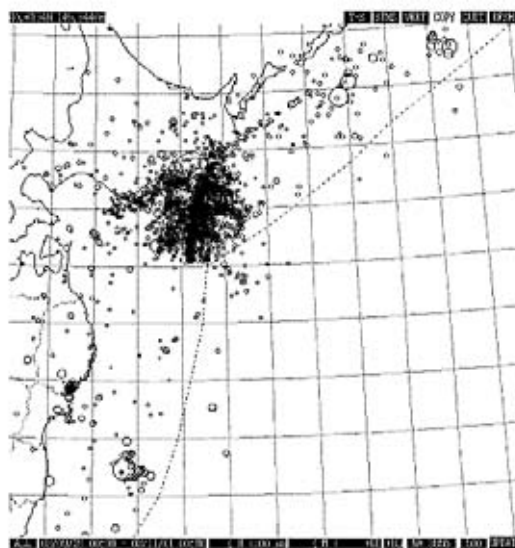


Fig.10 Aftershock distribution off southern coast of Hokkaido from September 26 to October 31, 2003. Cabled ocean-bottom seismographs and land-based seismic network are used in this determination.

data recorded just seaward of the focal area for a M8 class subduction-zone earthquake. Fig.10 shows the aftershock distribution between September 26 and October 31. Fig.11 demonstrates pressure gauge data just before and after the main shock. Four different components that caused the pressure fluctuation were identified; (1) sea-floor deformation, (2) acoustic wave, (3) seismic wave, and (4) tsunami. In addition, the farthest pressure gauge located at the end of the cable recorded the earthquake-induced turbidity current two hours after the earthquake. The bottom current meter recorded a strong current velocity. Noteworthy to mention is that the bottom temperature decreased by about 0.5°C when the turbidity current head arrived. The data from the observation system are telemetered to Japan Meteorological Agency and to Yokohama Institute for Earth Sciences of JAMSTEC (www.jamstec.go.jp/scdc/top_e.html).

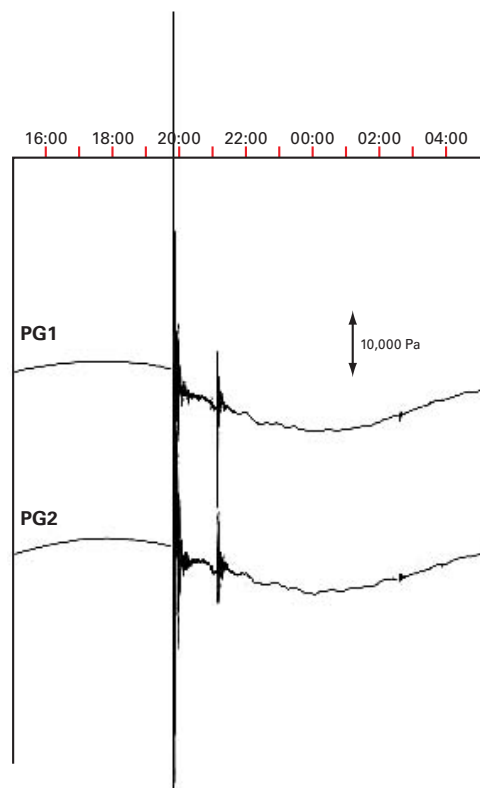


Fig.11 Pressure fluctuations recorded by PG1 and PG2 during the Tokachi-oki earthquake. They consist of (1) sea-floor deformation, (2) acoustic wave, (3) seismic wave, and (4) tsunami itself.

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b) Development of Deep Seafloor Network System

A significant progress was achieved in the development of cable branching system that enables a multi-purpose, in-situ and real-time monitoring in deep-water environment. The NEPTUNE project has started in USA and Canada. The project enables to cover over 3000 km long area in the Juan de Fuca and Gorda Plates in the Eastern Pacific with seafloor stations linked with cables. NEPTUNE primarily aims to monitor hydrodynamic and geodynamic phenomena of the deep water environment including bottom current and temperature fluctuation, earthquake and subbottom volcanic eruption. On the other hand, earth scientific network system (ESONET) planning is ongoing within the European communities.

JAMSTEC is going to design its own project "ARENA"(Fig.12), under which JAMSTEC offers the opportunities to discuss on the development of deep-seafloor network systems. For instance, we have been trying to improve the signal-to-noise ratio as well as to obtain the capabilities for broad-band and wide dynamic range particularly in seismic observations. The seismic sensors installed as in-line cable systems do not possess the state-of-the-art specifications available for on land systems. Improvement

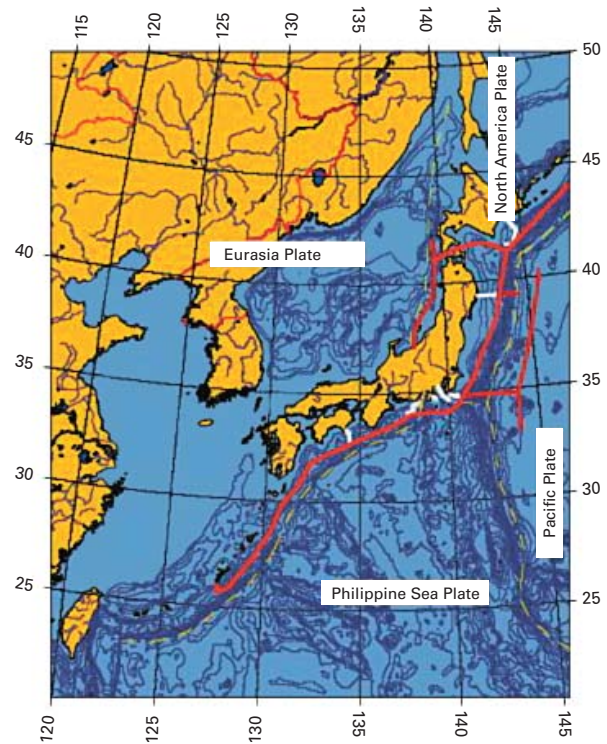


Fig.12 Cable route of the ARENA project. Red lines represent the cable route. Yellow broken lines indicate major plate boundaries around Japan.

of branching system enabling various and flexible measurements is crucial. Technical development to expand our network system will be emphasized next.

Research Activities

Marine Technology Department

Outline and research policy

The Marine Technology Department provides the means to gain a better understanding of the ocean and the earth through the research and development of marine research vessels and marine system such as deep-sea research submersibles, remotely operated vehicles, and ocean observation buoys, and also the research and development of underwater acoustic technology and other important, broadly usable and innovative technologies needed for ocean observation. Research vessels, marine systems and technologies developed by the Department are widely used and highly regarded by researchers not just in JAMSTEC, but from many other research institutions as well.

The Department aims at actively contributing to the advancement of the ocean and the earth science and technology through research and development of sub-surface exploration systems for obtaining information on the earth's interior under the deep seafloor, such as the deep-sea drilling vessel, ocean survey systems such as the autonomous underwater vehicle capable of independently cruising long distances while gathering data on the ocean, and intelligent robots, and basic systems for marine research or development such as ocean development equipment for effectively utilizing vast marine resources including energy, and for protecting and improving the global environment, and also through research and development into underwater acoustic technology, underwater power sources, sensors, and other advanced technologies that can meet increasingly sophisticated ocean survey and research needs.

1. Research Project ; Category 1

(1) Research and development on advanced technologies

From Fiscal 1998

(a) Research on structural material for marine equipment

It is important in submersible development to reduce the weight of the water pressure-vessel protecting electronic devices from seawater and pressure. The research and development target is a material with higher specific strength than the titanium alloy currently used for pressure vessels.

This fiscal year, the properties of the comparative standard material (Ti-6V-4Al alloy) and several selected alloys were tested for evaluation of their material characteristics. As a result, the test piece of new titanium alloy had a 25% higher specific strength.

(b) Research on power sources

The Department is conducting research to improve autonomous underwater vehicle (AUV) power source efficiency to extend cruising distances. This fiscal year, to increase the electric conductivity of the separator, which is a component of fuel cells, and to improve its efficiency by making it thinner, we made a



Fig. 1 The single cell with titanium separator

sample separator using titanium and conducted experiments (Fig. 1). We also began constructing a bench to evaluate those devices.

(c) Research on underwater acoustic technology

We are undertaking research on communicating with manned submersibles, un-tethered remotely operated vehicles (ROVs) and deployed observation systems using acoustic signals. From this fiscal year, we start the second stage aiming at higher speed communication. For applications such as image transmission to control un-tethered ROVs and large-volume data

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Fig. 2 High frequency transducer (80 ~ 120kHz bandwidth)

transmission for seismometers on seafloor, a transmission rate of 64 kbps at a distance of several hundred meters is sought.

To obtain a wide transmission band width, 100 kHz frequency was considered for communication. At this frequency, although absorption loss by seawater is great and the communication distance is relatively short, the transmission delay is also shorter, which promises a better response in ROV control. Also, untethered ROVs are expected to have better maneuverability as research vehicles.

This fiscal year we got materials and parts for a test equipment for sea trials, and started construction and programming. A high-frequency transducer was also made (Fig. 2) and tested in the anechoic tank.

Next fiscal year, we plan to collect transmission data in actual sea conditions.

(d) Measurement and sensor technology

The survey and observation are currently in progress in the arctic to forecast global change. Utilization of the autonomous underwater vehicle (AUV) is considered an effective method of observation under the arctic ice field. In this method, the AUV needs to cruise autonomously over several thousand kilometers and a sensor to identify the vessel's location is required as GPS cannot be used under the sea.

This research aims to improve performance of the inertial navigation system (INS), a sensor to measure the location of AUV, composed of an optical ring laser gyro (RLG) and accelerometer as the nucleus. From fiscal 1998 to 2002, we made and tested an RLG with a modified mirror and extended light path diameter. As a result, a reduction in the RLG's random drift and a performance improvement in the INS were confirmed. In fiscal 2003, a turntable rotating at a constant speed was installed on the INS, and we performed a test to cancel long-term drift by the RLG's rotation. The results indicated a performance improvement due to a reduction in the INS's bias drift error.

(2) Research on a stratospheric platform airship-installed atmospheric observation system

From Fiscal 2000

We are carrying out research aimed at deploying an unmanned airship equipped with communication systems in the stratosphere at an altitude of about 20 km for use in communication, broadcasting and global observation.

It was decided that as a part of the initial plan, stratospheric trials would be carried out as a Millennium Project. JAMSTEC was responsible for the mission test, and developed the mission equipment (air sampling and measuring system (Fig. 3)) for the stratospheric platform airship prototype. We will mount this system in the airship prototype to take direct measurements of atmospheric CO₂ levels, and take air samples in the stratosphere.

In fiscal 2003, the air sampling and measuring system made in fiscal 2002 was modified to extend its operating time, and a reliability test was again conducted to meet the requirements alongside the airship. The air sampling and measuring system was installed on the airship and simulated tests were conducted in preparation for the actual launch. On August 4, a test flight in the stratosphere was performed (Fig. 4).

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Fig. 3 Air sampling and measuring system



Fig. 4 Snapshot of launch for test flight in stratosphere

(3) AUV research and development

From Fiscal 1998

Autonomous Underwater Vehicles (AUVs) are unmanned submersibles capable of cruising underwater independently according to a preset schedule program. Through this research, the Department is developing a test AUV with the major principal particulars shown in Table 1. The AUV has capabilities of maximum operational depth of 3,500 m, a cruising speed of 3 kn, and a cruising range of 300 km. The body is stream line to minimize drag force in advance. A high-performance power source and navigation system are essential to the AUV cruising over long distances. For the power source the AUV will use a Polymer Electrode Fuel Cell (PEFC) backed up by a lithium-ion secondary battery, and for the navigation system, we have combined optical ring laser gyros and doppler speed meters to minimize errors that occur in inertial navigation. To collect data and conduct observations under the sea, the AUV is equipped with a sensor and side scan sonar for

Table 1 AUV specifications

Dimensions	Length	10.0 [m]
	Width	1.3 [m]
	Height	1.5 [m]
	Weight	10 [ton]
Maximum Range (Plan)	300 [km]	(Fuel Cell)
	100 [km]	(Lithium ion battery)
Maximum Depth	3,500 [m]	
Cruising Speed	3 kn (Maximum 4 kn)	
Navigation	Inertial Navigations System	
	Doppler Velocity Log	
	Homing Sonar	
Operation Mode	Autonomous	
	Remote (Optical, Acoustic)	
Equipments	Side Scan Sonar	
	Snap Shot Digital Camera	
	Forward Looking Sonar	
	CTDO (Conductivity, Temperature, Depth, Dissolved Oxygen)	



Fig. 5 External view of test AUV

marine data collection and seafloor surveys. Figure 5 shows an external view of the test AUV.

The test AUV was named the deep sea cruising AUV URASHIMA, and sea trials began in fiscal 2000. In fiscal 2003, the AUV was equipped with a fuel battery system using hydrogen and oxygen and five diving tests were conducted. Seven-hour cruising backed up by the fuel battery system confirmed proper operation as planned. Figure 6 shows the URASHIMA's general layout with its fuel battery system. After fiscal 2004, we plan to conduct sea trials with a target cruising distance of 300 km.

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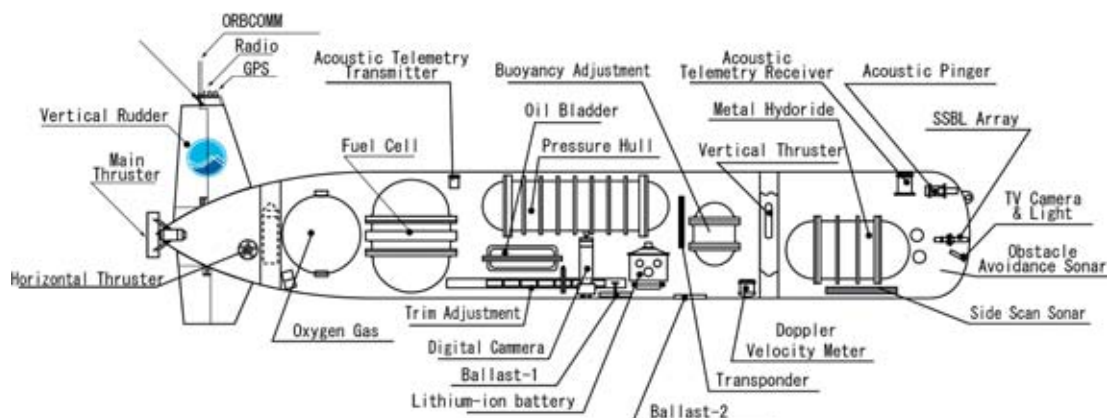


Fig. 6 General layout of URASHIMA (with fuel battery)

(4) Ocean energy utilization technologies

From Fiscal 1989

As general awareness about global environmental problems continues to rise, the use of clean inexhaustible natural energy is again taken interest. In this R&D project, we are focusing on wave energy in coastal waters as natural energy from the ocean, and have been carrying out R&D on the "Mighty Whale" offshore floating wave power device since fiscal 1989. The Mighty Whale system efficiently absorbs wave energy for effective use in coastal regions, and creates calm waters behind the devices, enabling those areas to be used for fishery and other marine activities.

At the end of March 2002 we completed an open sea test of a Mighty Whale prototype (length 50 m, width 30 m) (Fig. 7) in the mouth of Gokasho Bay, Nansei-cho, Watarai-gun in Mie Prefecture. Following last fiscal year's removal and dismantlement of the



Fig. 7 Offshore floating wave power device the "Mighty Whale"

prototype floating body of the Mighty Whale, this fiscal year the mooring system (mooring chain and anchor) (Fig. 8) placed on the sea bottom of the test site was removed between June and July 2003 (Fig. 9). Using the chain samples obtained in the removal work, we conducted various tests to examine the mooring system's durability.

This fiscal year is the research project's closing year, and final achievements were summarized in a report, putting together the results of the open sea experiments and associated tests.

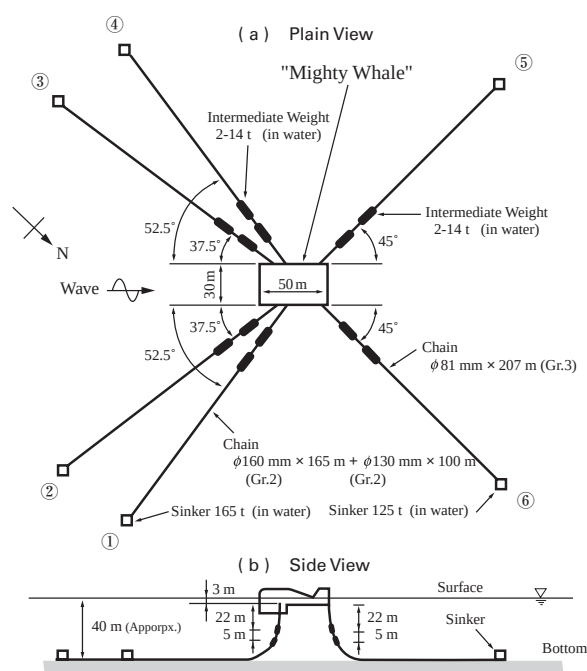


Fig. 8 Moorage system of the Mighty Whale

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Fig. 9 Mooring chain hauled up from the bottom of the experimental sea area

(5) Research on scientific characteristics and cascade utilization system of Suruga Bay deep seawater.

From Fiscal 1998

The Shizuoka Prefectural Government is promoting effective utilization of deep seawater in Suruga Bay. This research seeks to efficiently promote the program and establish technology for practical use of deep seawater. For this purpose, we developed analysis and observation devices, scientifically elucidated deep seawater in the water intake site and sea surrounding Suruga Bay, and examined a cascade utilization system for the effective use of deep seawater in collaboration with the government.

The government built deep seawater intake facilities in September 2001. Since then, we have continuously conducted water quality surveys of pumped-up deep seawater (from a depth of 397 m and 687 m) and surface water (from a depth of 24 m).

In fiscal 2003, the project's final fiscal year, we investigated temperatures, nitrate salts, suspended particles and dissolved organic carbon of ocean water pumped in from the intake facilities. The results are given in Fig.10.

The surface water temperature (at 24 m) fluctuated largely, while the temperature of the deep seawater at 397 m remained stable around an average of 9.4°C (max: 11.4°C, min: 8.1°C, 44 samples) and the tem-

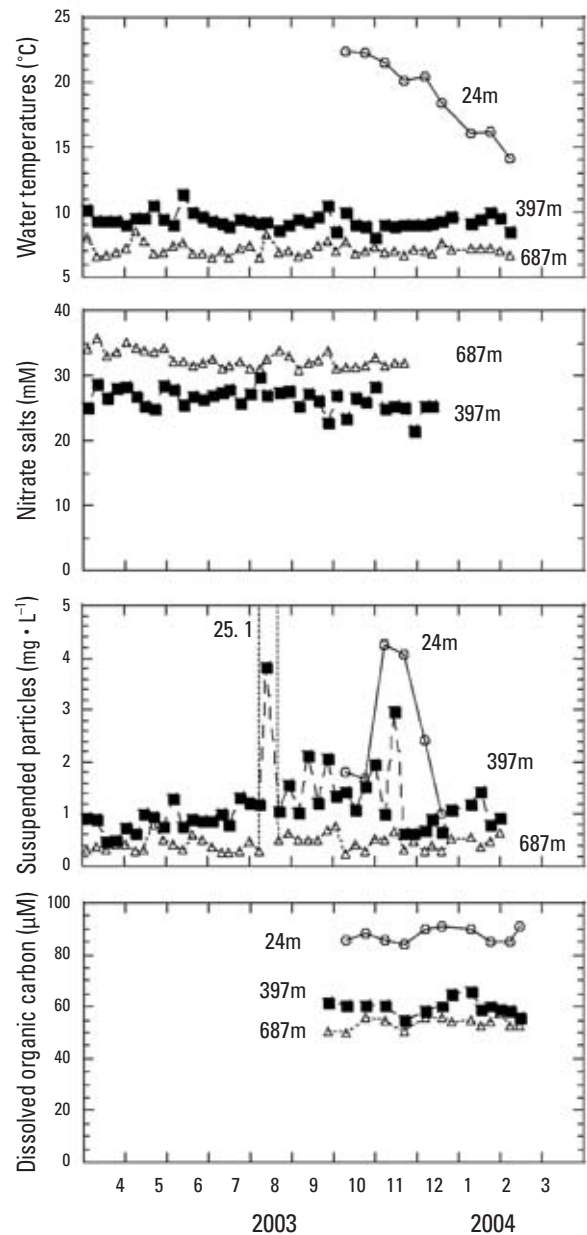


Fig.10 Annual changes in temperature, nitrate salt concentration, suspended particle and dissolved organic carbon concentrations in seawater pumped from a depth of 24m, 397m and 687m at the deep seawater intake facilities in Shizuoka Prefecture.

perature of the deep seawater at 687 m stayed around an average of 7.1°C (max: 8.5°C, min: 6.5°C, 44 samples). The temperature of the deep seawater was thus relatively stable and low throughout the year.

The concentration of nitrate salts was 26 μM on average in the deep seawater at 397 m (max: 30 μM , min: 21 μM , 37 samples) and 33 μM on average in the

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deep seawater of 687 m (max: 36 μM , min: 31 μM , 34 samples). It was relatively stable at a high concentration throughout the year in both cases.

Suspended material from rivers sometimes increased because of heavy rain, which caused sudden increases in the concentration of suspended particles in the sea. Omitting this high concentration (2 mg/L^{-1} or over), we obtained an average concentration of 1.0 mg/L^{-1} (39 samples) in the deep seawater of 397 m and 0.4 mg/L^{-1} (42 samples) in the deep seawater of 687 m. The concentration in the deep seawater of 397 m is slightly high in terms of the utilization of deep seawater.

The concentration of dissolved organic carbon was slightly high in the surface water of 24 m depth, 87 μM on average (max: 91 μM , min: 84 μM , 9 samples), while it was an average of 60 μM in the water of 397 m depth (max: 66 μM , min: 55 μM , 13 samples) and an average of 54 μM in the water of 687 m (max: 58 μM , min: 50 μM , 13 samples). The concentration of dissolved organic carbon thus remained at relatively low throughout the year.

These results indicate water pumped at the Shizuoka intake facilities had low, stable temperatures and a high, stable nutrient salt (nitrate salts) concentration throughout the year. However, the concentration of the suspended particles, related to the clearing, was relatively low in the deep seawater of 687 m, but slightly high in the water of 397 m, which might require filtering, depending on the intended application. The deep seawater of 397 m and 687 m has a low concentration of dissolved organic carbon and can be considered less susceptible to putrefaction. From these results, water from 397 m should become better quality if suspended particles are removed by filter. Our advice to the Shizuoka Prefectural Government water intake facilities is therefore to equip a filtering apparatus and to operate it depending on the application of the intake's deep seawater.

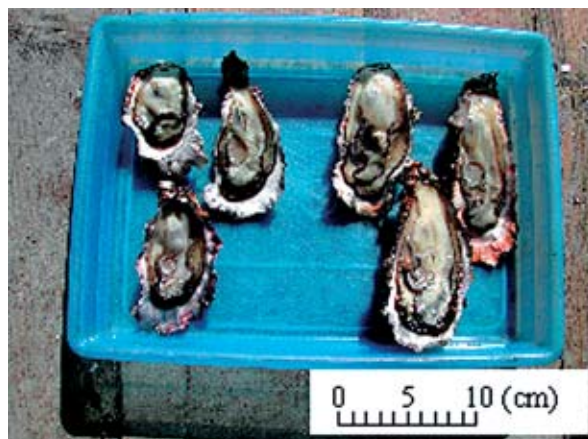


Fig.11 Right: Oysters grown in the experimental area. Left: Common cultured oysters. Not only is there a clear difference in their sizes but also the oysters grown in the experimental area (right) have a large white portion (glycogen), said to enhance flavor.

(6) Research on estuary environmental remediation

From Fiscal 2001

This regional collaborative research began with the Nagasaki Prefectural Government to search for a fundamental and consistent method of remediation for eutrophicated estuaries, removing eutrophication materials such as N and P.

The in situ experiment was started at the northern end of Katagami Bay in Kinkai-cho, Nagasaki in January 2003, and experiments have been successively conducted until February 2004 to survey climate, water quality, ocean bottom materials and organisms.

Results showed oysters in the experimental area grow larger and fatter as the oyster raft sinks (Fig.11).

We successively measured the dissolved oxygen concentration around the sea bottom of the experimental area from the beginning of July until the beginning of October, and turned out that the concentration remained at an average of 6.4 mg/l , which was favorable as the target was 4.3 mg/l or over (Fig.12). Oysters in the ordinary farm at the southern end of Katagami Bay died and could not be harvested this year.

From these results we believe we can validate the assumption that "sustainable use and environmental remediation of the eutrophicated estuary can coexisted".

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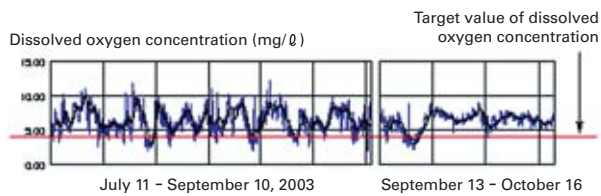


Fig.12 Result of successive measurements on dissolved oxygen concentrations lying directly on the experimental sea bottom.

2. Research Project ; Category 2

(1) A marine robot for the deep-sea exploration and the arctic survey

From Fiscal 2003

The polar region is significantly affected by global warming, and this research looks into the measurement technologies needed when gathering CTD, ice thickness, and CO₂ data in this region by AUV.

This fiscal year we developed a control platform suitable for autonomic operation, and made a hardware prototype (Fig.13). We also made software to control it and conducted a diving test in actual sea conditions (Fig.14). In addition, we made and examined a small and inexpensive test model of the ARGOS/GPS wireless communication device.



Fig.13 Hardware prototype for control platform

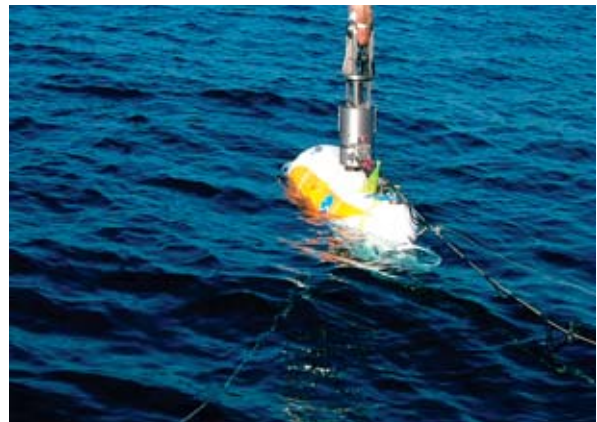


Fig.14 During sea tests

3. Personal Research

(1) Electromagnetic pulse subsurface exploration system

From Fiscal 2002

Plate subduction and fault structures can be examined by transmitting a strong electromagnetic pulse into the earth's interior and measuring the reflected echo. It also has the potential for discovering water reservoirs and buried objects. The advantages of using electromagnetic pulse in exploration is that it generates more information than the conventional sound wave or magnetic field methods used in subsurface exploration to date.

This fiscal year, we designed and made a test model of a filter-bank type receiver using DSP, and made an electromagnetic pulse generator (Fig.15). We also conducted a propagation simulation under the sea floor with a simulation code using the FDTD (Finite Difference Time Domain) method.



Fig.15 Electromagnetic pulse generator and receiving antenna

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(2) High-performance (low specific gravity, high strength) buoyancy material

From Fiscal 2001

To improve the maneuverability and increase the payload of manned submersibles and deep sea ROVs, these pressure hulls must be made smaller and lighter. The greater the operating depth, the greater the weight of the pressure hull, so buoyancy material must have a low specific gravity and high strength.

This research aims at using hollow spheres made of engineering ceramics as buoyancy material that is lightweight and has a high specific compressive strength. Because of their material properties, engineering ceramics have been long considered a candidate material for deep-sea pressure hulls. However, the brittleness of ceramics has been a major barrier to their more extensive use.

In fiscal 2003, we made hollow spheres using alumina, a kind of engineering ceramics, and examined shape measurement methods for small spheres. We also compared the manufacturing precision of our sample spheres and the ceramics spheres made about 20 years ago and confirmed that shape distortion is considerably reduced in our sample. Based on this result, we discussed improvement of the manufacturing process.

(3) Research on underwater acoustic technology by phase conjugate waves

From Fiscal 2003

In fiscal 2003 we performed a simulation and water tank test to observe convergence, a fundamental characteristic of phase conjugate waves.

The simulation examined a shallow sea area of about 100 m and manifested the following features:

- (i) Phase conjugate waves can converge to a focal point even at a horizontal distance of several thousands of meters, which enables a desired signal to be received.
- (ii) Convergence of phase conjugate waves is not significantly marred by decreasing the number of ele-

ments in the receiving-transmitting wave array.

(iii) The convergence of phase conjugate waves is not significantly marred by tilting or moving the receiving-transmitting array vertically.

(iv) Horizontal arrays placed on the ocean bottom can generate phase conjugate waves.

(v) Phase conjugate waves can converge even when the sound velocity profile along the propagation path is not uniform.

(vi) The convergence of phase conjugate waves is not ruined much by changes in sound velocity profile along the propagation path.

We also conducted a water tank test simulating a shallow sea with a uniform sound speed distribution and confirmed the actual acoustic convergence by phase conjugate waves, and the features (ii) and (iii) above.

(4) Empirical research with a prototype of synthetic aperture sonar

From Fiscal 2003

Synthetic aperture sonar makes seafloor images of remarkably high resolution by receiving reflected waves from a target a number of times while moving, and virtually synthesizing a long array. Since the resolution is about the same for long and short distances, research efficiency on the deep ocean bottom will increase dramatically when the sonar is finalized.

Based on previous basic research, this research will make a synthetic aperture sonar prototype installable on submersibles and collect data by actually scanning the ocean bottom. With these data, we examine performance necessary to the sonar equipment, and how the submersible's turbulence affects the sonar and how to compensate for it and conduct empirical research aimed at production of practical synthetic aperture sonar.

This fiscal year, we developed a program to compensate for the influence of the submersible's turbulence, performed a compensation simulation and made a conceptual design of the prototype.

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(5) Information transmission of the deep sea cruising AUV URASHIMA using ETS VIII

From Fiscal 2003

The Engineering Test Satellite (ETS) of type VIII enables high-speed communication such as compressed image transmission between the deep sea cruising AUV URASHIMA on the surface of the water and onshore facilities, or between mother vessels and onshore facilities.

However, there is no compact, durable satellite tracking antenna that can be installed in the URASHIMA. We intend to conduct research and development of an installable antenna and tracking system and will install them in URASHIMA for testing.

This fiscal year, we made a conceptual examination and designed a satellite communication line using the ETS VIII. We also produced a prototype of the antenna (Fig.16) and performed a characteristic test in a radio anechoic chamber.



Fig.16 Prototype of the antenna

investigate the relation between its functions and components, and clarify the expression factors of its functions. Furthermore, with this fundamental understanding of deep seawater, we intended to promote industrial use.

This collaborative research ends this fiscal year, and we summarized the functions of deep seawater in various fields. The following is the overview of our activity.

Deep seawater pumped up at water intake facilities in Japan's surrounding sea areas (Toyama, Shizuoka, Kochi and Okinawa prefectures, and Kumaishi-cho in Hokkaido) was examined, especially in terms of cleanliness. As a result, our assessment is that the deep seawater was clean and had a low concentration of suspended matter, dissolved organic matter, particulate organic matter, total bacteria, viable bacteria, toxic microbes and dioxins.

As a test for deep seawater to be used for brewing, we conducted a culture test and a manufacturing test of the yeast used for fermented seasoning. Results indicate enhanced yeast growth. Some yeasts may grow specifically with deep seawater contents and the importance of searching for such yeasts was pointed out.

In its application to dental health, we investigated simultaneous use of deep seawater and a drug ensured to have a disinfectant function, to observe the effect of deep seawater on hygienic and cleansing functions in oral cavities. Results showed the mixture of deep seawater and the drug suppressed the medicinal function,

(6) Research on electric power unit based on thermoelectric conversion technology in hydrothermal eruption area

From Fiscal 2003

Thermoelectric conversion technology that can convert directly from thermal to electric energy using a thermoelectric conversion element is considered useful in supplying power to deep-sea observation equipment. We examine and investigate existing thermoelectric conversion technology, to develop it for use in an extreme underwater environment with high pressure, aiming at thermoelectric conversion technology in deep-sea use, particularly in hydrothermal eruption areas. In fiscal 2003, we examined and investigated existing thermoelectric conversion technology.

4. Cooperative Research

(1) Research on industrial deep seawater use

From Fiscal 2001

This collaborative research aims to survey the functions of deep seawater in various applications,

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but the deep seawater masked the drug's bitter taste, indicating a possible effective application of deep seawater in this field.

In the investigation of deep seawater's potency for foods, safety was considered as the most important factor (the water should have an extremely small content of artificial contaminants). We made drinking water with selectively enhanced magnesium content found in deep seawater and checked its influence on human health. Results showed a decrease of neutral fat in blood and blood sugar levels. This information was used in the commercialization of drinking water produced from deep seawater (available in stores from February 2003).

As for fishery processing, we made a sample of salted salmon roe using deep seawater salt and examined its influence on quality after freezing and unfreezing. As a result, the roe looked slightly brighter and had better taste, sweetness and salty sting, compared with roe salted with typical salt. Clarification of reasons for this favorable result is our future goal.

Only one product was developed in this collaborative research period but the development of products in other research fields is also in progress. Several more years will be necessary to complete product development in each field.

(2) Research on hydrothermal plume observation technology

From Fiscal 2000

Observing hydrothermal plumes spouting out from the seafloor is important for understanding the dynamics of the earth's interior and global material circulation. This research is mainly aimed at developing plume chemical observation methods required for the efficient exploration of hydrothermal plume source and for gaining a temporal and spatial understanding of changes in hydrothermal plumes, and in-situ observation to confirm their effectiveness.

As in the last fiscal year, this fiscal year we continued to check the cause of functional error with ISFET

and found a problem in the shielding method of the n-type Si as a semiconductor base. As a countermeasure, we suggest it would be effective to use a shielding mask in the production process of ISFET. As for the optical sensor, we made a device to test properties of parts such as optical connectors and optical fibers used under high hydrostatic pressure, and initially tested an optical connector sample. We found its sealing performed well under high hydrostatic pressure. Field observation was conducted in the Kuroshima Sea using the AUV "r2D4", owned by the Institute of Industrial Science, the University of Tokyo, and in Kagoshima Bay using the "HYPER-DOLPHIN".

(3) Development of an AUV-ROV hybrid submersible for use in shallow water

From Fiscal 2001

Oceanic data on such aspects as water temperature, dissolved gases, and microorganisms vary significantly in water shallower than 500 m, so a submersible capable of efficiently measuring data over a broad range in shallow waters would be an important asset. To this end, we are developing a simple submersible capable of movement in a horizontal direction over a wide area that can be deployed either as an AUV or ROV.

This fiscal year we built a body and examined remote control methods. The manufactured submersible was examined in a pool (Fig.17).



Fig.17 Pool testing of the AUV-ROV hybrid submersible

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(4) Gas storage using nano-material

From fiscal 2002

JAMSTEC is developing fuel cells to power the autonomous underwater vehicle (AUV). Fuel cells use hydrogen and oxygen, and we research on high efficiency storage materials. This research aims at establishing the technology for gas storage and discharge using nano-carbon material as a fuel storage system for fuel cells used to power AUVs etc.

This fiscal year, we conducted tests on the gas absorption characteristics of carbonaceous samples. We also investigated a sample confined in a pressure vessel.

(5) Research on a heat-resistant cultivation tank in deep-sea microbe cultivation equipment

From Fiscal 2002

The deep-sea microbe experiment system has a silicon suppression bellows in the cultivation tank. However, problems arise in endurance, heat resistance, and H_2S resistance in high temperature zones, so under current conditions, cultivation at above $150^{\circ}C$ has been difficult. Considering that the cultivation tank is the obstacle to cultivation at high temperatures, this research plans to develop a heat-resistant cultivation tank (suppression bellows, internal tank) capable of operating in temperatures up to $300^{\circ}C$.

This fiscal year, as in fiscal 2002, we conducted a basic test ($200^{\circ}C$, one-week continuous test on heat resistance and durability) for rubber material durability in high temperature usage. From the results of the rubber's hardness and volume strain, we found the possibility of using rubber for the bellows and O-rings up to $200^{\circ}C$. We then appreciated the necessity of detailed tests on material, and designed and made high temperature O-ring testing equipment (test conditions: maximum $300^{\circ}C$, pressure 67MPa) necessary for the experiment.

We performed a high temperature, high pressure test (test conditions: $150^{\circ}C$, pressure 67MPa) for an

internal glass tank with the modified rubber bellows made in fiscal 2002 (bellows: made by Viton; the lid was replaced with a stainless clamp).

The experiment showed that the lid was tighter than the former one and we obtained good performance. We also performed a high temperature, high pressure test (test conditions: $150^{\circ}C$, pressure 67MPa) for a piston-type titanium internal tank (Fig.18) made in the fiscal 2002 with the research theme "Development and research on retaining technology in extreme environments". After the test, the backup ring was protruding from the piston and the O-ring was damaged and deformed. We assumed the cause of the trouble was a large space between the outside diameter of the piston and the titanium internal tank and its pressure difference made the O-ring to protrude.



Fig.18 Piston type internal titanium tank

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(6) Research on optical fiber sensor arrays

From Fiscal 2003

Optical fiber is used not only for communication but also for sensors in various onshore applications such as thermal sensors, stress sensors, gyros, etc. It has advantages such as insensibility to electrically induced noise, long-term high stability and reliability, small diameter, lightweight and stable temperature characteristics, so it has great potential as a sensor in special environments such as deep seawater. Also, combined with recently developed optical wave multiplex communication technology and optical amplification techniques, it allows improvement of the entire system's

reliability by covering the ocean with many sensors, increasing space resolution and sensitivity, and placing the complex electronic device onshore. This research plans to develop a prototype optical fiber sensor that combines with optical communication systems to enable underwater two-dimensional development.

This fiscal year we compared and examined various kinds of observation methods, and made a theoretical review of an optical sensor with the two-frequency interference system, which combines well with the optical fiber transmission system. We then purchased the main equipment and materials and prepared for the experiment.

Research Activities

Ocean Observation and Research Department

Overview

Our research focuses on ocean observation to support understanding the ocean's role in global climate change. We conduct observational cruises mainly via the R/V Mirai in the western Pacific, eastern Indian, north Pacific and Arctic Oceans. We also deploy moorings and floating buoys to monitor oceanic and atmospheric conditions in these oceans.

To enhance our research, we complement our efforts through cooperative institutes. We conducted four projects, three personal studies, and 3 cooperative studies in FY 2003. The results of these projects are described below.

Project

Theme 1: Tropical Ocean Climate Study (TOCS)

The tropical ocean is heated by the sun's high radiation and the poleward redistribution of heat from the tropical ocean governs the global climate. Thus, investigation of ocean and atmosphere variability in the tropics is important for a better understanding of global climate change. In particular, the western tropical Pacific and eastern Indian Oceans are recognized as key regions; the former for ENSO (El Niño/Southern Oscillation), the latter for the Asian monsoon and dipole mode phenomenon that affect climate in East Asian countries, including Japan. In this project, we attempt to clarify ocean and atmosphere variabilities, focusing on the generation and dissipation of the Indo-Pacific warm pool by conducting shipboard hydrographic observation, time-series observation with TRI-

TON and subsurface ADCP moorings, and driving a high-resolution global ocean circulation model.

In the FY2003, we conducted four cruises using the R/Vs Mirai, Kaiyo and Yokosuka as summarized in Table 1. During the cruises, we deployed TRITON and subsurface ADCP moorings, conducted continuous atmospheric and hydrographic observations using CTD, XCTD and shipboard ADCP all at one station.

We have also established data correction methods for the time drifts of subsurface temperature and salinity data. We have started the following analyses using temperature, salinity and current time-series data and results from a high-resolution ocean circulation model.

In the Pacific warm pool region, temperature and salinity variations in the Halmahera eddy region are described using TRITON data in collaboration with Bogor Agricultural University and the Agency for

Table 1 Summary of cruises conducted under the TOCS project in FY2003.

Cruise ID	Period	Ship	Ports of call	Major work
MR03-K03	2003.6.7~7.30	R/V Mirai	Guam (U.S.A.)	TRITON buoy: 7 deployment
			–Okinawa (Nakagusuku)	8 recovery
			–Brisbane (Australia)	ADCP buoy: 2 deployment 3 recovery
KY03-12	2003.10.30~11.29	R/V Kaiyo	Yokosuka	TRITON buoy: 3 deployment
			–Koror (Palau)	3 recovery
				ADCP buoy: 2 deployment 2 recovery
YK04-02	2004.1.19~2.26	R/V Yokosuka	Guam (U.S.A.)	TRITON buoy: 6 deployment
			–Guam (U.S.A.)	7 recovery
			–Yokosuka	ADCP buoy: 1 deployment 1 recovery
MR04-01	2004.2.22~3.22	R/V Mirai	Freemantle (Australia) –Yokohama	Doppler radar measurements

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Assessment and Application of Technology (BPPT), Indonesia. Low-salinity water occupied the thermocline layer in the first month of observation (Fig. 1). The low-salinity water is considered North Pacific Tropical Water originating in the northern hemisphere. This was associated with a southward shift of the North Equatorial Counter Current branching from the Mindanao Current. After the first month, high-salinity water originating in the southern hemisphere dominated the region in association with enhancement of the Halmahera eddy, although it indicated large intra-seasonal variations. It suggests that the westernmost Pacific's water mass varies dramatically with Mindanao Current and Halmahera eddy activities. This is an important process - how the water mass characteristics of the Equatorial Underwater and the Indonesian Throughflow can be determined.

In the upstream of the Halmahera eddy region, we analyzed current data from the subsurface ADCP mooring deployed southeast of Mindanao. The results indicate the Mindanao Current has been remarkably enhanced during the development phase of the 2002-2003 El Niño. Adding the above, we showed that warm water accumulation off the Philippines before El Niño's arrival can be traced in monthly temperature and salinity OI maps derived from the TRITON/Argo data.

These are consistent with the results of a numerical experiment. Since meridional warm water transport between equatorial and off-equatorial areas is known to be important to the El Niño cycle, we have diag-

nosed the variability of water volumes at temperatures above 20°C in the equatorial Pacific using a global high-resolution model with a grid spacing of 1/4 degrees. A large accumulation of warm water was recognized east of the Philippine islands before the onset of the 2002/03 El Niño event, and it is transported to the equator and to the east as the development of El Niño. A time-series measurement of warm water volume off the Philippines (Fig. 2a) indicates an increase (decrease) of warm water during La Niña (El Niño) periods. The period between the 1997/98 El Niño and 2002/03 El Niño events is found to have been a period of the greatest accumulated warm water volume in 20 years. In this period, the wind stress curl was negative over the area (Fig. 2b), and the wind stress curl had a high correlation with sea surface temperatures (Fig. 2c). These results suggest the importance of local air-sea interaction in the western off-equatorial Pacific.

Besides the above studies, convergence zone characteristics at the eastern edge of the warm pool are being studied using the ADCP current meter data in collaboration with IRD, France. Analysis of the Antarctic Intermediate Water path off New Guinea has commenced based on the data from RAFOS floats, subsurface ADCP mooring, hydrographic observations, and particle tracking with a numerical model in collaboration with Kiel University, Germany.

In the Indian Ocean, we demonstrated intraseasonal and semiannual variations with vertical phase differences from the TRITON buoy's data. We also started

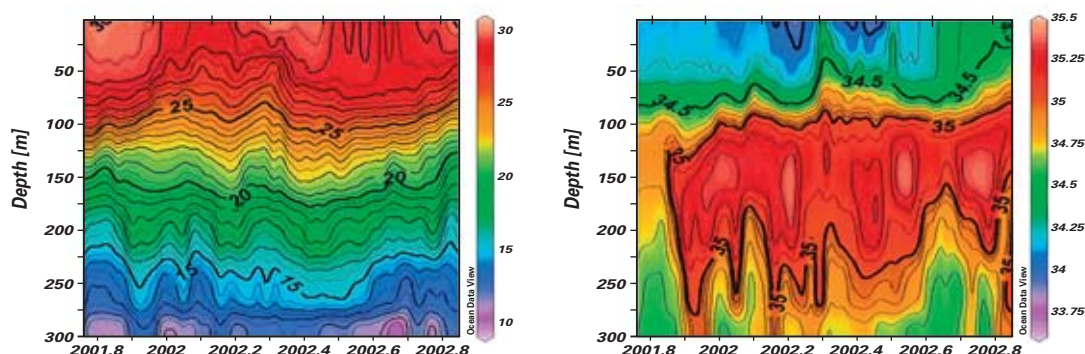


Fig. 1 TRITON temperature (a) and salinity (b) time series in the Halmahera eddy region at 2°N, 130°E.

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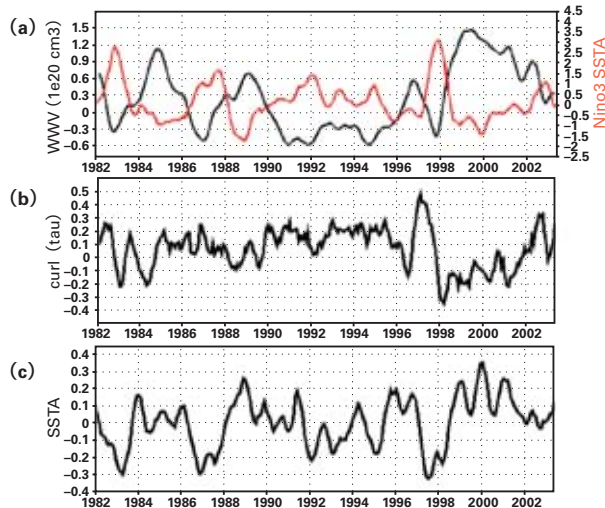


Fig. 2 (a) Time series of warm water volume anomaly (black lines) off Philippine Islands (8°N - 16°N , coast to 156°E) and sea surface temperature anomaly (red) over the Niño 3 area. (b) Area averages of wind stress curl over the area northwestern equatorial Pacific (5°N - 15°N , 130°E - 170°E), and (c) sea surface temperature anomaly.

studying surface layer responses with intraseasonal atmospheric pressure in collaboration with the International Pacific Research Center. To promote these studies, continuous measurements are necessary.

Air-sea interaction is a key factor in understanding atmospheric and oceanic phenomena over the tropical western Pacific Ocean, where the warmest sea surface temperatures exist, and it is known as the warm pool region. The Madden-Julian oscillation (MJO) is the dominant intraseasonal mode of variability of convection and circulation over this warm pool region. In order to reveal the precipitation mechanism of meso-scale (in the order of 100 km) convective systems accompanied by MJO, stationary observation was carried out using the R/V Mirai (cruise code: MR04-01) at (2°N , 138°E) from March 3 through 14, 2004 (refer to IOP; Intensive Observation Period). During the IOP, C-band Doppler weather radar, atmospheric sounding by radiosonde, surface meteorological measurement, CTD casting, and ADCP current measurement were carried out.

According to an analysis conducted by the National Oceanic and Atmospheric Administration / Climate

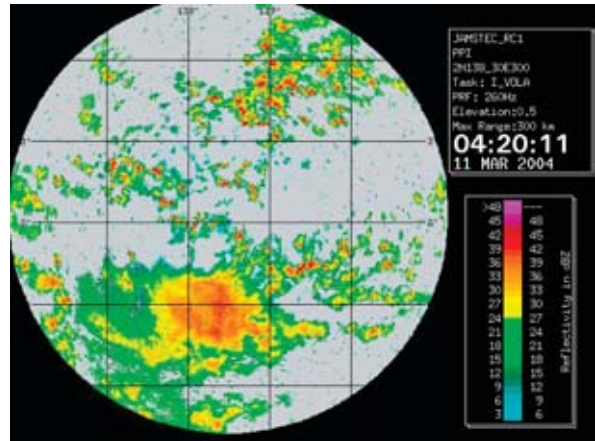


Fig. 3 Radar reflectivity image obtained at 2°N , 138°E at 04:20UTC on March 11, 2004.

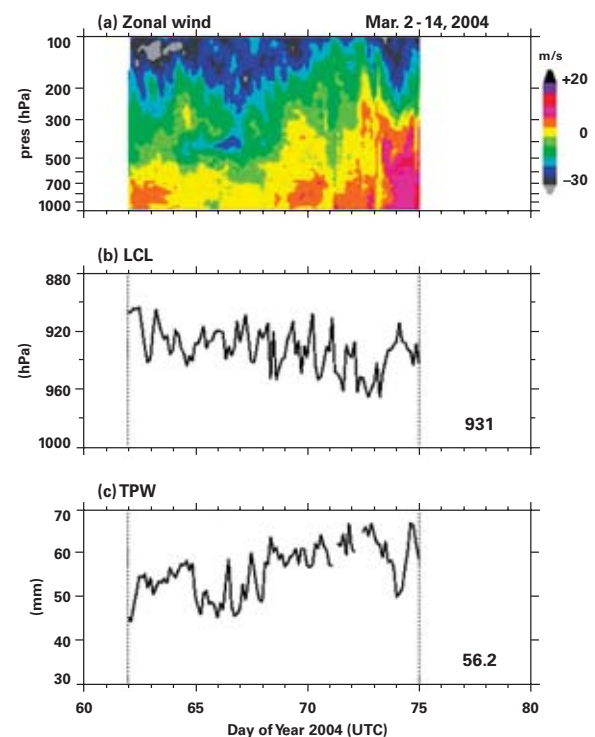


Fig. 4 (a) Time-height cross section of zonal wind component, and time series of (b) lifted condensation level and (c) total precipitable water vapor.

Diagnostic Center (<http://www.cdc.noaa.gov>), the active phase of MJO arrived over the observational area in the later period of IOP. Indeed, many convective systems over 100 km scale were observed (Fig. 3). It is evident that westerlies become dominant in the lower troposphere when the active phase of MJO arrives over the site (Fig. 4a). Time-series of

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lifted condensation level (Fig. 4b) and total precipitable water vapor (Fig. 4c) also show a gradual decrease/increase as the active phase of MJO approaches. We intend to further analyze these data sets to reveal the relationship between cumulus and atmospheric conditions, and to study the vertical profile of heating and water vapor distribution.

Theme 2: A study of heat and material transports and their variability in Pacific/Indian Ocean general circulation

The ocean plays a central role in climate system and its change, the most fundamental environment for human beings. However, the quantitative role of the ocean in climate system and its change is still unknown. The project goals are (1) to obtain up-to-date snapshots of basin-scale heat and material transports by conducting reoccupation of WOCE (World Ocean Circulation Experiment) Hydrographic Programme (WHP) lines and new land-to-land hydrographic lines with high accuracy and (2) to quantify heat and material transports and their short-term variability by abyssal circulation flowing into the North Pacific from the South Pacific through the Wake Island Passage, by mooring CTDs and current meters and (3) to analyze WOCE and historical oceanic data, including sea surface wind data accumulated in the Pacific and Indian Oceans. From 2002 to 2008, by conducting the above three studies, we plan to

reveal basin-scale changes in heat and material transports between the 1990s and 2000s.

1) WHP revisits

Japan Marine Science and Technology Center (JAMSTEC) conducted the research cruise along World Ocean Circulation Experiment (WOCE) Hydrographic Program (WHP) lines in the southern hemisphere with the oceanographic research vessel "MIRAI" from August 2003 to February 2004, to commemorate the 30th anniversary of its establishment (BEAGLE2003). The cruise track is shown in Fig. 5.

She departed Brisbane (Australia) on 30th July, 2003, anchored at Papeete (Tahiti) from 5th to 9th September en route and arrived at Valparaíso (Chile) on 16th October. She left Valparaíso on 19th October, called Santos (Brazil) from 2nd to 6th November, Cape Town (South Africa) from 5th to 9th December, Tamatave (Madagascar) on 20th December, Port Louis (Mauritius) on 27th December, and arrived at Fremantle (Australia) on 24th January, 2004. She then headed to south to the Kerugelen Plateau, and returned to Fremantle on 19th February, 2004. In our study we conducted observations between Brisbane and Valparaíso (Leg1 and Leg2), Santos and Cape-town (Leg4), and Cape-town and Fremantle (Leg5). These Sections are correspond to WHP lines P6, A10 and I3/I4, respectively. Observations at 493 stations (Fig. 6) were conducted during the cruise.

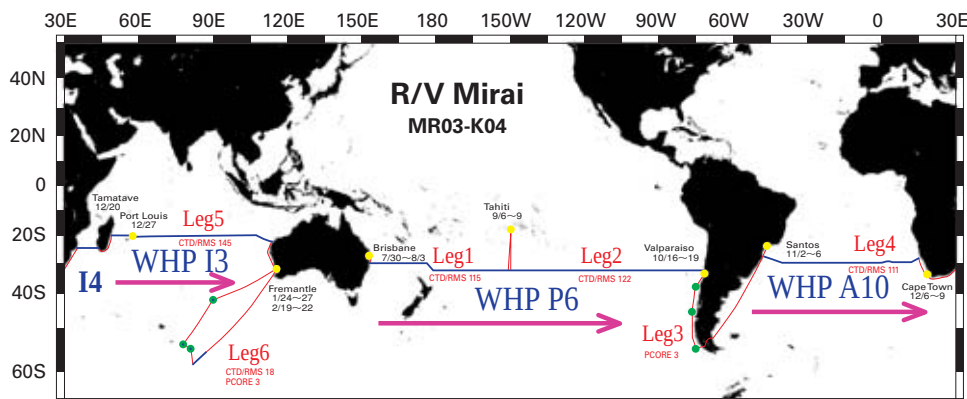


Fig. 5 Cruise Track

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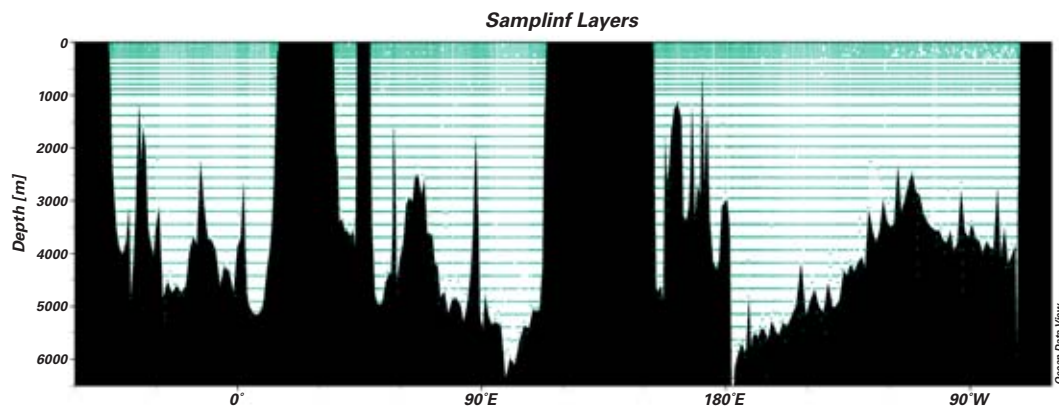


Fig. 6 Stations and Sampling Layers WHP P6/A10/I3/I4.

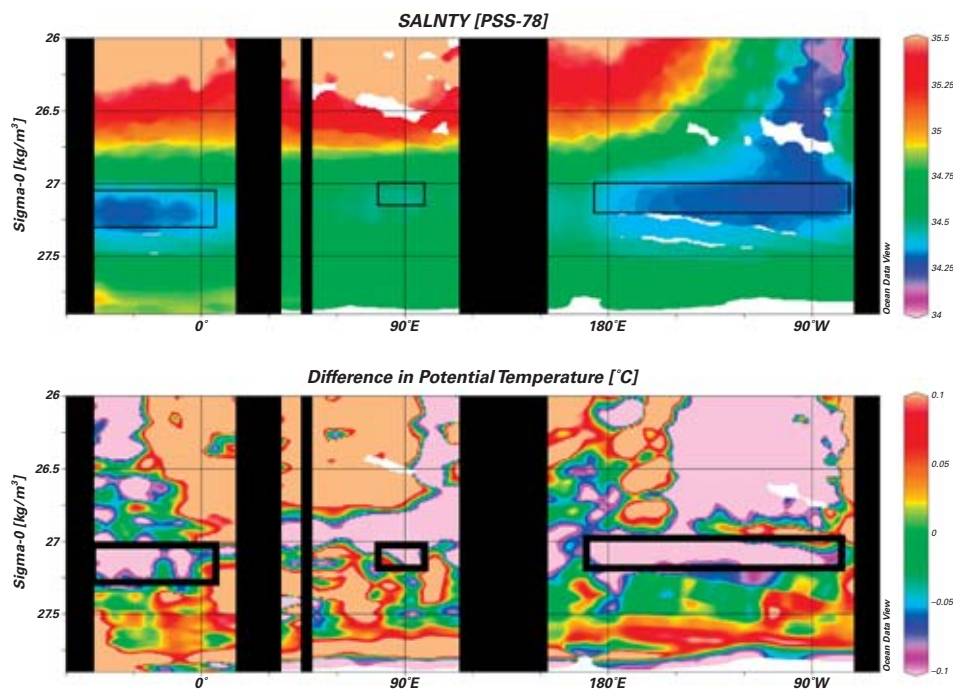


Fig. 7 Potential Density ~ Longitude Section of Salinity (Upper Panel) and Difference in Potential Temperature (lower Panel). Black borders represent AAIW.

Items that were measured are as follows;

- (a) CTD lowered down to the bottom with Lowering ADCP, acoustic altimeter, dissolved oxygen sensor, fluorescence meter, transmission meter and 36 Niskin bottles.
- (b) Water sample collection with 36 12-liter Niskin bottles.
- (c) Water sample analysis for salinity, dissolved oxygen, nutrients (phosphate, nitrate, nitrite, silicate), chlorofluorocarbons (CFC11, CFC12, CFC113, SF6), dissolved inorganic carbon, alkalinity, pH.

Water samples for ^{14}C , ^{13}C and $4\text{He}/3\text{He}$ will be collected and analyzed after the cruise.

- (d) Primary productivity and plant pigment
- (e) Underway measurements of meteorological parameters such as sea surface temperature, air temperature, humidity, etc, ocean current by ADCP, sea surface pCO_2 , bathymetry by a multi-narrow beam and gravity and geomagnetism along the cruise track

As a preliminary result, Fig. 7 shows a potential density-longitude section of salinity (upper panel) and

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that of the difference in potential temperature between this study and previous observations (lower panel). The Antarctic Intermediate Water (AAIW), which was formed in the southern ocean and characterized by salinity minimum water in the Southern hemisphere, cooled by about 0.05°C in the Indian, Atlantic and Pacific Oceans.

2) Kuroshio Extension Study

Abyssal current structures in the area of the Kuroshio Extension are examined using lowered ADCP data obtained along $146^{\circ}25'\text{E}$ and $152^{\circ}30'\text{E}$.

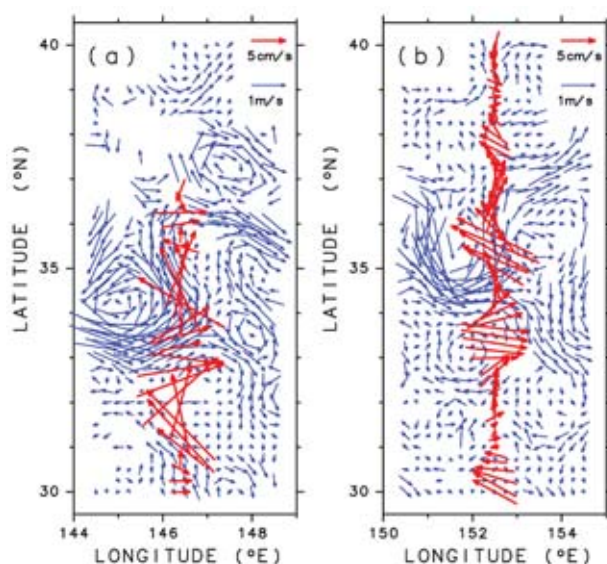


Fig. 8 Near bottom currents based on LADCP data (red arrows), and surface flow based on satellite altimeter data (blue arrows) around (a) $146^{\circ}25'\text{E}$ in May 2001 and (b) $152^{\circ}30'\text{E}$ in July 2000.

The flow of the Kuroshio reaches the ocean floor with a shift of the current to the right with depth. The abyssal flows have speeds of over 10 cm/s. Westward deep counter-currents are observed to the north and south of the abyssal Kuroshio current. The eastward Kuroshio transport is 163 Sv ($1 \text{ Sv} = 10^6 \text{ m}^3/\text{s}$) across $146^{\circ}25'\text{E}$ and 113 Sv across $152^{\circ}30'\text{E}$, larger than previous studies because the contribution of the abyssal Kuroshio flow is twice as that of geostrophic flow. The downstream variation of the transport suggests the Kuroshio strength increases after separating from the coast of Japan and decreases before $152^{\circ}30'\text{E}$.

3) Wake Island Passage Flux Experiment (WIFE)

In FY 2003, we began the Wake Island Passage Flux Experiment (WIFE). The WIFE mooring array was designed to observe Circumpolar Deep Water (CDW) flowing into the North Pacific from the Southern Ocean as a deep western boundary current (Fig.10a). CDW is defined by potential temperatures less than 1.2°C in the Samoan passage. Five moorings were deployed across a deep passage near the Wake Island Passage (Fig.10b) on R/V Mirai MR03-K02 cruise. Velocity observation is being conducted in cooperation with Kyushu University. CTD/RMS/ LADCP observations were carried out at nine stations along the observation line (Fig.10c). From the hydrographic section data, a vertical section of geostrophic velocity was estimated with the application of a 1.2°C reference surface (Fig.10d).

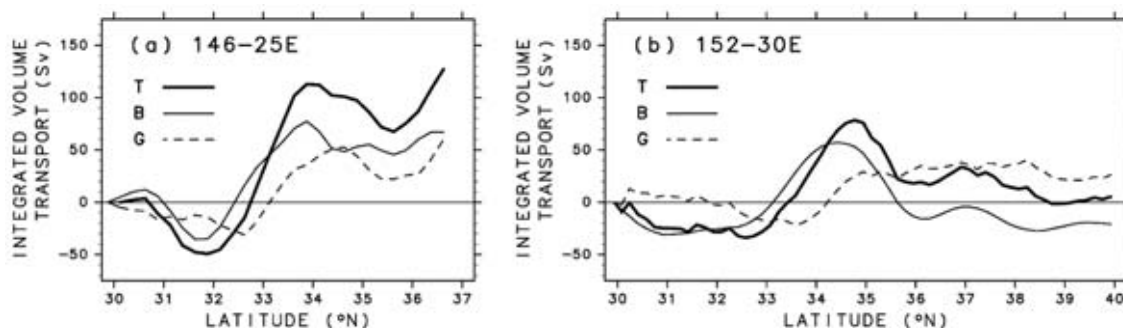


Fig. 9 Latitudinal distribution of integrated volume transport (thick line), barotropic component based on bottom velocity (thin line), and baroclinic component based on geostrophic flow relative to the bottom (dashed line) along (a) $146^{\circ}25'\text{E}$ and (b) $152^{\circ}30'\text{E}$. The baroclinic transport of the Kuroshio Extension is offset to the north from the barotropic transport. Northern counter-current of the Kuroshio Extension appears only after consideration of the barotropic flow.

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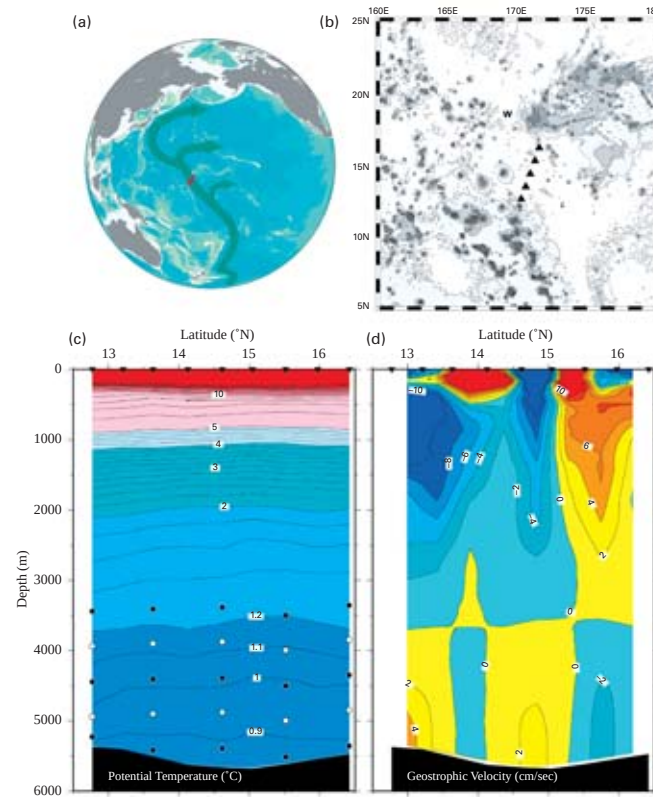


Fig.10 (a) Sketch of the bottom water flow in the Pacific. The red line represents mooring positions. (b) Mooring stations. "W" shows the position of the Wake Island Passage. The contour interval of bathymetry is 1,000m. Areas shallower than 5,000m are shaded. (c) Vertical section of temperature obtained by CTD observation from the ship. The solid circle (●) represents the position of the moored CTD and current meter, the open circle (○) represents the position of the moored CTD. (d) Vertical section of geostrophic velocity. The west-northwest component is positive.

Using the velocity data, volume transport of CDW across the observation line was estimated to be 2.5 Sv. The moored CTDs were attached to a water-sampling frame at CTD/RMS casts before deployment to simultaneously obtain the moored CTDs' data and accurate in-situ CTD/RMS data. In the same way, the moored CTDs are going to be compared with accurate in-situ CTD/RMS data after recovery. From the results of comparison before deployment and after recovery, the moored CTDs are going to be calibrated.

4) Monitoring by VOS

Observation of the Kuroshio current structure and its volume transport over the Izu Ridge continues using shipborne ADCP mounted on the ferry 'Ogasawara-Maru'. Upper thermal sections along the ship-course are

also observed by XBT in collaboration with Tohoku University. Another VOS observation of subtropical gyre between the Japanese coast and Hawaii began this year, using the Miyagi Prefecture training vessel 'Miyagi-Maru'. Three cruises are conducted per year between Ishinomaki (and Misaki), Japan and Honolulu, Hawaii. We observe the current structures, transport of the Kuroshio Extension and return flows of the subtropical gyre along the ship-course by using a shipborne ADCP. This observation is also conducted with Tohoku University.

Theme 3: Arctic Ocean Research

1) JWACS 2003 (Canada Basin, Chukchi and Beaufort Sea)

The Japan-Canada JWACS (Joint Western Arctic

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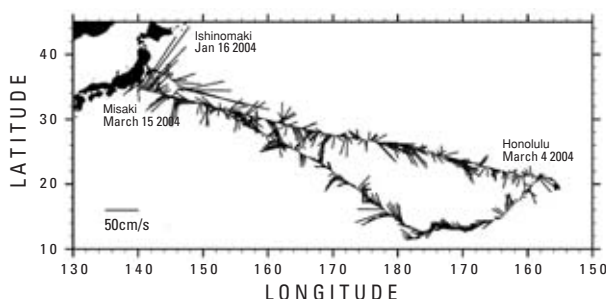


Fig.11 Surface flows averaged between sea surface and 200m during the third cruise in FY15 (January to March 2004).

Climate Studies) project conducted hydrographic survey and mooring observation in the Canada Basin jointly with NSF-funded project. The center of the oceanic Beaufort Gyre is located near 75°N, 150°W. This location is further south of the center of the sea ice Beaufort Gyre. This indicates not only wind forcing or sea ice motion drives the oceanic gyre, but also ocean dynamics and shelf water spreading determine the oceanic gyre. For example, winter shelf water with low potential vorticity occupied the center of the oceanic gyre. Focusing on the winter water formation region, after the late 1990s, sea ice concentration along the Alaskan Coast of the eastern Chukchi Sea had considerably decreased. It means effective coastal polynya formation occurred concurrently with the wintertime strengthening of the Beaufort High. Coherent salinization of winter dense water was also observed in the long-term mooring records. Salinization not only occurred by brine rejection in the polynya but also by joint effects of coastal upwelling and cooling.

2) J-CAD observation in the NPEO Project

During 2000, we began to conduct sustainable time-series observations using ice-drifting buoy, J-CAD (JAMSTEC Compact Arctic Drifter). By the end of 2002, five J-CADs were deployed in the Arctic Ocean and were providing hourly temperatures, salinity, upper-ocean currents, and meteorological data. Some J-CAD deployments have been carried out as part of NPEO (North Pole Environmental Observatory)

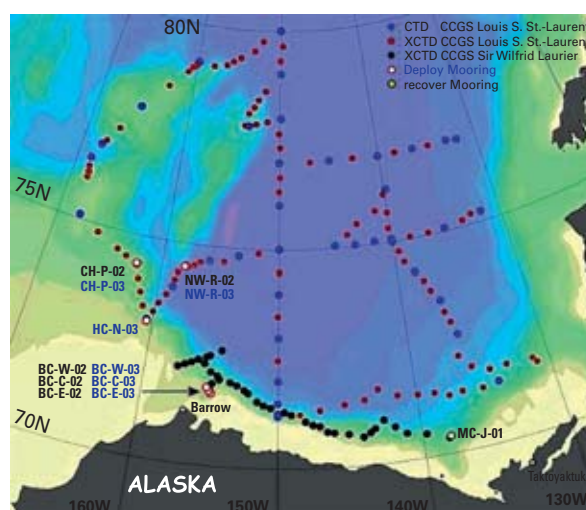


Fig.12 Map for JWACS 2003 hydrographic and mooring stations.

Project in collaboration with University of Washington and PMEL/NOAA. These observational results showed important change in the Arctic Ocean.

On April 28 2003, J-CAD 6 was deployed in the Alaskan side of Lomonosov Ridge (88.59°N, 167.38°E), in addition to two GPS buoys and an Ice Mass Balance Buoy (IMB). Figure 13 illustrates a schematic view of the buoy deployment in NPEO 2003. The GPS buoys were used to correct the compass data of J-CAD 6. From comparisons of compass data with GPS accurate azimuthal it is clearly found that Watson compass (3-axis fluxgate compass) can measure correct heading even near the magnetic dip pole. On the other hands, we found that WH-ADCP compass (2-axis fluxgate compass) illustrated good heading measurement results where horizontal magnetic intensity exceeded 3000 nT.

Figure 14 presents the distribution of freezing temperature departure (FTD) on the 34.1 salinity surface from observational results of the early 2000s (2000-2002). The data were mainly collected by J-CADs, NPEO CTD surveys, and SCICEX (the submarine-based Scientific Ice Expedition) cruise in 2000. The thick dotted line corresponds to FTD = 0.2.

From analysis of water mass properties in the eastern Arctic Ocean, we found that FTD less than 0.2 at a salinity of 34.1 is indicative of convectively formed

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Lower Halocline Water (cLHW). In the early 2000s, cLHW was prevalent in the Arctic Mid Ocean Ridge and the Nansen Basin but not the Amundsen Basin. Figure 15 (a)-(c) illustrate distributions of FTD on the salinity 34.1 in the early 1990s (1991-93), the mid 1990s (1994-96), and the late 1990s (1997-99). In the early 1990s, cLHW covered only the Nansen Basin, but extended to the northern side of the Arctic Mid Ocean Ridge in the mid 1990s and covered the whole of the Amundsen Basin by the late 1990s. In the early 2000s, the area of cLHW moved back to its present boundary on the northern side of the Arctic Mid

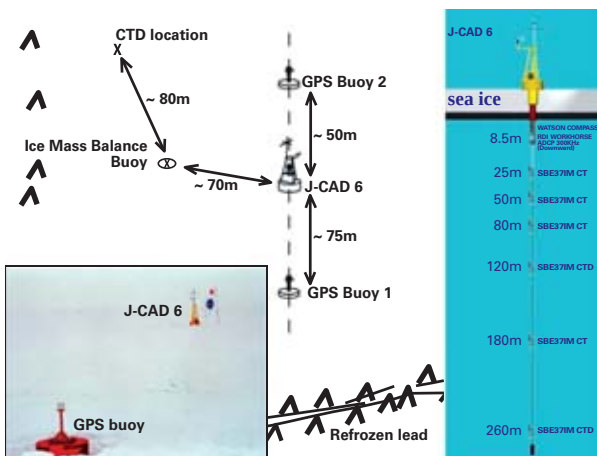


Fig.13 Schematic map of J-CAD 6 deployment in 2003 and J-CAD 6 sensor composition.

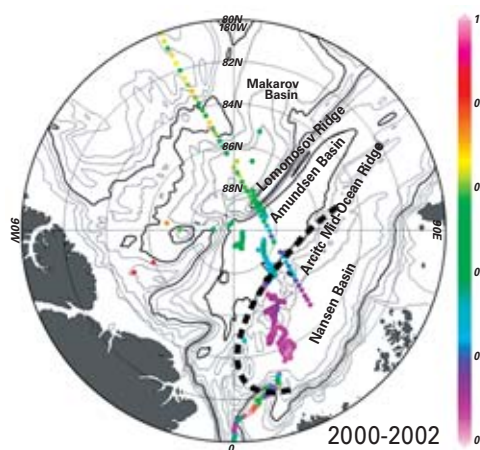


Fig.14 Distribution of Freezing Temperature Departure (FTD) on the 34.1 salinity surface in the early 2000s (2000-02). The thick dotted line shows FTD = 0.2. Contour lines show bottom topography with an interval of 500 m.

Ocean Ridge (Fig.14). These results correspond roughly to other changes in the Arctic Ocean circulation and water mass structure, but with a time delay.

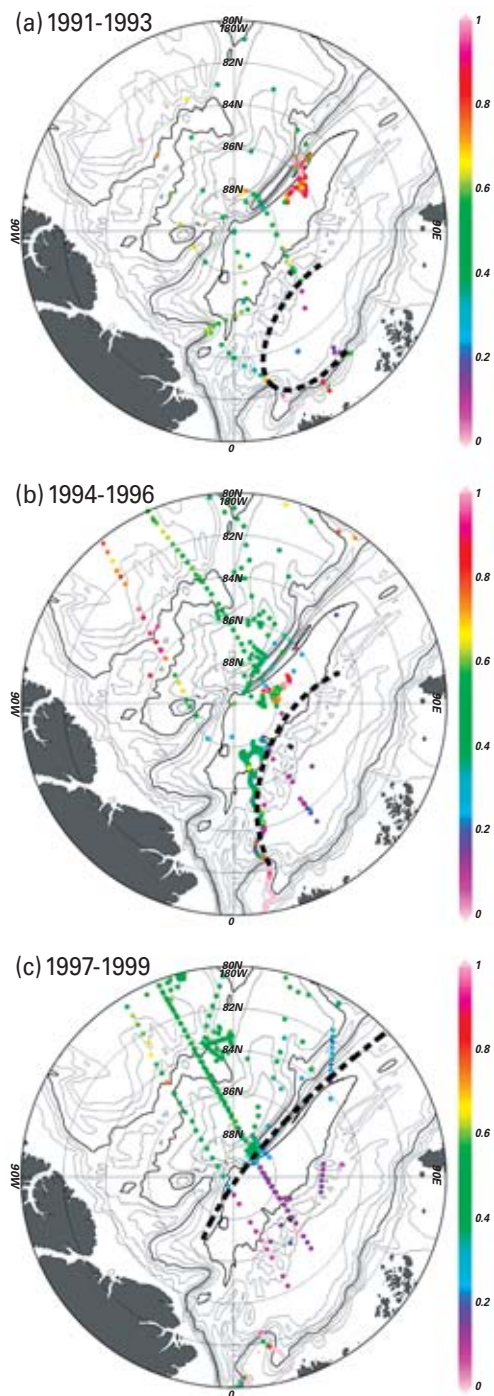


Fig.15 As in Fig.14, but the data were observed in (a) the early 1990s (1991-93), (b) the mid 1990s (1994-96), and (c) the late 1990s (1997-99).

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Theme 4: Research on the chemical environment and its changes in the ocean

We conducted hydrographic survey cruises along the World Ocean Circulation Experiment (WOCE) Hydrographic Program (WHP) lines in the Southern Hemisphere (R/V Mirai MR03-04 cruise, BEAGLE2003). The primary purpose of this cruise was to understand the role of the Antarctic Overturn System, (basic thermohaline circulation originating around the Antarctic Continent) in re-distributing anthropogenic CO_2 absorbed in the Southern Ocean. During this cruise, we obtained distributions of inorganic carbon, chlorofluorocarbons, and other chemical components along about 30°S from surface to bottom. Samples for radiocarbons and total organic carbon were also collected.

In leg 6 of this cruise, we made observations concentrating on the eastern slope of the Kerguelen Plateau to understand the formation and characteristics of Antarctic Bottom Water and to study biogeochemical processes in the Antarctic Ocean.

1) CO_2 in the Southern Hemisphere

The primary purpose of this cruise was to re-occupy the WHP lines of the Pacific (P6), Atlantic (A10) and Indian Oceans (I4 and I3) to understand the role of the Antarctic Overturn System (basic thermohaline circulation originating around the Antarctic Continent), in re-distributing anthropogenic CO_2 absorbed in the Southern Ocean.

Dissolved inorganic carbon (C_T), total alkalinity (A_T), pH and underway pCO_2 were measured. At about 250 stations, we collected seawater samples of CO_2 -system parameters in a full water column, and finished all analyses onboard the R/V Mirai. Precision of C_T , A_T and pH was estimated to be $\sim 1.0 \mu\text{mol kg}^{-1}$, $\sim 2.2 \mu\text{mol kg}^{-1}$ and $\sim 11 \times 10^{-4}$ pH unit, respectively. Detailed distribution of CO_2 -system parameters (Fig.16, 17, 18) were obtained with high precision, which help to estimate accurate distribution of anthropogenic CO_2 . Decadal changes of anthropogenic CO_2 associated with the Antarctic Overturn System can be

detected by comparing distributions with previous WOCE results, because CO_2 -related properties such as CFCs, nutrients, dissolved oxygen, etc. were also measured precisely.

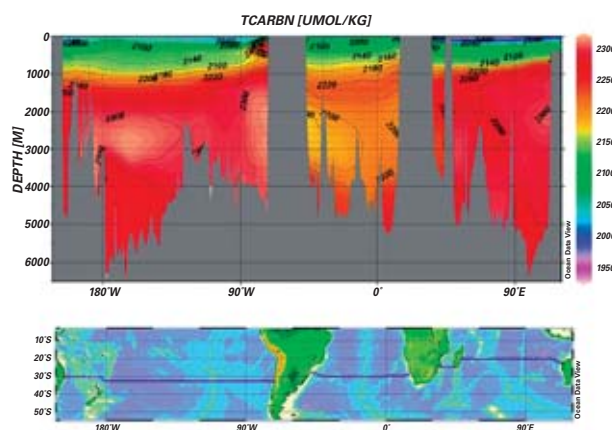


Fig.16 Distributions of C_T along the cruise track of BEAGLE2003 in the Southern Hemisphere.

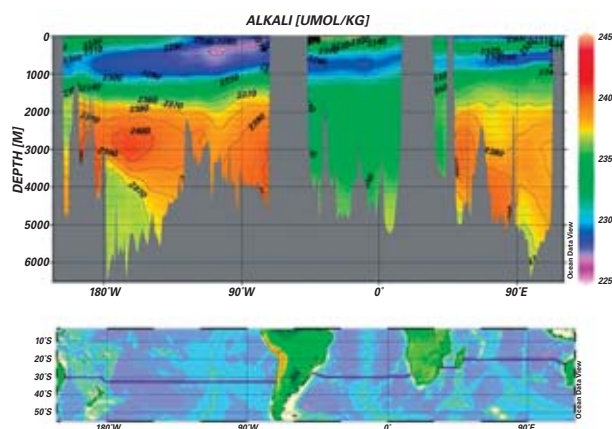


Fig.17 Same as Fig.16, but for A_T .

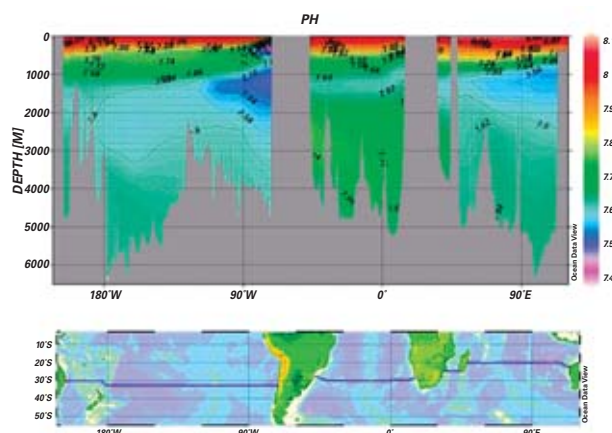


Fig.18 Same as Fig.16, but for pH.

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2) CFCs in the South Atlantic

CFC concentrations in seawater were measured at about half of 500 hydrographic stations during a hydrographic survey cruise in the Southern Hemisphere (BEAGLE 2003 Cruise). A cross section of CFC-11 obtained in the South Atlantic is shown in Fig.19a, together with that of CFC-11 obtained in 1993 (Fig.19b). CFC-11 concentrations above 1000 m increased remarkably. This increase would be related with changes in Antarctic Intermediate Water. CFC-11 concentrations in bottom water can be attributed to the age of water occupying the basin. CFC-11 in deep water was detectable only in the western (Argentine) Basin in 1993. Concentrations increased in 2003, and areas with detectable CFCs expanded into the central basin. The most important information from CFC distribution in the South Atlantic is that detectable CFC-11 existed in the eastern basin. It implies that water which occupied the eastern basin was affected by younger Antarctic Bottom Water after the 1950s.

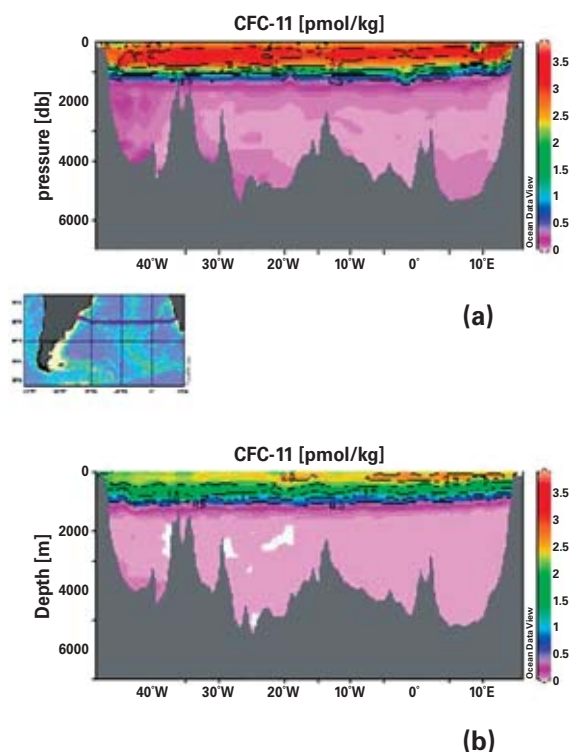


Fig.19 Distributions of CFC-11 along the section in the Southern Ocean during (a) MR03-04 cruise leg4, 2003 and (b) WOCE in 1993.

3) Observation near the Kerguelen Plateau

In the eastern slope of the Kerguelen Plateau, we measured water temperature, salinity, nutrients, carbonate properties, CFCs and some biogenic gases related to climate change. Distributions of water temperature, salinity, dissolved oxygen, CFC-11, CFC-12 and CFC-113 near the Kerguelen Plateau are shown in Figures 20a, b, c, d, e and f, respectively. It was discovered that dissolved-oxygen and CFC-dense water existed at the slope's end, where water temperatures were low. High dissolved oxygen and CFC content found in this water are estimated to have formed in the surface ocean, because both chemical components are usually dissolved into surface water from the atmosphere. The distributions are similar to results obtained along the WOCE I08 line ten years ago. The age of the bottom water estimated with both CFC concentrations is about 20 years. The bottom water near the eastern slope of the Kerguelen Plateau is known to form near the Adelie Coast. Thus, bottom water observed near the Kerguelen Plateau is estimated to reach it about 20 years after sinking from the surface near the Adelie Coast.

Personal Research

Study on measurement of chlorofluorocarbons and its application in oceanography

Chlorofluorocarbons (CFCs) are useful key tracers for understanding water circulation in surface, subsurface and fresh bottom waters. CFC-11, CFC-12, CFC-113 and tetra-chlorocarbon (CCl_4) are man-made CFCs, and each has different increasing rates in the atmosphere. The distributions of these gases are related to water circulation, and the ratios between CFCs indicate water age transported from the ocean surface. Improvement of analytical methods for high quality and simultaneous measurement of CFC-11, CFC-12, CFC-113 and CCl_4 has been examined. Analytical results obtained with a new sample preparation system had a higher performance than an international standard method. This system was used during hydrographic survey cruises in the Southern Hemisphere (BEAGLE2003 cruise).

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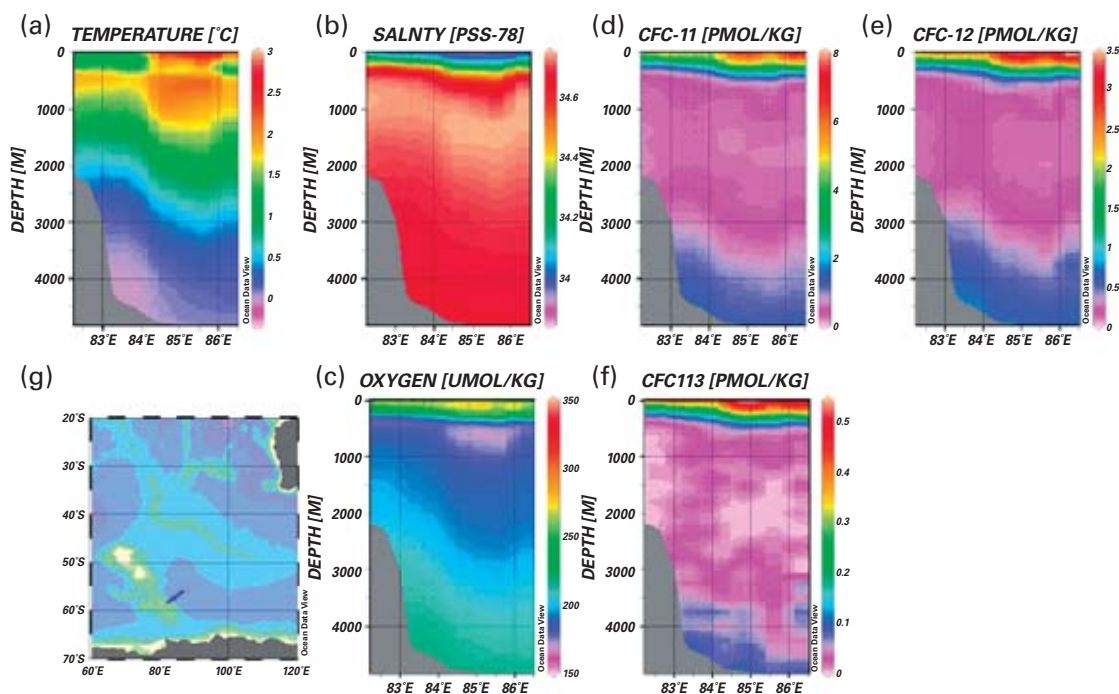


Fig.20 Distributions of hydrographic and chemical properties in the eastern slope of Kerguelen plateau. (a) water temperature, (b) salinity, (c) dissolved oxygen contents, (d) CFC-11, (e) CFC-12, (f) CFC-113, and (g) observation area.

Research on paths of ENSO signals from mid-latitude to tropical region in the Pacific Ocean.

The ENSO (El Niño/Southern Oscillation) affects to global climate change. Recently, modulation of the ENSO signal, that period is longer than that of the regular ENSO cycle, is known in some studies. The cause of the modulation may be propagations of the signals from the mid-latitude to the tropical Pacific Ocean. The purpose of this study is to investigate the path of the signals and the variability in the western tropical Pacific Ocean by the results of ocean general circulation model and observed data.

In the period between the 1997/98 and 2002/03 El Niño events, extremely large accumulation of warm water volume in the off-western tropical Pacific region (off Philippine coast) is found in the model analysis. The large accumulation also can be seen clearly in the Argo float data. The warm water volume migrates to the equatorial region in the 2002/03 El Niño developing period, this movement contributes the increasing of warm water volume in the eastern equatorial Pacific region.

From XCTD observations, the difference of temperature observed in two periods between 2003 summer (MR03-K03) and 2002 summer (MR02-K04) is represented (Fig.21). Along 130°E, warming and cooling trends are observed in the south and north of 8°N, respectively. Along 8°N, though temperature becomes lower in 2003 than in 2002 in the western boundary region (130°E), it is warmed off western boundary region (138°E). This variability is also seen in distribution of 20°C isotherm depth obtained by the TAO/TRITON buoy array. The warming signal is propagated via Rossby wave from the central tropical Pacific but cannot reach in the western boundary region. The temperature difference in east-west direction is also observed along the section across the Mindanao current. This suggests the westward propagation of temperature anomaly may affect the western boundary current that plays an important role in meridional heat transport.

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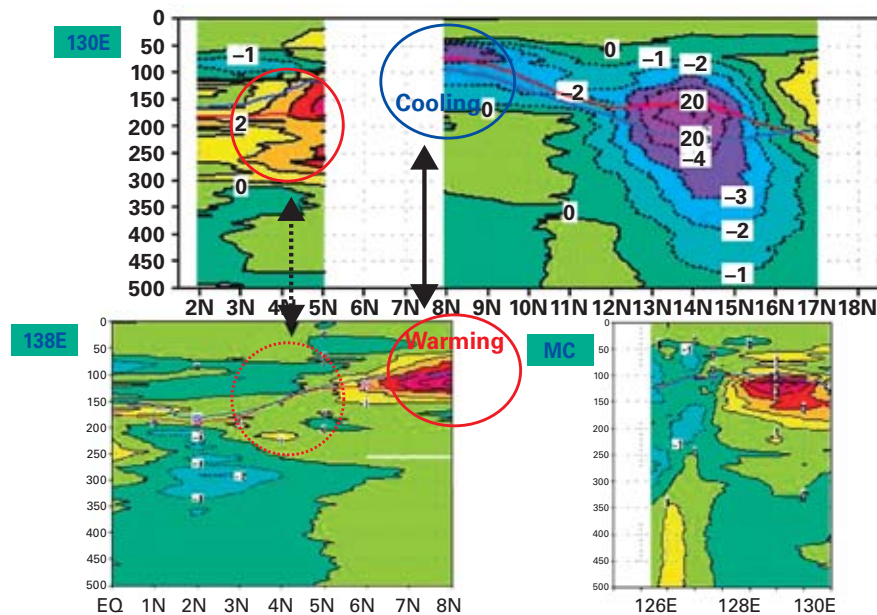


Fig.21 The difference of temperature observed in two periods between 2003 summer and 2002 summer in XCTD sections along 130°E (top), 138°E (bottom left) and the Mindanao current (bottom right). Warming (cooling) region after the El Niño is drawn by warmer (colder) color. Blue and red circles indicate remarkable cooling and warming regions. Blue and red lines are 20°C isotherm depth in summer 2002 and 2003, respectively.

Study for the better estimation of the rainfall amount over the tropical ocean

The fresh water flux is the one of the most important factors to understand the behavior of the tropical western Pacific "warm water pool". We start this study from this year, to investigate better estimation of the rainfall amount, by combining different raingauges: buoy-installed raingauges providing direct-measured continuous data, shipborne radar including information about the behavior of precipitating systems, and satellite-borne sensors covering wide area.

In the second year of this study, we continued deployment and recovering of the optional capacitance raingauges on the TRITON buoys. The recovered raingauges are damaged and affected by the bird droppings. The newly-deployed buoy and raingauges are improved to avoid the droppings. On the other hand, optical rain gauges are examined in the field intercomparison experiment at Okinawa land site, where the characteristics of the rain are similar to that in the tropics (than at Mutsu). In addition, we presented the results of the

intercomparison analysis in the oceanic field on the conference of the Oceanographic Society of Japan.

Cooperative Research

Study on estimation of CO₂ flux in the North Pacific

The purpose of this study is to estimate CO₂ flux in the North Pacific by an inter-comparison of CO₂ data between JAMSTEC and Meteorological Research Institute. In doing so, influences of climate variations and changes on the CO₂ flux are considered, which have been ignored in previous studies.

In this year, we obtained high accurate and spatially dense data for water column dissolved inorganic carbon, total alkalinity, pH and underway pCO₂ along the WOCE P6 line in the Southern Hemisphere.

Vicarious calibration study of the ocean color sensor GLI in the East China Sea

The continental shelf of the East China Sea is bordered by the Okinawa Trough to the east. The

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Kuroshio flows to the east of Taiwan, and enters to the East China Sea. The nutrients are supplied on the continental shelf by the Yangtze River and the upwelling of the Kuroshio. Therefore, phytoplankton biomass and the primary productivities are elevated by the nutrient rich water. We carried out the observational cruise in the East China Sea along the eastern edge of the continental shelf by the R/V KAIYO, which was surveyed simultaneously with the satellite from February to March 2004 by cooperation with JAXA. We detected the warm water derived from the Kuroshio (Fig.22) and the high concentration of chlorophyll a in the East China Sea during this cruise. Although primary productivity is high, it is difficult to estimate it from the satellite data because of in situ many suspended matters. We measured various parameters (nutrients, chlorophyll a, primary productivity, spectral absorption, CDOM, etc.) in this cruise. Therefore, our cruise and the data will be useful to improve the present satellite algorithms.

Study on oceanic radiocarbon in the western North Pacific and adjacent seas

The purpose of this study is evaluation of water circulation in the North Pacific and adjacent seas including the Japan Sea, the Okhotsk Sea, and the Bering Sea using oceanic ^{14}C and ^{129}I as chemical tracers. In FY2003, we carried out analysis of data obtained in FY2001 and FY2002.

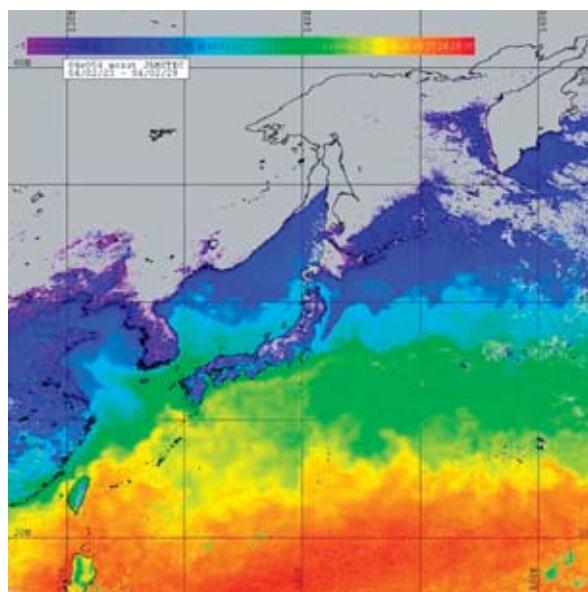


Fig.22 Sea surface temperature observed by NOAA/AVHRR during an observation cruise (one-week composite map for 23~29, February 2004).

Research Activities

Marine Ecosystems Research Department

Aim, Outline and Content of Research

Recent marine biological research has revealed extensive populations of great diversity from midwater to ocean bottom layers, and also within the earth's crust beneath the seafloor. These discoveries have altered our whole concept of the global biosphere, and have given rise to the need to tackle issues such as reconstruction of the marine ecosystem model into a dynamic model of material circulation with interaction between photosynthetic ecosystems in shallow sea areas and chemosynthetic ecosystems primarily on the deep seafloor, and elucidation of marine biological evolution and the interaction between the environment and organisms. The Marine Ecosystems Research Department therefore started a project to study the function and structure of the marine ecosystem as part of the whole the Earth system, and is proceeding with two main avenues of research: research on biological production and material circulation in marine ecosystems and clarification of the mechanism governing diversity among marine organisms. The Department is also engaged in research on the physical, chemical and biological environment of marine organisms to support the foundation of that research. We are collecting basic data necessary to clarify the structure and role of marine ecosystems from surface water to deep seabed and sea floor sediments. Embracing the research project we have personal and collaborative research aiming at more effective development.

1. Research Project

Study for Understanding the Structure and Role of Marine Ecosystems in the Earth System

(1) Clarification of the mechanism governing diversity among marine organisms

Marine ecosystems are composed of a wide range of living species that have various physiologies to cope with complex marine environments. It was once believed that adaptive evolution caused by genetic variation is the main process of biological evolution. However, the latest genomic analysis and superfine structure cellular analyses suggest it is highly probable that genetic acquisition caused by symbiosis has been promoting biological evolution.

There are two types of symbiosis categorized by the relationship between host species and symbiotic microorganism: intracellular symbiosis with high physiologic dependence, and extracellular symbiosis with low physiologic dependence. We still have unsolved questions: the evolutionary process whereby mutual dependence leads to close intracellular symbiosis, the physiological functions and control mechanism necessary for symbiosis, and how these microorganisms differ from parasites or infections that damage the host. On the other hand, organisms living in

hydrothermal areas resulting from submarine volcano activities adapt to a high-concentration heavy metal environment or high temperature environment and live symbiotically with chemosynthetic bacteria. In this kind of environmental adaptation, energy metabolism due to chemical synthesis is provided by symbiotic bacteria, but it is likely that durability to hydrothermal environments is acquired not by symbiotic interaction, but by genetic variation. The aim of this research and development is not only to conduct phylogenetic systematics and genetic analysis of collected marine

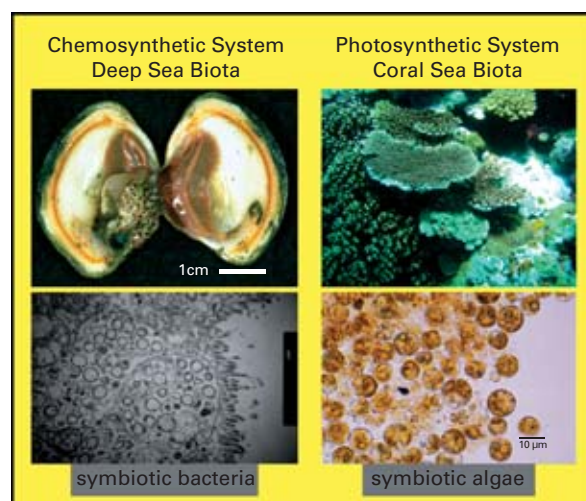


Fig. 1 Symbiotic adaptation to environments

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organisms, but also to validate the evolution hypothesis that the diversity of physiological functions and species of marine organisms was a consequence of symbiosis and environmental adaptation, using genome analysis of symbiotic systems, analysis of physiological functions and functional analysis of the environmental adaptation of organisms living in hydrothermal areas.

(2) Research on biological production and material circulation in marine ecosystems

Biological production in marine ecosystems has been estimated mainly by looking at photosynthetic biological production in shallow seas or ocean surface layers. However, recent marine biological research has revealed that a number of organisms live from the midwater to the deep seabed and also within the earth's crust beneath the ocean floor. From the midwater to deep seabed, photosynthetic ecosystems are dependent upon organic matter produced by solar energy. In volcanic areas at plate boundaries or plate subduction areas, or within the earth's crust beneath the ocean floor, chemosynthetic ecosystems absorb

chemicals as an energy source provided from inside the Earth. Thus far, research on biomass and material production in marine ecosystems has accumulated data from the ocean surface and coastal areas but there are few quantitative analyses on the structure of ecosystems in the midwater or the deep seabed, or within the earth's crust beneath the ocean floor. It is only presumed that the biomass of benthos in deep-sea chemosynthetic ecosystems is ten thousand times as much as on and in the "regular" deep seabed. It is also hypothesized that, although photosynthetic production dominates in most marine ecosystems, chemosynthetic biological production cannot be ignored when thinking about ecosystems at plate boundaries around the earth. It is therefore necessary to clarify the nature of photosynthesis derived matter from the surface layer to the midwater and chemosynthesis at the deep seabed, and to investigate material balance and circulation along the vertical axis, and material exchange (consumption and reproduction) in midwater, as a process among biological communities, to precisely estimate biological production in marine ecosystems.

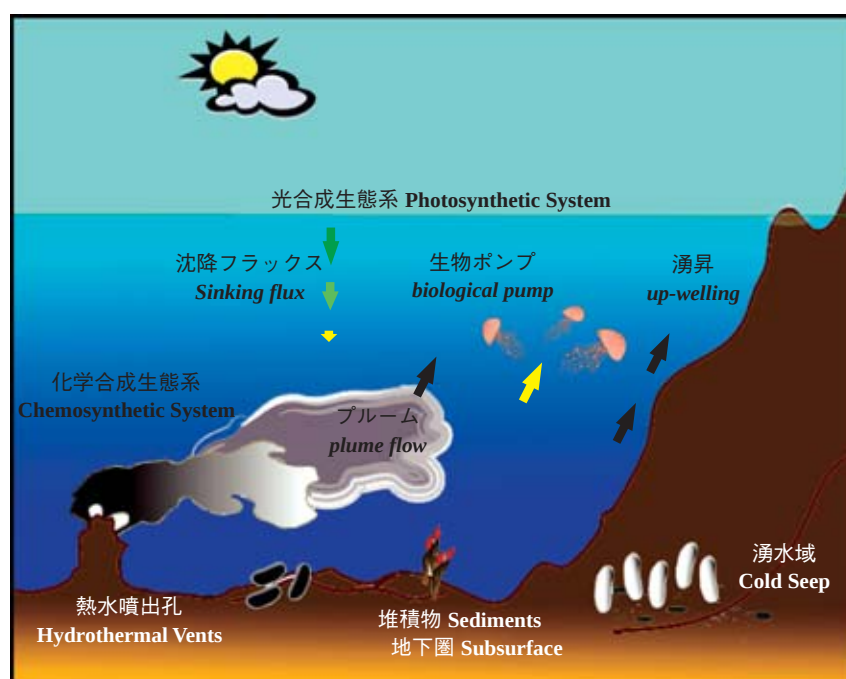


Fig. 2 Conceptual model for marine ecosystems extending from the ocean surface to the deep seabed

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To establish a method for effective, sustainable marine resource use, we need to elucidate the processes of biological production and material circulation among biological communities. It has been demonstrated that undersea volcanic and plate subduction areas extending over the West Pacific Ocean from the Japanese islands to East Asia are actually a reservoir of chemosynthetic ecosystems. Thus we believe Japan should take the lead in clarifying how biological production's benefits in deep seabeds affects biological resources in the sea. The aim of this research is to quantify community structure (food chain, composition, population size, etc.), productivity and material circulation (microorganism loop, proliferation, standing quantity, etc.) of deep seabed chemosynthetic ecosystems and their surrounding midwater ecosystems, whose data have been poorly collected in comparison to photosynthetic ecosystems. We also intend to develop research toward high-precision time-series analyses of dynamic states of biological communities by long-term observation of biological communities.

(3) Research on the surrounding environment of marine organisms

Marine ecosystems are formed not in an environment full of uniform, homogeneous seawater, but in a local environment or an environment with fine organisms under diverse physical and chemical conditions. The diversity, biomass and biological productivity of marine organisms are influenced strongly by the surrounding environment. To understand the behavior of marine organisms, the change of environmental conditions in a local living environment should be observed rather than in a large ocean environment. Also, accumulation of basic data in long-term observation of organisms and environmental factors is necessary to estimate the influence of environmental change on ecosystems. In order to analyze behaviors of marine organisms and ecosystems, we need not only organism farming and experimentation on model environments at facilities, but also long-term on-site observation. We also plan to carry out an on-site model experiment, which is difficult to perform at onshore facilities, at an

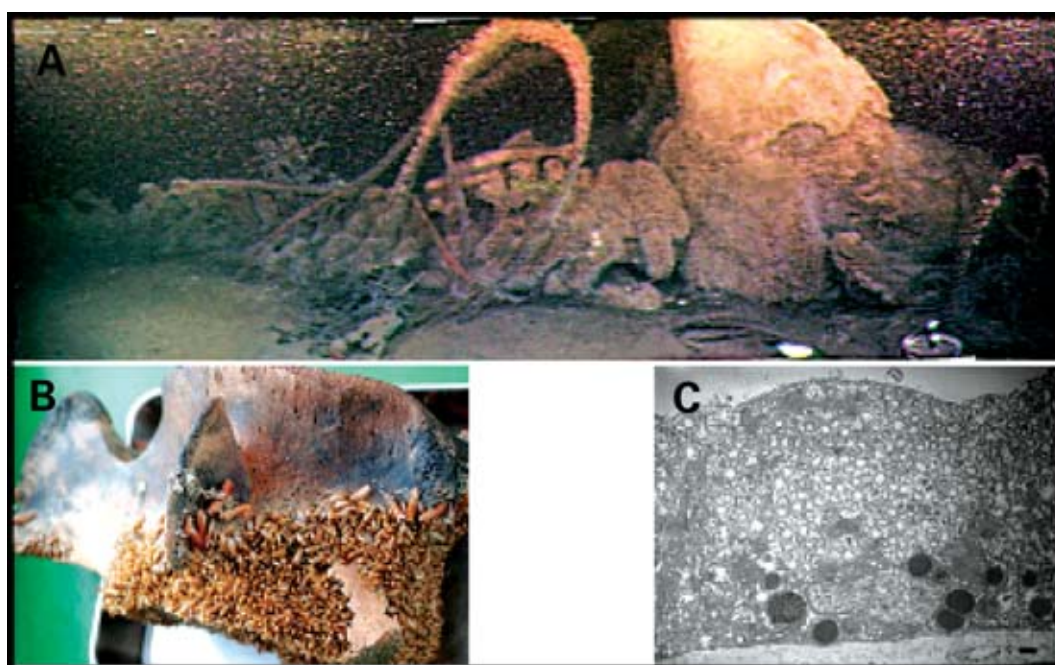


Fig. 3 Survey of a whale carcass community

A: A sperm whale carcass lying on the ocean bottom at 300m. It was dumped 18 months ago and the softest structure had already decayed. B: Bivalves clinging to the collected whale carcass (backbone). C: Microscopic image of epithelial cell tissue in *Adipicola pacifica*'s grill. The existence of symbiotic bacteria was confirmed.

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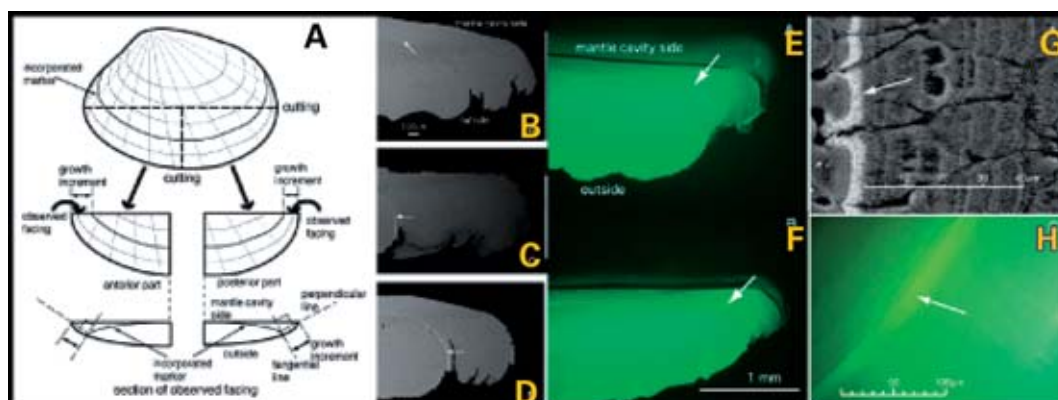


Fig. 4 Detection of growth lines on a bivalve's shell

A: The marked shell of a bivalve was cut and ground. B, C, D: SEM backscatter image of the cut surface of the shell. Strontium has a larger atomic mass than calcium, the main constituent of bivalve shells, and it looks white in the primary electron image. A clear strontium band was observed in the shell with a high marking concentration (D). E, F: A fluorescent microscope image of the marking using calcein, a fluorescent dye. The marking band is a fluorescent lime green. G: Strontium marking. 1200-fold magnification by electron microscope enables the identification of growth lines in micrometer units. H: Observation image of the marking band of calcein at a 600-fold magnification by a fluorescent microscope. The boundary of the bands is blurred when using fluorescent dye.

experimental station suitably constructed for an ocean environment. In this kind of model experiment, we monitor and analyze on-site environmental physico-chemical factors. This research is conducted through close coordination with research on biological production and material circulation of marine ecosystems, and research on marine ecosystem diversity. It will also be developed aiming to construct a predictive model of changes in environments and ecosystems and an evolutionary model of marine ecosystems, by time-series analyses of accumulated data on the relationship between organisms and their environmental conditions.

(4) Project research achievements in fiscal 2003

(a) Validation of the whale carcass "stepping stone" hypothesis and research on the transition of whale carcass communities

Considering a dispersion of organisms in hydrothermal vents and cold seep areas, we have to assume propagation of the same living species as the deep-sea chemosynthetic community to be able to explain the "stepping stone" function of whale carcass communities. To verify this, we investigated twelve sperm whale carcasses dumped off the Noma Cape in

Kagoshima Prefecture on February 1, 2002. In particular, we are focusing on an analysis of the propagation of Mussel bivalves and Solemyidae bivalves, which are the equivalent or close species to the deep-sea chemosynthetic community, by using the histochemical method to measure sexual maturation.

(b) Development of measurement techniques for minimal growth of bivalves

We marked the tree-ring type growth lines of bivalves, introducing strontium into them. We then measured the growth of bivalves on micrometers with an electron microscope. Up to now, the measurement was only possible in units of tens of micrometers. This method can be applied to estimate the maturation of slow growth deep-sea bivalves and used as a tool to analyze the material circulation of deep-sea ecosystems.

(c) Genome analysis of symbiotic bacteria in a chemosynthetic symbiotic organism

In fiscal 2003, we surveyed chemosynthetic communities mainly in the Japan Sea, Sagami Bay and Kagoshima Bay. We analyzed microorganisms living in the environments and collected benthos to clarify

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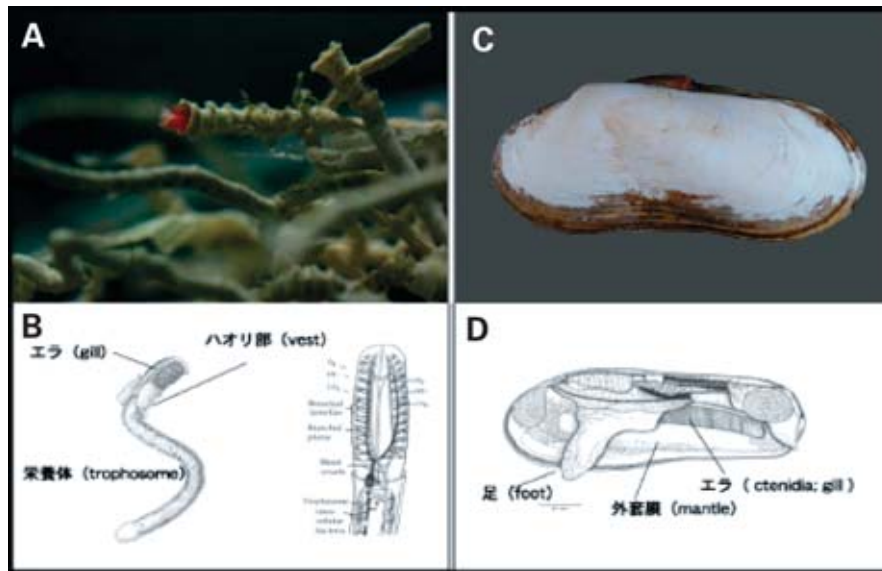


Fig. 5 Chemosynthetic organisms dependent on symbiotic bacteria

A-B: *Lamellibrachia satsuma* has symbiotic bacteria in the trophosome hidden in the tube.

C-D: *Calyptogenia laubieri* has symbiotic bacteria in the grill epithelial cell tissue.

the mechanism of symbiotic systems based on chemosynthesis. We separated the symbiotic bacteria from the collected samples of *Calyptogenia laubieri* and *Lamellibrachia satsuma*, etc. and are proceeding with genome analysis.

2. Personal Research

(1) Studies on the transport process of eggs and larvae in coral reef regions

In recent years coral communities (species) in coral reef regions have tended to shift northward with high seawater temperatures, and the Kuroshio Current appears to be an important environmental factor in this phenomenon. However, it is not clear how coral eggs and larvae are transported (washed away) from reef regions such as the Sekisei Lagoon offshore (the Kuroshio Current), nor is it clear how coral eggs and larvae released into offshore are transported (washed away) to other reef regions. These are fundamental questions that have not been clarified. Water flow in reef regions is an important environmental factor affecting the growth, distribution and structure (regional characteristics) of various coral populations. The Kuroshio Current (or the Kuroshio Counter

Current) passes off Japan's offshore coral reef regions. The flowing in and out of the offshore water (the Kuroshio Current water), along with the Kuroshio Current's path variation into coral reef regions is considered to play an important role not only in tidal or meteorological factors but also the transport process of coral reef eggs and larvae.

In this study, we classified long-term Kuroshio path variations and examined the correlation between the distribution of coral populations in reefs and seawater exchange using satellite images, water temperature distribution and oceanographic data collected in the seas near Okinawa (from Iriomote Island to the main island of Okinawa) over the past 20 years. We also made a short-term observation of path variations using current meters in the coral reef region (Sekisei Lagoon and Sesoko Island) to shed light on the process of coral egg and larvae transportation and examine its correlation with these path variations. We analyzed seawater exchange in Sekisei Lagoon using a box model.

(2) Research on phenotypic diversity of benthic arborescent organisms

The sea area around Japan contains a great diversity

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of benthic fauna such as Octocorallia and black coral species. Unlike hermatypic coral species, which can only live in shallow tropical and subtropical waters, Octocorallia also inhabits the high-latitude regions and deep-sea areas. In this research, we verified reproductive patterns for adaptation to low water temperatures to confirm factors through which this coral has extended its habitat from shallow sea areas to the deep sea, and from low to high latitudes. We also conducted basic classification of Octocorallia and research on genetic diversity in its evolution.

In the primary stage, plans are made to conduct research on the reproductive pattern and its period and genetic diversity of species inhabiting shallow waters, and to build a taxonomic base for species inhabiting the deep sea. We focus on the classification and distribution of species inhabiting the deep sea using samples provided by the Ocean Research Institute, the University of Tokyo, and in-field collection as well as research on reproductive patterns and periods of species inhabiting shallow waters.

(3) Study on the uptake of various elements using *Porites* corals

Coral growth and distribution are affected by environmental factors such as water temperature, salt concentration, the amount of solar radiation, etc. Long-term variation of these environmental factors is believed to have caused the present coral distribution in coral reef sea areas. Detection of this variation is essential in understanding coral growth and distribution process. The coral skeleton has an annual ring pattern. By measuring the content or ratio of specific elements along this pattern, it is believed that we can see changes in environmental factors in the formative history of coral. In this research, we measure qualitatively and quantitatively the content of various ocean elements in coral insects and skeletons, using coral samples collected from oceans (*Porites* Coral) and coral in captivity, to search for the elements and element ratios usable as indices. So far we have succeed-

ed in tracing the change of element uptake in coral at an interval shorter than a month (about two weeks). A correlation between the carbon/oxygen stable isotopic ratio and coral growth was also found. We analyzed the reason and came to the conclusion that, although the reactions of oxygen and carbon to the growth of *Porites* Coral occur in the same way, only carbon reacts to photosynthesis, which might be valuable for indexing old environments. By increasing the number of samples, we discovered a regional difference in the characteristics of coral growth and element ratio. This suggests that coral grows differently depending on the environment, and the degree of difference can be estimated. In ICP-MS analysis on the ratio of strontium, magnesium and calcium, we found that it tended to have a certain correlation with water temperature variations. Furthermore, we started in-captivity experiments with different light conditions to validate the high possibility that the variation of carbon and oxygen stable isotope ratios would be due mainly to the amount of solar radiation and growth rate.

(4) Research on the relationship between shape, swimming and stomach contents in jellyfish species

Jellyfish play a key role within ecosystems as predators, but little is known about their predatory behavior. In this research, we have established the following hypothesis relating to the jellyfish's umbrella shape, swimming pattern and prey type, and seek to verify this hypothesis.

Shallow umbrella → continuous swimming → greater opportunity to encounter smaller prey → prey on smaller animals

Deep umbrella → neutral drifting → greater opportunities to encounter strong-swimming prey → prey on larger animals

This research consists of (1) observing the shape of specimens, (2) observing and measuring swimming actions and speed through video, (3) estimating the rate at which jellyfish encounter prey, and (4) analyzing jellyfish stomach contents. These observations/

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analyses were made on several species of jellyfish. This fiscal year, we obtained a result that confirms the hypothesis, from experiments and observation of five species inhabiting coastal areas. We reexamined the breeding tank and plankton net and made new forms more suitable to jellyfish. It was made clear that the fixed jellyfish expels stomach contents in a different manner depending on the classified group. For further study, we (1) collected data sets of shapes, swimming actions and stomach contents of jellyfish other than our five species, (2) observed the swimming actions not only in captivity but also in the on-site environment, (3) estimated the prey encounter rate (derived from swimming speed and possible area range) and compared the rate among species.

(5) Establishment of method to measure the genome size using fluorophotometry

Generally, microbes with small genome size had been utilized to analyze whole genomes. Recently, analysis of genome was expanded in human being and some model organisms with large genome size. *Arabidopsis thaliana* and Gramineae were chosen as a target plant for whole genome analysis. The analysis of these two species has been almost completed now, and another target is being sought from among the metaphytes. Pulsed-field gel electrophoresis was often used to measure the genome size. However, in this method the measurable genome size is restricted and much time and expensive reagents are needed to measure. On the other hand, fluorophotometry is a simple method but relatively high reliability in the measured value. In this method, however, not only DNA but also some other materials such as plant pigment are fluorescent, which is a big problem. Laminariaceae (Kombu) has been eaten since ancient times, and is known to have various health benefits. It has recently been found to contain the anticancer macromolecular polysaccharide such as fucoidan, so it is an extremely useful and beneficial plant. In this research, we established an efficient method to measure genome size using fluorophotome-

try, and measured the genome size of Laminariaceae growing in warm and cold waters. This fiscal year, the method for promoting the maturation of Laminariaceae sporophytes has not yet been established. Therefore, zoospores can be harvested once annually and the timing varies from year to year. Also, sample preparation before measuring is important if one is to perform a highly precise and effective measurement. We examined preparation methods for stages other than the zoospore, but could not obtain samples suitable for measurement. We also tried to prepare by separating drosophila sperm and tetrahymena micronuclei to use as a control, but could not obtain suitable samples. We therefore concluded it would be appropriate to use zoospores as a control to measure the Laminariaceae genome size.

(6) Analysis of jellyfish growth and studies on daily measurement method

A huge number of jellyfish inhabit midwater and ocean bottoms close to land. It is unknown if there are sufficient prey for jellyfish, and the jellyfish may be absorbing dissolved organic material. Jellyfish have the ability to shrink their body when prey shortages occur so that body size is not proportionate with age, which obstructs understanding of population dynamics. For future research of midwater ecosystems it is essential to highlight the jellyfish's uptake of dissolved organic material and population dynamics, and this research is characterized as a fundamental one. This fiscal year, we bred jellyfish under various conditions (with animal plankton or dissolved organic material, etc.) and investigated the influence of habitat on organ formation in the growth process in order to see the jellyfish's time-series traits (age traits) when undisturbed by the environment.

3. Cooperative Research

(1) Deep-sea organism research with the long-term observation station offshore Muroto

This research is to improve and establish use of a

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long-term observation station as a future means of observing marine ecosystems from deep seabed. For this purpose, we have the following research themes:

- Observation of Calyptogenia's emission of spawn and sperm: We observe reproduction on monitors and examine its relevance to environmental factors.
- Observation of seasonality in deep sea and organism activity: By analyzing data from underground thermometers, current direction and velocity meters, CTD and ADCP, we see if the data reflect the seasonality of surface water. We also observe changes in biomass, biobehavior and changes in emerging species on monitor screens and examine their relevance to seasonality.
- Organism dispersion and deep-water currents: With

data from current direction and velocity meters, CTD and ADCP, we quantitatively surveyed the travel distance and direction of deep currents around Muroto and estimated the current's capacity to carry larvae. We also analyzed the data and compared them with data from the Sagami Bay long-term observation station. This fiscal year, problems occurred in the TV camera system of the long-term observation station offshore Muroto almost simultaneously with the start of the research. Only one underwater light was usable, and the panning and tilting functions of the camera were disabled. To maintain effective observational conditions under these circumstances, we recorded images for six minutes twice a day.

Research Activities

Computer and Information Department

Policy for Research and Development

The Computer and Information Department promotes various research and development programs aimed at advancing computer technologies applicable to marine phenomena. These programs include database development of various observed data, research support for development of numerical and other models for supercomputers, visualization rendering technology for the results of numerical simulations, development of innovative computation methods, and surveys on computer utilization environments.

In fiscal 2003 we continued working on the program "Establishment of a Deep Sea Image Distribution System on JGN (Joint Research)".

1. Outline of Research and Development Themes

(1) Establishment of a Deep Sea Image Distribution System on JGN (Joint Research)

JAMSTEC has accumulated massive volumes of image data from marine surveys and research carried out using manned research submersibles, e.g., SHINKAI 6500, and remotely operated vehicles. The Global Oceanographic Data Center (GODAC) in Nago, Okinawa is responsible for digitizing, indexing, storing and disseminating these image data. This enormous mission requires a high-speed network to transmit high-definition images and videos between GODAC and the Yokohama Institute for Earth Sciences.

This research is conducted cooperatively using the JGN (Japan Gigabit Network; a super-high-speed optical fiber transmission and broadcasting network). Initially, we built a 6Mbps circuit test environment. In

the test environment, a 100Mbps ATM circuit was connected from the Yokohama Institute for Earth Sciences to the Yokosuka headquarters and from the headquarters to JGN access points (Kanto-7: YRP). A Fast Ethernet was also used to connect from GODAC directly to JGN access points (Okinawa-: Multimedia Center in Nago City).

This fiscal year, we increased circuit speed from 6Mbps to 44Mbps and examined appropriate connection settings by regulating connection parameters, which lead to success in smooth image transmission. We encoded and indexed deep-sea images, and enabled the public to access a section of these images on a trial basis from the earth environment portal Web (<http://www.godac.jp/>) using Real Video streaming. This research won the Application prize in Education, Science and Technology category at the Gigabit

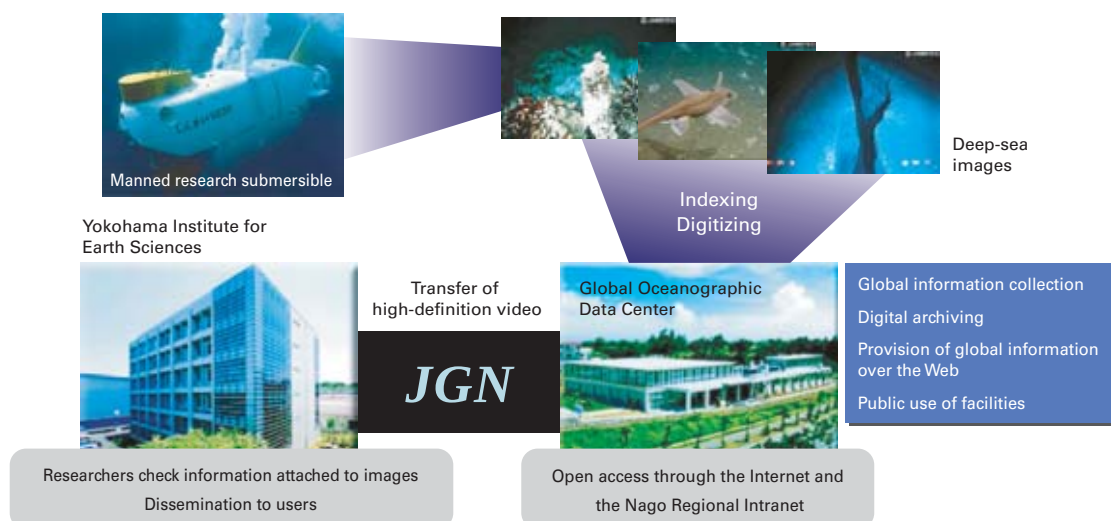


Fig. 1 Overview of the system

Computer and Information Department

Symposium 2004 held in Tokyo, January 2004, and its achievements gained wide public recognition.

2. Personal Research

Research on the promotion of efficiency and upgrading of deep-sea image archives

From fiscal 2003 to fiscal 2005

JAMSTEC stores huge amounts of image data, mostly on videotapes. These images have been collected from long-term observation in diving and oceanographic investigation and at the deep-sea observation station. The image data will continue to increase. Use of the video and data has been requested not only by researchers but also by educational organizations and content production companies. Also, there could be a chance to discover precious information from past data, leading to the important discovery of a so-called "Treasure Image", such as an image of a new species. The archiving of a total of approximately 17,000 deep-sea image tapes collected in the diving research is in progress at the Global Oceanographic Data Center (GODAC) in Nago City, Okinawa, and it will take years just to complete the digitizing. For effective use of a massive amount of image data, proper indexing (event extraction from the images and assignment of the corresponding information) is essential. On the other hand, other image data, e.g. a

total of about 4,500 videotapes of images collected at the Hatsushima offshore Real-Time Deep Sea Floor Observatory in Sagami Bay, has not been archived. Considering deep-sea images will continue to be collected and stocked, we need to develop a more effective archiving method.

With this situation in mind, the aim of this research begun in the second half of fiscal 2003 is to promote efficient archiving by developing methods to automatically extract events and by developing an indexing method equipped with an automatic identification technique as well as an information base. For this we use image data collected at the Hatsushima offshore station, whose background does not change much compared to images collected in diving research. We then aim to apply these methods to the images in diving research.

In fiscal 2003, we examined domestic and foreign technologies, such as the existing automatic recognition technology used in electronic circuit board production sites or in anti-crime monitoring cameras, and conducted research on indexing technologies developed for broadcasting stations. We also started to digitize the images collected at the Hatsushima offshore station using civilian DVD recorders to create and archive subject material for this research.

Research Activities

Frontier Research System for Extremophiles

Overview

The Frontier Research System for Extremophiles ("DEEPSTAR") focuses on organisms thriving in the deep-sea and in the deep subsurface by concentrating on extremophiles: what kinds of organisms live in such extreme environments, what are their distinctive features, and what is their potential usefulness to our lives and/or industrial applications. Our research targets include elucidation of the adaptation of living cells to such extreme environments, understanding the origin of life, and the development of new biotechnologies by the discovery and supply of new organisms.

In fiscal 2003, many novel microorganisms were isolated from deep-sea sediment and deep subsurface core samples. The vertical profile and diversity of microorganisms in the ODP leg. 201 sediment core samples were investigated. The ODP leg. 201 was the first expedition in ODP mainly targeting microbiology and biogeochemistry in the seafloor biosphere. Deep-sea multicellular organisms were captured and their tissues have been cultivated under laboratory conditions. The entire genomic sequence of thermophilic *Geobacillus kaustophilus* HTA-426 has been determined and comparative analyses of genomes are proceeding. The behavior of biomaterials and colloidal dispersions in extreme environments such as supercritical water was studied. Research collaboration with companies was conducted on an ongoing basis.

Research Results

1. Microbial genome analysis

Since we already finished the random shotgun sequencing of the *G. kaustophilus* genome with approximately 7-fold statistical coverage by the end of 2003 fiscal year, we tried to complete the genome sequencing project by filling the gaps between the contigs. By the end of June, we successfully finished the third genome sequencing project in our group and deposited whole genome sequence data into the DDBJ/EMBL/GenBank. Subsequently, we tried to characterize the genomic features of thermophilic *G. kaustophilus* by comparative analysis with other mesophilic *Bacillus*-related species. On the other hand, we also continued the post-sequencing study to figure out the mechanisms of adaptation to alkaline environments through the transcriptome and proteome analyses of alkaliphilic *B. halosurans* C-125 as well as in the last fiscal year. In addition, we initiated genome analysis with a new approach from the statistical and mathematical point of view to reconsider organisms from a different aspect.

1.1. Genome sequencing of *Geobacillus kaustophilus* HTA426

We announced in our last annual report that the entire genome sequence of *G. kaustophilus* has been mostly determined. To finish the sequencing of the entire genome, we tried to fill the single remaining gap. It was theorized that incorrect assembly was caused by ambiguities in the sequence or repetitive sequences. To detect the incorrect assembly, the layout around ambiguous or repetitive sequences was double-checked using the PCR method. The result revealed that chimeric contigs were generated by repetitive sequences. After removing the repetitive sequence, PCR products using correct primer pairs successfully linked the remaining gap. Finally, the original sequence of this genome was completely reconstructed. The genome of *G. kaustophilus* contained a single circular chromosome consisting of 3,544,776 bp and a single plasmid consisting of 47,890 bp. The average GC contents are 52.1% and 44.2%, respectively. The change of GC content in a sliding window along the *G. kaustophilus* chromosome is shown in Fig. 1A.

It was discovered that there are eleven AT-rich islands (No. 1 to No.11 in Fig. 1A) distinct from those

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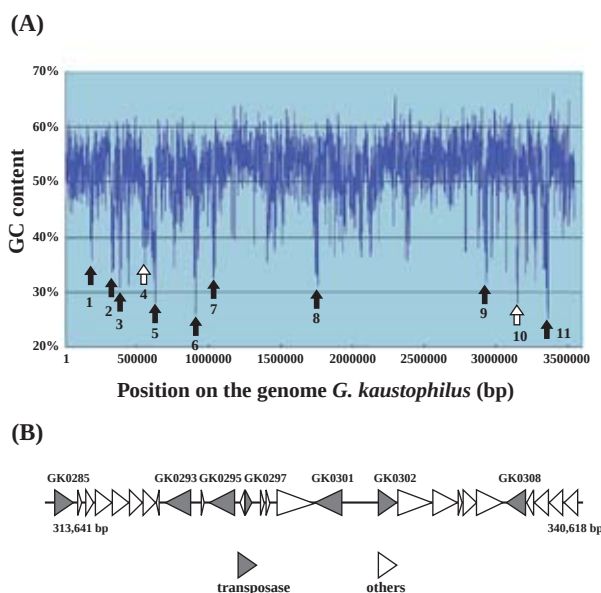


Fig. 1 Distribution of AT-rich region along the chromosome of *G. kaustophilus* and gene order in the AT-rich region. (A) GC content distribution of *G. kaustophilus* chromosome, in a sliding window of 1,000 bp, with a step of 500 bp. Eleven AT-rich regions are indicated by arrows, (No.1; 169 kbp~184 kbp, No.2; 314 kbp~341 kbp, No.3; 377 kbp~392 kbp, No.4; 537 kbp~580 kbp, No.5; 595 kbp~629 kbp, No.6; 891 kbp~907 kbp, No.7; 1,019 kbp~1,042 kbp, No.8; 1,737 kbp~1,757 kbp, No.9; 2,926 kbp~2,940 kbp, No.10; 3,142 kbp~3,155 kbp, No.11; 3,325 kbp~3,366 kbp). The black arrows represent a region abundant in transposase genes, white represents a region abundant in prophage-associated genes. (B) Gene order in the No. 2 region (314 kbp~341 kbp). This region contains the largest number of transposase genes among AT-rich regions.

of the rest of the chromosome. These genomic islands are likely to reveal the signature of bacteriophage lysogens or transposons. Actually, a number of prophage-associated genes were located in the No. 1 region (537 kbp to 580 kbp). In addition, the transposase genes densely occupy the No. 2 region (314 kbp to 341 kbp), specifically seven genes among twenty-eight identified genes encoded with distinct transposases (Fig. 1B). These high-frequency occurrences of the mobile element allow us to speculate that internal rearrangement of the genome, or "horizontal gene transfer", occurs actively. Repetitive sequences of the *G. kaustophilus* genome were identified based on nucleotide sequence similarities using the BLAST program, which searches exhaustively for stretches

of sequences greater than 100 bp with at least 90% similarity. Thirty-three kinds of repetitive sequences (REP01~REP33) were identified in this genome that included both dispersed and tandem repeats. These repeats encoded 17 distinct transposases of IS elements and one reverse transcriptase/maturase/endonuclease of the group II intron. In particular, REP08 was repeated 16 times in the chromosome and encoded transposase similar to one of the IS4 family in the *Photobacterium luminescens* genome. The reverse transcriptase/maturase/endo-nuclease encoded in REP07 was similar to one of the group II introns in *Oceanobacillus iheyensis*.

1.2. Group II self-splicing intron within the *recA* gene of *Geobacillus kaustophilus*

During the analysis of the *G. kaustophilus* HTA426 genome, we discovered a group II intron (Gk.Int), which interrupted the *recA* gene in the genome of the strain HTA426. In BLAST search analysis, it was shown that the spliced *recA* gene was 83% identical to the RecA protein of *B. anthracis* Ames. Group II introns are catalytic RNAs that function as mobile genetic elements by inserting directly into target sites in double-stranded DNA. Group II introns have been found to be widespread in bacterial species. Although some of them are inserted in genes with unknown functions, there is no example of them having been inserted into housekeeping genes. Here, we describe that a putative group II intron inserted into a *recA* gene is self-splicing *in vivo* and *in vitro*.

To investigate the splicing of Gk.Int *in vivo*, RT-PCR was conducted for the total RNA from *G. kaustophilus*, using primers specific to *recA*-A and *recA*-B (RECA3, RECA4) (Fig. 2-I). Amplified cDNA (463 bp) was approximately 2.7 kb smaller than the product amplified by PCR from the chromosomal DNA of the HTA 426 strain with the same primers (Fig. 3).

To obtain the whole *recA* ORF, the chromosomal DNA was used as a template for PCR with oligonu-

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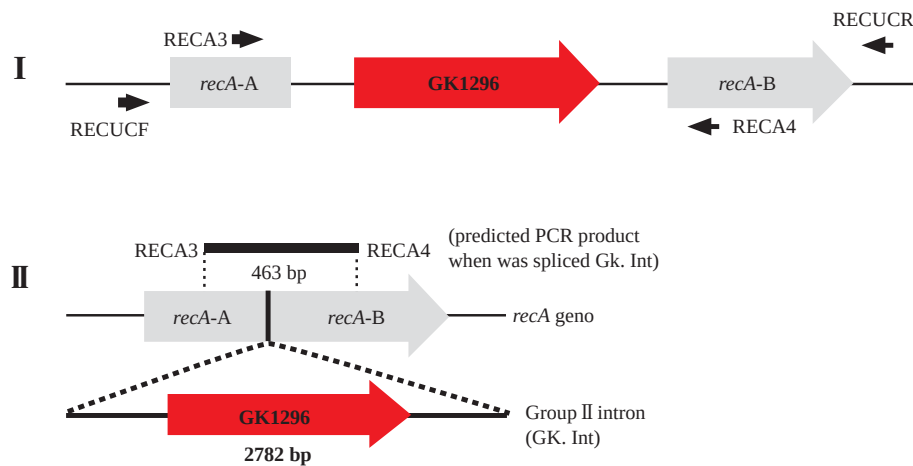


Fig. 2 Schematic diagram of a *recA* gene and group II intron in the *G. kaustophilus* genome. I, a region of *recA* gene; II, predicted *recA* gene when spliced with the Gk.Int intron. The thick arrows indicate locations of the oligonucleotides used.

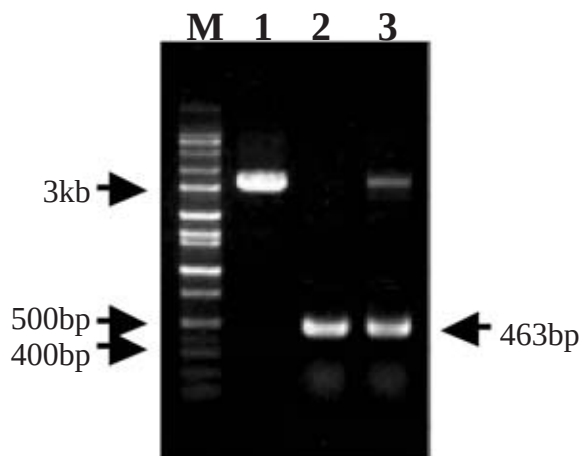


Fig. 3 The splicing of *recA* transcript *in vivo* and *in vitro*. Lane 1, PCR product obtained by using a primer set (RECA-3 and RECA-4) and *G. kaustophilus* DNA as a template.

cleotide primers (RECUCF, RECUCR) from 64 bp upstream of the start codon to 76 bp downstream of the stop codon. A PCR-generated fragment was cloned into the NotI-KpnI of pSD64TF to generate pSDrecA [int⁺]. *In vitro* splicing used RNA obtained from the SP6 RNA polymerase from pSDrecA [int⁺] plasmid linearized with Hind III. The *in vitro* splicing experiment showed the same results as those of *in vivo* with the total RNA from *G. kaustophilus*.

The exact exon-intron junctions were identified from the sequencing of the spliced RT-PCR products. The Gk.Int intron spans 2,782 nucleotides containing 22 stop codons when translated continuously (Fig. 2-

II). Therefore, *in vivo* and *in vitro* experiment results indicated that the *recA* gene of *G. kaustophilus* splicing occurs by a self-splicing mechanism. The 5' and 3' splice site sequences showed the consensus sequence GUGYGYAY at the 5' and 3' ends of the intron.

Examples such as all group II intron ORFs, Gk.Int encoded-ORF, GK1296 characterized by three different domains, which consisted of a reverse transcriptase (RT), a maturase (X), and an DNA endonuclease (Zn) domain (Fig. 4). Domains X and Zn are generally either poorly conserved or lacking in bacterial group II intron, whereas both domains in Gk.Int were well conserved. Subdomain RT5 also completely conserved the YADD motif, which is well-known as part of the active center of the HIV-1 retrovirus. As shown in Fig. 4, however, the RT domains of GK1296 contained only subdomains from RT2 to RT7.

Further, we will reveal the splicing mechanism of

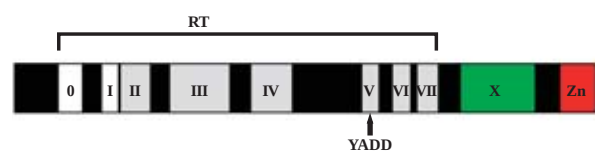


Fig. 4 Group II intron-encoded ORF. Schematic representation of the ORF (GK1296) encoded by the Gk.Int intron. The GK1296 consists of a reverse transcriptase (RT) domain, X domain (maturase), and Zn domain (endonuclease). A YADD motif, the active site of the RT, is fully conserved in subdomain V, but subdomains 0 and I are defective in GK1296.

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Gk.Int intron lacked subdomains RT0 and RT1, and the characterization of its RNA secondary structure.

1.3. Prediction of protein thermostability based on genome sequence data

Many thermophiles (optimal growth $<80^{\circ}\text{C}$) have been isolated from hot springs and other thermal environments. Hyperthermophilic archaea and bacteria with optimal growth temperatures between 80 and 110°C have been isolated from geo- and hydrothermally heated terrestrial and submarine environments. The complete genome sequences of 17 thermophilic or hyperthermophilic prokaryotic species have been determined. The genomic sequence information should facilitate the study of thermophily in prokaryotic cells and of the thermo-stability of proteins. The features of the genomic sequence which discriminate between thermophiles and mesophiles can be simply identified using principal component analysis (PCA) of amino acid composition or relative synonymous codon usage. In both types of analyses, whereas the

first principal component (PC) correlated with the G+C content of the chromosome, the second PC (PC2) clearly correlated with optimal growth temperatures, and thus thermophiles and mesophiles can be distinguished from each other along the second axis.

Most species positioned on the second axis at a value greater than 0.0152 are hyperthermophilic archaea, although two hyperthermophilic and one thermophilic bacteria are placed above this line (Fig. 5). However, mesophilic archaea such as *Methanosarcina mazei*, *Methanosarcina acetivorans*, and *Halobacterium* sp. are positioned near two hyperthermophiles, *Sulfolobus solfataricus* and *Sulfolobus tokodai*. In addition, since three mesophilic bacteria, *Clostridium perfringens*, *C. tetanii*, and *Fusobacterium nucleatum*, take positions near these two hyperthermophiles, it is still unclear whether the second axis yielded by PCA actually corresponds to thermophily or whether it simply reflects archaeal features or other features of particular bacterial species. Thus, comparison of the amino acid compositions of orthologs among closely-related species should

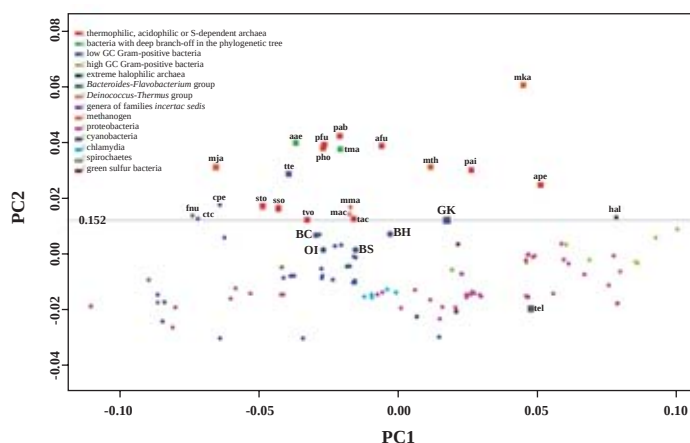


Fig. 5 Principal component analysis of amino acid compositions of 120 prokaryotic genomes. The first principal axis (horizontal) corresponds to the GC ratio and the second principal axis (vertical) corresponds to the thermophily of prokaryotic microbes. The line at 0.0152 shows a clear separation of thermophiles and mesophiles, denoted by squares and circles, respectively. *Bacillus*-related genomes are highlighted in uppercase. Abbreviations: aae, *Aquifex aeolicus*; ape, *Aeropyrum pernix*; afu, *Archaeoglobus fulgidus*; cpe, *Clostridium perfringens*; cpe, *Clostridium tetani*; fnu, *Fusobacterium nucleatum*; hal, *Halobacterium* sp. NRC-1; mac, *Methanosarcina acetivorans*; mja, *Methanococcus jannaschii*; mka, *Methanopyrus kandleri*; mma, *Methanosarcina mazei*; mth, *Methanobacterium thermoautotrophicum*; pab, *Pyrococcus abissi*; pai, *Pyrobaculum aerophilum*; pfu, *Pyrococcus furiosus*; pho, *Pyrococcus horikoshii*; sso, *Sulfolobus solfataricus*; sto, *Sulfolobus tokodai*; tac, *Thermoplasma acidophilum*; tel, *Thermosynechococcus elongatus*; tte, *Thermoanaerobacter tengcongensis*; tvo, *Thermoplasma volcanicum*; BC, *B. cereus*; BH, *B. halodurans*; BS, *B. subtilis*; GK, *G. kaustophilus*; Ol, *O. iheyensis*.

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lead to a resolution of this question.

Aerobic endospore-forming Gram-positive *Bacillus*-related species have been isolated from various terrestrial soils and deep-sea sediments of varying temperatures. It is known that *Bacillus*-related species have a wide range of growth temperatures from 5 to 78°C. Thermophilic and mesophilic *Bacillus*-related species belong to the same phylogenetic clade, and thermophilic species constitute a large cluster in the phylogenetic tree based on 16 rDNA sequences. *Geobacillus kaustophilus* HTA426 in the thermophilic cluster is one strain recovered from the deep-sea sediment of the Mariana Trench. The upper temperature limit for growth of this isolate is 74°C. The complete genome sequences of four mesophilic bacilli with different maximum temperatures for growth (42–58°C) have been determined, although the complete genome sequence of thermophilic *Bacillus*-related species has not been obtained. On the other hand, it has been shown that 1803 genes are shared among three mesophilic bacilli; *Bacillus subtilis*, *Bacillus halodurans*, and *Oceanobacillus iheyensis*. Many of them show significant sequence similarities to each other, and there is no marked difference in codon usage of each ortholog. Considering the diversity and commonality of *Bacillus*-related species, the complete genome sequences of thermophilic *Bacillus*-related species will provide much information for the further study of the thermostability of proteins at the molecular level.

A PCA of amino acid compositions was performed on all proteins from 120 prokaryotic species containing *G. kaustophilus*, *B. halodurans*, *B. subtilis*, *O. iheyensis*, *B. cereus*, and *B. anthracis*, except for the proteins smaller than 150 amino acids or membrane proteins possessing at least two transmembrane segments. Whereas *G. kaustophilus* was positioned on the line of 0.0152 of the PC2 score (along with thermophilic *Thermoplasma acidophilum* and *Thermoplasma volcanicum*), which is the borderline distinguishing thermophiles from mesophiles, other mesophilic *Bacillus*-related species were placed below this line as

expected (Fig. 5). On the other hand, when the PC2 score of individual *G. kaustophilus* proteins was calculated based on the eigen-vector value of each amino acid and compared with that of *G. stearothermophilus* (which has a similar upper-temperature limit for growth (72°C), the difference in the PC2 score of each corresponding protein between the two species was scattered within the range of ± 0.01 . Since all proteins that constitute thermophiles should be thermostable to allow them to thrive in thermal environments, the proteins distributed in the region with a score greater than -0.01 indicate that they have thermostability (Fig. 6). On the basis of this concept, when the PC2 score of 965 orthologs in each mesophile which has one-to-one correspondence among the five bacilli were compared with those of *G. kaustophilus*, many of which were pink colored (Fig. 6a-d) were found to be distributed in the area represented by a PC2 score greater than -0.01 .

The ratio of these orthologs predicted to be thermostable proteins among the total 965 orthologues varied in each species and the order of the ratio was *B. cereus* (73.6%) > *B. halodurans* (70.6%) > *B. subtilis* (61.0%) > *O. iheyensis* (48.1%). The ratio correlates linearly with the maximum growth temperature except in the case of *B. cereus*. The complete genomic sequence of thermophilic *G. kaustophilus* provided a unique opportunity to investigate the relationships between the thermostability of the protein and amino acid composition and between the thermophily of the *Bacillus*-related species and thermostable proteins. Consequently, it was assumed that the bacterial maximum growth temperature (thermophily) would be determined by the occupation ratio of the thermostable proteins to the total proteins and simultaneously that there would be some critical proteins directly regulating the rule of bacterial thermophily. The sequence data should also provide important clues to the understanding of the evolutionary relationship between thermophilic and mesophilic bacilli.

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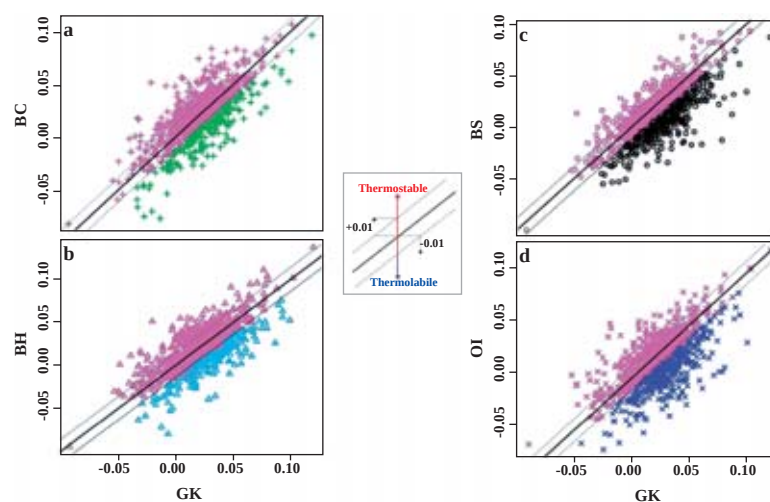


Fig. 6 Profile of thermostable proteins predicted in the genome of mesophilic bacilli. Scattering pattern of the difference of principal component score of orthologous proteins to those of *G. kaustophilus* in the second principal component. Nine hundred and sixty-five orthologues among five bacilli were used for analysis. The membrane proteins possessing more than two transmembrane domains are not contained in each orthologue group. Abbreviations: BC, *B. cereus*; BH, *B. halodurans*; BS, *B. subtilis*; GK, *G. kaustophilus*; GS, *G. stearothermophilus*; OI, *O. iheyensis*.

1.4. Proteome Analysis of facultative alkaliphilic *Bacillus halodurans* C-125

(a) An alkali-inducible flotillin-like protein in *B. halodurans* C-125

B. halodurans C-125 is an alkaliphilic bacterium that can grow in a wide range of pH conditions (pH7-11). Our current DNA microarray analysis showed that the BH3500 gene from *B. halodurans* is the gene most highly-induced by alkaline pH. BLAST search analysis suggested that the BH3500 gene is the homologue of flotillin. It is known that flotillins are the marker for lipid microdomains and have emerged as a key concept in cellular biology. However, no prokaryotic flotillin protein has been discovered thus far. Hence, as a first step toward understanding the role of the flotillin-like gene in prokaryotic cells, we carried out the sequence analysis, extraction and purification of the BH3500 protein, along with the investigation of its expression pattern.

The BH3500 protein showed approximately 30% correspondence to human flotillin-1 and approximately 29% correspondence to human flotillin-2. Motif analysis revealed that several specific residues (SPFH-

and FLOTILLIN-domains, AEA-repeat structure) and 5 potential phosphorylation sites are conserved in the BH3500 protein. Hydropathy analysis found that the BH3500 protein possesses two transmembrane-spanning domains at the N-terminus, which is consistent with the common properties of flotillin-1. Thus, these results strongly support the view that the BH3500 protein is a new member of the flotillin family. The neighbor-joining tree defines four major groups by phylogenetic analysis. BH3500 did not belong to known eukaryotic flotillin-1 and flotillin-2 groups, suggesting a novel type of flotillin.

The expression of the BH3500 gene was induced by a transformed *Escherichia coli* BL21 (DE3) star strain. Approximately 40 μ g of recombinant BH3500 protein (58 kDa) could be purified by affinity chromatography from 1 ml of culture ($OD_{600} \approx 0.7$) (Fig. 7A). It was insoluble in Triton X-100 at 4°C, showing a common characteristic of flotillins. For production of the BH3500 protein from strain C-125, cells were grown in three different media: Horikoshi IIA, medium adjusted to pH10 with 2%-Na₂CO₃; Horikoshi IIN, medium containing 2% NaCl without pH adjustment (pH7);

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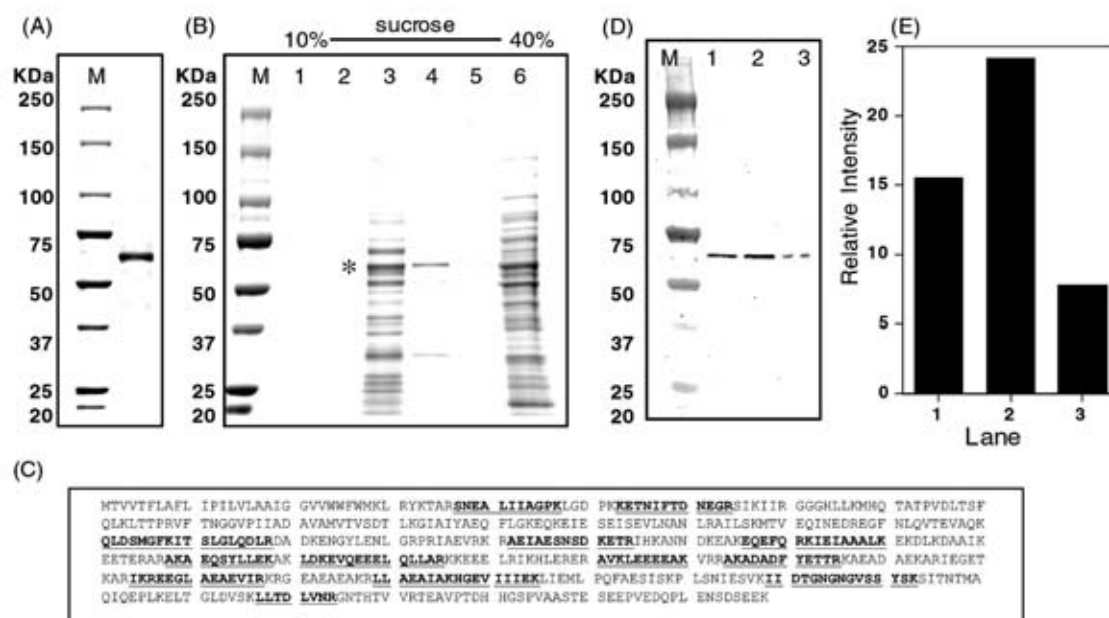


Fig. 7 Characterization of the BH3500 protein. (A) The expression of the His-tagged BH3500 protein in *E. coli*. (B) Separation of detergent-resistant membrane (DRM) fractions by sucrose gradient centrifugation. Six 500 μ l-fractions (Lane1-6) were collected from the top. Aliquots of these samples were analyzed by polyacrylamide gel electro-phoresis. (C) Identification by mass spectrometry of the 58 kDa protein (*) present in the low-density fraction (Lane 3). The bold and underlined letters indicate those peptides identified by mass spectrometry and linked to the BH3500 sequence. (D) Detection of the BH3500 protein by Western Blotting. Lane 1, Horikoshi IIAK; Lane 2, Horikoshi IIN; Lane 3, Horikoshi IIA. (E) Relative intensity of Western Blotting.

Horikoshi IIAK, medium adjusted to pH10 with KOH instead of Na_2CO_3 . The homogenized C-125 cells were incubated with Triton-X100 on ice, followed by sucrose density gradient centrifugation. Step gradient ultracentrifugation yielded an opalescent band floating in the low-density region of the gradient (10-30% sucrose interface). The prominent 58 kDa band in the low-density fractions (fraction 3) was identified as the BH3500 protein by mass spectrometry (Fig. 7B and C) and with the help of anti-BH3500 rabbit polyclonal antibody (Fig. 7D). These results suggest that the BH3500 protein is a Triton-insoluble, buoyant integral membrane protein, indicating that it should be categorized as a new member of the flotillin family. Western Blot analysis shows that the rate of generation of the BH3500 protein under conditions of pH10 was about threefold higher than under conditions of pH7.0 (Fig. 7D and E). This increase was also observed at pH10 without the addition of sodium ions, suggesting that the increase in the amount of BH3500 protein is alkaline-dependent, but not sodium-dependent.

For Northern Blot analysis, the bacteria were cultivated in a Horikoshi II medium adjusted with KOH to various pH levels, and the corresponding moles of KCl (8-48 moles) were added to the pH7 culture to adjust K^+ ion concentration. To eliminate the influence of sodium ions, the bacteria were cultured in low levels of sodium ions (0.5% NaCl). The mRNA of the BH3500 gene was observed to be significantly more regulated under alkaline conditions (pH10-11) (Fig. 8). The level of expression at pH11 showed an approximate increase of up to 4.5 times, compared with that at pH7. This increased expression was not observed in the K^+ ion controls at pH7. These findings support the view that the BH3500 protein should be classified as an alkali-inducible protein. *B. halodurans* C-125 is an alkaliphilic bacterium that can grow in a wide range of pH conditions (pH7-11). However, we have no evidence thus far that the BH3500 protein is directly related to the alkaliphilic phenotype. In mammalian cells, flotillins play a central role in cellular organization and are crucial for membrane trafficking events, and for specific signaling cas-

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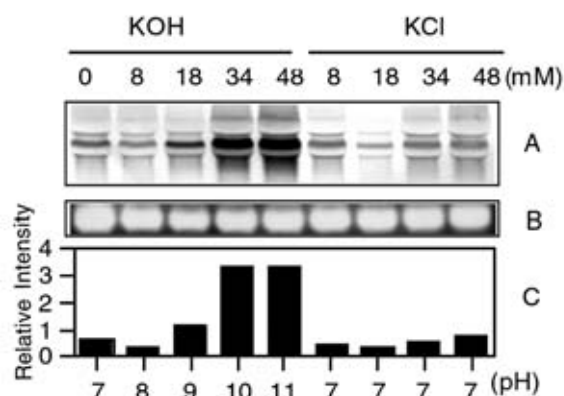


Fig. 8 BH3500 gene expression under various pH conditions. (A) Hybridization signals detected with an antidigoxigenin alkaline phosphatase conjugate. (B) 16S rRNA transferred to the same membrane. (C) The relative intensity of BH3500 mRNA under various pH conditions.

cares. It is unclear whether the BH3500 protein plays the same biological roles in prokaryotes, but it can be expected that these questions will be answered upon further proteome and transcriptome analysis. In conclusion, flotillin-like proteins that are conserved even in prokaryotic cells seem to be very active across the plasma membrane, in fundamental ways.

(b) Exploration of alkaliphily-related protein

Proteomic analysis is now considered to be one of the most important 'post-genome' approaches for understanding gene functions. The comprehensive analysis of the gene products is indispensable to link genomic data to biological function. *Bacillus halodurans* C-125 is one of the best-characterized alkaliphiles. To clarify the mechanism of adaptation to high alkaline conditions, we have investigated alkali-inducible proteins in *Bacillus halodurans* C-125 cells using proteomic techniques. At first, the production patterns of the total proteins and membrane proteins extracted under neutral and alkaline pH culture conditions were investigated by sensitive mass spectrometry subsequent to high-resolution two-dimensional electrophoresis. About 30 gene products were found to be induced by medium pH conditions. The proteins which notably increased in different pH conditions were identified by N-terminus amino acid sequence analysis and a capillary LC-MS/MS system

using the complete genome sequence database of *B. halodurans* C-125. Eight proteins that notably increased in alkaline pH culture conditions were further analyzed at a transcriptional level by northern hybridization. The data were consistent with observations of translational product patterns by 2D-electrophoresis. The most specific induced proteins in alkaline conditions were oxidoreductases, hydrolases and other enzymes (F₀F₁-ATP synthase, etc.). These proteins were closely related to proton generation reaction, respiration and fermentation. We also found some chaperonin-like proteins -- ClpP, GroEL and thioredoxin -- which were involved in the pH-dependent expressions. It is known that these chaperonin-like proteins are involved in response to stresses in eukaryotic cells. The gene production increase in higher pH conditions seems to be potentially important for growth in an alkaline environment.

B. halodurans C-125 exhibits a remarkable ability to maintain a cytoplasmic pH lower than external pH values. We supposed that the proton shortage was fulfilled by the proton-generating reactions or by the protons entering back into the membrane through channels in the ATP synthase enzyme complex in the early stages. Further work is needed to determine the role of each protein and find new factors to support our hypothesis. We used the *B. halodurans* C-125 as a model organism to analyze alkaline stress conditions, and examined whether certain genes are induced by pH shock and how they are regulated. The results showed that the alanine dehydrogenase (ADH), flagellin (a small protein with an unknown function), and some other genes were induced by alkaline shock (Fig. 9). On the other hand, some heat shock proteins, stress proteins and proteases were found to increase more in a pH10.0 culture condition than in a pH7.0 culture condition. Thus, it has become clear that chaperons and some proteases respond to alkaline pH conditions. Although the mechanism of pH homeostasis in alkalophilic-bacterium was not simple, the analysis of the protein pattern of *B. halodurans* C-125 suggested pH-dependent gene products are deeply associated with adaptation to different pH conditions.

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An 11 kDa protein with unknown functions, whose amount of expression increased notably under alkaline conditions, was named ARP11 (alkaline response protein 11 kDa). To clarify the role of this protein in adapting to alkaline environments, ARP11 was quantitatively analyzed by northern hybridization in different pH conditions. It is well-known that many gene products are significantly induced by sodium ions in alkaliphilic *Bacillus*. To eliminate the influence of sodium ions on the gene products, we adjusted the medium's pH with 1 M KOH for alkali cultures, and the same amount of KCl was supplemented to neutral cultures as control. The results revealed that ARP11 was induced only by alkali, and the transcription level of this gene showed the same tendency for the protein product, which was induced more than fivefold in alkaline conditions. On the other hand, ARP11 was also found in the membrane when the cells grew in a pH10.0-culture. This observation suggests that ARP11 is a membrane-associated protein, but not an integral membrane protein. Flagellin, one of the proteins induced by alkaline pH, was also found in either the cytoplasm or membrane. The northern hybridization analysis of flagellin showed the same tendency to increase as ARP11 in different alkaline pH conditions. Alkaline shock experiments indicated that ARP11 and flagellin quickly respond to alkaline condition as the neutral culture cells were shift-

ed to the alkaline medium (Fig. 9). Generally, membrane proteins or membrane associate proteins are thought to play a major role in maintaining cellular pH homeostasis. Thus, these response proteins are possibly associated with intercellular pH homeostasis. To understand the real function of ARP11, it was overproduced and purified in *E. coli*. The entire genes were amplified by PCR using primers whose design was based on the genome sequence, and the amplified fragment was cloned into pET15a. This plasmid allowed an in-frame fusion of the *ARP 11* gene to six histidine codons at the N-terminus and transcription from a T7 promoter. Overproduction of the His6-ARP11 protein with the T7 RNA polymerase was performed in the *E. coli* strain BL21 (DE3), and the recombinant was purified under native conditions by Ni-nitriloacetic acid affinity chromatography. Polyclonal antibodies raised against the recombinant ARP11 were used to detect the protein-protein interactions using immunoprecipitation assays. Several proteins were precipitated together with ARP11. The most strongly interacting protein was identified as a flagellin protein. This finding is the first direct evidence for the role of ARP11 in mobility and adaptation to the environment, since it behaves as a flagellin binding protein. For further investigation of alkaline pH-inducible proteins, protein-protein interaction analysis is in progress.

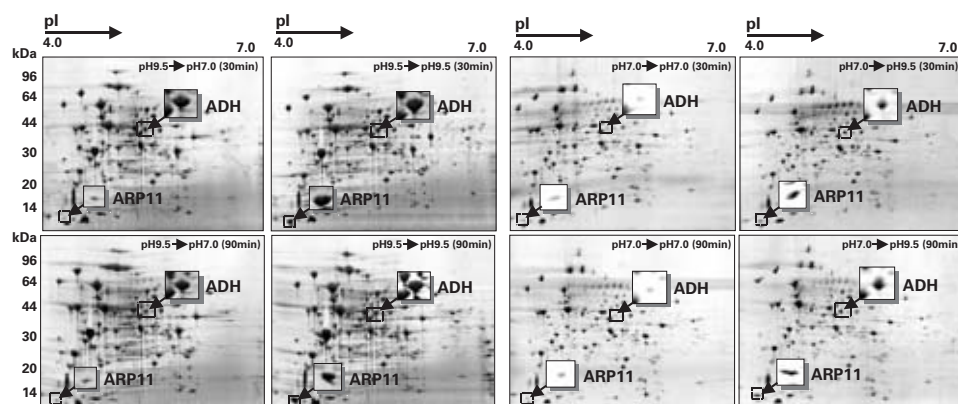


Fig. 9 Alkaline shock induced the expressions of several genes briefly following the exposure of neutral-cultured cells to an alkaline medium. *B. halodurans* C-125 (OD₆₀₀=1.5) of a logarithmic growth phase were shifted from a pH 7.0 neutral medium to a pH 9.5 alkaline medium and vice versa, the cells were cultivated for 30 or 60 minutes, and the protein patterns were analyzed by two-dimensional electrophoresis. Spots of ADH and ARP11 are revealed in the square box which is enlarged in the same ratio.

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1.5. The meaning of gene expression.

Recently, many genome sequences have been completely determined and the information derived from them has been used in various disciplines. Nevertheless, the biological procedure for reading DNA information has only been explained using *purposive and intuitive* words or with *putative* models. Thus, its principle has yet to be understood objectively. Therefore, we first discussed the mathematical meaning of gene expression. To exclude superfluous information about a genome, such as our preconceptions and purposive explanations, we shall begin by expressing a DNA structure in terms of algebraic topology. Thus, we recognize that there are two significant features in the structure: a *noncommutative* structure and an *algebraic* structure. Furthermore, we can demonstrate that the structure also has the properties of a *complex line bundle*.

We calculated the interaction energy between a DNA space and an environmental space in an abstract space: here, we assumed that the system satisfied the principle of least action under stable conditions.

Next, we deduced integration of the interaction energy converging to a value, which contains only the sequential information of deoxyribonucleosides. Usually, biologists attempt to ascribe gene expression to the proteins' function, which is required under a given condition. In other words, they prefer to interpret the gene expression as a purposive phenomenon: of course, this may be true at the "life" level. However, we aim to clarify the meaning of the expression at the "molecular" level. Therefore, we must describe the phenomenon without the assistance of biological interpre-

tation. We interpreted the above results as follows: the sum of deoxyribonucleoside information expressed under a given condition was equivalent to the variation of environmental energy in the total energy. Thus, they play a role in compensating for defects or excessive energy in the environmental space.

A microorganism generally possesses plural systems responding to the information which enters a cell. Next, we must consider the meaning of redundancy in a biological information system (Fig.10). Redundancy is an important system for the survival of microorganisms, for example, when there are problems with metabolic pathways. Thus redundancy systems play a role in avoiding the fatal damage of faulty metabolic pathways. Incidentally, when biologists explain redundant systems, they often use the word "economic" even though counter-examples exist. Thus, the situation where purposive and intuitive words are used to explain biological phenomena occurring in redundant systems is almost the same as that of reading information from a genome. However, our purpose is to explain redundant systems objectively; in other words, to describe the biological system in terms of mathematics. We have attempted to deduce the *necessary* conditions for the redundancy's existence: we discussed this issue in terms of homological algebra as follows.

First, we decompose a DNA space into a proper space and then represent the biological redundant system in the space. To emphasize the essential meaning of a redundant system, we should completely exclude the 'junk' spaces (the superfluous sequential information), from the total space in a redundant system. Note

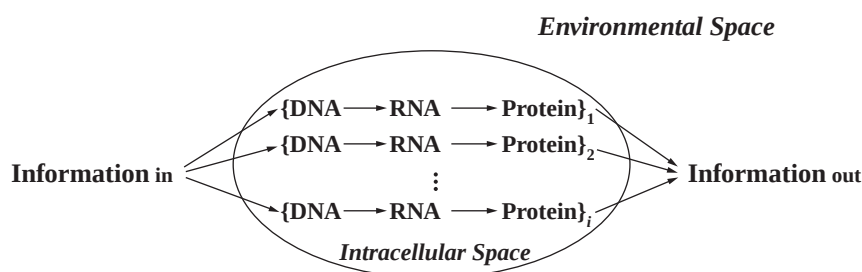


Fig.10 The redundancy of a biological system

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here that, roughly speaking, biologists have discussed not a "quotient space", but the magnitude of the space (Fig.11 (b)); therefore, *biological* homology is not sufficient to compare with each piece of sequential information. Consequently, these biologists have overlooked gene sequence information and therefore have not completely explained some biological phenomena by *biological* homology (i.e. similarity).

We should be aware here that each component denoted by a redundant system object shares a common space, which we denote by X (Fig.11). What then is the shared space X ? In the previous discussion, we deduced that after interacting between an environmental space and a DNA space, a sum of DNA sequential information emerged. Thus, if an object belongs to the redundant system, it must share a common *information space* with other objects contained in the same redundant system. Thus, the common space X of the redundant system can be represented by the common information space. Therefore, redundant genes, which are possible in response to a piece of environmental information (Information_{in}) and yield the same result (Information_{out}) (see, Fig.10), possess a homological relationship with respect to each other: in other words,

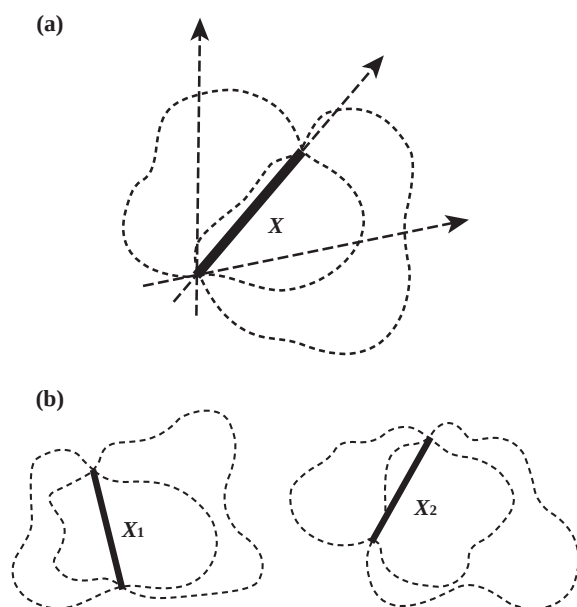


Fig.11 (a) The intuitive image of the energy space X which is connected. (b) An example of $X_1 \neq X_2$, but $\|X_1\| = \|X_2\|$.

the redundancy of a biological system can be represented in terms of homological algebra. Therefore, we must investigate gene information from the viewpoint of homological algebra. Thereby, we concluded that each metabolic pathway in a redundant system must have the same homology module: this is just the necessary condition for the existence of the redundancy.

Finally, in terms of mathematics we also considered the *uniqueness* of the object; for instance, *homeoviscous adaptation*. Even though various combinations of membrane composition---that is, the redundancy---would be allowed to satisfy a given condition such as membrane fluidity, bacteria select their membrane composition uniquely under given conditions. We dealt with the issue as a multiple-body problem, and connected the biological phenomenon with the existence of a solution of an infinite product, thus the uniqueness and convergence of the grand partition of function.

2. Metabolism and Adaptation Research

2.1. Taxonomy and preservation of newly isolated deep-sea microorganisms

(a) Isolation of new microorganisms.

In 2003, sediment samples were collected from the cold-seep environment with a bacteria mat site in the Japan Sea at a depth of 3,100m (Fig.12), and a whale birth site at a depth of 230m near Kagoshima (Fig.13). These samples were cultivated at several temperatures in several types of media. We isolated about 1000 new strains of mesophilic bacteria, psychophilic bacteria, useful enzyme-produced bacteria and yeast from these deep-sea sediment samples.

(b) Identification of agarase-produced bacteria.

Last year, we isolated three strains of agarase-produced bacteria from the deep-sea sediment at Sagami Bay and Suruga Bay. Phylogenetic analysis based on 16S rDNA sequence similarity showed that the three isolates included *Microbulbifer* genes (Fig.14). The isolates were separate and distinct species from each other (DNA-DNA reassociation and phenotypic character).

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Fig.12 Bacteria mat at a depth of 3,100m in the Japan Sea.



Fig.13 Whale born at a depth of 230m in the Nomamisaki, Kagoshima expedition.

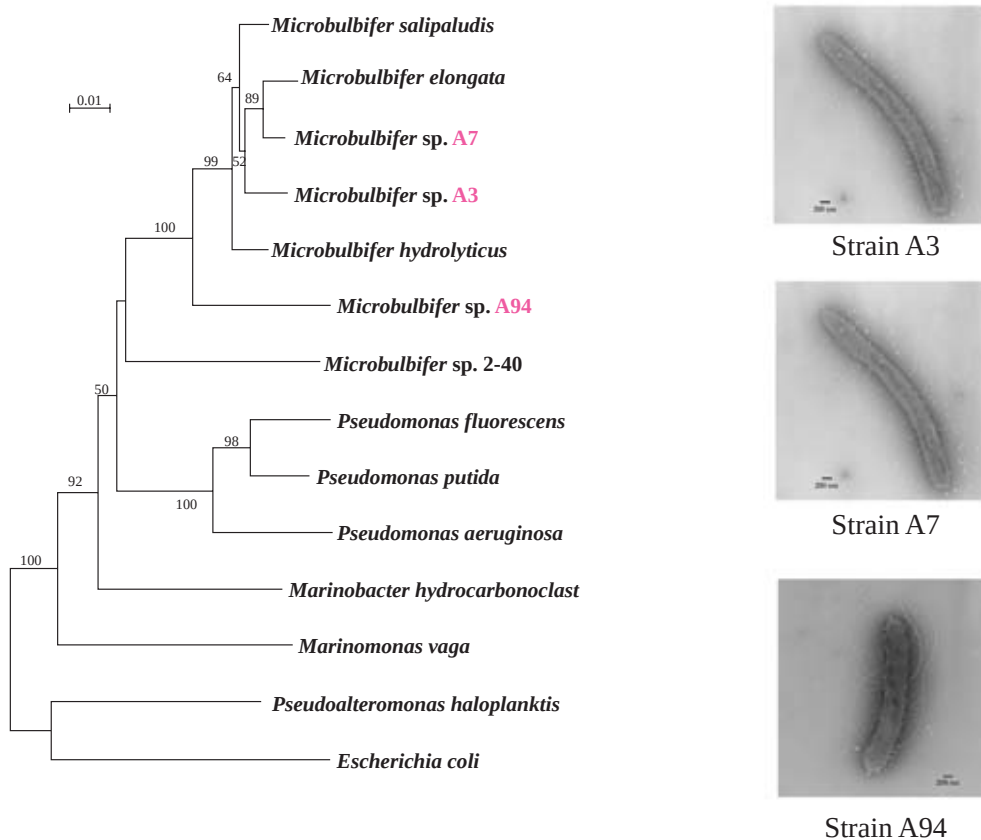


Fig.14 Phylogenetic tree showing the relationships of the isolated strains A3, A7 and A94 within the genus *Microbulbifer*, constructed by the neighbor-joining method and based on 16S rDNA gene sequences.

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(c) *Cryptococcus surugaensis* sp. nov., a novel yeast species from sediment collected on the deep-sea floor of Suruga Bay

A novel species of the genus *Cryptococcus* was isolated from sediment collected on the deep-sea floor of Suruga Bay, Japan. The nucleotide sequence of 18S rDNA, internal transcribed spacers 5.8S rDNA (Fig.15), and the D1/D2 region of 26S rDNA (Fig.16) of strain SY-260^T suggested affinities to a phylogenetic lineage that included *Cryptococcus luteolus*. Comparisons of the rDNA sequences of each region clarified that strain SY-260^T is related distantly to *Bullera coprosmaensis* and *Bullera oryzae*, but is distinct at the species level. As ballistoconidia and sexual reproduction were not observed in strain SY-260^T, this strain is described as *Cryptococcus surugaensis* sp. nov. (type strain SY-260^T = JCM 11903^T = CBS 9426^T).

(d) Phylogenetic analyses of basidiomycetous yeasts within the *Erythrobasidium* clade.

Many yeast species found in benthic animals were placed phylogenetically in the *Erythrobasidium* clade, an evolutionary lineage of urediniomycetous yeasts that included *Erythrobasidium hasegawianum* as a representative species. But representative phylogenies formerly proposed for this clade based on 26S rDNA, 18S rDNA

and ITS analysis differed in some aspects. We examined phylogenetic relationships within the *Erythrobasidium* clade by using partial regions of 18S rDNA, 5.8S rDNA, 26S rDNA, ITSs and elongation factor (EF)-1 α . Combined data analysis of all segments successfully yielded a reliable phylogeny and confirmed the cohesion of species characterized by Q-10 (H₂) as a major ubiquinone (Fig.17). We believe the subgroups *Bannoa* and *Erythrobasidium* should be fused into a single one, redefined as the subgroup *Bannoa-Erythrobasidium*. However, the relation between the subgroups *Sakaguchia* and *Bannoa-Erythrobasidium* was only supported by a rather low bootstrap value (62%).

Species in the subgroups *Bannoa-Erythrobasidium* and *Sakaguchia* commonly possess a deletion corresponding to position 456 in the 26S rDNA of *Filobasidiella neoformans*. A sequence deletion shared among these species was expected to occur in the C1 helices family. Predicted secondary structures of the C1 helix regions for all species in the *Erythrobasidium* clade were drawn and their representative structures are shown in Fig.18.

C1/e1 and C1/e4 showed distinct structural characters. Our comparative analysis showed that the sequence deletion common to the subgroups shortened the C1/e1 helix of these species. Structural differences

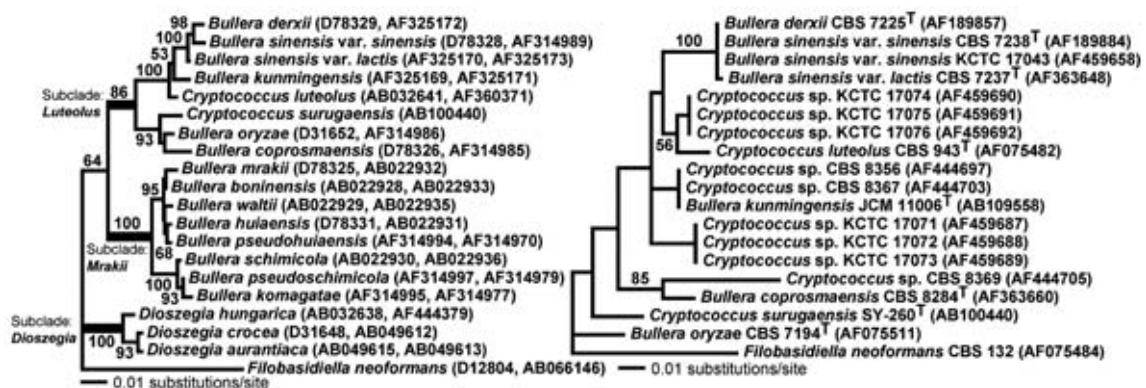


Fig.15 Maximum-likelihood tree (HKY85, ts/tv = 1.175931) within the *C. luteolus* lineage on the basis of a total of 2077 aligned nucleotide sites in 18S rDNA, ITSs, and 5.8S rDNA. Numbers with branches are bootstrap values derived only for the nodes supported by greater than 50% (100 replicates).

Fig.16 Maximum-likelihood tree (HKY85, ts/tv = 3.136150) of *C. surugaensis* and related species on the basis of a total of 603 aligned nucleotide sites in the D1/D2 region of 26S rDNA. Numbers with branches are bootstrap values derived only for the nodes supported by greater than 50% (100 replicates).

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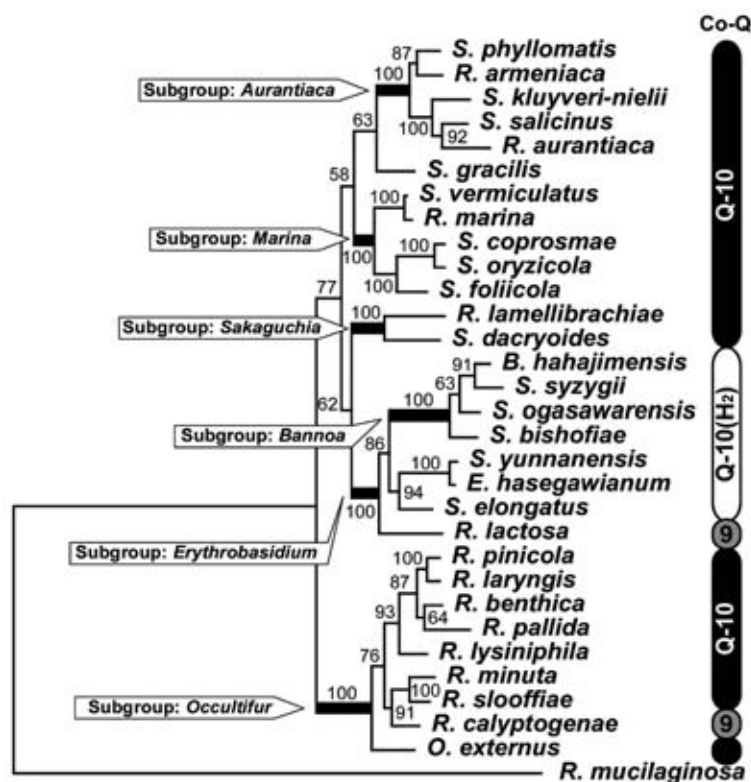


Fig.17 ML tree based on a combined data set composed of partial nucleotide sequences of 18S rDNA, ITS + 5.8S rDNA, 26S rDNA, and first + second codons of EF-1 α . Bar, 0.01 substitution per site.

Table 1 Comparisons of predicted secondary structures of the C1 helix of 26S rRNA among subgroups in the *Erythrobasidium* clade.

Subgroup	Species	C1 helix structure	
		C1/e1	C1/e4
<i>Aurantiaca</i>	5 spp.	Long	2 stems
<i>Aurantiaca</i> or <i>Marina</i>	<i>S. gracilis</i>	Long	Loop+2 stems
<i>Marina</i>	5 spp.	Long	Loop+2 stems
<i>Sakaguchia</i> ^a	<i>Sa. dacryoides</i>	Short	Short
	<i>R. lamellibrachiae</i>	Short	2 stems
<i>Bannoa</i>	4 spp.	Short	2 stems
<i>Erythrobasidium</i> ^b	4 spp.	Short	Loop+2 stems
<i>Occultifur</i> ^c	9 spp.	Long	2 stems

^a, ^b, ^cRepresentatives shown as Figure 5a, 5b, and 5c, respectively.

in the helices C1/e1 and C1/e4 among each subgroup are shown in Table 1. Differences in C1/e1 and C1/e4 corresponded to major divergences in the phylogenetic tree based on the primary sequence. The common presence of a shortened helix in this region was considered to be evidence of monophyly for species with Q-10 (H₂) (*Sakaguchia dacryoides*, *Rhodotorula lactosa*, and *Rhodotorula lamellibrachiae*), although it was not as

strongly supported by the combined data tree. Many phylogenetic analyses based on primary sequences have not utilized sites with length mutations or unalignable regions, which mainly consist of sites with faster evolutionary rates. But such regions have the strong possibility of expressing variation in the RNA secondary structures. Prediction of RNA secondary structures is considered to retrieve additional information for phyloge-

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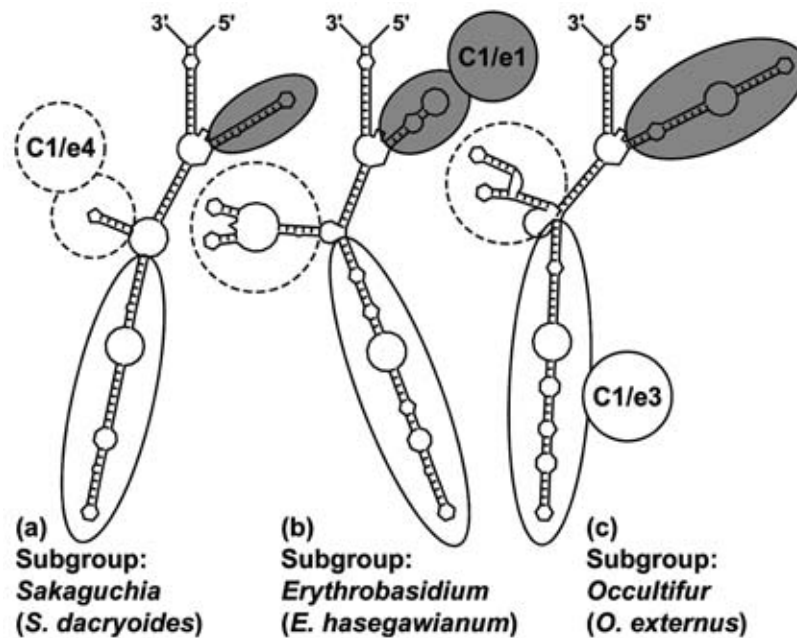


Fig.18 Predicted secondary structures of the C1 helix (De Rijk et al., 1999) in 26S rRNA of three representative strains. Helices of C1/e1, C1/e3, and C1/e4 are surrounded by an oval in gray, a circle with a broken line, and an oval with a solid line, respectively. For (a), (b), and (c) in this figure, see the footnote to Table 1.

netic inference from the unusable regions.

(e) Preservation of newly isolated deep-sea microorganisms and samples

In 2003, newly isolated microorganisms preserved in our facility included 585 bacteria strains (550 isolates and 35 others) and 25 yeast strains (from Kagoshima and Sagami Bay), and these strains are being stored in liquid nitrogen conditions. Twenty-seven deep-sea sediment samples obtained by several research vessels in 2003 were also preserved in liquid nitrogen conditions. We now have 328 types of deep-sea sediment samples in the liquid nitrogen storage tank.

2.2. Piezophysiology of yeast

(a) The ubiquitin system is responsible for pressure-induced limiting-regulation of membrane proteins in the yeast *Saccharomyces cerevisiae*

This study aims to establish the molecular basis for biological responses to changes in hydrostatic pressure.

We have reported that the availability of tryptophan is primarily important for high-pressure growth in

S. cerevisiae. Upon incubation of the wild-type cells at 25 MPa (approximately 250 atm), the tryptophan permease Tat2 degrades. Consequently, cell growth is arrested in the G1 phase of the cell cycle. Pressure-induced limiting-regulation of Tat2 was revealed to occur in a manner dependent on the ubiquitin system. Ubiquitin is a small protein molecule consisting of 76 amino acids. Once ubiquitin is covalently bound to a target protein, the protein degrades in the 26S proteasome or the vacuole. *HPG1*, one of the four high-pressure growth (*HPG*) genes, was allelic to *RSP5*, encoding a HECT-type ubiquitin ligase Rsp5. The *HPG1* mutation dramatically stabilized Tat2 in the plasma membrane at 25 MPa. Another gene, *HPG2*, was allelic to *TAT2*. The *HPG2* mutation sites are located in the *N*- and *C*-terminal domain of the Tat2 protein (i.e., Hpg2). The Hpg2 mutation prevented Tat2 from ubiquitination followed by remarkable stabilization of this protein at high pressure. Considering all results simultaneously, we propose a model for the high-pressure sensing pathway, hypothesizing that Rsp5, in combination with the binding protein Bull,

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regulates Tat2 through its cytoplasmic *N*- or *C*-terminus ubiquitination in response to increasing hydrostatic pressure. This is the first case in which a high-pressure response was investigated molecularly in eukaryotic cells. We will next analyze the physiological interaction between Rsp5 and the cytoplasmic domains of Tat2 under high-pressure conditions.

(b) Probing membrane protein dynamics using hydrostatic pressure

We showed the dynamics of tryptophan import through the tryptophan permeases Tat1 and Tat2 using hydrostatic pressure as a parameter. The activation volume $DV^\ddagger$ represents the difference in volume between the initial state and the activated state of the reaction and can only be obtained by measuring the rate constants of the reaction as a function of hydrostatic pressure. Notably, there is a significant difference in the activation volume for tryptophan import between Tat1 and Tat2, which are 89.3 ml/mol and 50.8 ml/mol, respectively. This indicates that Tat1 undergoes a more dramatic conformational change during the activation associated with tryptophan import than Tat2 (Fig.19).

Biochemical analyses indicate that Tat1 exists in tight and ordered lipid microdomains, so-called "rafts", whereas Tat2 exists in disordered fluid domains, so-called "non-rafts". Therefore, the remarkable difference in the activation volume could be accounted for by the difference in the volume of the initial states, i. e., the initial volume of Tat1 is likely to be smaller than that of Tat2. This explanation is consistent with the findings that Tat1 is localized in the highly ordered lipid phase in which the volume is small, whereas Tat2 is localized in the disordered phase in which the volume is large. In this sense, hydrostatic pressure would be a unique tool to elucidate lipid microdomains and membrane protein dynamics. To generalize this approach, we will next analyze the dynamics of other membrane proteins, including amino acid permeases, ion channels or membrane ATPases.

3. Biological response to Deep-Sea Environments

3.1. Biological response research

(a) Research into the adaptation mechanisms of deep-sea multicellular organisms in extreme environments

Deep-sea organisms, not only microbes, but also multicellular organisms, live in the deep sea. Clarifying the relationship of deep-sea environment and deep-sea multicellular organisms was the purpose of this research, especially regarding correlations in single cells. We conducted the following: development of a deep-sea multicellular organism capture device, development of a life support system for high-pressure underwater environments, and development of an optical microscope system for cultured-cell observation in high-pressure environments. Furthermore, we have tried maintaining deep-sea multicellular organisms in atmospheric pressure environments, developing primary cultivation of deep-sea multicellular organism cells, and biological response research on animal cultivation cells in high-pressure environments. Also this year, we attempted capturing deep-sea multicellular organisms, and performed maintenance in high-pressure environments, maintaining atmospheric pressure environments, and tissue cell culture. As a reference experiment, high-pressure morphological change of an animal cultivation cell was observed.

(i) The deep-sea multicellular organism capture device

The capture device was deployed in the payload pallet of the research submersible Shinkai 6500, and its operation was confirmed. We captured *Simenchelys parasiticus*, *Alvinocaris shrimp*, *Buccinidae* sp. and *Zoarcidae* sp. from the seabed using a pressurized tank at a depth of 1,200 m off Hatsushima in Sagami Bay. Moreover, the pressurized capture of *Bathycoccus* sp. was conducted at a depth of 2,000 m in the Shiribeshi Seamount, Sea of Japan. Pressure was maintained by adjusting a switch valve and the procedure was improved by 80%.

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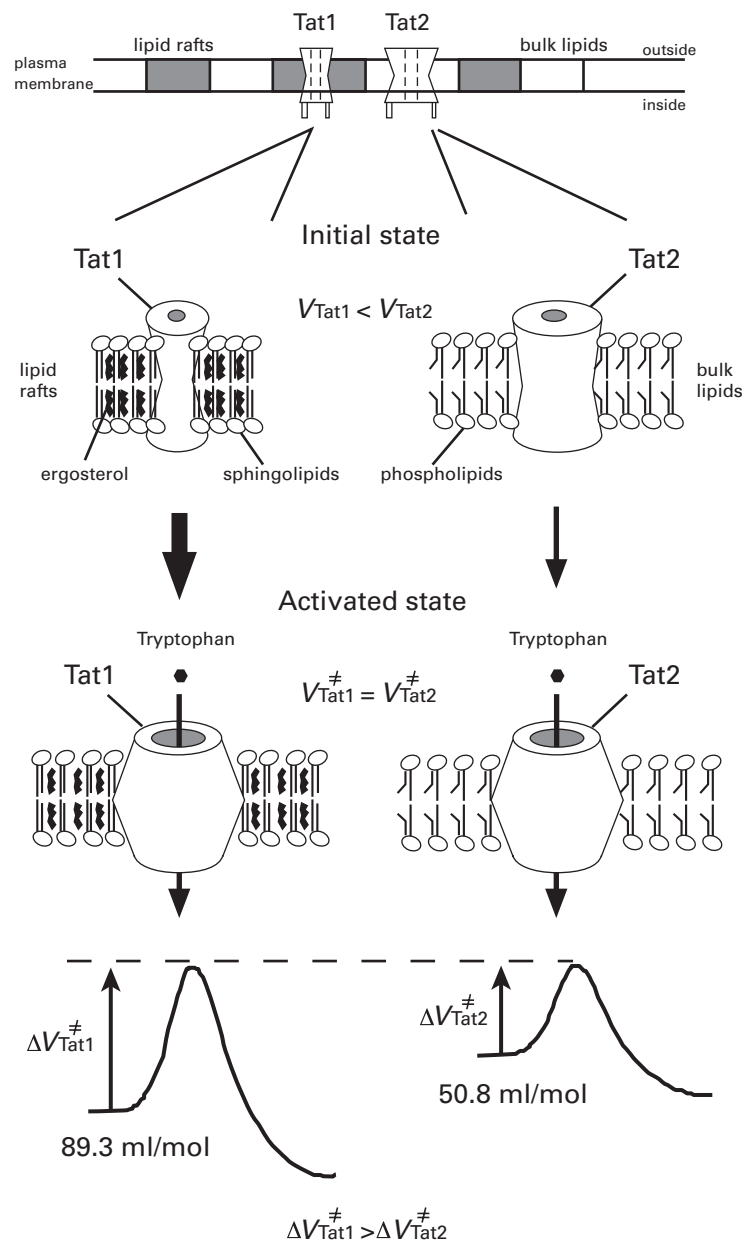


Fig.19 A model for depicting the differential localization and dynamics of the two tryptophan permeases. Tat1 is associated with lipid rafts, whereas Tat2 is localized in bulk lipids. The large activation volumes ($\Delta V^{\ddagger}$) for Tat1- and Tat2-mediated tryptophan import are accounted for mainly by volume changes associated with protein conformational changes. The initial volume of Tat1 is smaller than that of Tat2 because Tat1 is localized in the highly ordered lipid microdomain of lipid rafts. V , the volume of the permease in the initial state; $V^{\ddagger}$, the volume of the permease in the activated state; $\Delta V^{\ddagger}$, the activation volume accompanied by tryptophan import through the permease.

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(ii) Maintenance of deep-sea organisms (DEEPAQUARIUM)

In a three-month high-pressure environment breeding experiment using DEEPAQUARIUM (equipment which measures breeding among captured deep-sea organisms), 60% of breeding was possible. The cause of extinction originated in equipment trouble, specifically the tank and circulation unit's liquid leakage, and the junction of the plunger ring by degradation of a pressurization pump was a fatal problem. DEEPAQUARIUM continues to improve.

Three *Alvinocaris* shrimps captured in the Sagami Bay seabed continued breeding under high-pressure seawater. *Alvinocaris* is a shrimp without eyes that lives near hydrothermal vents. This shrimp has organs in its head which detect heat waves. It was decompressed from 10 MPa to 0.1 MPa for two months, and an ecological study was conducted under atmospheric pressure. Among the three animals, two shrimps carried eggs from the beginning. Hatching was guided by decompression and we have captured the moment of hatching with a camera (Fig.21). Breeding was

conducted using a small static glass tank. Food given to *Artemia*. The breeding water temperature was set at 2-4°C. While observing the transformation from hatching to larva, the bodily form changed over 15 days, and a eye appeared. Ecdysis was not a factor in the generation of this eye. The *Alvinocaris* shrimp larva died because of mold infection on the 74th day.

Helicolenus hilgendorfi is a deep-sea fish. Captured at a depth of 300 m in Suruga Bay, it was used for pressurized breeding. Behavioral problems from heat shock were observed at a water temperature of 9°C. When pressurized at the rate of 0.02-28 MPa/hr, *Helicolenus hilgendorfi* appeared on the tank bottom at 6.5 MPa, and took evasive action over 7 MPa. After breeding for 120 hours at 6.5 MPa, when pressurized to 0.3 MPa/hr, evasion action was not shown at 9 MPa (Fig.22).

We continue to examine the possibility of long-term breeding of live organisms within a tank which simulates the deep-sea environment. We sought a solution with breeding equipment like aquariums. Research on

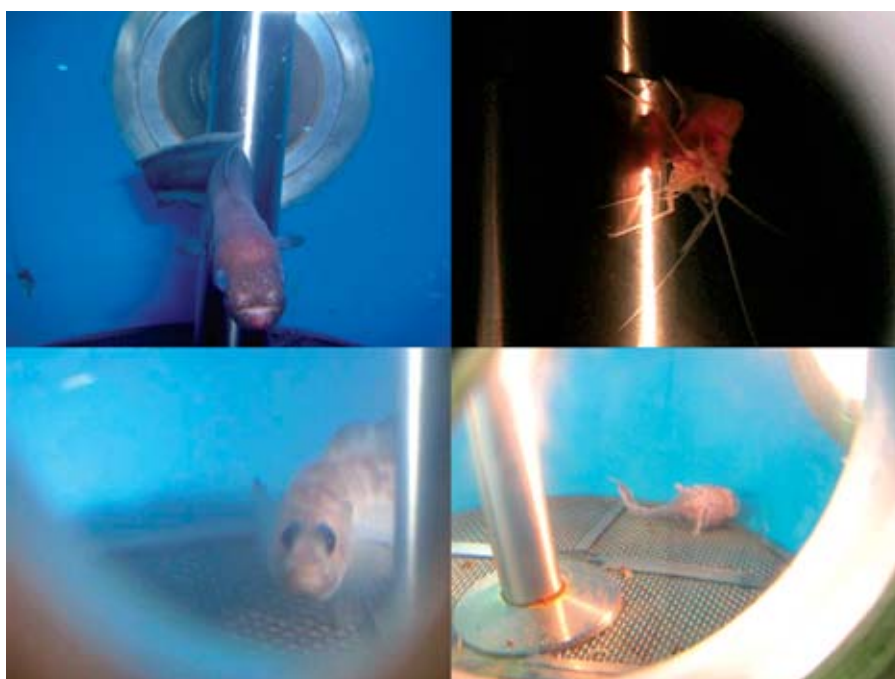


Fig.20 Upper left: *Simenchelys parasiticus* (10 MPa: survived three months), upper right: *Alvinocaris shrimp* (10 MPa: survived three months), lower left: *Zoarcidae* sp. (10 MPa: survived three months), lower right: *Bathycetus* sp. (Sea of Japan, 20 MPa, survived one day.)

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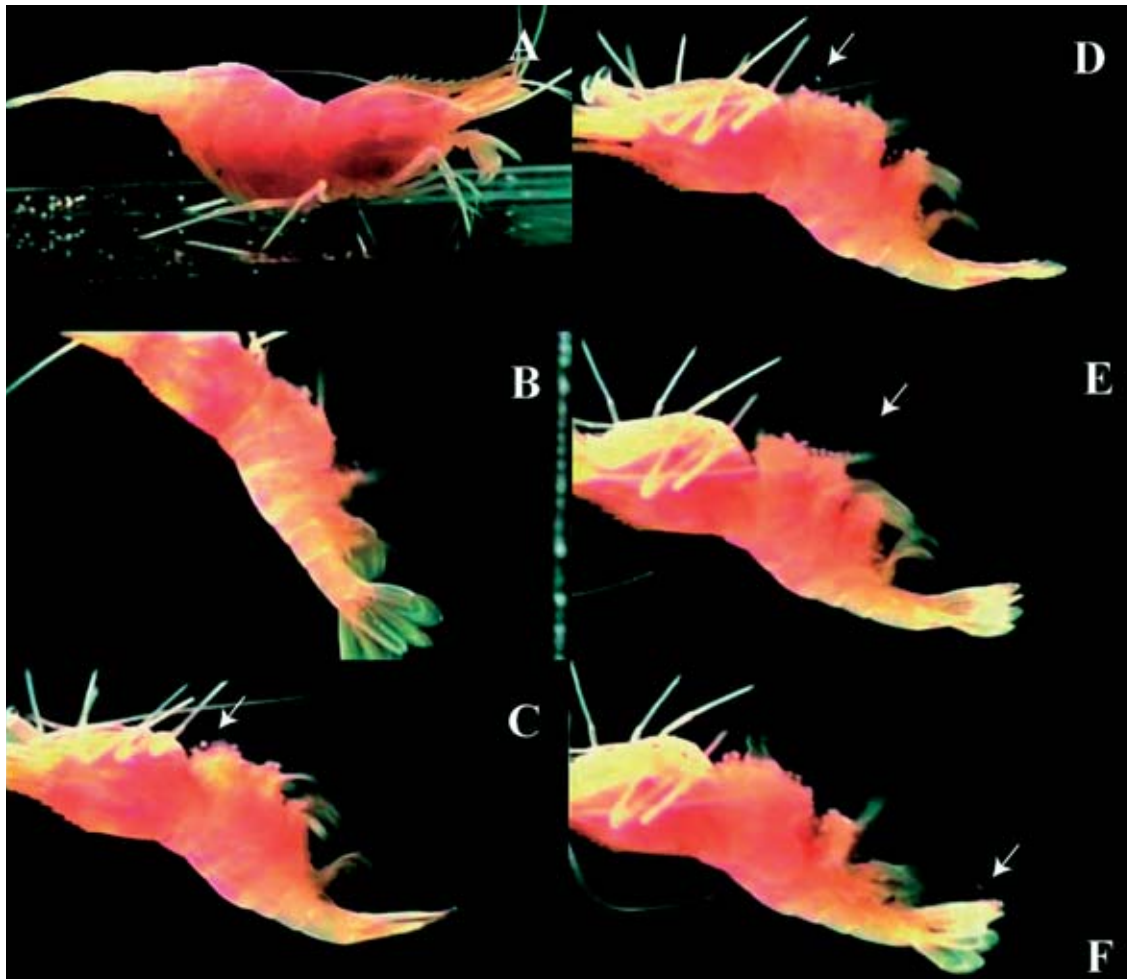


Fig.21 Hatching of *Alvinocaris* shrimp. A: The dot in the tank is larva. B-F: Moving its leg slightly, the *Alvinocaris* shrimp distributed the larva. An arrow shows hatching.

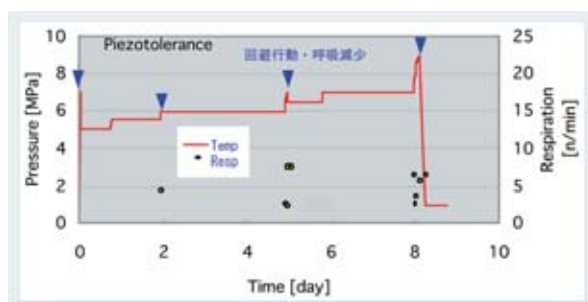


Fig.22 A response to pressurization of *Helicolenus hilgendorfi*.

the long-term breeding of deep-sea organisms began in cooperation with Enoshima PFI. Enoshima PFI manages the Enoshima Aquarium, which opened on April 16, 2004.

(iii) Tissue culture technology

Because of single-cell research, the tissue culture of a cell is required. The primary culture of a fibroblast cell from a fillet of *Simenchelys parasiticus* was performed. The fibroblast cell of *Simenchelys parasiticus* was cultivated using an L-15 medium with 20% FBS. The optimal temperature was 15°C, and cell doubling time was 0.02h⁻¹. We observed cell growth under high pressure, and tolerance of pressure. New tissue culture cells (KMHA-1) are cultivated and kept in frozen storage in the laboratory. We are attempting to develop tissue culture using deep-sea vertebrates.

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Fig.23 Contraction process of a PC12 cell neurite under high pressure. The process contracted from an axon terminal was observed by pressure at 40 MPa.

(iv) Biological response of cultured cell in high pressure environments

Functions peculiar to a multicellular organism are cytoskeleton structure formation, specialization, etc. We conducted research into a new phenomenon in the simulated deep-sea environment using the cultured cell of an experimental animal. We considered the correlation of pressure and structure formation using a nerve cell which was specialized in the cytoskeleton. Axial filament growth was examined using a PC12 cell. Consequently, pressure blocked axon terminal growth (Fig.23).

3.2. Behaviors of Biological Substances and Colloidal Dispersions in Supercritical Water

(a) Microscopic Observations of Biological Substances in Supercritical Water

We have developed an optical microscope equipped with a high temperature and pressure chamber, and have studied the behavior of various biological substances in nearcritical and supercritical water. The effects of acid concentration on the dissolution of crystalline cellulose in nearcritical water were studied this year. *In situ* microscopic observations were conducted on cellulose in the presence of various concentrations of H_2SO_4 . From images taken at different temperatures, relative transmittance was calculated (Fig.24). A semi-quantitative comparison of the dissolution behavior could be made, as dissolution of cellulose leads to an increase in transmittance.

The relative transmittance remained almost constant up to 260°C, regardless of the concentration of added H_2SO_4 , but increased above 260°C. The rate of increase depended on acid concentration, and became greater as acid concentration increased. The glass transition temperature of cellulose has been estimated at approximately 250°C. Thus, the onset of an increase in transmittance at around 260°C could be ascribed to a change in the crystalline structure of cellulose. On the other hand, the difference in the rate of transmittance change above 260°C might be related to the difference in the hydrolysis rate of swollen cellulose chains. This work has been supported by a Grant-in-Aid for Young Scientists (B) (No.15750109) from the Ministry of Education, Culture, Sports, Science and Technology.

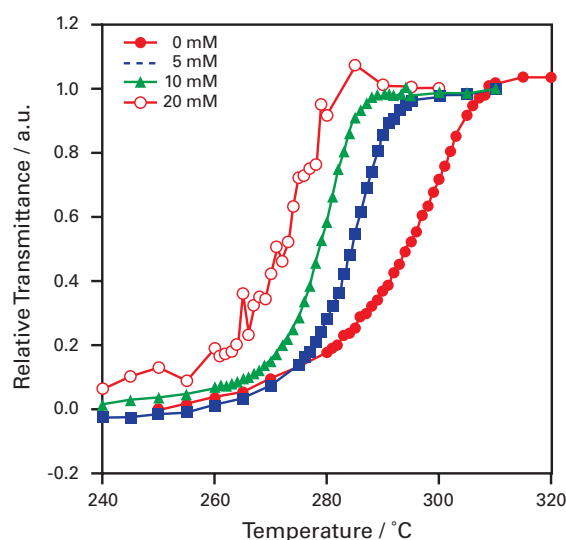


Fig.24 Relative transmittance computed from micrographs as a function of temperature.

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(b) Thermotolerance of hyperthermophiles under subcritical-water conditions

Viable hyperthermophiles have been isolated from superheated ($>200^{\circ}\text{C}$) hydrothermal fluids or materials. What is puzzling here is that *in situ* temperature is considerably higher than the maximum temperature limits of growth with microorganisms. In hydrothermal vents, recharging flow draws the microorganisms into the superheated hydrothermal fluids (the temperatures of which probably exceed 300°C), or the input of discharging flow temporarily elevates habitat temperatures far above maximum temperature growth limits. The heated habitats are then quenched when they come in contact with the surrounding cold seawater. The timescale for such temperature fluctuation is supposed to be as short as a few seconds or even shorter. To understand the ecological distribution of a microorganism in such dynamic environments, new measures other than the growth temperature have to be introduced and thermotolerance is one of them. Thermotolerance of hyperthermophiles is studied by measuring the survival rate of microorganisms after exposing them to temperatures above their maximum growth limit. This work studies the thermotolerance of hyperthermophiles under subcritical water conditions when the exposure time is on the second order, which has not been investigated so far. For this purpose, we developed a new flow-type apparatus to study the thermotolerance of hyperthermophiles under conditions simulating submarine hydrothermal circulation last year.

This year, using the apparatus, we measured the thermotolerance of *Thermococcus* sp. strain Tc-1-95, which was isolated at a hydrothermal vent in the Central Indian Ridge by the SUGAR group. The cell culture was heated to temperatures between 95.0 and 125.0°C for 1.5 sec, and the survival rate was measured. Experiments were performed at 0.5 MPa and 25 MPa, the latter of which corresponds to the hydrostatic pressure at the depth of isolation. At 0.5 MPa, no decrease in the survival rate was observed even at 114°C . Survival rates decreased with temperatures above 114°C , and no viable

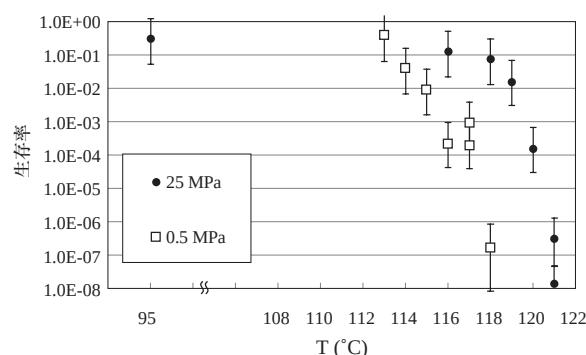


Fig.25 Thermotolerance of Tc-1-95 at 0.5 and 25 MPa.

cells were detected at 122°C . The thermostable temperature was raised to 118°C , with a hydrostatic pressure of 25 MPa applied (Fig.25). Microscopic observation suggests that the thermal death of *Thermococcus* sp. strain Tc-1-95 is induced by cell rupture at high temperatures. This is in marked contrast to the thermal death of *E. coli*, where thermal denaturation of the ribosomes may be the primary process and is not associated with cellular morphological change.

(c) Colloid science in supercritical water

Water from hydrothermal vents often contains a high amount of inorganic particles that are colloidal in size. This motivated us to study colloidal dispersion in supercritical water (SCW). From the viewpoint of colloid science, SCW is a unique media in the following aspects.

- Solvent properties can be manipulated widely and continuously by temperature and pressure
- Intense density fluctuation is present in the vicinity of the critical point

Surface forces between colloidal particles change through relative permittivity, refractive index, etc., which depend on temperature and pressure. In ambient conditions, these solvent properties are inherent constants. Using additives is the only way to change surface forces between colloidal particles through solvent properties. In this way, a change in the composition of the sample solution is unavoidable. However, using supercritical fluids as a solvent, we can change surface forces between colloidal particles by varying temperature and pressure, without changing the com-

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position of the sample solution. On the other hand, it is believed that diffusion and colloidal stability are strongly affected by critical density fluctuation. There is no theoretical or experimental study of colloids under such an inhomogeneous environment. In our study, we regard supercritical water as a unique dispersion medium, in which solvent properties are controllable, and we pay particular attention to the behavior of colloidal particles in supercritical water.

We have developed a high temperature and pressure dynamic light scattering system, and measured the colloidal stability of various colloids. We found that polystyrene latex and colloidal gold, which exhibit high colloidal stability at ambient conditions, flocculate in nearcritical and supercritical water. This year, we have tried to confirm universality of this phenomenon by measuring the dispersal stability of a chemical variety of colloids. We used aqueous dispersions of C₆₀ nanocrystals and clay minerals. All samples flocculated in subcritical water (Table 2). In addition, we made a new high temperature and pressure cell, which improved temperature uniformity, to direct observation of colloidal particles under critical density fluctuation.

This research was supported by a "Ground-based Research Announcement for Space Utilization" promoted by the Japan Space Forum and the Sumitomo Foundation.

Table 2 Threshold temperature for flocculation of various colloids

Colloid	Threshold temperature/ °C
Polystyrene latex	300
Colloidal gold	350
C60 nanocrystal	275
Clay mineral	250

4. Subsurface Microbiology

4.1. Distribution and diversity of subsurface microbial communities

(a) Iheya North deep-sea hydrothermal field in the Mid-Okinawa Trough

The possible existence of a functionally active, metabolically diverse microbial ecosystem beneath the deep-sea hydrothermal seafloor (the so-called "subvent biosphere"), has been revealed by a number of multidisciplinary investigations in a variety of hydrothermal systems with different tectonic and geologic settings, but it has not yet been proven. We propose to undertake a drilling expedition of the subvent biosphere we call "DEEP HOT BIOSPHERE (subseafloor biosphere in deep-sea hydrothermal systems in the Mid-Okinawa Trough) Drilling", with the goal of characterizing the architecture of the microbial ecosystem in physical, geochemical and hydrogeologic variations strongly associated with hydrothermal activities in the mid-Okinawa Trough, a sediment-hosted, backarc rifting, continental margin. The proposed project focuses on the shift in biologically essential chemical components in fluids such as carbon dioxide, methane, hydrogen, sulfur/sulfide, oxygen and organics, which are enriched or depleted by physical, chemical and biological processes occurring in the overall hydrothermal fluid circulation of the Mid-Okinawa Trough. These chemical substrates energize the formation of unique subseafloor microbial communities in different phases of hydrothermal fluid circulation, even just around the >300°C superheated hydrothermal fluids, where hyperthermophilic subsurface litho(auto)trophic microbial ecosystem (HyperSLiME) may occur. Extremely high concentrations of gaseous carbon compounds (CO₂ and CH₄) in the hydrothermal fluids, their stable isotopic characteristics, widely distributed CO₂-hydrate deposit in sediments and phase-separation-controlled hydrothermal fluids provide key clues to understanding the novel geomicrobiology, geochemistry, mineralogy and hydrogeology of Mid-Okinawa Trough deep-sea

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hydrothermal systems.

We have investigated geochemical and microbiological contexts in Okinawa Trough deep-sea hydrothermal systems to achieve DEEP HOT BIOSPHERE drilling. In this fiscal year, semi-quantitative cultivation and 16S rRNA gene clone analyses were used to examine the culturability and composition of microbial communities occurring in natural (sectioned chimneys) and anthropogenic (colonization devices) niches associated with phase-separation-controlled hydrothermal fluids in the Iheya North deep-sea hydrothermal field. The culturable microbial population was evaluated using liquid serial dilution techniques, targeting aerobic and anaerobic heterotrophs, methanogens, sulfate-reducers, and autotrophic hydrogen- and/or sulfur-oxidizers. The total culturability of the microbial components varied 0 to 69.4% to the total cell count among the habitats. Phylogenetic and physiological characterizations of a total of 126 isolates obtained from the cultivation experiments demonstrated that the microbial communities consisted for the most part of the members of the orders *Thermococcales*, *Aquificales*, *Methanococcales*, *Archaeoglobales*, *Thermales* and *Clostridiales*, and within several subgroups of epsilon-*Proteobacteria*. Specifically, the members of epsilon-*Proteobacteria* exhibiting extensive metabolic diversity were likely the most predominant and widespread microbial components in deep-sea hydrothermal environments from even superheated hydrothermal fluids to the mixing zones with seawater. The abundant occurrence and distribution profile of these isolates from the culture-dependent analysis was generally consistent with microbial community structures in the habitats inferred from culture-independent analyses. The heterogeneities in microbial communities indicated that microbial communities associated not only with steeply varied physical and geochemical conditions of the given habitats but also with subseafloor geohydrology controlling the phase separation and segregation of hydrothermal fluids.

(b) Yonaguni Knoll IV and Izena Hole deep-sea hydrothermal fields

(i) Yonaguni Knoll IV

We conducted a cruise for the expedition of Yonaguni Knoll IV (YK03-05, Yokosuka-Shinkai 6500) and analyzed the microbial community structures associated with hydrothermal vents by culture dependent and independent methods.

In the center of the hydrothermally active area of Yonaguni Knoll IV, there were several black smokers and one, which we call 'Tiger chimney', had both black and clear smoke. This phenomenon indicated phase separation occurred under this chimney and suggested the heat source of this hydrothermal field was shallow.

In culture-dependent analysis, the amount of methanogen was less than 10³ cells /g and this result was consistent with the shallow heat source of the field. In addition, we succeeded in isolating several interesting strains of Bacteria; three new genera that belong to *Aquificae*, e-proteobacteria, and d-proteobacteria, and a new species of *Marinitoga*. Both the culture-dependent and independent analyses showed the absence of hyperthermophilic *Aquificales* is the interesting feature of the microbial community in this field. Detailed culture-independent analyses are currently in progress.

(ii) Izena Hole

In the NT03-09 Geomicrobiology cruise, we mainly investigated two hydrothermally active areas, the JADE and HAKUREI sites in the Izena Hole. The JADE site was found in 1988 at the northeastern slope of the Izena Calderon, while the presence of the HAKUREI site was known in the hydrothermal mounds presumably bigger than the JADE site at the southern part of the Izena Calderon interior. The presence of a very active black smoker and of carbon dioxide hydrate have been found and reported previously; however, research in this field has not been conducted within the past decade because of the safety problems caused by the setting of floating buoys. On the basis of these backgrounds, the NT03-09 geomicrobiology cruise has been proposed.

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Our primary objectives during this expedition were:

- ① To visit the JADE site and confirm the location of hydrothermal vents,
- ② To compare hydrothermal activity at the JADE site with that of the past decade,
- ③ To take samples, for both microbiology and geochemistry, from the black smoker and other hydrothermal vents at the JADE site,
- ④ To observe carbon dioxide hydrate formation and take samples for microbiology,
- ⑤ To take samples of sulfur deposits at the JADE site for biogeochemical analyses,
- ⑥ To visit the HAKUREI site and observe hydrothermal vent activity,
- ⑦ To compare microbial community structures and geochemical characteristics between the JADE and HAKUREI sites, and also between the Izena Hole and Iheya North Fields,
- ⑧ To measure heat flow values at various points in the Iheya North area.

To understand biogeochemical hydrothermal vent systems, it is very significant to know the environment's physical properties, so pH, temperature, oxygen, hydrogen, methane, and Eh redox have already been measured during dives as thoroughly as possible. All samples such as sediment, rock, fluid, seawater and gas were treated immediately in the onboard laboratory for geochemical, microbiological, mineralogical, and geological analysis.

During the NT03-09 monthlong cruise, we accomplished a surprising 19 dives using the ROV 'Hyper-Dolphin'. Major achievements and discoveries were as follows:

- ① The distribution of hydrothermal vents and their activity in the JADE and HAKUREI sites were identified.
- ② The most active black smoker chimney in the JADE site, named 'TBS', was rediscovered, and vent fluid and chimney samples for geochemistry and microbiology were successfully obtained.
- ③ A very big hydrothermal mound composed primarily of elemental sulfur (named 'Sulfur Reef'), was

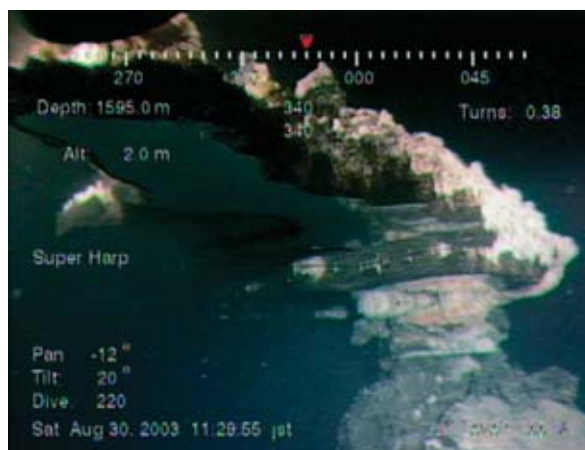


Fig.26 A huge flange structure and buoyant hydrothermal fluid under the flange (which resembles a mirror) at the Dragon Chimney in the Hakurei site of the Izena Hole.

discovered at the JADE site.

- ④ 'Dragon chimney' a black smoker chimney covered with the biggest flange structure in the world was discovered (Fig.26), and its geophysical characteristics were successfully investigated.
- ⑤ Heat flow values to monitor sub-vent geo-hydrology were successfully collected at various points in the Iheya North Field.

Using samples and onboard data collected during this cruise, the relationship between microbial distribution, diversity, metabolic activities and geochemical and geological characteristics will be extensively demonstrated from multidisciplinary aspects in shore-based studies. In general, the scientific cruise NT03-09 ('Geomicrobiology cruise in the Okinawa Trough hydrothermal systems: Izena Hole and Iheya North') has been successfully accomplished, and will provide great insight into total understanding of biogeochemical cycling in the hydrothermal systems of the Okinawa Trough Back Arc Basin.

(c) ODP Legs#201 & 204

ODP cores from offshore South (Peru Margin) and North (Cascadia Margin) America were examined for this study. Testing for infiltration of the drilling fluids indicated only minimal levels of contamination. Site 1227 is located in the Trujillo Basin on the Peru conti-

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mental shelf at a water depth of 427 m; the sediments are rich in organic carbon (~10.6% TOC), lack methane hydrate, and exhibit relatively low C1/C2 ratios (100 to 1,000). Although the C1/C2 values at Site 1227 were lower than other examined hydrate-bearing core sediments, the $\delta^{13}\text{C}$ values of the head-space methane suggested its formation by biologically mediated methanogenesis. In contrast, Site 1230 is located on the lower slope of the Peru Trench at a water depth of 5,086 m where several horizons lower than 70 m below the seafloor (mbsf) contain methane hydrate and gaseous hydrocarbons with a C1/C2 ratio of over 10,000. Site 1225 sediments contained trace concentrations of methane (<0.01 mM). On the Cascadia Margin, Sites 1244 and 1245 were located in the middle of the SHR at a water depth of 900 m, whereas Site 1251 was located shoreward of SHR at a water depth of 1,200 m. At these three sites, methane hydrate was detected; gaseous hydrocarbons had C1/C2 ratios of 1,000 to 10,000.

Methane hydrate-bearing deep marine sediments on

the Peru and Cascadia Margins harbor previously unknown prokaryotic communities. 16S rRNA phylogenotypes present in vertically-distinct sediment samples above hydrates revealed the predominance of as-yet uncultured and unidentified archaea within the Deep-Sea Archaeal Group. Bacterial communities were predominantly composed of the 'JS1' candidate group and Planctomycetes. Both population size and phylogenetic diversity are distinct from sediments lacking hydrates. RNA-based analyses indicate that some deeply-buried cells are potentially active on a geologic timescale. Scarcity of known mesophilic methanogens and detection of hyperthermophilic methanogens suggest a hitherto unexpected complexity of biogenic methane formation.

(d) Serpentine Seamounts in the Mariana Forearc

The deep-sea hydrothermal seafloor and its sub-seafloor terrain in the tectonic margins are considered to be the primary regions on Earth where potential energy and carbon sources for the active subsurface

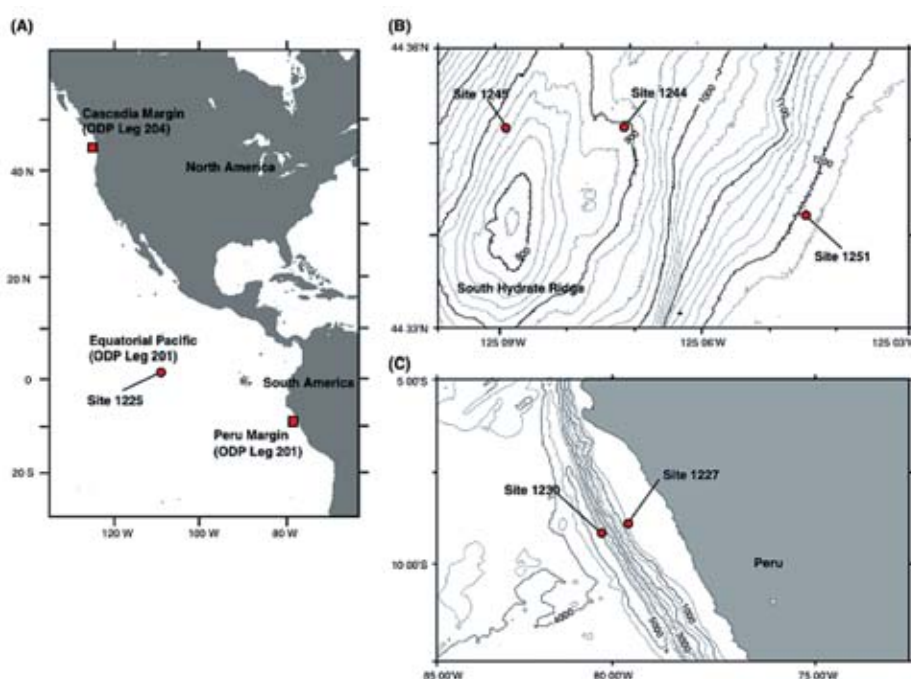


Fig.27 Location maps of the study sites in the eastern equatorial Pacific (A). Detail map of South Hydrate Ridge on the Cascadia Margin off Oregon showing ODP Sites 1244, 1245, and 1251 (Leg 204) (B), and the continental slope on the Peru Margin showing ODP sites 1227 and 1230 (Leg 201) (C).

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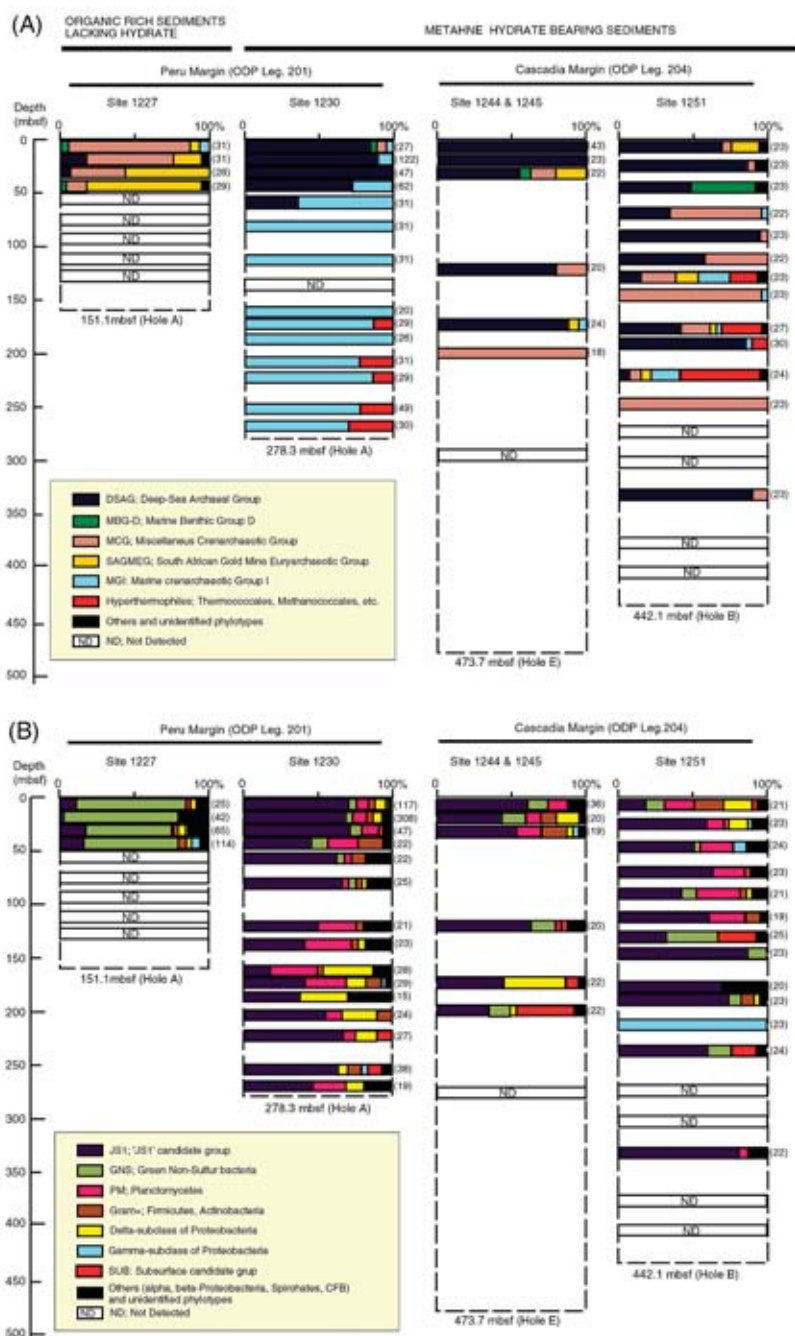


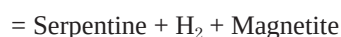
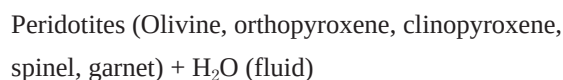
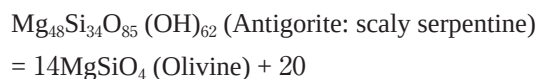
Fig.28 Phylogenetic community structures of 16S rRNA gene clone libraries of domains Archaea (A) and Bacteria (B). Clone libraries were constructed from a series of whole round core sediment subsamples recovered from the Peru Margin (Leg 201) and Cascadia Margin (Leg 204). Numbers of clones that were examined at each depth are indicated in parentheses.

biosphere are constantly provided from the Earth's interior. However, sites other than magmatism-associated hydrothermal systems (like the subducting oceanic lithosphere occurring in the Mariana Forearc), could serve as hosts for SLiME where geochemical and min-

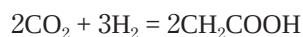
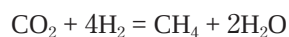
eralogical components are being generated and recycled. Called a 'Subduction Factory', the Mariana subduction system is composed of subducting oceanic slab and the upper mantle, which generates liquid water, carbon dioxide, hydrogen, methane, and other

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oxidized chemical components under much lower temperature conditions than hydrothermal systems, corresponding to the following reactions:



During this process, called serpentinization, part of the hydrogen gas may reduce coexisting carbon dioxide to produce methane or hydrocarbon with the Fischer-Tropsch reaction in the presence of metal oxide catalysts.



Although these geochemical reactions occur in the deeper zone of the crust near the upper mantle, the chemical products can be ejected with the serpentine diapir due to their buoyancy. In fact, geochemical analysis of the sediments and core-liner gases at site 1200 (the south Chamorro seamount, ODP leg. 195), suggest that high concentrations of C₁ through C₆ hydrocarbons (presumably produced by the Fischer-Tropsch reaction) were rising upward with deep upwelling fluids. Such geochemically-produced substrates as water, hydrogen, carbonate, methane and hydrocarbons could supply the needed energy and carbon for chemolitho-autotrophic or hydrocarbonotrophic micro-organisms and support microbial activity in deep-subseafloor environments.

In this study, we examined the culturability of subseafloor alkaline serpentine mud microorganisms retrieved during ODP Leg 195 in March 2001 from ODP Hole 1200D of the South Chamorro Seamount, Mariana Forearc. A variety of alkaline media with organic and/or inorganic substrates were tested for cultivation of alkaliphilic microbial components in the core samples at different depths. Heterotrophic alkaliphiles were successfully cultivated from the relatively shallow zone of the core, and then purified. 16S

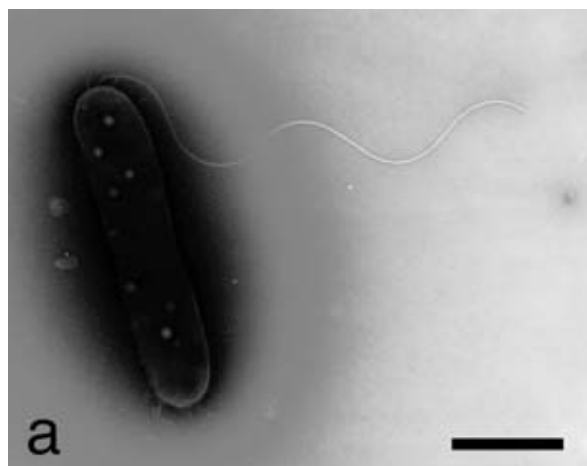


Fig.29 Electron micrographs of a negatively-stained cell of *Marinobacter alkaliphilus* strain ODP1200D-1.5^T. Single cell in the mid-exponential growth phase. The bar indicates 1.0 μm.

rRNA gene sequence analysis of the alkaliphilic isolates revealed that most were very closely related. Two representative strains were further characterized. On the basis of physiological and molecular properties of the new isolates, we propose here that a new species of *Marinobacter* be named *Marinobacter alkaliphilus* (Fig.29). This is the second new species taxonomically described from the core samples derived from the ODP in its long history, after the *Desulfovibrio profundus* strain 500-1T from the Japan Sea.

(e) Subsurface microbial ecosystems in the Hishikari Gold Mine

FISH analysis was performed using specific oligonucleotide probes targeting unique regions of 16S rRNA in the predominant phylotypes (HAuD-UB26, HAuD-UB5, HAuD-UA44, HAuD-MB27, and HAuD-LB38). Three probes (HAuD-UB26, AF175, and HAuD-UA44) were hybridized with cells in the upper mat. To quantify each clone in the mat, the cells visualized with probes were counted and calculated as a ratio of the number of probe-positive cells to the total number of DAPI-stained cells. The probe-positive populations of HAuD-UB26, HAuD-UB5, and HAuD-UA44 were 25%, 17%, and 11% of the total DAPI-stained microbial population in the upper mat, respectively (Table 3). In contrast, only 0.1-2% of

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Table 3 Probes for FISH analysis and estimated population ratios of detected mat phylotypes.

Probe designation	Group detected	% of total cells		
		Upper	Middle	Lower
HAuD-UB26	HAuD-UB26 ^a pHAuB- P ^b (<i>γ-Proteobacteria</i>)	25	0.1	1
AF175	HAuD-UB5 ^a pHAuB-D ^b (<i>Aquificales</i>)	17	2	0.4
HAuD-UA44	HAuD-UA44 ^a (HWCG)	11	1	1
HAuD-MB27	<i>Nitrosomonas europaea</i> / <i>Nitrosococcus mobilis</i> -cluster spp. & relative clones (<i>β-Proteobacteria</i>)	0.1	30	26
HAuD-LB38	<i>Nitrospira moscoviensis</i> & relative clones (<i>Nitrospira</i> group)	0.1	52	66

^a Clone from the stream mat^b Clone from the vein water

cells were probe-positive in the middle and lower mats with these probes. Probes HAuD-MB27 and HAuD-LB38 were designed to detect predominant clone types in the middle and lower mats. FISH analysis of the middle mat with probes HAuD-MB27 and HAuD-LB38 demonstrated that each population ratio was 30% and 52%, respectively. In the lower mat, the estimated population ratios by FISH-count were 26% for HAuD-MB27 and 66% for HAuD-LB38. Both probes HAuD-MB27 and HAuD-LB38 detected only 0.1% of the total cells in the upper mat.

An example FISH image is shown in Fig.30. As a result of FISH analyses of microbial mat structures, the examination successfully distinguished the predominant mat microorganisms.

Three key enzyme genes, *pmoA* for methane oxidation, *amoA* for ammonia oxidation, and *norB* for nitrite oxidation in the microbial mat DNA assemblages were quantified by a competitive PCR (cPCR) assay (Fig.31).

In the upper mat, $1.15 \times 10^8 \pm 4.24 \times 10^7$ copies of *pmoA* and $9.91 \times 10^5 \pm 1.65 \times 10^5$ copies of *norB* per

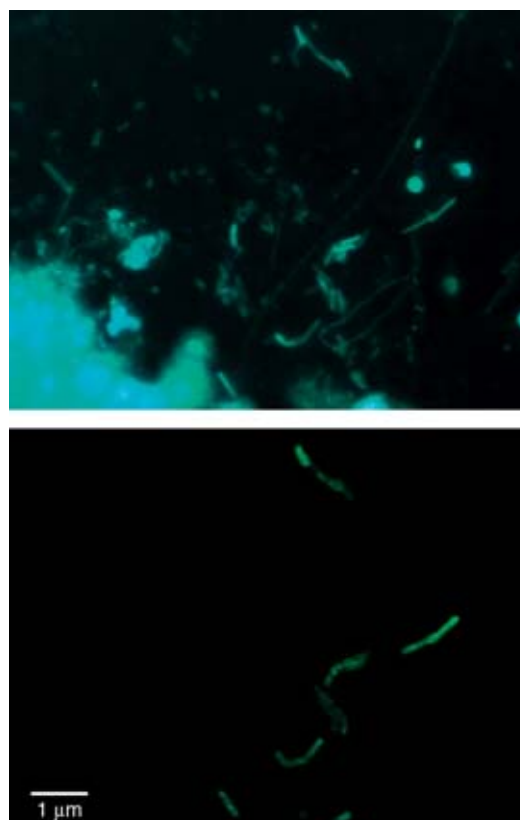


Fig.30 FISH analysis using HauD-MB27 clone-specific probe. The upper picture shows DAPI-stained cells, and the lower picture shows hybridized cells with probes.

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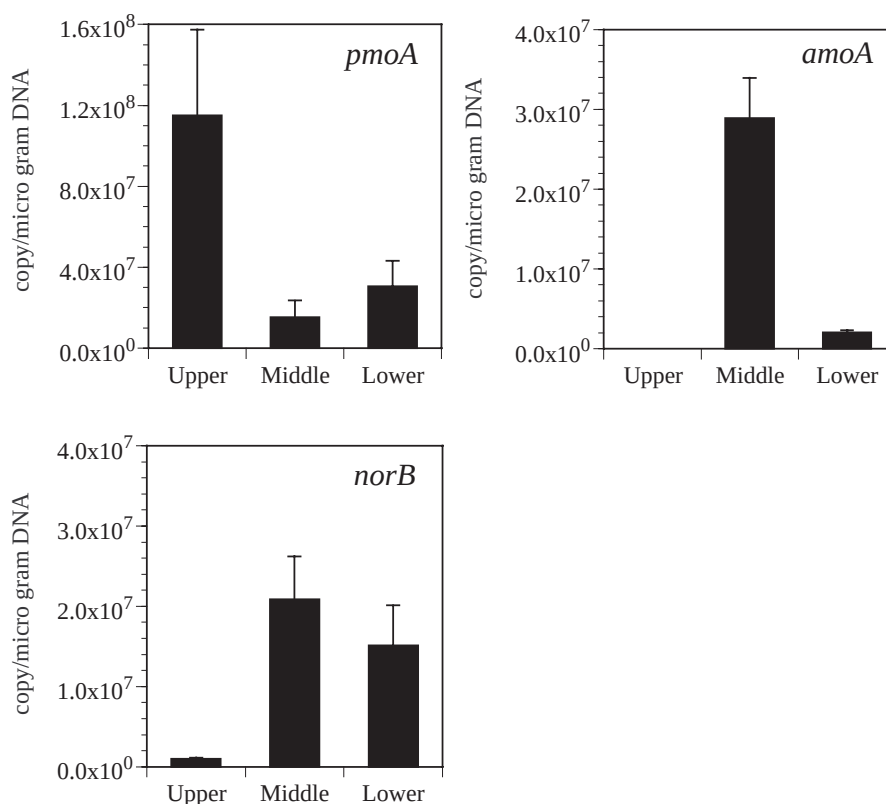


Fig.31 Competitive PCR quantification of *pmoA*, *amoA*, and *norB* in the geothermal water stream.

μg of mat DNA were detected, whereas the *amoA* was below the detection limit (approximately $<5 \times 10^4$ copies per μg DNA). This result revealed the predominant occurrence of methane oxidation metabolism by γ -*Proteobacteria* and very little ammonia oxidation by β -*Proteobacteria* in the upper mat. The middle mat contained $1.52 \times 10^7 \pm 8.37 \times 10^6$ copies of *pmoA*, $2.89 \times 10^7 \pm 5.05 \times 10^6$ copies of *amoA*, and $2.09 \times 10^7 \pm 5.32 \times 10^6$ copies of *norB* per μg of mat DNA, in relative agreement with the co-existence of members of the methane-oxidizing *Methylococcus*, ammonia-oxidizing *Nitrosomonas/Nitrosococcus*, and nitrite-oxidizing *Nitrospira* on the basis of 16S rRNA gene clone analysis and FISH observation. The lower mat showed $3.05 \times 10^7 \pm 1.26 \times 10^7$ copies of *pmoA*, $2.04 \times 10^6 \pm 2.85 \times 10^5$ copies of *amoA*, and $1.51 \times 10^7 \pm 5.00 \times 10^6$ copies of *norB* per μg of mat DNA, relatively similar to the patterns seen in the middle mat, and indicative of a strong population capable of oxidizing nitrite. In the lower mat, however, the estimated copy number of

pmoA was significantly higher than expected. It was reported that methane-oxidizing γ -*Proteobacteria* and ammonia-oxidizing β -*Proteobacteria* generally had several copies of *pmoA* or *amoA* in their genomic DNA. Given that *norB* is present as a single copy in the genome of the nitrite-oxidizing *Nitrospira* members, the magnitude of nitrite-oxidizing evaluated by copy numbers of *norB* gene may be underestimated compared with those of methane and ammonia oxidation.

(f) Approach to subsurface microbial communities using functional genes (DSR)

The phylogenetic diversity of sulfate-reducing prokaryotes occurring in active deep-sea hydrothermal vent chimney structures was characterized based on deduced amino acid sequence analysis of the polymerase chain reaction-amplified dissimilatory sulfite reductase (DSR) gene. The DSR genes were successfully amplified from microbial assemblages of the chimney structures derived from three geographically and

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geologically distinct deep-sea hydrothermal systems in the Central Indian Ridge (CIR) the Izu-Bonin Arc (IBA), and the Okinawa Trough (OT), respectively. Phylogenetic analysis revealed seven major phylogenetic groups. More than half of the clones from the CIR chimney structure were related to DSR amino acid sequences of the hyperthermophilic archaeal members of the genus *Archaeoglobus*, and those of environmental DSR clones within the class *Thermodesulfobacteria*. From the OT chimney structure, a different group was obtained, which comprised a novel, deep lineage associated with the DSRs of the thermophilic sulfate-reducing bacterium *Thermodesulfovibrio*. Most of the DSR clones from the IBA chimney structure were phylogenetically associated with the delta-proteobacterial sulfate-reducing bacteria represented by the genus *Desulfobulbus*. Sequence analysis of DSR clones demonstrated a diverse sulfate-reducing prokaryotic community in the active deep-sea hydrothermal chimney structures.

4.2. Isolation of novel microorganisms from subsurface and other extreme environments

(a) *Sulfurimonas autotrophica* gen. nov., sp. nov.

A novel mesophilic, sulfur- and thiosulfate-oxidizing bacterium, strain OK10^T (Fig.32), was isolated from deep-sea sediments in the Hatoma Knoll of the Mid-Okinawa Trough hydrothermal field. Cells of strain OK10^T were short rods, each motile by means

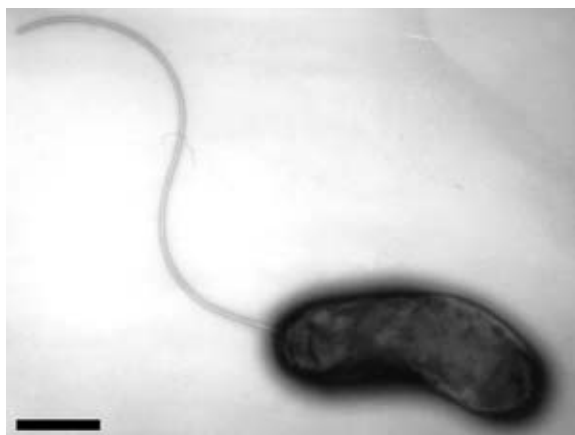


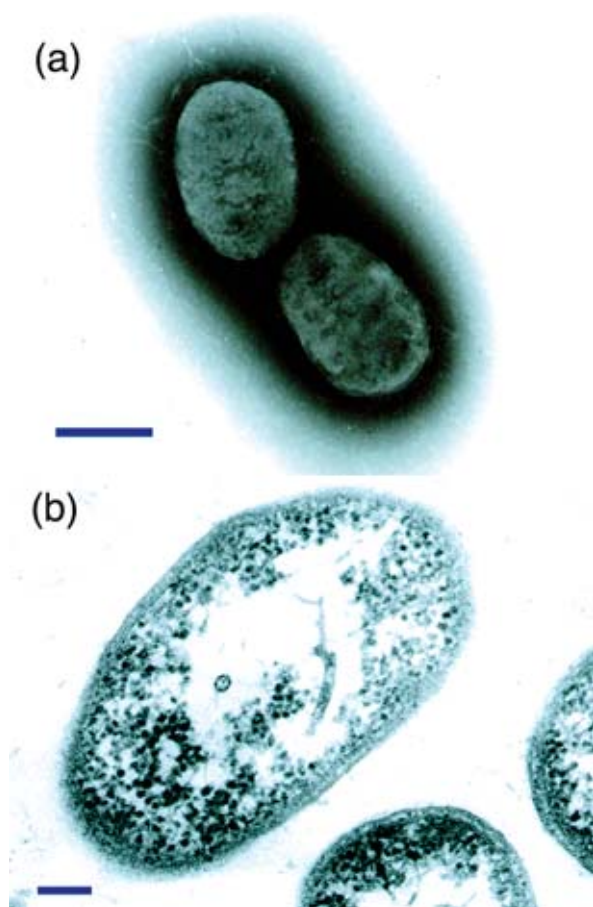
Fig.32 An electron micrograph of strain OK10^T.

of a single polar flagellum. The isolate grew at 10–40°C (optimum 25°C) and pH 4.5–9.0 (optimum pH 6.5). It grew chemolithoautotrophically with elemental sulfur, sulfide and thiosulfate as sole electron donors and oxygen as an electron acceptor. Molecular hydrogen did not support growth. The G+C content of the genomic DNA of strain OK10^T was 35.2 mol%. Phylogenetic analysis based on 16S rRNA gene sequences indicated that the isolate belonged to the *epsilon-Proteobacteria*. On the basis of its physiological and molecular characteristics, strain OK10^T (=ATCC BAA-671^T=JCM 11897^T) represents the sole species of a new genus, *Sulfurimonas*, for which the name *Sulfurimonas autotrophica* is proposed.

(b) *Sulfurovum lithotrophicum* gen. nov., sp. nov.

A novel mesophilic sulfur- and thiosulfate-oxidizing bacterium, strain 42BKT^T (Fig.33), was isolated from the gas-bubbling sediment at the Iheya North hydrothermal system in the mid-Okinawa Trough, Japan. The isolate was a gram-negative, non-motile, and coccoid to oval-shaped bacterium. Growth was observed at 10–40°C (optimum 28–30°C), and at the pH range 5.0–9.0 (optimum 6.5–7.0). The strain 42BKT^T grew chemolithoautotrophically with elemental sulfur or thiosulfate as a sole electron donor and oxygen (optimum 5% in gas phase) or nitrate as an electron acceptor. The G+C content of the genomic DNA was 48.0 mol%. Phylogenetic analysis based on the 16S rRNA gene sequence indicated that the isolate belonged to the previously uncultivated Group F within the epsilon-subclass of the *Proteobacteria*, which includes phylotypes of vent epibiont and environmental sequences from global deep-sea cold seep and hydrothermal vent fields. On the basis of the physiological and molecular characteristics of the new isolate, the species of a new genus, *Sulfurovum lithotrophicum* gen. nov., sp. nov., is proposed. The type is strain 42BKT^T (=ATCC BAA-797^T=JCM 12117^T).

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Fig.33 Electron micrographs of strain 42BKT^T.(c) *Thiobacter subterraneus* gen. nov., sp. nov.

A novel thermophilic, obligately autotrophic, sulfur/thiosulfate-oxidizing bacterium was isolated from subsurface geothermal aquifer water (temperature of approximately 70°C) in the Hishikari Gold Mine, Japan. The cells of the isolate, designated as strain C55^T (Fig.34), were motile, straight rods with a single polar flagellum. Growth was observed at temperatures between 35 and 62°C (optimum: 50–55°C; 60 min doubling time) and pH between 5.2 and 7.7 (optimum: pH 6.5–7.0). High growth rate of strain C55^T was observed with either thiosulfate or elemental sulfur as a sole energy source, with molecular oxygen as the only electron acceptor. No organic compounds tested support or stimulated the growth of strain C55^T. The G+C content of the genomic DNA was 66.9 mol%. Phylogenetic analysis based on 16S rRNA gene sequences indicated that strain C55^T was affiliated to the β -subclass of

Fig.34 An electron micrograph of strain C55^T.

Proteobacteria, but was distantly related to previously identified genera. On the basis of physiological and molecular properties, strain C55^T (= JCM12421T = ATCC BAA-941T) is proposed as *Thiobacter subterraneus* gen. nov., sp. nov.

(d) *Methylothermococcus subterraneus* gen. nov., sp. nov.

Strain HTM55 grew aerobically using methane as the sole source of energy and carbon, with optimal growth at 50–55°C. TEM observation of strain HTM55 clearly indicated the existence of typical intracellular membrane structures in cells of type I methanotrophs. The 16S rRNA gene sequence of strain HTM55 was distantly related to those of previously identified type I methanotrophs and represented a novel lineage of methane-oxidizing bacteria within the γ -*Proteobacteria* (Fig.35). The highest similarities were observed with the sequences of uncultivated phylotype HAUd-UB26, prevalent in the upper stream, and thermophilic methanotroph strain HB, isolated from a hot spring in Hungary. Phylogenetic analysis of genes of particulate methane monooxygenase (*pmoA*) for methane oxidation also delineated the close relationship among strain HTM55, phylotype HAUd-UB26, and thermophilic methanotroph strain HB.

Phylotype HAUd-UB26 was previously detected as the most abundant phylotype in the upper stream; therefore, the isolation of closely-related strain HTM55 representing a novel lineage of methanotroph has great significance in understanding both microbial ecology in

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the subsurface geothermal environment and evolutions of type I methanotrophs.

(e) *Balnearium lithotrophum* gen. nov., sp. nov.

A novel extremely thermophilic bacterium, designated as strain 17S^T (Fig.36), was isolated from a deep-sea hydrothermal vent chimney at the Suiyo Seamount in the Izu-Bonin Arc, Japan. The cells were rods with no apparent motility, most of which were narrow in the middle in the exponential growth phase and had several polar flagella at both ends. Growth was observed between 45 and 80°C (optimum temperature: 70–75°C; 80 min doubling time) and between



Fig.36 An electron micrograph of strain 17S^T.

pH 5.0 and 7.0 (optimum pH 5.4). The isolate was a strictly anaerobic hemolithoautotroph capable of using molecular hydrogen as its sole energy source and car-

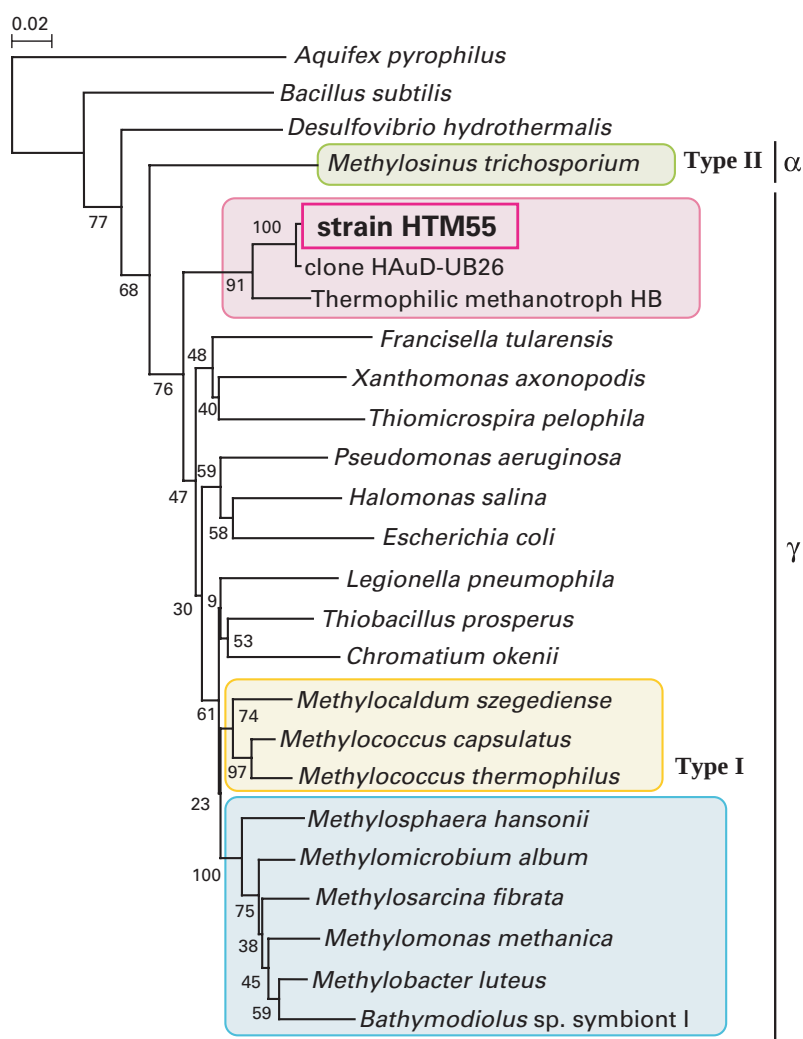


Fig.35 Phylogenetic tree of 16S rDNA sequences of representative strains and clones within γ -Proteobacteria using the neighbor-joining method with 805 homologous positions in sequences. HAuD-UB26 is a predominant clone in the upper mat of the discharging hot stream.

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bon dioxide as its sole carbon source. Elemental sulfur (S^0) is required for growth as an electron acceptor. The G+C content of the genomic DNA was 34.6 mol%. Phylogenetic analysis based on 16S rDNA sequences indicated that the isolate was related to *Thermovibrio ruber* strain ED11/3LLK^T and *Desulfurobacterium thermolithotrophum* strain BSA^T, while it appeared to be a novel lineage prior to divergence between *T. ruber* strain ED11/3LLK^T and *D. thermolithotrophum* strain BSA^T. This isolate could be also differentiated from either *T. ruber* strain ED11/3LLK^T or *D. thermolithotrophum* strain BSA^T on the basis of its physiological properties. We propose the name *Balnearium lithotrophicum* gen. nov., sp. nov. (type strain: 17S^T; JCM 11970^T and ATCC BAA-736).

(f) *Hydrogenimonas thermophila* gen. nov., sp. nov.

A novel thermophilic bacterium, designated as strain EP1-55-1%^T (Fig.37), was isolated from an in situ colonization system (ISCS) deployed in the superheated deep-sea hydrothermal vent emission of the Kairei Field in the Central Indian Ridge (CIR), Indian Ocean. The cells were highly motile rods with a single polar flagellum. Growth was observed between 35 and 65°C (optimum temperature: 55°C; 70 min doubling time) and between pH 4.9 and 7.2 (optimum pH 5.9). The isolate was a microaerobic to anaerobic chemolithoautotroph capable of using molecular hydrogen as its sole energy source and carbon dioxide as its sole carbon source. Molecular oxygen, nitrate, or

elemental sulfur (S^0) could serve as an electron acceptor to support growth. The G+C content of the genomic DNA was 34.6 mol%. Phylogenetic analysis based on 16S rDNA sequences indicated that the isolate represented the first strain, of which taxonomic properties have been characterized, within the previously uncultivated epsilon-*Proteobacteria* Group A. We propose here the name *Hydrogenomonas thermophilus* gen. nov., sp. nov. (type strain: EP1-55-1%^T; JCM 11971^T and ATCC BAA-737^T).

(g) *Aeropyrum camini* sp. nov.

A novel hyperthermophilic archaeon, designated strain SY1^T (Fig.38), was isolated from a deep-sea hydrothermal vent chimney sample collected from the Suiyo Seamount in the Izu-Bonin Arc, Japan, at a depth of 1385 m. The cells were irregular cocci (1.2 to 2.1 µm in diameter), occurring singly or in pairs, and stained Gram-negative. Growth was observed between 70 and 97°C (optimum, 85°C; 220 min doubling time), pH 6.5 and 8.8 (optimum, pH 8.0), and salinity of 2.2 and 5.3% (optimum, 3.5%). It was a strictly aerobic heterotroph capable of growing on complex proteinaceous substrates such as yeast extract and tryptone. The G+C content of the genomic DNA was 54.4 mol%. Phylogenetic analysis based on the 16S rDNA sequence of the isolate indicated that the isolate was closely related to *Aeropyrum*

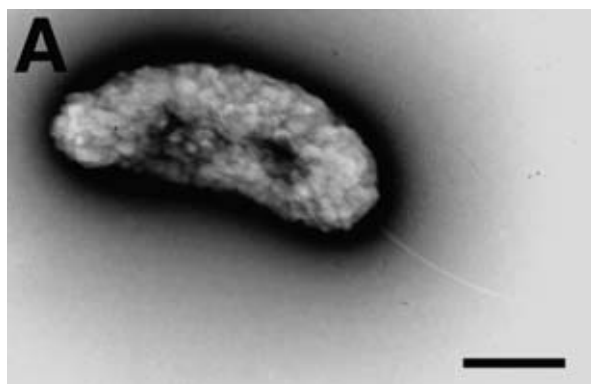


Fig.37 An electron micrograph of strain EP1-55-1%^T.

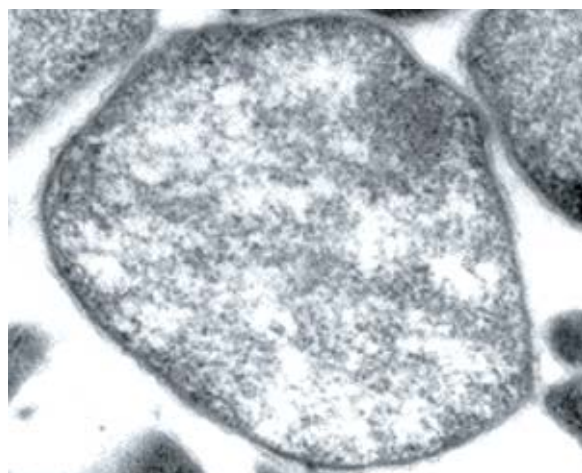


Fig.38 An electron micrograph of strain SY1^T.

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pernix strain K1^T. However, no significant genetic relatedness was observed between them by DNA-DNA hybridization. On the basis of the molecular and physiological traits of the new isolate, the name *Aeropyrum camini* sp. nov. is proposed, with the type strain SY1^T (=JCM 12091^T = ATCC BAA-758^T).

4.3. Biomineralization

The "scaly-foot" gastropod, known only from a deep-sea hydrothermal field in the Central Indian Ridge, has a foot covered with scale-shaped sclerites composed of proteins and iron sulfides. The sulfides (mackinawite [FeS], greigite [Fe₃S₄] and pyrite [FeS₂]), shown here to exist as nanometer-size inclusions, are formed as distinct strata inward from the surface of the sclerites. The presence of sulfate-reducing bacteria (SRB) related to *Desulfobulbus* spp. in the sclerite tissue strongly suggests that the unique nano-size sulfide inclusions reported here are the result of a novel endosymbiosis. We are currently conducting magnetic measurements of the sclerites in collaboration with Joseph Kirschvink at the California Institute of Technology.

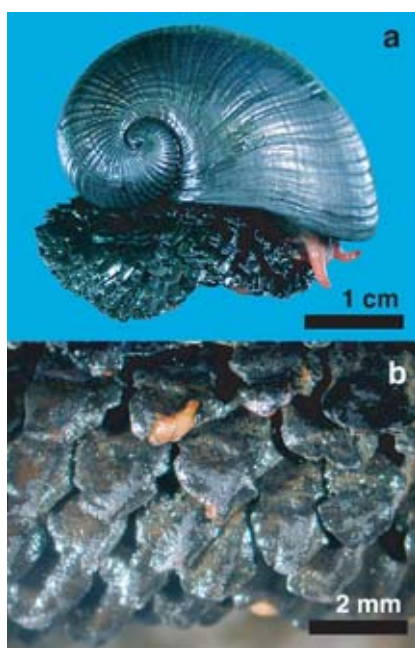


Fig.39

4.4. Metagenome from subsurface

We constructed a fosmid library from the sediment of a subsurface hot spring (70°C) in the Hishikari Gold Mine and explored the gene fragments that contain the genes of DNA polymerase and/or 16S rRNA of the hot water crenarchaeotic group (HWCG). From the report of Hirayama et al., HWCG is the predominant member (20–80%) of the microbial community in this subsurface hot spring. The 16S rRNA genes of group HWCG have been detected in Iceland hot springs and other hot temperature environments and the phylogenetic position is located between the cluster of hyperthermophilic crenarchaeota and that of Marine crenarchaeotic I-Soil group crenarchaeota. Considering the temperature of the environment where HWCG was detected, HWCG is a putative thermophile and new possible genetic resource for biotechnology, but has not yet been cultured. Therefore, we will try to obtain gene fragments of HWCG by environmental genetics. We finally obtained a gene fragment of putative B1 type DNA polymerase from HWCG by PCR using degenerate primers as the probe for screening (Fig.40). The screening of a gene fragment of HWCG from the fosmid library is now in progress.

4.5. Evaluation of methods for obtaining subsurface core samples without microbial contamination

The effectiveness of the gel-core barrel system, developed to recover core samples without microbial contamination, was evaluated. By using coring equipment developed by JAMSTEC, drilling tests were performed with or without the antimicrobial gel (Fig.41). Fluid circulated during the drilling was made to contain a known amount of microbial cells (4.0×10^5 cells/ml). When drilling was performed without the antimicrobial gel, viable microbial cells of 2.0×10^3 cells/g-sample were detected on the core surface. However, this number was reduced to 10 cells/g-sample with the antimicrobial gel. The gel-core barrel system has proven effective in preventing microbial contamination when drilling.

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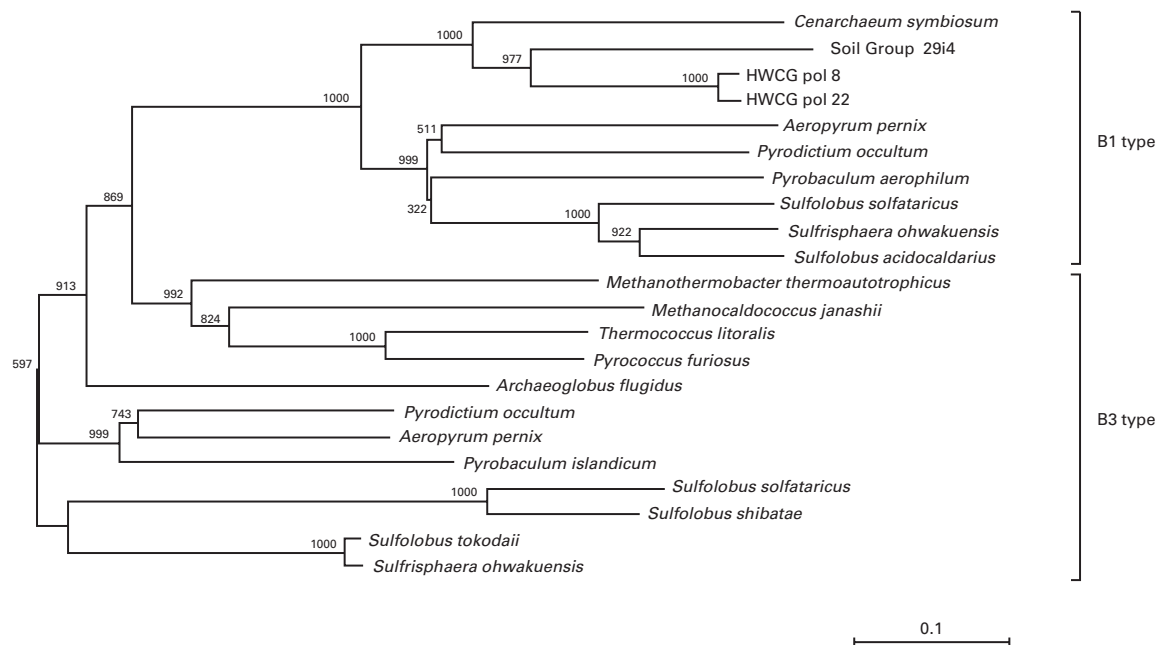


Fig.40 Phylogenetic analysis of DNA polymerase amino acid sequences obtained from a metagenomic approach in the Hishikari Gold Mine.

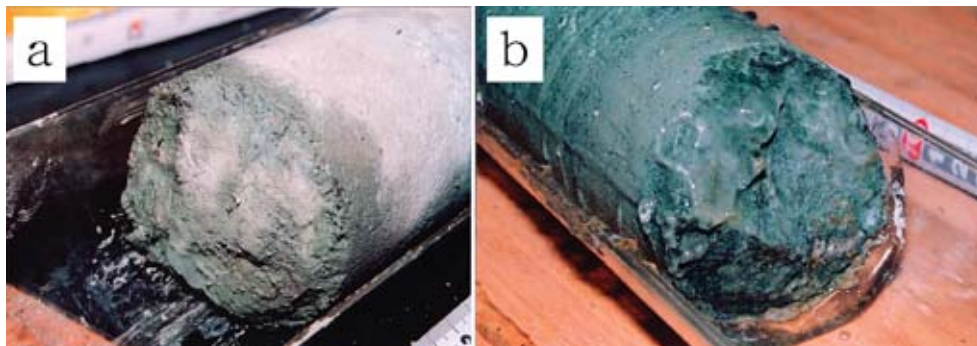


Fig.41 A core sample recovered without using the antimicrobial gel (a). A core sample recovered using the antimicrobial gel (b).

The antimicrobial polymer-coating mechanism has also been applied to a piston corer. A piston corer, equipped with a piston head and a reservoir for the antimicrobial gel, has been developed and tested using two types of the gel with different viscosity (10,000 mPa's and 1,000 mPa's). Fluorescent beads were added to the gel as a tracer. After coring, the core surface was divided into grids (5.0 cm × 2.5 cm), the surface of each grid was collected separately, and the number of fluorescent beads in the samples was counted by fluorescent microscopy. Twenty-nine grids were found to contain no fluorescent beads when the gel

viscosity was high, indicating incomplete coverage of the core surface with the gel. However, when gel viscosity was low, almost the entire core surface was coated, and an absence of fluorescent beads was observed in only three grids. Gel viscosity was found to be important in successful piston corer operation with a antimicrobial polymer-coating mechanism. Other research activities include development of biopolymer gels containing inorganic antimicrobial agents, and the evaluation of a water-jet system for cutting the core sample without contamination.

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Activities of the Bio-Venture Center for Extremophiles

1. The third Bio-Venture forum

The third forum was held at the Sasagawa Memorial Hall (Mita, Minato-ku, Tokyo) on 18th July, 2003. The achievements of the Frontier Research System for Extremophiles were introduced orally to participants from companies and universities and opportunities for collaborative work were sought. The forum attracted approximately 70 participants, and lecturers and participants discussed and exchanged ideas on the presentations.

2. Studies on microbial applications for bioindustries

To collaborate with contracted companies effectively, our researches have further focused on the screening of new, extremophilic microorganisms from the deep sea and subsurfaces, which could be potential seeds for industrial applications. Our main goals are the discovery of new enzymes, genes, and useful microorganisms that contribute to bioindustries in Japan. Our research also covers the analysis of genomes to find new functional

proteins (enzymes) and genes, construction of a host-vector system for overexpression of proteins, enzyme protein engineering, analysis of enzyme tertiary structures, and etc.

3. Collaborative research with companies

This year, we found new lipolytic enzymes, agar-degrading enzymes, mannose-hydrolyzing enzymes, highly alkaline serine protease, and alkaline xylanases for biobleaching. Further, medically-useful compounds were found in deep-sea microorganism cultures. One striking finding is a new process for industrial trehalose production, by combining maltose phosphorylase and trehalose phosphorylase produced by a new deep-sea species of *Paenibacillus*. The genes for both enzymes were cloned and sequenced, and the gene products successfully overproduced by our host-vector system.

Moreover, we succeeded in crystallizing several enzymes of industrial importance for the first time, using SPring 8, located in Harima, Japan, and are analyzing the tertiary structures of these enzymes.

Research Activities

Institute for Frontier Research on Earth Evolution (IFREE)

Overview of research activities during the 2003 fiscal year

IFREE research activity advanced significantly during 2003, the third year since IFREE was founded. Principal IFREE research has been focused on the structure and physical properties of the mantle in the southern Pacific region using global geophysical observation networks, the formation and evolution of island arc crusts in the western Pacific region, the fine structure and dynamics of the Philippine Sea and the Pacific plates near the Nankai trough and the Japan trench, the sedimentation process and the Cretaceous anomalous warm environment, as well as computer simulations that clarify the earth's interior dynamics using the Earth Simulator.

One hundred forty papers presenting original research have been published in international refereed journals and forty have been published in non-refereed journals. One hundred sixty papers have been presented in both national and international scientific meetings. Five of these were selected and press released. The most noteworthy amongst these involved computer simulations of seismic wave propagation triggered by the large earthquake that occurred in Alaska on Nov. 3, 2002. In these simulations, the earth's interior was divided into 13.8 billion global grid points and the propagation of seismic waves at each grid was calculated using a model in which various physical properties were installed. These simulations successfully reproduced the actual observations of the seismic waves. This work was selected as the highest computer performance in the SC2003 Conference and was given the Gordon Bell Award for 2003. Other awards received by IFREE members in 2003 included the Wollaston Medal of the Geological Society of London (I. Kushiro), the Geological Society of Japan Award (Y. Tatsumi) and the Society of Exploration Geophysicists of Japan Award (Y. Kaneda, T. Tsuru and J.-Oh Park).

Multi-disciplinary research, an IFREE objective, actively continued during 2003. Research focusing on water in the earth's interior, the Izu-Bonin-Mariana arc, and global anomalous environments significantly advanced. Collaborative research also continued, with researchers in 28 national and foreign universities and research institutes, including the University of Tokyo, Kyoto University, Hokkaido University, University of Shizuoka, University of Hawaii, University of California at Berkeley, University of Southampton, University of Paris, and California Institute of Technology. In addition, several IFREE researchers contributed to the activities of IODP as principal members of committees for science planning, management, and site survey, and to J-DESC.

IFREE will continue to contribute to and promote international projects, including IODP, and to advance the lines of research outlined above. IFREE has quickly become an international center of excellence in earth science and will further build upon this established excellence.

I. Research Program for Mantle Core Dynamics

Research Overview:

A history of the Earth's geologic activity is recorded within the structure of the Earth's mantle and core. In the Mantle-Core Dynamics Research Program, we perform three-dimensional imaging of the mantle and core in order to better understand the present status and the past record of this activity. The images obtained, along with the simulated results of convections in the mantle and core, enable us to reconstruct present and past activity within the Earth and to clarify

the factors that control Earth evolution.

We have made excellent use of data from the Ocean Hemisphere Project (OHP) Network and the Deep Sea Geophysical Observatories, research infrastructure developed and deployed by Japanese universities such as Earthquake Research Institute of the University of Tokyo in cooperation with JAMSTEC. This infrastructure has been established in order to foster the development of new generation models of the Earth's interior, on scales both regional and global. In regional studies, we have concentrated on seismological and electro-

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magnetic observation of the seafloor beneath regions significant in earth science: the subduction zone, the back-arc, and the upwelling regions. Combining the seismological and electromagnetic parameters determined by such observations, we have inferred thermal and compositional models for the Earth.

As we go forward, three-dimensional Earth models should be used to better understand the pattern and nature of the mantle and core convection. Convection modeling studies, by both analog experiment and computer simulation with the Earth Simulator, may more fully elucidate the convection patterns within Earth and the factors controlling convection itself, as well as the role of convection in the evolution of the Earth.

1. Tomographic studies on structure of the Earth's interior

1.1. All Seismic Phase Project

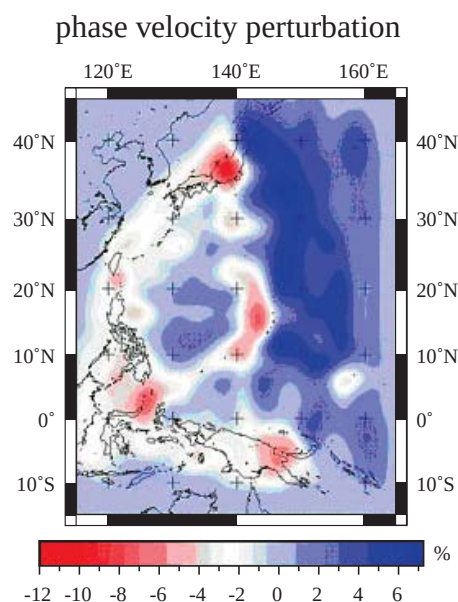
We have implemented the All Seismic Phase Project, in which various seismic phases, including later phases, are analyzed in order to obtain their arrival times. Arrival times are measured in suitable ways depending on phase type and are assembled within a data base comprised of accurate arrival time data. This data is then used for seismic tomography in order to obtain new models describing the Earth's structure. We have analyzed waveform data from global networks such as IRIS, regional networks such as OHP, SPANET, JISNET, SKIPPY, and Hi-net. We have accumulated 110,000 arrival time data entries which comprise the hand-picked data of P, pP, sP, and PcP waves, the differential travel times of PP-P and S-P, and arrival time data by cross-correlating observed and synthetic seismograms for P, PP, and Pdiff.

We have found a systematic discrepancy between the S-P differential travel times measured by waveform fitting and hand-picked S-P times. This discrepancy can be removed by changing the reference frequency of physical dispersion from the historically adopted value of 1 Hz to 2 Hz. This change of reference frequency requires a correction in Q of a spherical Earth model: PREM.

1.2. Upper mantle structure of the Philippine Sea using semi-broadband data from the long-term ocean bottom observation

Recently, around the Philippine Sea plate, the number of broadband seismic stations has increased, providing opportunity for long term broadband seismic observations on the seafloor. These seismic observations enable us to reveal the seismic structure beneath the Philippine Sea plate with higher resolution than in the previous studies.

We have analyzed the fundamental Rayleigh wave phase velocity structure of the Philippine Sea plate and the surrounding regions. The seismic stations and events we have used are located at between 20°S and 45°N latitude and between 110°E and 165°E longitude. We have measured Rayleigh wave phase velocity along each path using the method developed by Yoshizawa and Kennett (2002). The 1114 phase velocities obtained have been inverted to phase velocity distribution maps for each period using a 2-D tomographic technique. Figure 1 shows the phase velocity distribution map for the period of 40s. The results



T = 41.67 sec, Reference velocity = 3.93 km/s

Fig. 1 Rayleigh wave phase velocity anomalies for the period 41.67 sec. High and low velocity anomalies are indicated in blue and red, respectively.

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show the slow phase velocity of the Philippine Sea plate compared to the Pacific Ocean and the very slow phase velocity along the Mariana Trough which is spreading along the axis of the Philippine Sea plate.

1.3. Mapping of the 410- and 660-km boundaries-beneath the Japanese island using sScS post-cursors

A family of core-reflected S waves from the 2002 Vladivostok deep shock, including those near vertical reflections from the 410- and 660-km boundaries, were recorded by ~500 tiltmeters of the Hi-net and ~60 broadband seismometers of the F-net in Japan. The observed reflections were cross-correlated with synthetics calculated by the spectral-element method for a fully three-dimensional Earth model using the world's fastest supercomputer, the Earth Simulator, to accurately measure the depths of the reflection points. Figure 2 shows the undulations of the 410km- and 660km- discontinuities. The mapped boundaries were examined against a high-resolution P-wave tomographic image. The 660-km boundary is depressed at a constant level of ~15 km along the bottom of the horizontally extending aseismic slab under southwestern Japan. The transition from the normal to the depressed level occurs within a distance of less than ~200 km. Observations suggest that the reflections from the 410-km boundary are interfered with by those from the slab-related structures on the top of this boundary, leading to the spuriously high elevation of the 410-km boundary in and near the subducted slab. Records at stations relatively free from such interference effects, however, still show the relative elevation of this boundary within the slab.

1.4. Temperature and water content in the mantle transition zone

We have determined mantle discontinuity depths using broadband data from the trans-Philippine Sea ocean bottom seismograph array. The '660' depths are 659 ± 14 km, 705 ± 9 km, and 708 ± 16 km, beneath the Mariana Trough, the Parece Vela Basin, and the Daito

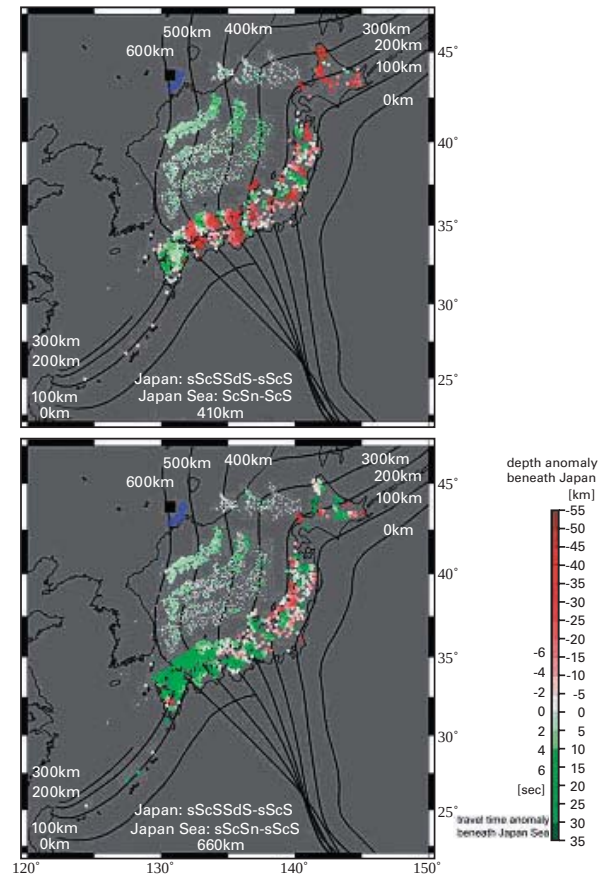


Fig. 2 Maps of the depth anomalies of the 410-km (a) and the 660-km boundaries (b) beneath the Japanese islands. Anomaly values are indicated by the colors of the circles plotted at the reflection points of the sScS post-cursors.

Ridge, respectively. The previous P-velocity tomography gave results 0.5%, 0.8%, and 1.4% faster than average, at depths around the '660' beneath the Mariana Trough, the Parece Vela Basin, and the Daito Ridge, respectively. Using the '660' depths and P-velocity anomalies along with experimental data, we determined temperature and water content in the mantle transition zone beneath the Philippine Sea. Temperature and water content are estimated to be lower by 300–500 K and more by 0.6–0.7 wt% than global averages.

1.5. On the S-P converted waves observed for the 2003 Off Kii peninsula deep earthquake

An anomalous seismic phase was observed between the P and S arrivals on the Hi-net seismograms for the 398 km-depth earthquake off the southeast coast of the

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Kii Peninsula, 12 November, 2003. This phase has the following characteristics.

- 1) The phase arrives about 20 s after P and its apparent velocity is slightly faster than that of P.
- 2) The particle motion indicates that this is a longitudinal wave.
- 3) The phase is recorded only in the Chubu region (epicentral distance 1.5–4 degree; azimuth 345–15 degrees).

These characteristics indicate that the observed phase corresponds to the S-P converted wave. Assuming the conversions occurred on a flat plane, we estimated the plane using the measured traveltimes data. With this estimate, we also assumed that the ray-paths satisfy Snell's law at the conversion point. The resultant conversion plane is located at epicentral distance and depth ranges of (1.2 degree–440 km) to (1.7 degree–370 km). The dip angle is about 73 degrees and the strike direction is at about 110 degree clockwise from north (Fig. 3). Compared with the P-wave tomographic image and the seismicity data, this conversion plane seems to be situated in the vicinity of the bottom face of the slab subducted from Japan. The

dip angle of the conversion plane is, however, much larger than that of the slab.

The conversion plane may correspond to the bottom face of the subducted slab. In this case the bottom face of subducted slab is not parallel to the Wadati-Benioff zone. The plane may be interpreted as a normal fault that occurred in the subducted slab.

2. Marine experiments and data analysis for seismic and electromagnetic studies

The Marine Maneuver Observation Group works on imaging of the mantle structure using seismic and electromagnetic approaches, in the part which is not yet well resolved if only data derived on land are used. The main research targets are the northwest Pacific and the adjoining back-arc basins that comprise a region of mantle down-welling, and French Polynesia, a region of mantle upwelling. We have systematically conducted experiments and acquired data since the Mantle Core Dynamics group was established. The achievements for these groups in 2003 are:

- 1) The start of a large and long-term cooperative US-JP seismic experiment in Mariana,
- 2) Analyses of data previously obtained in Mariana and the eastern Japan Sea, and
- 3) The deployment of electromagnetic observation sites in the northeastern Pacific.

2.1. Cooperative large and long-term seismic experiment in Mariana

From June 2003 until April 2004, a large and long-term ocean bottom seismic experiment was conducted as a part of the multi scale studies of the MARGINS project funded by the NSF. This experiment, a cooperative endeavor with scientists and many instruments from the USA, established several temporary land seismic stations on the north Mariana Islands (Fig. 4).

The main aim of this venture is 3-D imaging of the mantle structure along the island-arc and back-arc basin using seismic waves of the active deep events in this area. Semi 3-D air gun shootings to investigate the

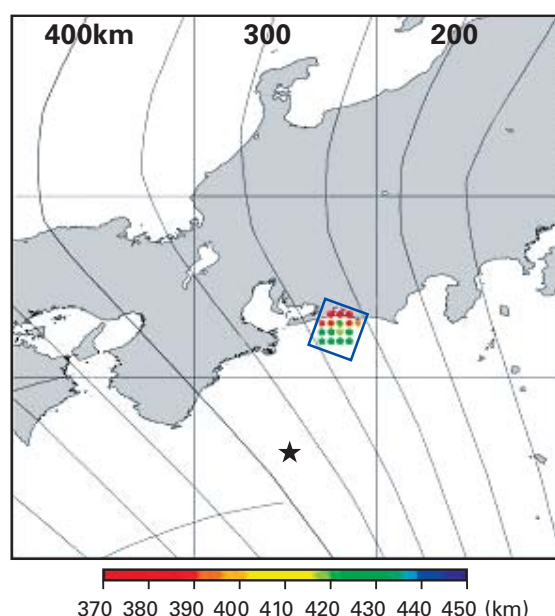


Fig. 3 Estimated S-P conversion plane. The depths of the conversion points are indicated by color. The hypocenter is shown by asterisk.

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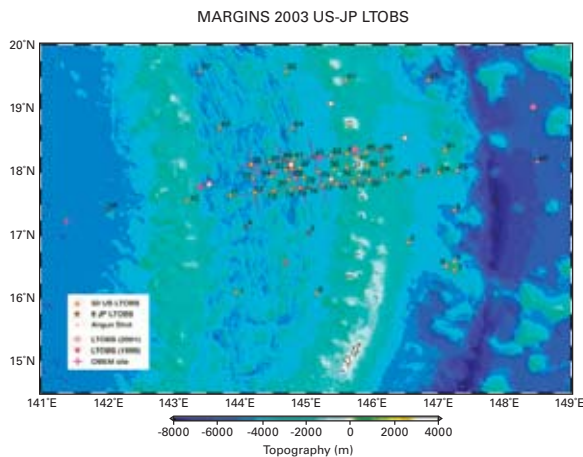


Fig. 4 Locations of OBSs and airgun profiles. Previous OBS and OBEM sites are also indicated. Temporal land stations were at all islands between 15°N and 19°N.

shallow structure, an activity monitoring a serpentine sea mount at the fore-arc, a surface wave analysis of tele-seismic waves, S-wave splitting, as well as other activities, are planned for this experiment.

2.2. Analyses of data previously obtained in Mariana and eastern Japan Sea

2.2.1. Seismic deep structure and precise hypocenters at Mariana

As a pilot study for the experiment above, a long-term seismic observation using 10 ocean bottom seismometers was performed [indicated as LTOBS (2001)

in Fig. 4] from October 2001 until February 2003. The precise hypocenters and the activity of many deep events in the subducting slab, information impossible to derive only from global land data, were investigated (Fig. 5). More than 3000 events were determined from the one year long OBS data set; the simultaneous inversion of the hypocenter and velocity structure will be finished in FY2004.

2.2.2. Upper mantle electrical structure in the Mariana subduction system

The electrical conductivity structure of the upper mantle beneath the central Mariana region has been studied since 2001 in order to construct an electrical model for the backarc-island arc-subduction system. Seafloor magnetotelluric data from eight sites along a line crossing the central Mariana Trough parallel to the present spreading direction were analyzed. The two-dimensional model obtained shows a decrease of resistivity from hundreds to tens Ohm-m at the depth of 70 km beneath the Mariana Trough (Fig. 6). This feature can be interpreted in terms of the redistribution of water due to partial melting beneath the spreading axis. Below 70 km, the mantle beneath the Mariana Trough and the Parece Vela Basin seems somewhat more conductive than the

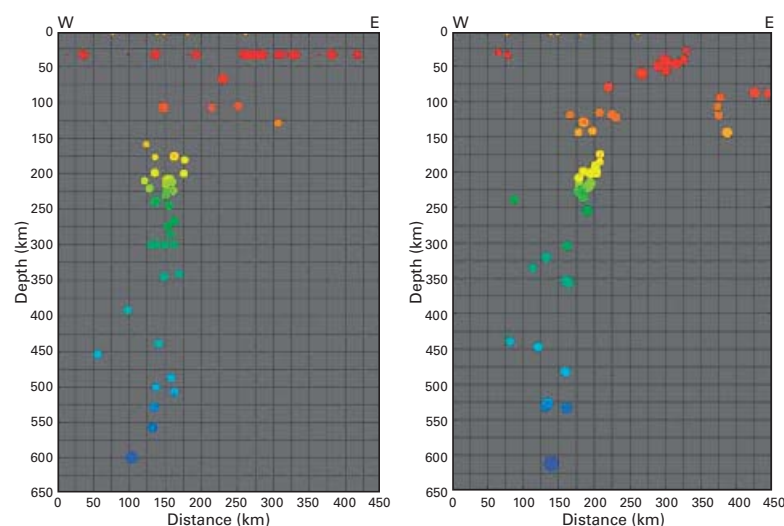


Fig. 5 Vertical sections of events listed in the PDE catalogue. Hypocenters on the PDE (left) and those determined using only OBS data (right). The 1-D velocity structure used was based on the iasp91 model, except for the crust.

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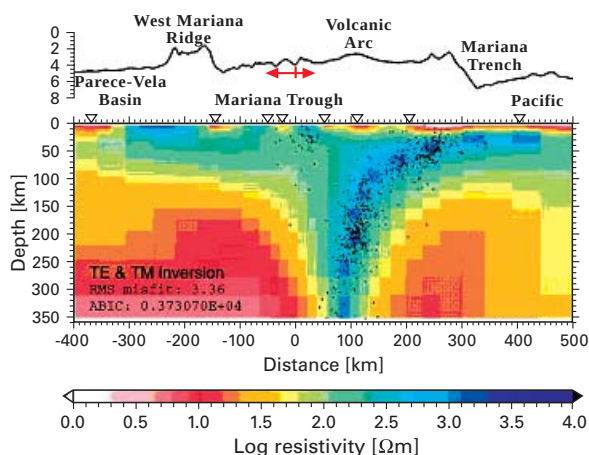


Fig. 6 2D electrical conductivity structure model in the Mariana region. The horizontal axis is the distance from the spreading axis of Mariana Trough. Triangles indicate the site locations (these correspond to the crosses in Figure 4). Dots indicate hypocenters. Bathymetry along the survey line is shown at the top.

mantle beneath the Pacific plate, suggesting hot thermal anomaly and/or an abundance of water in the back-arc mantle.

2.2.3. Upper mantle electrical structure in eastern Japan Sea

The dynamics of the upper mantle beneath the eastern margin of Japan Sea has been investigated by a magnetotelluric (MT) survey, both on land and at the seafloor. The MT profile traverses the back-arc basin of Northeast Japan and of the arc itself along approximately 39.5°N (Fig. 7). The seafloor MT experiment was carried out using six ocean bottom electrometers (OBEMs) from October 2002 to July 2003. High quality data were acquired by the four OBEMs. The land data were collected at four stations on the Ou backbone range.

The conductivity structure models obtained by preliminary inversions of the TE mode responses show that a conductive zone exists in the mantle deeper than 100 km depth at 300 km offshore and extends to the shallower mantle toward the east (Fig. 8). However, the transition to the mantle beneath the Japan arc is not well constrained.

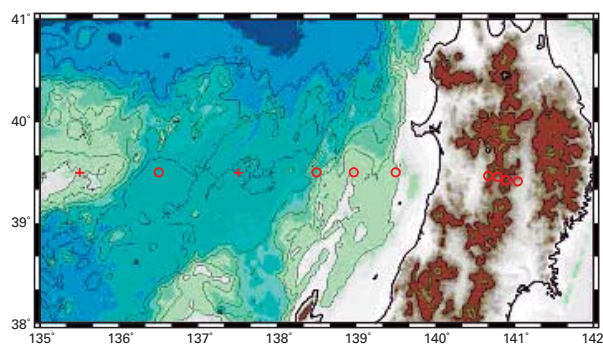


Fig. 7 Bathymetric and topographic map of the eastern Japan Sea and the northern Japan arc. The contour interval is 500 m. Site locations are indicated by red symbols. Circles indicate the sites where available data were acquired.

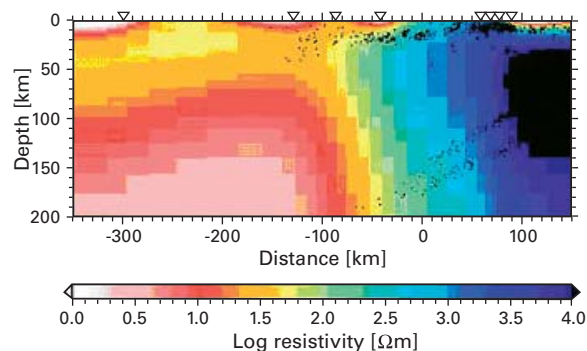


Fig. 8 2D electrical conductivity structure model in eastern Japan Sea. The horizontal axis is the distance from the coast line. Triangles indicate the site locations. Dots indicate hypocenters.

2.3. Deployment of the electromagnetic observation sites in northeastern Pacific

Seismic P-wave tomographic studies seem to indicate the upwelling counterflow in the ocean side beneath the subducting Pacific plate (Fig. 9). Two ocean bottom electrometers (OBEMs) were deployed above the counterflow in July 2003 in order to reveal the electrical conductivity distribution in and around the flow (Fig. 9). The aim of revealing the conductivity distribution is to detect the origin of the upwelling counterflow—whether it is the mantle transition zone or the lower mantle. Although various kind of reactions in the back-arc side of subducting plate have been explored in mantle convection studies, our study elucidates the dynamics on mantle convection in the ocean side beneath the subducting plate.

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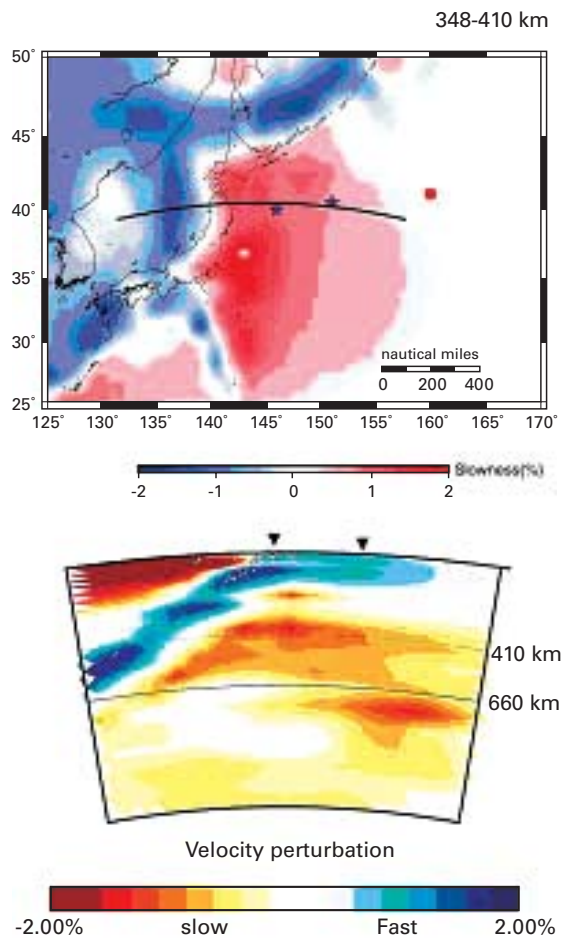


Fig. 9 Top: Two OBEM sites (star symbols) superimposed on a seismic P-wave velocity structure between 348-410 km in depth (Obayashi & Fukao, 2001). The solid line shows the place of the radial profile of the bottom figure. Bottom: The radial profile of P-wave velocity structure and the OBEM sites (reverse triangles).

3. Modeling

The various phenomena occurring at the surface of the Earth are caused by convective motions in the mantle and core. The structural evolution of the Earth is also controlled by heat transport due to convective motion. Therefore it is very important to clarify the characteristics of convection in the core and mantle in order to better understand the dynamics and the evolution of the Earth. Convection in the mantle generates anomalies of density and temperature, both of which are detectable by seismological observation. Our aim is to propose a new view of the global dynamics at play in the Earth's interior, a view consistent with the

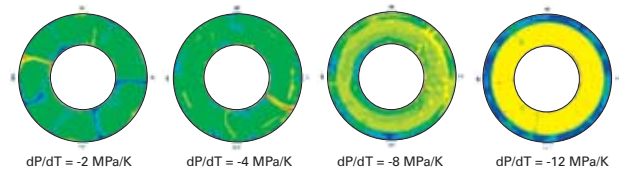


Fig.10 The numerical results of thermal convection in the 3D spherical shell derived using the Earth Simulator as the cross-sections of the temperature fields. The resolution is about 30 km on the surface. The number of grid points is about one hundred million. These are the results for Rayleigh number, 7×10^6 . With the increase of the absolute value of the Clapeyron-slope, the convection pattern changes from whole layered convection to intermittent convection.

results of seismic tomography. We are presently investigating the physics of convection using both numerical and laboratory experiments.

There are several factors that complicate the dynamics of mantle convection. These include large variations in viscosity, internal heating, phase changes of mantle materials, etc. Especially important is the phase boundary existing at a 660 km depth, which has a negative Clapeyron slope and which disturbs the smooth passing of the sinking and rising mantle plumes. The periodic behaviors of continental aggregation or LIPs formation and the sudden change in the direction of plate motion are thought to relate to the collapse of the stagnant slabs in the transition zone. We investigated the effect of the negative Clapeyron slope on mantle convection at a 660 km depth and estimated the time scale of the intermittent passing of the descending slabs and rising plumes. When we set the Earth-like parameters, convection showed an intermittent pattern; moreover, the time-scale of the collapse of the slabs is consistent with the view from the plate reconstruction. We can thus conclude that the rhythm of the interior activity of the Earth is produced by the intermittency of mantle convection due to the 660 km transition zone (Fig.10).

On the other hand, the outer core consists of molten iron, the viscosity of which is low and the thermal diffusivity of which is large. That is, the Prandtl number of the outer core material is much lower than that of

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the mantle. The convective flow in the outer core is supposed to be extremely turbulent, and it is very difficult to directly simulate the convection in the outer core numerically. Laboratory experiment is the only way to understand such highly turbulent thermal convection at a low Prandtl number; an important consideration in studying the dynamics of the Earth's core. We can use liquid gallium for the analogue material of the molten iron. Its melting temperature is at around room temperature. Molten metals, however, are opaque fluids, so optical methods for flow measurement cannot be applied. We therefore adopted the Ultrasound Velocity Profiling method in order to measure the flow occurring in liquid metal. This method is usually used for forced flows with higher velocity. We improved this method in order to apply it to the study of natural convection; its flow speed is generally lower. By using a new algorithm developed for the slower flows, we succeeded in observing the nearly two-dimensional

roll-like convection pattern in liquid gallium (Fig.11). This is the organized structure in the turbulent convection regime. In the next step, we will introduce rotation and the magnetic field, and will examine the characteristics of turbulence and the organized flow structure under more Earth-like conditions.

II. Research Program for Geochemical Evolution

Research Overview:

The subduction zone, where oceanic plates subduct from trench into mantle, works as if a factory, playing a significant role in the evolution of the solid Earth. This factory processes raw materials such as oceanic materials, including both altered and fresh oceanic crust, and the pre-subduction, original mantle wedge materials, and produces products such as magmas and their solidified forms, continental crusts. Waste materials, such as chemically modified subducted oceanic crust and anti-continental crust separated from the ini-

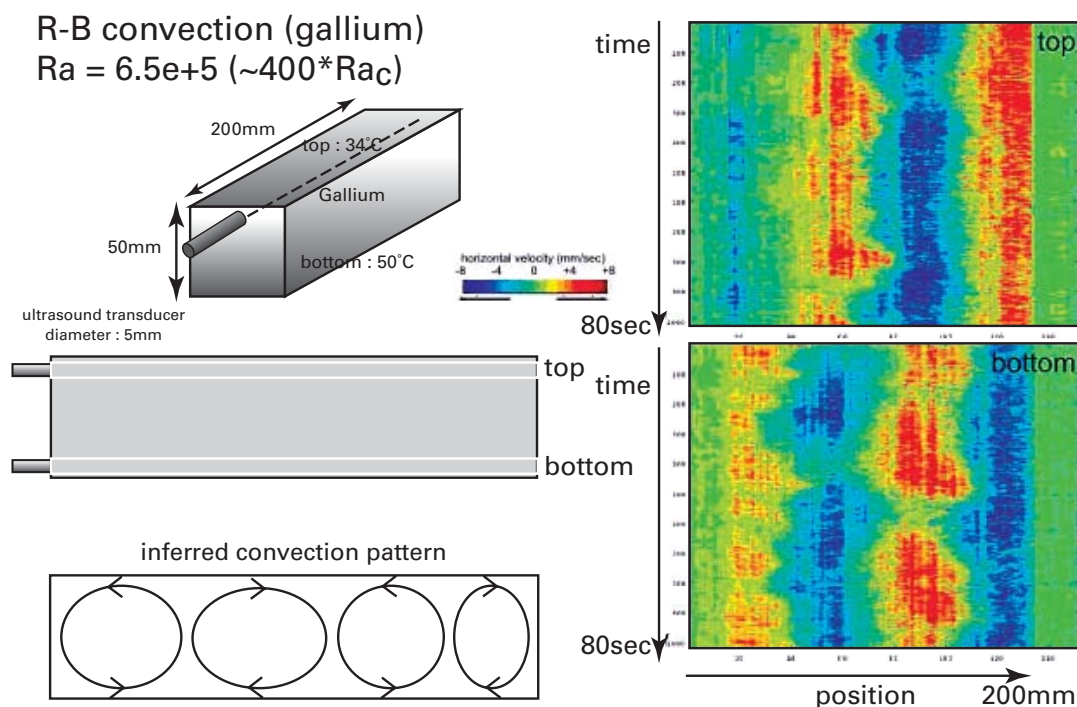


Fig.11 Laboratory experiment of thermal convection with liquid gallium. The upper left figure is the setting of the apparatus. On the middle left, the positions of the transducer are shown. On the bottom left, the convective pattern inferred by the measurement of the flow velocity is shown. The right figures are the time series of the horizontal flow velocity. The result shows the periodic oscillations of the convective roll patterns.

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tial arc crust during the continental crust formation, are transported with plate subduction into the deep mantle and are ultimately reused as the source material for mantle plumes and hotspot magmas.

The Research Program for Geochemical Evolution seeks comprehensive understandings of the evolution of the solid Earth, based on petrological and geochemical approaches for studying the subduction zone and hotspot magmas, and conducts experimental studies for Earth materials at high pressures and temperatures. These activities are conducted in collaboration with satellite laboratories in Kyoto University, University of Tokyo, Tokyo Institute of Technology, and Okayama Institute of Science, as well as with other research programs and divisions within JAMSTEC.

1. Slab melting and subsequent melt-mantle interaction: origin of high-Mg andesite magma

Magmas formed in subduction zones are noted for their distinct chemistry compared to those formed in other tectonic settings, such as mid-oceanic ridge basalts (MORBs) and intraplate magmas. In particular, they are characterized by an over-abundance of large-ion-lithophile elements and a depletion of high-field-strength elements. It is generally accepted that the metasomatic overprinting of particular elements from the subducting lithosphere is responsible for this distinctive geochemical signature. Aqueous fluids and silicate melts, produced by dehydration and the partial melting of the sinking oceanic lithosphere, respectively, are potential metasomatic agents for such overprinting. The identification of which metasomatic agents are responsible for enriching the source region with subduction zone magmas, i.e., aqueous fluids or silicate melts, is a topic of great importance, not only for subduction zone processes but also for material circulation within the Earth's mantle in that the composition of the residual slab differs depending on whether melts or fluids were extracted. A significant majority of researchers currently favors the hypothesis that the metasomatic agent is not a

melt but rather is an aqueous fluid. However, in subduction zones where rather young, and hence hot, oceanic crust is being subducted into the mantle, partial melting of the foundering oceanic lithosphere may play a significant role in the magma production of the subarc mantle.

One of the major products that typify magmatism in the subduction zone is andesite. Furthermore, the continental crust, one of the major geochemical reservoirs within the solid Earth, possesses an andesitic composition and is believed to have been created in ancient subduction zones. Most andesite is essentially derived from parental basaltic magmas through variable differentiation processes such as fractional crystallization, the mixing of basaltic and felsic magmas, crustal contamination, and the anatexis of pre-existing crustal materials. However, andesitic magmas produced by the partial melting of upper mantle peridotite do exist in arcs. Such mantle-derived andesites are referred to as high-Mg andesites (HMAs), as they are characterized by high MgO contents and/or $Mg\# (= 100 \times Mg/(Mg + Fe))$. This suggests that they are equilibrated with Mg-rich mantle olivine. Examples of HMAs include boninites on the Bonin Islands and sanukitoids in SW Japan.

Melting experiments at high pressure on both simple and natural peridotite systems have established that the hydrous melting of upper mantle peridotite is a possible mechanism for HMA magma production. These experimental results, however, do not necessarily mean that the direct addition of an aqueous fluid produced by slab dehydration into the mantle wedge is a likely mechanism for HMA generation. A process including the partial melting of the subducting lithosphere and the subsequent reaction of hydrous felsic slab melts with mantle wedge peridotite can also achieve such conditions. Thus, possible mechanisms for the production of mantle-derived, high-Mg andesite magmas include (1) the partial melting of mantle wedge peridotite by the addition of aqueous fluids from the subducting lithosphere and (2) the partial melting of subducting sediments and the altered

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oceanic crust along with subsequent melt-mantle interaction. These possibilities were examined by the geochemical formulation of dehydration and by partial melting and melt-solid reactions.

Modeling results demonstrate that both mechanisms can reasonably explain the incompatible trace element characteristics of high-Mg andesites in the Setouchi volcanic belt, SW Japan (Fig.12). However, simple hydrous melting of mantle wedge peridotite cannot account for the Sr-Nd-Pb-Hf isotopic compositions of such andesites. The results of mixing calculations with 20% and 100% sediment contribution, relative to amphibolite and slab-fluid formation, are shown in Figure 13. The Sr and Nd isotopic ratios of the Setouchi HMAs can be explained by 0.5 to 1% addition of sediment-derived aqueous fluids. However, a significantly small amount of the sediment-derived fluid (<0.1%) is enough to explain the rather enriched Pb isotopic characteristics of the Setouchi HMAs (Fig.13). The degree to which slab-derived aqueous fluids contribute to the formation of the HMA magma source required for explain-

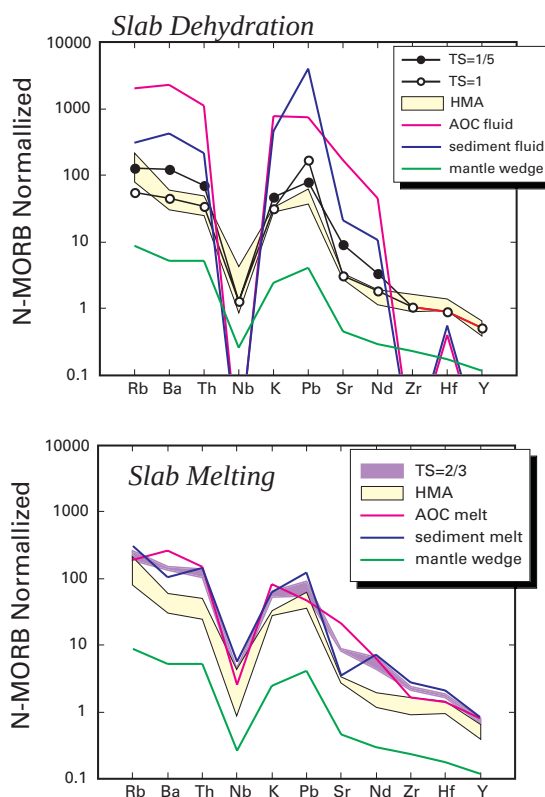


Fig.12 Results of trace element modeling of transport and HMA magma generation caused by slab dehydration and slab melting. TS, terrigenous sediments; AOC, amphibolitic altered oceanic crust.

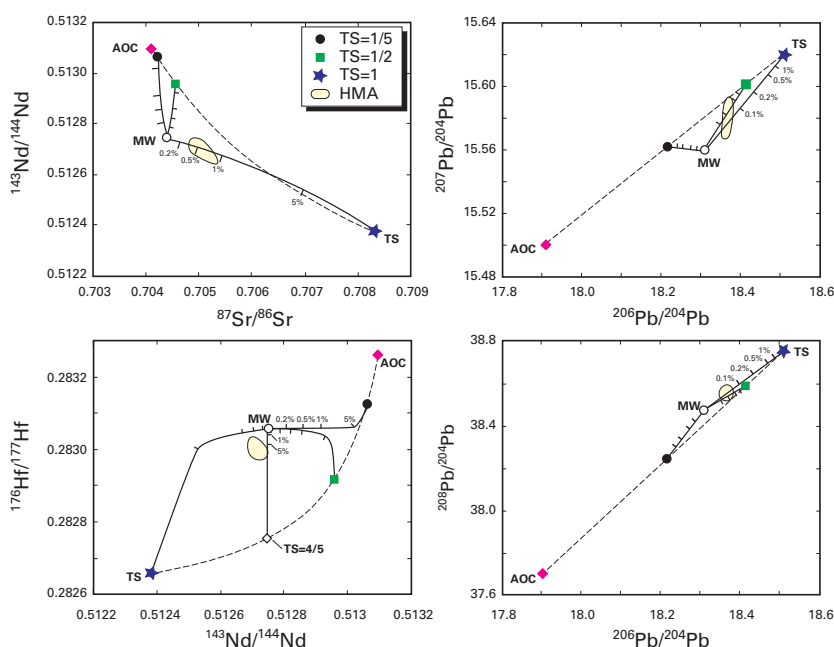


Fig.13 Results of isotopic modeling of transport and HMA magma generation caused by slab dehydration. TS, terrigenous sediments; AOC, amphibolitic altered oceanic crust; MW, the original mantle wedge deduced from basalt compositions.

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ing the Pb isotopic characteristics is more than five times smaller than that required for the Sr and Nd isotopes. Furthermore, the Nd-Hf isotopic compositions of the Setouchi HMAs do not fit any mixing lines derived from slab fluids, either from amphibolite- or sediment-derived fluids (Fig.13). The $^{176}\text{Hf}/^{177}\text{Hf}$ and $^{143}\text{Nd}/^{144}\text{Nd}$ ratios of HMA may be accounted for if the contribution from sediment fluid against AOC fluid is between 1/2 and 1 (Fig.13). The ratio of mixing between slab-fluids and the original mantle required for these isotopes is, however, at around 0.5%, which is again inconsistent with the estimated mixing ratio based on Pb isotope data.

By contrast, the process including the partial melting of the subducting sediments and of the altered oceanic crust, and subsequent melt-mantle interaction, can well reproduce the isotopic signature of these high-Mg andesites (Fig.14), although a contribution of pelagic sediments in addition to terrigenous sediments may be needed in order to explain the Hf-Nd isotopic signatures of the HMAs (Fig.14).

2. Remelting of an andesite magma body within the crust: an example from the SW Japan arc

Primary magmas, produced in the mantle wedge of subduction zones, differentiate into silicic (high- SiO_2) and low-MgO magmas on their way to the surface. Especially, the crystallization of minerals from magma during cooling causes the liquid to change composition. Voluminous andesite and dacite lavas in the Daisen volcano, SW Japan, contain petrographic features suggesting the reverse of this normal fractionation, in the sense that magma genesis progressed from dacite to andesite, accompanied by rises in temperature. For example, Figure 15 shows that orthopyroxene phenocrysts have overgrowth rims with a high Ca content, a feature consistent with crystallization from higher-temperature magma than that of their cores. These zoning patterns indicate that the temperature rises from 800°C to 1100°C. The absence of phenocrysts in the aphyric magmas suggests they were ultimately superheated in the near-surface environment. We suggest a two-stage process involving mid-crustal solidification of calc-alkaline magmas

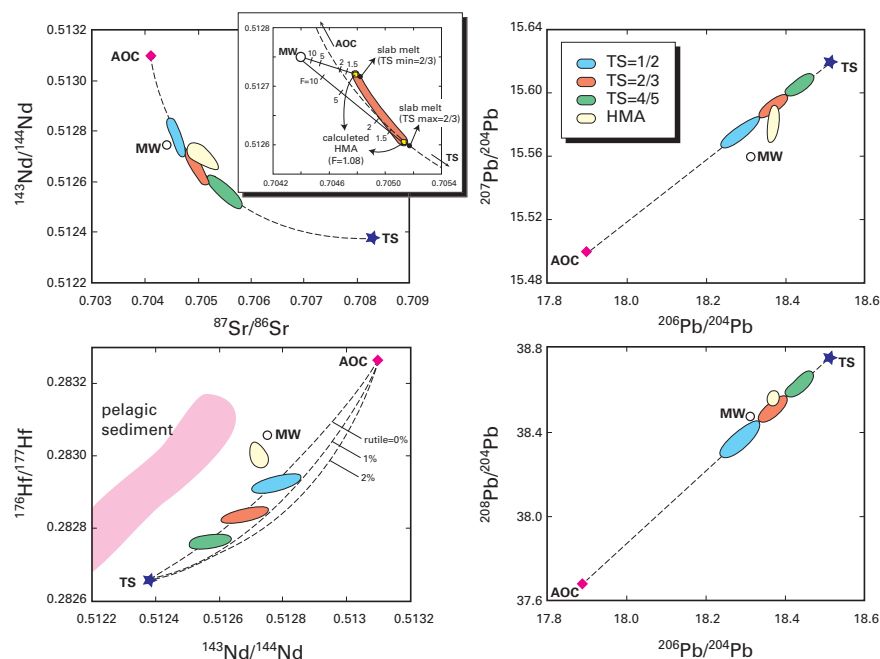


Fig.14 Results of isotopic modeling of transport and HMA magma generation caused by slab melting. TS, terrigenous sediments; AOC, amphibolitic altered oceanic crust; MW, the original mantle wedge deduced from basalt compositions.

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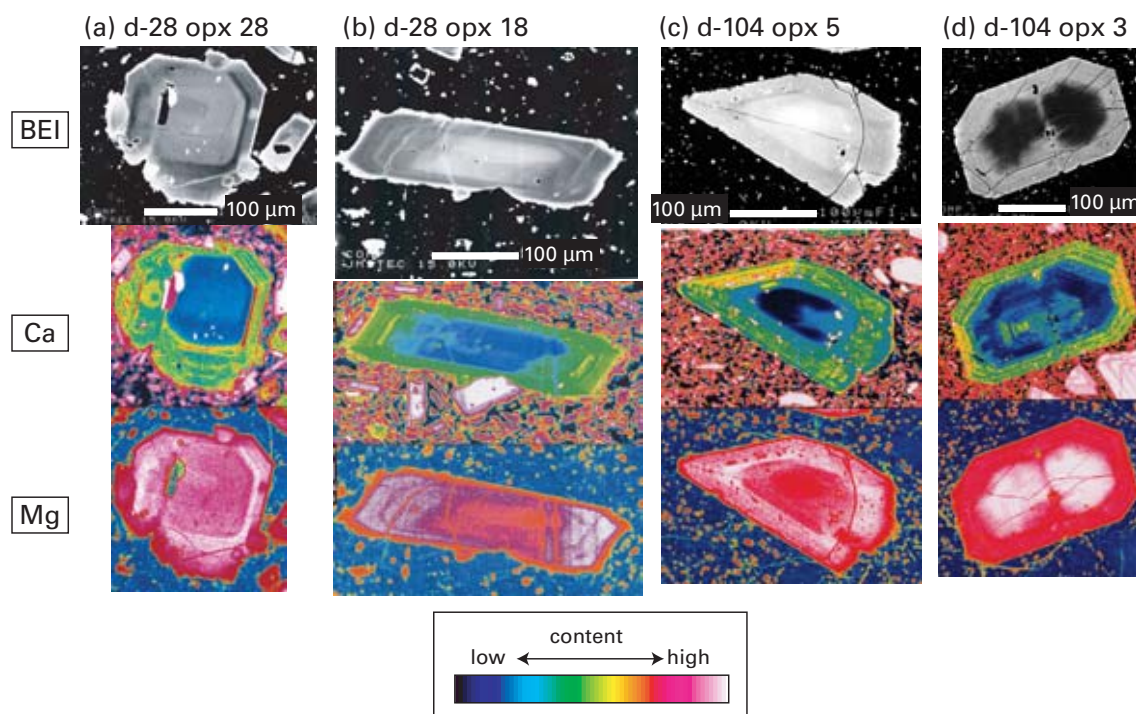


Fig.15 Reversely zoned phenocrysts in dacites from the Daisen Volcano.

followed by their recurring partial melting, thus generating the magmatic trends and phenocryst zoning patterns observed at the Daisen volcano (Fig.16). The heat required for this melting was probably supplied by the intermittent rise of subjacent basaltic magma.

3. Heterogeneous mantle melting below an arc volcano: an example from the Izu-Bonin Mariana arc

The Izu-Bonin-Mariana arc system is an excellent example of an intra-oceanic convergent margin. Inputs from the sub-arc crust are minimized at the oceanic arcs and mantle-to-crust fluxes can be more confidently assessed than arcs that build on the continental crust. We thus sampled the Sumisu caldera volcano in the Izu-Bonin arc for the purpose of examining arc magma genesis in September, October and December of 2002 using JAMSTEC's manned submersible Shinkai 2000 and the ROV Dolphin 3K. Additional surveys included SeaBeam mapping and single and multi-channel seismic traverses (Fig.17). Figure 18 shows a C1 chondrite-normalized plot of rare earth element data for two kinds of basalts in the Sumisu caldera volcano. More

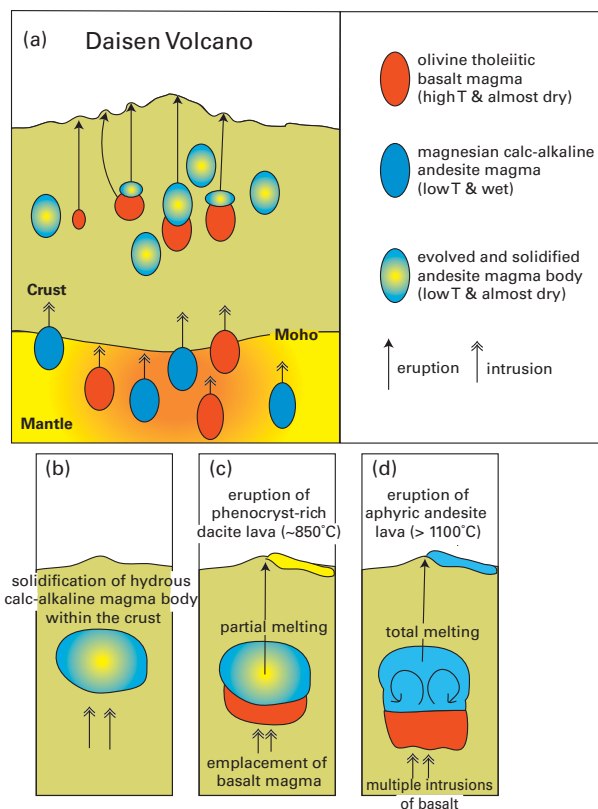


Fig.16 A model for a newly proposed subduction factory process, including remelting of a solidified andesite body and the generation of dacitic magmas.

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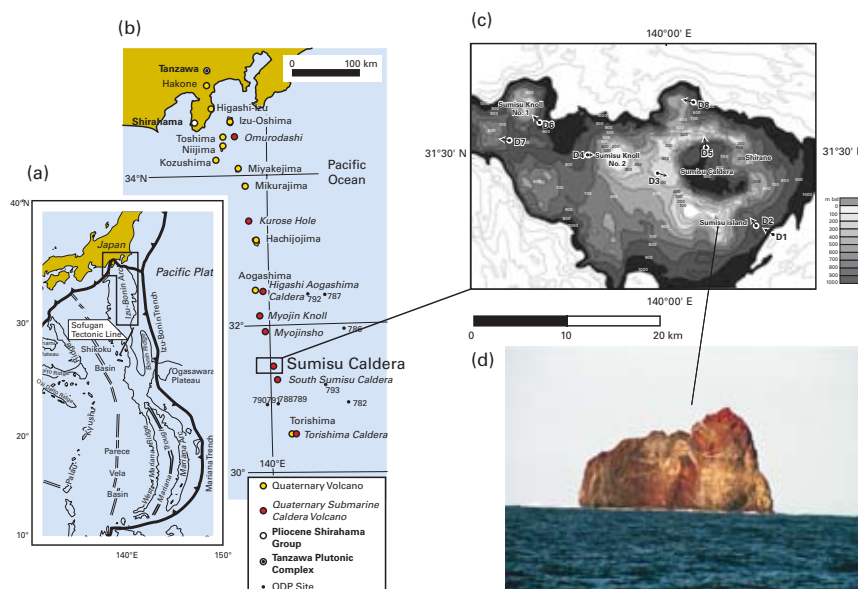


Fig.17 The location and topography of the Sumisu caldera in the Izu-Bonin-Mariana arc.

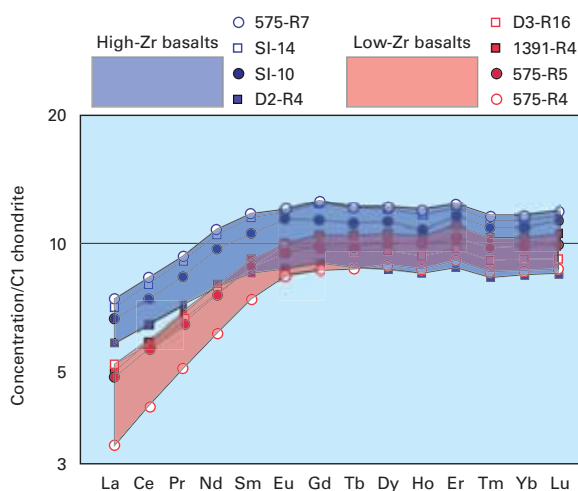


Fig.18 Rare earth element characteristics for two types of basalt series in a single magmatic system of the Sumisu volcano.

light-REE depleted patterns may suggest higher degrees of partial melting of the source mantle; this suggests that basalts produced by different degrees of source mantle partial melting may coexist in a single magmatic system. Moreover, we recognized that these two kinds of basalts have differing phenocryst assemblages and differing fluid mobile-element/immobile-element ratios. Our results suggest that within a single volcanic complex, the water content in the mantle source region can be heterogeneous, causing different degrees of melting of this source.

4. Post – Perovskite Phase Transition in MgSiO_3

MgSiO_3 perovskite is believed to be a principal mineral in the upper part of the lower mantle, but its stability and possible phase transition at greater depths remains uncertain. Solid-solid phase transitions that may occur in this region are under debate because seismic observations have shown unexplained features in the lowermost mantle. Previous experiments have confirmed the conservation of orthorhombic (Mg, Fe) SiO_3 perovskite (space group: $Pbnm$) up to 127 GPa; this is consistent with first-principles total energy calculations. In contrast, there is an experimental result that suggests a subtle change in the perovskite structure above 83 GPa and 1700 K. The dissociation of MgSiO_3 into mixed oxides was also previously found at 70–80 GPa, but this dissociation was possibly due to melting or diffusion caused by the large temperature gradient used in these earlier studies. The purpose of the present study is to document and confirm the structure change of MgSiO_3 at pressures close to those present at the base of the lower mantle, based on in-situ x-ray diffraction measurements at ultra-high pressures and temperatures generated in a laser-heated diamond anvil cell. The experiments were conducted at Spring-8.

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Our results demonstrate that MgSiO_3 perovskite transforms to a new high-pressure form with stacked SiO_6 -octahedral sheet structure above 125 GPa and 2500 kelvin (2700 km depth near the base of the mantle) with an increase in density by 1.0–1.2 % (Fig.19). Phase transition of MgSiO_3 -rich perovskite may cause large seismic heterogeneities in the lowermost mantle. The D" layer discontinuity is observed in many regions around the world at about 200–300-km above the core-mantle boundary (119–125 GPa) with a velocity increase of $\sim 3\%$. Post-perovskite phase transition occurs at depths matching those of the D" layer discontinuity (Fig.19). Although the effects of minor elements such as FeO , Fe_2O_3 , and Al_2O_3 at transition pressure remain to be evaluated, this phase transition may be responsible for the D" seismic discontinuity. A variation in the depth of the discontinuity could be due to temperature heavily effecting phase transition pressure. Furthermore, an expected density increase of 1.0–1.2 % for the bottom ~ 200 –300-km layer, owing to the post- MgSiO_3 perovskite transition, is consistent with recent observation that includes an excess density of 0.4 % in the bottom 500-km of the lower mantle.

III. Research Program for Plate Dynamics

Research Overview:

The objective of this program is focused on subduction zones, where observations can be made on various aspects of plate structure and deformation, aspects ranging from the rapid, large-scale rupture of plates to the micro-fractures found in fault rocks. Research into lithospheric structure, seismogenic zone material science, and plate dynamics modeling will continue to be integrated into a comprehensive understanding of plate behavior and surface phenomena of the Earth.

The main research activities in 2003 were as follows:

- 1) The Lithospheric Structure Research Group investigated the seismogenic zone boundary between the Nankai and Tonankai earthquakes in order to better understand the structural factors involved in the segmentation around the Nankai trough seismogenic zone. Based on seismic imaging of the central Japan convergent margin off Tokai, it is proposed that the subducting ridge system acts as the main factor causing slow events around the presumed Tokai earthquake rupture zone. A new field experiment, off Sanriku seismogenic zone,

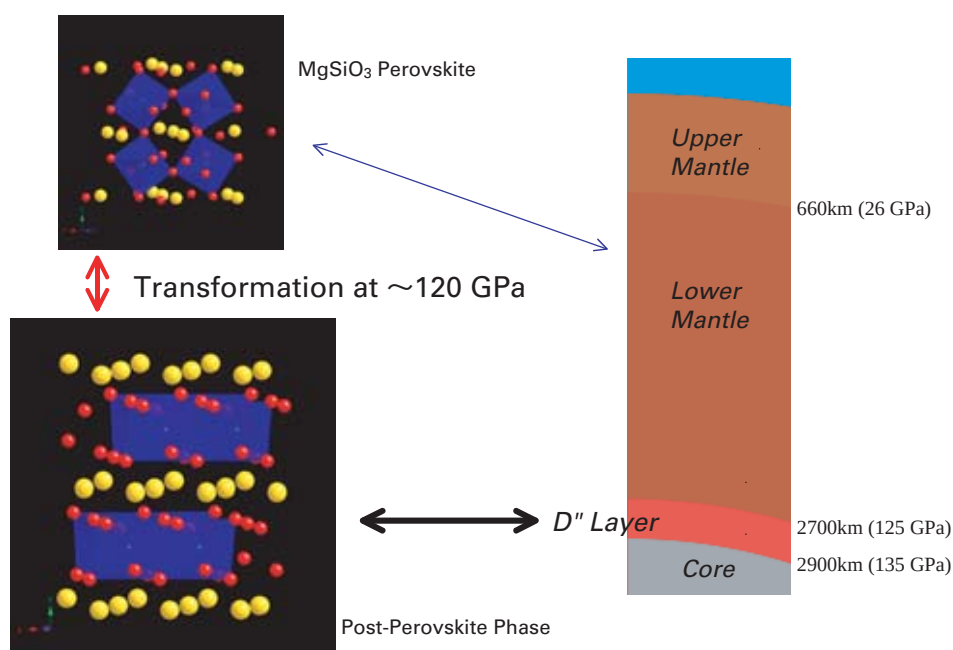


Fig.19 Transformation of MgSiO_3 perovskite into post-perovskite and the origin of the D" layer at the base of the mantle.

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was carried out in collaboration with ERI, University of Tokyo to understand the structural factors controlling the off Sanriku earthquake system in the Japan Trench.

- 2) The Seismogenic Zone Material Science Group sampled and analyzed exhumed ancient fault rocks in the Shikoku district and from the Chi-Chi Taiwan earthquake in order to better understand the micro-dynamic systems in seismogenic zones. As the result of laboratory experiments designed to better understand the frictional behavior of unconsolidated granular material at the seismic slip rate and its implication for shallow level faulting during the 1999 Chi-Chi, Taiwan earthquake, it is proposed that if the loosely packed granular material in the shallow portions of the fault is sheared under an undrained condition, the seismic rupture propagation from seismogenic depths into the shallow region will be enhanced. This seems consistent with the observed data at the 1999 Chi-Chi earthquake. In another experiment, permeability measurements were conducted on rocks sampled from an exhumed ancient subduction zone fault in the Shimanto accretionary complex. The result is that the permeability under seismogenic environment conditions shows a heterogeneous structure across the fault zone.
- 3) The Plate Dynamics Modeling Group produced modeling results for the regions around the Nankai Trough and the Japan Trench, using mainly the research results of the Structure Research Group. Coding for the Earth Simulator (ES) has been developed, and some large-scale simulations, such as those focusing on crustal activity, earthquake cycles, and mantle convection have been implemented on the ES. From numerical simulations of earthquake cycles along the Nankai Trough, it is proposed that the occurrence pattern of historical great earthquakes indicates the existence of rupture segments seemingly correlate with lateral variation in the dip angle of the subducting Philippine Sea plate.

Details of the research activities are summarized in the following:

1. Lithospheric structure research group

With a view toward understanding both the variety and universality of plate dynamics in various spatial-temporal scales, the Lithospheric Structure Research Group strives to clarify the structural factors constraining tectonic processes, factors ranging from the evolution of trench-arc-back arc systems to the generation of great subduction earthquakes.

1.1. Nankai seismogenic zone

- 1) Structural evidence for the causes of the Tokai slow slip event:

We have successfully imaged structural evidences of the Tokai slow slip event from the results of an onshore-offshore integrated seismic survey along a 485 km long profile crossing the eastern Nankai Trough and central Japan from the western edge of the Izu island arc. Seismic velocity and reflectivity images show ongoing subduction of repeated ridges. Two ridges are clearly resolved, the Paleo Zenisu – south ridge and north ridge – and are situated between the Nankai Trough and central Japan. The two subducting ridges are 12 km thick by 40 km wide and 20 km thick by 60 km wide, respectively (Fig.20a). We conclude that the north ridge may have prevented the eastward propagation of co-seismic slip during the 1944 earthquake due to strong coupling. The highly reflective subducting oceanic crust, imaged at 25 – 45 km depth beneath central Japan, has a 2 km high doming structure at 30 – 40 km depth, indicating an even deeper ridge structure. This highly reflective subducted oceanic crust overlaps with the high Poisson's ratio zone imaged in a seismic tomography study (Fig.20b). From these structures, we propose that the Tokai silent slip can be attributed to a high pore pressure zone, which significantly extends the conditionally stable region in the subducted crust.

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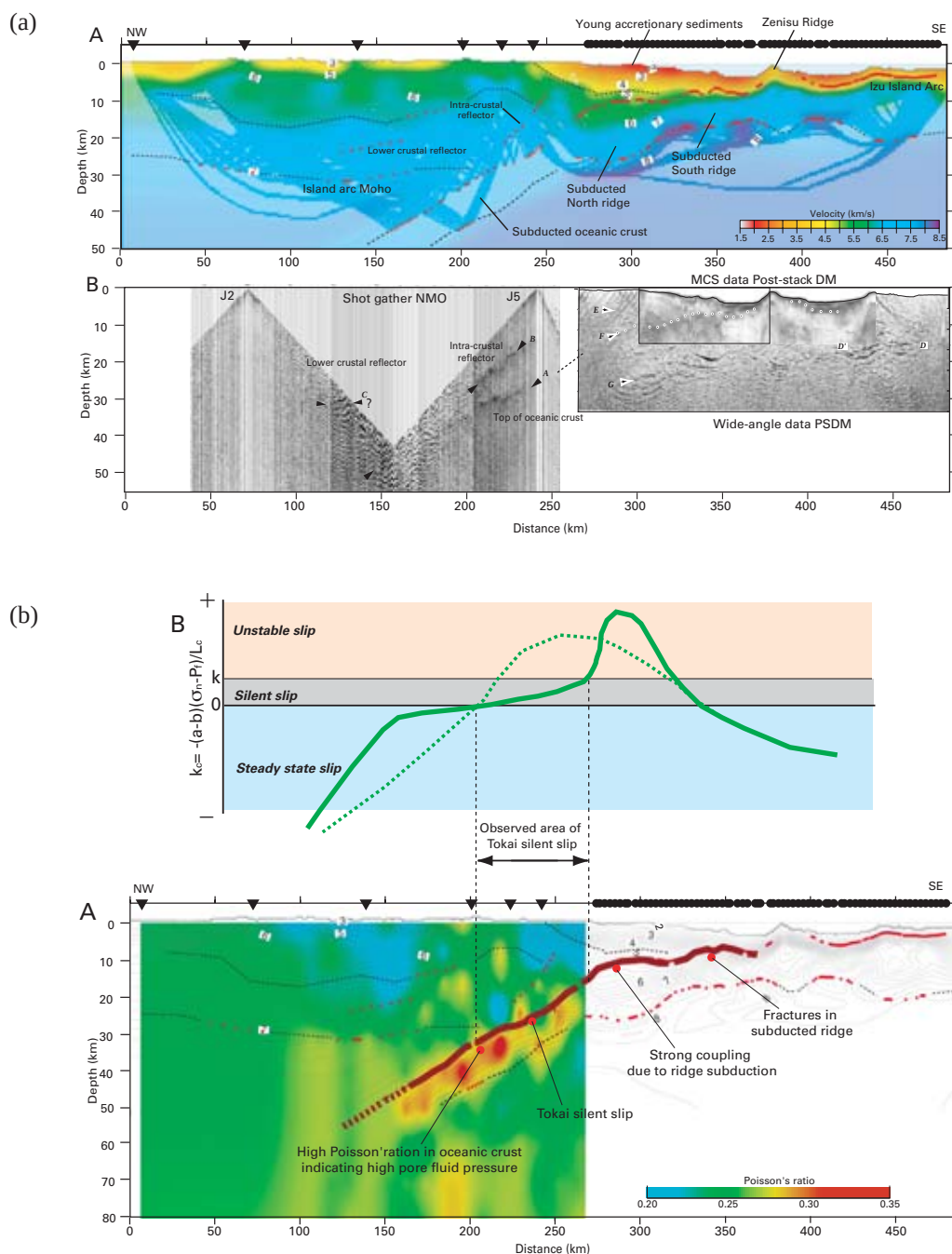


Fig.20 (a) Seismic velocity (top) and reflectivity images (bottom) obtained from the central Japan onshore – offshore seismic survey. (b) Seismic structure obtained from our study superimposed on the seismic tomography image (Kamiya and Kobayashi, 2004) (bottom) and a predicted variation of the critical stiffness crossing central Japan.

2) The Kyushu-Palau Ridge imaged at the westernmost Nankai subduction zone: Implications for the Hyuga megathrust earthquake rupture:

The Kyushu-Palau ridge, a ~2000-km-long remnant arc on the Philippine Sea Plate subducts beneath the

Eurasian Plate along the westernmost part of the Nankai Trough. A new seismic reflection profile (Fig.21) on the strike line images the ~70-km-wide, ~2-km-high Kyushu-Palau ridge where it subducts beneath the toe of the forearc accretionary wedge. The

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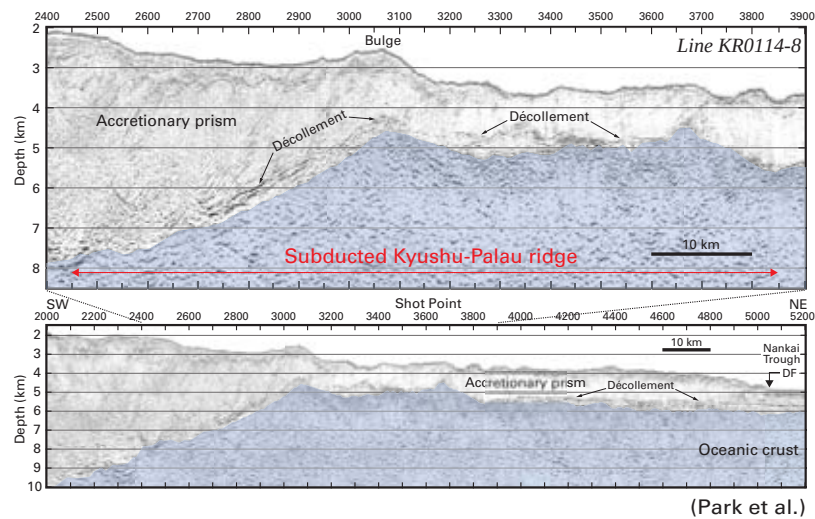


Fig.21 Poststack depth migrated MCS strike line KR0114-8 showing the subducted Kyushu-Palau ridge. The subducting oceanic crust is shaded in light blue. The vertical exaggeration is 4X.

geomagnetic anomaly signature, seafloor topographic features, wide-angle refraction data, and on-land geomorphologic evidence enable us to trace the forearc extension of the subducted ridge up to east Kyushu. The possible strong coupling zone between the subducted ridge and overriding plate at depth is marked by historic thrust-type intermediate-class (magnitude 6 or 7) earthquakes. Based on recent GPS and micro-seismicity observations, we propose that the subducted Kyushu-Palau ridge may serve not only as a seismic asperity at depth but also as a seismic barrier inhibiting the rupture propagation of the adjacent megathrust earthquakes in the Hyuga segment.

3) Seismicity observations at the Nankai Trough off the Kii Peninsula:

At the Nankai Trough off the Kii Peninsula, previous observations showed that the seismicity in the rupture area of the 1944 Tonankai earthquake was low. On the other hand, a relatively active seismicity was observed near the trough axis. To investigate the hypocenter locations and focal mechanisms of the earthquakes near the trough axis, 30 ocean bottom seismographs (OBS) were deployed at the trough axis and the trough landward slope. The seismic velocity structure used in the hypocenter determination was estimated from the three-dimensional tomography

using an air-gun array as a controlled source. The results are that there are several earthquake clusters located in the oceanic crust of the subducting Philippine Sea plate at the trough axis. These seismic activities are considered to relate to the deformation of the subducting Philippine Sea plate. Earthquakes in the upper mantle of the Philippine Sea plate were also observed (Fig.22).

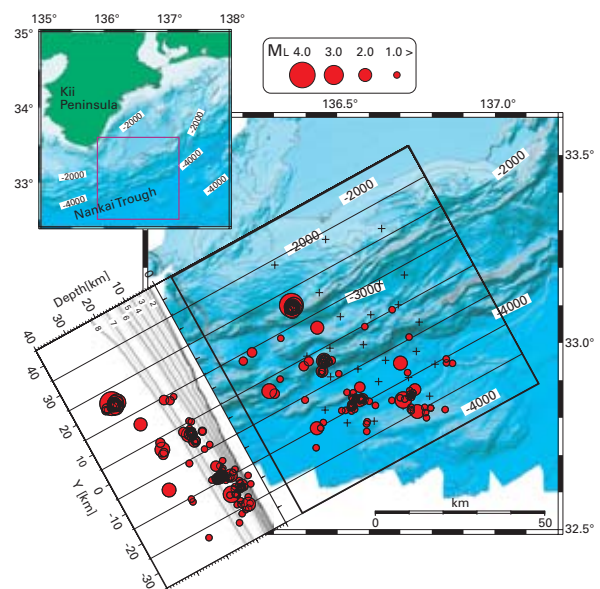


Fig.22 Hypocenter distribution obtained by OBS observations. The circles indicate the hypocenter locations. The size of the circles is proportional to the earthquake magnitude. The crosses indicate the ocean bottom seismographs.

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4) Imaging the plate geometry of the presumed rupture zones of the Tonankai and the Nankai earthquake:

In order to image the structure of the segmentation boundary between the Tonankai and the Nankai earthquake, wide-angle seismic data along three trough parallel profiles were acquired (Fig.23). In addition to the seismic survey, micro-earthquake monitoring has been implemented off western Shikoku. A preliminary

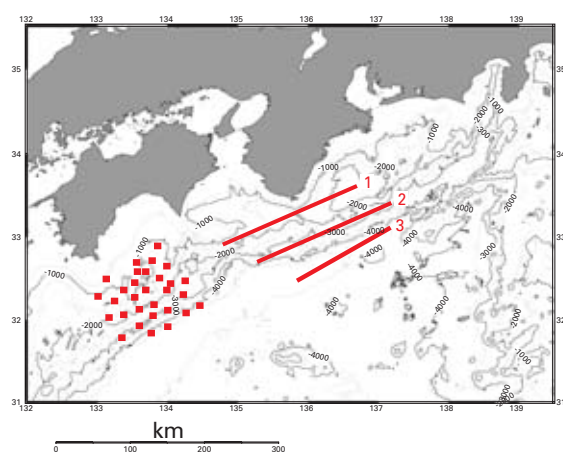


Fig.23 Wide angle seismic survey lines and micro-earthquake monitoring array around the Nankai Trough in fiscal 2003.

result of the seismic survey suggests a structural variation at the segmentation boundary; a precise image will be obtained by further processing.

1.2. Japan Trench seismogenic zone

In order to determine the geometry of the subducting plate boundaries precisely in the Japan Trench subduction zone, we apply a newly developed imaging method, a technique that projects reflection traveltimes directly onto the depth section, to the experimental data in the rupture zone of the 1994 Sanriku-Oki earthquake. The obtained reflection image reveals for the first time that the dip angle of the plate subduction suddenly changes at the longitude of 143.5 degrees east, 80 km landward of the trench axis (Fig.24). This bending point corresponds to the boundary of the repeating micro-earthquakes, a boundary in complementary relation to the rupture zone of the large earthquakes. This indicates that the geometry of the plate boundary has close relationship with the rupture zone of the large earthquakes in this subduction zone.

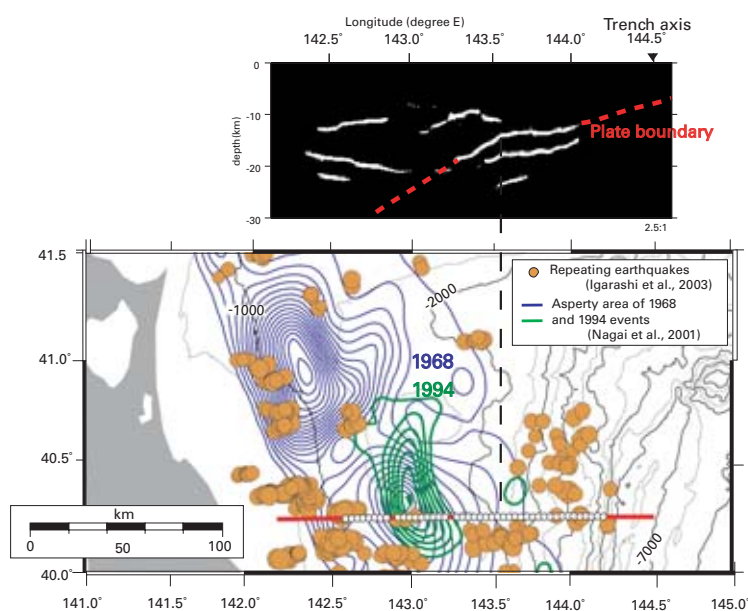


Fig.24 Location map and results of the seismic refraction experiment in the Japan Trench subduction-zone. Top: Reflection image obtained by our newly developed method in the northern Japan Trench subduction zone. Bottom: The distribution of repeating earthquakes (yellow circles) and the rupture zone of large earthquakes in this region. The red line is the experimental line and the white circles represent the Ocean Bottom Seismometers. The blue and green contour lines show the asperity (rupture zone) of the two of large earthquakes in this region.

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2. Material Science Group of Plate Dynamic Research Group

The objectives of Plate Dynamic Research Group are to clarify the details of plate subduction dynamics and to construct a comprehensive model of seismic preparation, rupture and recovery processes along the plate boundary. In order to understand these complicated processes in plate dynamics, the Material Science Subgroup conducts the following three research programs: the first is the experimental studies on frictional behavior and failure process of plate boundary materials, the second is the structural, petrological, and rheological studies of past plate boundary rocks, and the third is to construct a theoretical model of plate boundary dynamics involving thermodynamics, kinetics, and rheology of the plate boundary rocks in the subduction zone.

Laboratory experiments are partly carried out in collaborative study with universities, and the results of past plate boundary rock analyses are compared and discussed with the results of other subgroups.

2.1. Laboratory experiments

1) Frictional behavior of unconsolidated granular material at the seismic slip rate and its implication for shallow level faulting during the 1999 Chi-Chi,

Taiwan earthquake:

Laboratory experiments have shown that the frictional behavior of quartzose sands at the high slip rate ($\sim 2\text{m/s}$) depends on the initial consolidation state of sands before shear. When an undrained condition is maintained during shearing, the frictional coefficient of loosely packed sands decreases to $\sim 0.3\text{--}0.4$, possibly due to a grain boundary sliding under high pore pressure. In contrast, the densely packed sands show a higher frictional coefficient ($\sim 0.7\text{--}0.85$), possibly reflecting a pore pressure reduction associated with dilatancy. The key implication of experimental results is that if the loosely packed granular material on shallow portions of the fault is sheared under an undrained condition, the seismic rupture propagation from seismogenic depths into a shallow region will be enhanced. This may account for shallow level faulting in the northern part of the Chelungpu fault during the 1999 Chi-Chi, Taiwan earthquake, resulting in large surface displacements (10–15 m) (Fig.25).

2) Permeability measurements on rocks sampled from ancient subduction zone fault:

We conducted permeability measurements on rocks sampled from an exhumed ancient subduction zone fault in the Cretaceous Shimanto accretionary complex of Japan. The permeability under seismo-

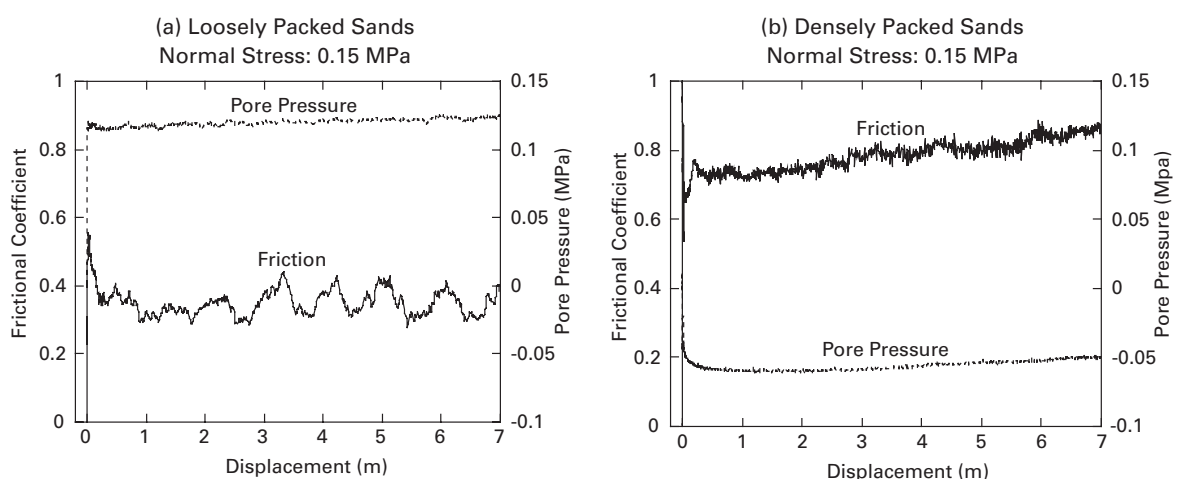


Fig.25 Results of undrained ring shear experiments (normal stress 0.15 MPa). (a) Friction and pore pressure as a function of displacement for the loosely packed sands. (b) Friction and pore pressure as a function of displacement for the densely packed sands.

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genic environment conditions shows a heterogeneous structure across the fault zone. The permeability of the sandstone in the turbidite sequence is the lowest, whereas the highly sheared zone has the largest permeability. A combination of permeability contrast between these two zones and fluid pressure source, including tectonically driven burial and dehydration, could result in a concentration of pore fluids along the fault, which causes Deep Seismic Reflections during the underplating stage as delineated in seismic reflection studies. Following a rise of temperature up to 250°C, the permeability of all sampled rock types became smaller than at room temperature, gradually decreasing with increasing hold time. The shear strength of the highly sheared zone and the black shales are weak, and the stability of the brittle failures is more stable than that of the granitic rock (Fig.26).

2.2. Field Research

1) Analysis of fault rock in the ancient seismogenic zone:

To understand the earthquake faulting process near the updip limit of the seismogenic zone, fault rock

analysis was performed in the Shimanto accretionary complex, eastern Shikoku. The fault bounds the coherent turbidites above from the imbricated *mélange* below without changes in vitrinite reflectance across the fault, suggesting that the fault is the roof thrust of a duplex structure. The fault zone is 1–2 m in thickness and is commonly composed of foliated cataclasite and thin (0.1–1 cm in thickness) layers of ultracataclasite. The ultracataclasite layers show a random fabric, which may reflect the loss of cohesion due to an elevated fluid pressure during the earthquake faulting (e.g., thermal pressurization). One ultracataclasite layer includes fragments of pseudotachylytes (PT). Microstructures of PT clearly show the evidences for frictional melting: rounded and irregularly shaped clasts and vesicles in a fine matrix, which are very similar to the deformation textures of experimentally generated PT. The EPMA, XRD, and Raman analyses indicate that the PT is derived from illite-rich shale accompanying frictional melting of sandstone and that the fine matrix is an amorphous illite formed in association with rapid cooling of melt. The maximum temperatures estimated from the breakdown temperatures

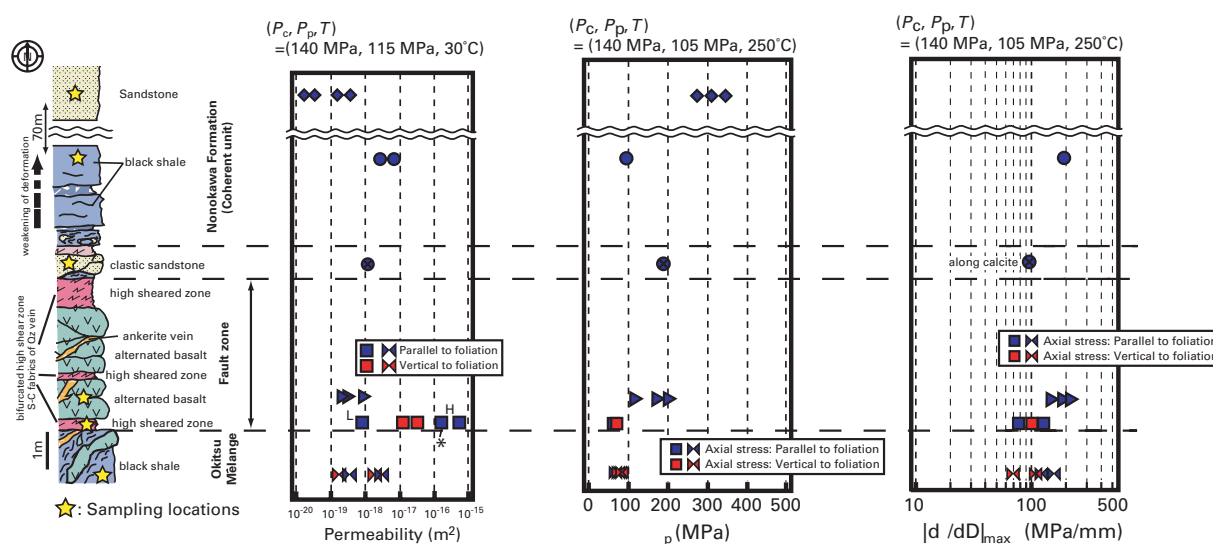


Fig.26 Geological column section of the fault zone. The white star denotes the sample locations. Permeability data distribution tested at conditions (P_c, P_p, T) = (140 MPa, 115 MPa, 30°C). *: tested at (P_c, P_p, T) = (50 MPa, 25 MPa, 30°C). H and L represent the high and low porosity of rocks in highly sheared zone, respectively. The symbol size reflects the measurement error. The shear strength of the highly sheared zone and the black shales are weak, and the stability of the brittle failures is more stable than the granitic rock.

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of orthoclase and quartz are 1150°C and 1730°C, greater than the maximum temperatures of the host rocks (170–200°C). The clast/matrix ratio in PT is less than 20%, suggesting a high degree of melting. The analysis of PT revealed that the frictional melting of illite-rich shale and sandstone could be a weakening mechanism in the seismogenic zone and that the cooling rate of PT in the accretionary prism is higher than that of microlitic PT in faults of other tectonic settings (Fig.27).

2) Structural evolution and rock-fluid interaction of the out-of-sequence thrust:

The Nobeoka Thrust in Kyushu, Southwest Japan

was investigated to further understand the relationship between the seismogenic out-of-sequence thrust (OST) and fluid flow in accretionary prisms. The Nobeoka Thrust is a fossilized OST, active at seismogenic depth. The hanging-wall exhibits a penetrative plastic deformation while a brittle, cataclastic *mélange* like occurrence characterizes the footwall, although both have the same shale-dominant protolith. Vitritinite reflectance analyses indicate that the maximum temperature of the hanging-wall and footwall is approximately 320 and 250°C, respectively. This thermal gap across the thrust corresponds to 8–10 km of displacement, assuming a 35–40°C/km geothermal gradient.

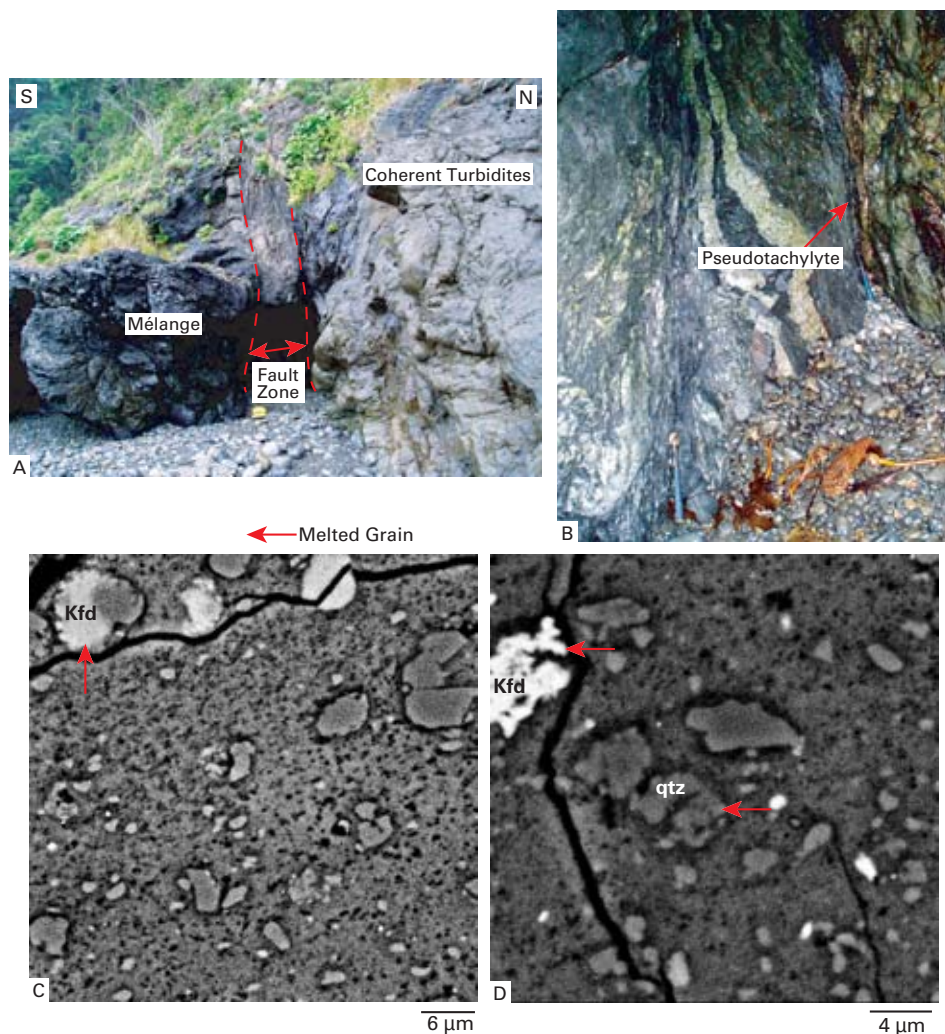


Fig.27 (a) The pseudotachylyte bearing fault bounding the coherent turbidites above the sandstone-shale *mélange* below. (b) A thin dark vein including fragments of pseudotachylyte. (c) Backscattered electron image of pseudotachylyte. The red and blue arrows indicate the melting of grain margins and vesicles, respectively.

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The brittle damage zone of the thrust is asymmetric: only two meters for the hanging-wall side and 100 m for footwall.

Two types of mineral vein, comprised of quartz and carbonate, are well developed, especially in the damaged footwall: a tension crack filling vein and a fault core vein. The former is harmonious with the fabric, perpendicular to the P surface. Fluid inclusion geothermobarometry indicates the P-T of fluid in the intensively damaged zone of the footwall is about 300°C, 230–250 MPa, higher than that from vitrinite reflectance, which suggests that thermal fluid flow is associated with deformation. The same type of vein in the lowest portion of the footwall-damaged zone includes a much lower P-T fluid. This difference

suggests that continuous underplating caused the damaged zone to propagate downward with cooling and shallowing, which differs from faults characterized by shear localization. This difference may be unique to aquiferous OST in accretionary complexes (Fig.28).

2.3. Rheology modeling of plate behavior

1) Molecular Dynamics (MD) simulation on lower mantle mineral:

Self diffusion coefficients of Peliclae, the lower mantle mineral, were numerically determined by using the "Earth Simulator" for 1 million MgO molecules. Despite old ideas that admit no pressure dependence, the self diffusion coefficients show continuous reduc-

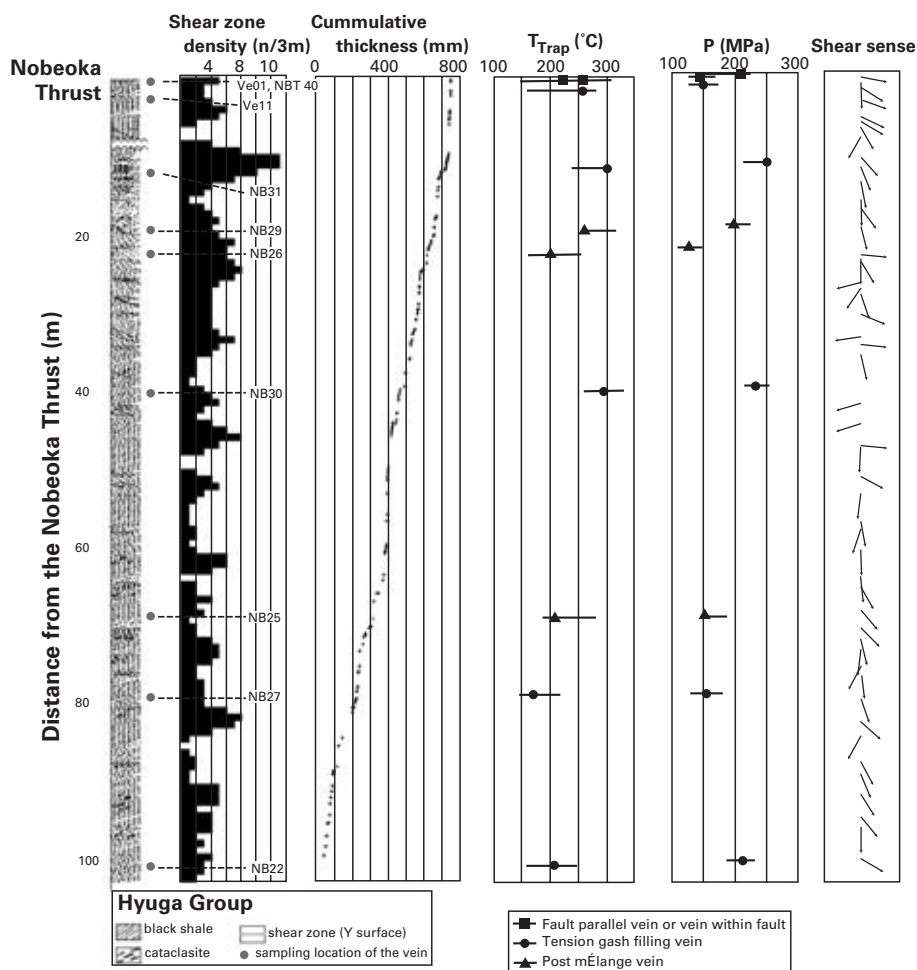


Fig.28 Structural elements and results of fluid inclusion analysis in the footwall damaged zone of the upper unit in the Hyuga Group. Shear sense is determined from the Y-P fabric. TTrap: Trap temperature.

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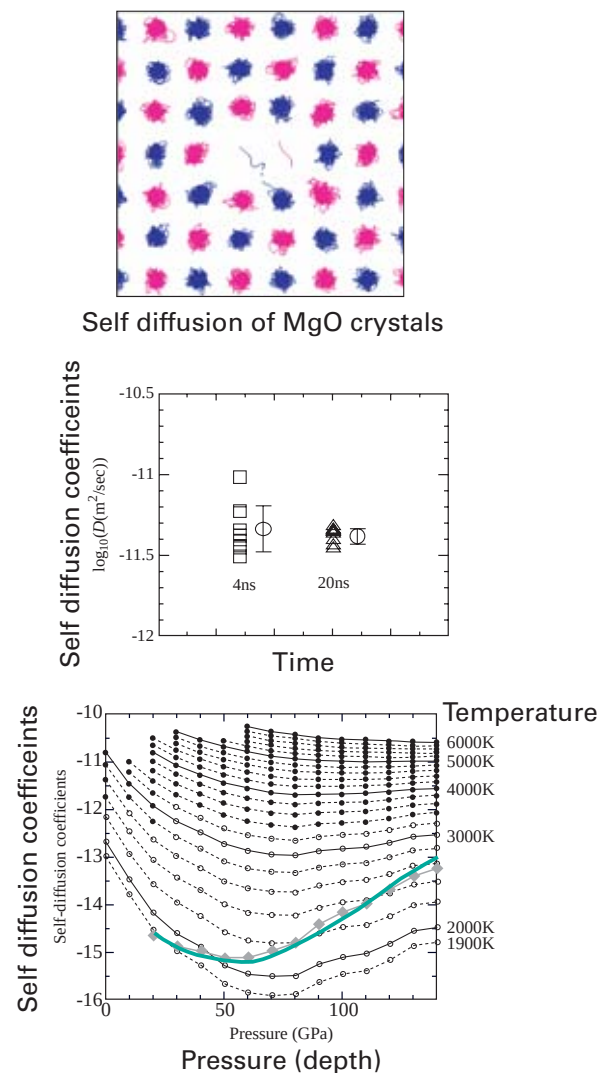


Fig.29 Self diffusion coefficient of Peliclaase and pressure dependency. Self diffusion was defined using Molecular Dynamics (MD) for 1 million MgO molecules (top). The inclination of the self-diffusion coefficient change at 50 GPa from reduction to rise suggest that the viscosity of the lower mantle decreases approximately by two orders below 1500 km (bottom).

tion with increasing pressure, rising above 50 GPa. These results consequently suggest that the viscosity of the lower mantle decreases by approximately two orders below the depth of 1500 km (Fig.29).

3. Plate dynamics modeling group

The Plate Dynamics Modeling Group's aim is to facilitate the understanding of solid earth dynamics and evolution through the development of predictive

models and advanced computational technologies using large scale super computers, such as the Earth Simulator. The underlying requirement is to understand the complex crustal structure and its dynamics by providing the Lithospheric Structure Research Group with models and numerical simulations. This kind of collaboration is also helpful for field observation planning. At the same time, research information obtained by the Seismogenic Zone Material Science Research Group can be used to better understand the relationship between the micro-mechanics and physical-chemical properties of fault zones and global crustal dynamics through modeling and simulation. In so doing, we are developing models addressing the scale of 1) the seismogenic fault zone, 2) the plate boundary, such as Nankai Trough, 3) the whole Japan area, including several plates, 4) the whole globe, including all the plates.

3.1. A numerical simulation of earthquake cycles along the Nankai Trough, southwest Japan considering complex slab geometry and heterogeneous plate convergence rate

The occurrence pattern of historical great earthquakes indicates the existence of rupture segments that seem to correlate with the lateral variation in the dip angle of the subducting Philippine Sea plate. To investigate how such heterogeneity in slab geometry affects the occurrence of earthquakes, we conducted a three-dimensional numerical simulation of earthquake cycles for a large source area using the Earth Simulator. Frictional parameters and effective normal stress were assumed to depend on the estimated depth of the real plate boundary based on seismic surveys and seismicity data. The depth-dependent frictional parameters were mapped on the flat model plane. The plate convergence rate in the model decreased eastward along the trough, consistent with a recent Global Positioning System analysis. In the simulation results, preslip occurred and rupture started off Kii Peninsula (Fig.30).

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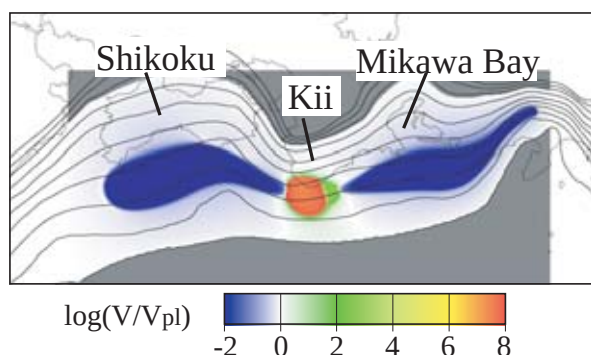


Fig.30 Snapshot of the slip velocity distribution normalized to the plate convergence rate. Blue and red indicate locking and instably slipping parts of the fault, respectively.

3.2. Tsunami magnitudes determined from ocean-bottom pressure gauge data around Japan

Tsunami magnitude is a fundamental parameter that measures the overall size of tsunamis and tsunami-genic earthquakes. According to Abe [1979, 1981], tsunami magnitude was defined using the amplitude of tsunamis observed at coastal tide gauges. We developed a method to calculate tsunami magnitude from ocean-bottom pressure gauge data collected from around Japan. Direct application of Abe's equations to ocean-bottom pressure gauge data underestimates tsunami magnitudes by about an order of a magnitude. This is because Abe's equations were derived only from tsunami amplitudes measured at coastal tide gauges where tsunamis are amplified by the shoaling of waves and the reflection at the coastline. For offshore bottom-pressure records, we introduced correction factors to Abe's original equations to account for tsunami amplitudes measured in open oceans. The modified equations produced pressure gauge determined tsunami magnitudes close to those determined using coastal tide gauges (Fig.31).

Tsunami amplitude mostly correlates with seismic magnitude except for tsunami earthquakes: the amplitude of tsunamis generated by a tsunami earthquake is larger than that expected from seismic magnitude. Prediction on the basis of seismic magnitudes is not applicable to tsunami earthquakes, as suggested by Pelayo and Wiens [1992]. Offshore tsunami observa-

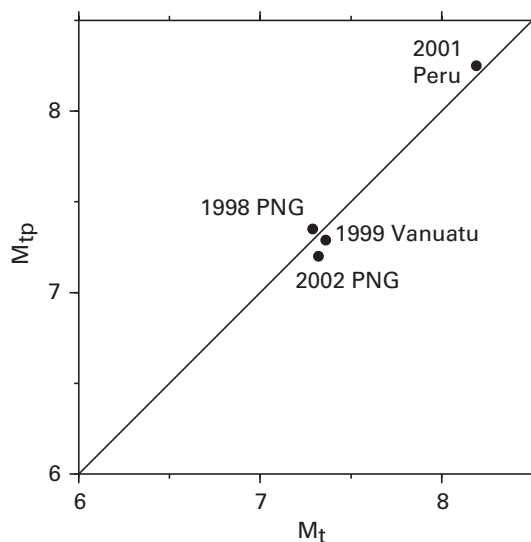


Fig.31 Tsunami magnitudes, M_t and M_{tp} , are determined from coastal tide gauge and ocean-bottom pressure gauge data, respectively. A modified empirical relation was applied to the pressure gauge data to determine M_{tp} (circle). The modified empirical relation produces pressure gauge determined tsunami magnitudes close to those determined using coastal tide gauges.

tions, if combined with the modified equations presented in the study, are useful for predicting tsunami amplitudes at the coastline, even for tsunami earthquakes.

3.3. Intra-plate seismicity in the subducting Philippine Sea Plate, southwest Japan: magnitude-depth correlations

Recent studies of intraplate seismicity have focused on detailed earthquake locations and potential hypotheses for intermediate depth events. The three main competing hypotheses for intraplate events are 1) transformational faulting, 2) shear melt instabilities, and 3) dehydration reactions. Recent work, using precise hypocenters and thermal-petrological models, indicates that the spatial distribution of intraplate events coincides with dehydration reactions. These studies have mainly focused on the location of events and the proposed reactions, with little attention given to the magnitude distribution of events. Presented here is a magnitude-depth correlation associated with intraplate events for SW Japan. Earthquake hypocenters were obtained from relocating a data set consist-

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ing of Japan Meteorological Agency (JMA) seismicity data and a consolidated catalogue of Japan university data (JUNEC). Data from 1985-1996 were combined and relocated using a standard location routine (HypoInverse) that allows regional variation in velocity models and station corrections. HypoInverse results show a well defined plane of seismicity associated with the subducting Philippine Sea plate (Fig.32).

The data was further relocated using a double difference relocation algorithm (HypoDD). HypoDD results show a magnitude-depth correlation for the Kii Peninsula and for Northern Kyushu. Histogram plots indicate that events near the plate interface are generally of magnitude 3 or less while most large events are located within the lower crust or possibly within the subducting oceanic mantle. This observation also appears to hold true for intraplate events beneath Tohoku (Japan Trench) and Hokkaido (Kuriles), but is not clearly observed beneath the Tokai Region. A dehydration reaction model can well explain the magnitude-depth correlation (Fig.33).

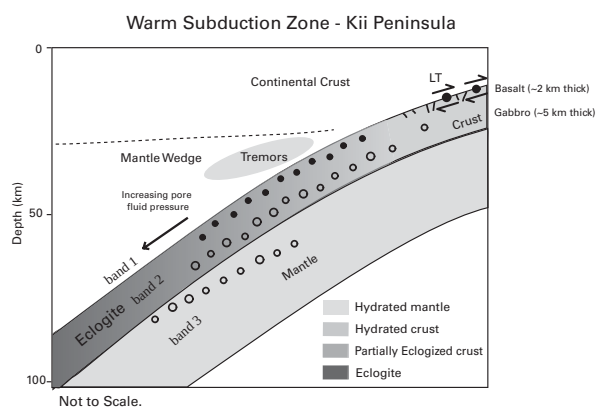


Fig.32 Warm subduction zone model. The upper band (roughly 2 km thick) of seismicity is contained within the basaltic layer of the oceanic crust. Events within the basaltic crust are generally small due to the fracture nature of the crust. Below this, events occur within the gabbroic crust. Events within the gabbroic crust can be larger due to the less fractured nature of the crust. The third band of seismicity is within the oceanic mantle and contains a greater portion of larger events compared to the gabbro band. This mantle band roughly follows a geotherm for a warm subduction zone and would therefore not necessarily be parallel to the subducting plate.

Kii Peninsula - HypoDD Relocations

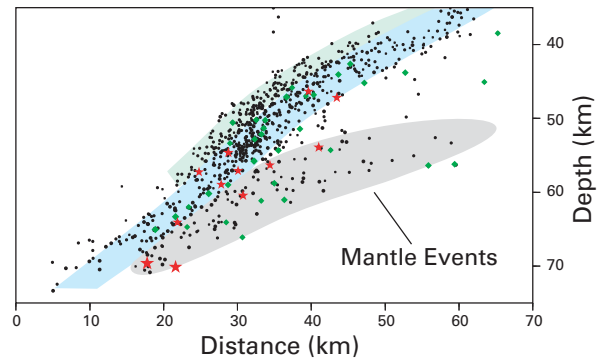


Fig.33 Warm subduction model bands applied to the Kii Peninsula. The light green shaded region we associate with seismicity within the basalt layer (band 1). The light blue shaded region is seismicity associated with the gabbroic layer (band 2). The gray shaded region we define as seismicity associated with the subducting oceanic mantle (band 3).

IV. Research Program for Paleoenvironment

Research overview:

Our Research Program aims to establish a new view for the evolution of the Earth-Life system, recognizing that both the environments of Earth and biotic evolution vary with crucial links to the activities of Earth's interior. We focus on the last 200 Ma when geological events were well recorded in the sediments. Currently, our research is concentrated in the following three fields:

- 1) Climatic changes in the Cretaceous Greenhouse and late Cenozoic Icehouse Earth
- 2) Production, sedimentation, and degradation processes of organic/inorganic materials in model oceans both for the Greenhouse and Icehouse Earth, in particular on the continental margin depositional setting
- 3) Database development for the paleoclimatology and paleogeography of continents and oceans

Here, we briefly summarize the results of each topic and present an overview of the progresses of our research during FY2003.

1. Cretaceous Greenhouse Earth

1.1. Model Ocean for Cretaceous OAEs

Chlorophylls are one of the most important organic compound groups in terms of the biogeochemical

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cycles on Earth, since they are the major antenna-pigments for most photoautotrophs. Eukaryotic phototrophs have chlorophylls (Chl) *a*, *b*, and *c*, while prokaryotic phototrophs, except for cyanobacteria, have bacteriochlorophylls (BChl) *a*, *b*, *c*, *d*, *e*, and *g*. We have recently succeeded in isolating and purifying Chl *a*, BChl *a*, and BChls *e* from the suspended particulate matter and sediments collected in saline meromictic Lake Kaiike and have determined the stable carbon and nitrogen isotopic compositions of these compounds (Fig.34; Ohkouchi et al., in press). Lake Kaiike is a modern analogue for oceanic environments during Cretaceous Oceanic Anoxic Events and Early Earth. Based on these isotopic results as well as on 16S rDNA analyses, we have found that a brown-strain of green sulfur bacteria, *Pelodyctyon luteolum* inhabits and photosynthesizes even in very dark (<0.01 Mphoton $m^{-2} sec^{-1}$) monimolimnion of the lake. Furthermore, we have found that in the chemocline the green sulfur bacteria *Chlorobium phaeovibrioides* conducts nitrogen fixation, whereas purple sulfur bacteria *Halochromatium* sp. and cyanobacteria *Synechococcus* sp. assimilates nitrite. By coupling geochemical and molecular genetic information, we can trace species-independent biogeochemical processes which have never before been recognized. Such an interdisciplinary process oriented study will contribute to paleoenvironmental reconstruction by providing basic biogeochemical frameworks.

It has been known that the porphyrin nucleus in the chloropigments are very stable in diagenetic/catagenetic processes and that they are found not only in sedimentary rocks but also in petroleum. In this sense, porphyrins are potentially useful and widely applicable geological tracers. Since they also contain the isotopic information of carbon, nitrogen, and hydrogen, they can be used as excellent biomarkers for biogeochemical cycles in the past. We are currently developing a high-throughput method to extract, isolate, and purify these geoporphyrins from geological samples in order to determine the isotopic compositions of these elements.

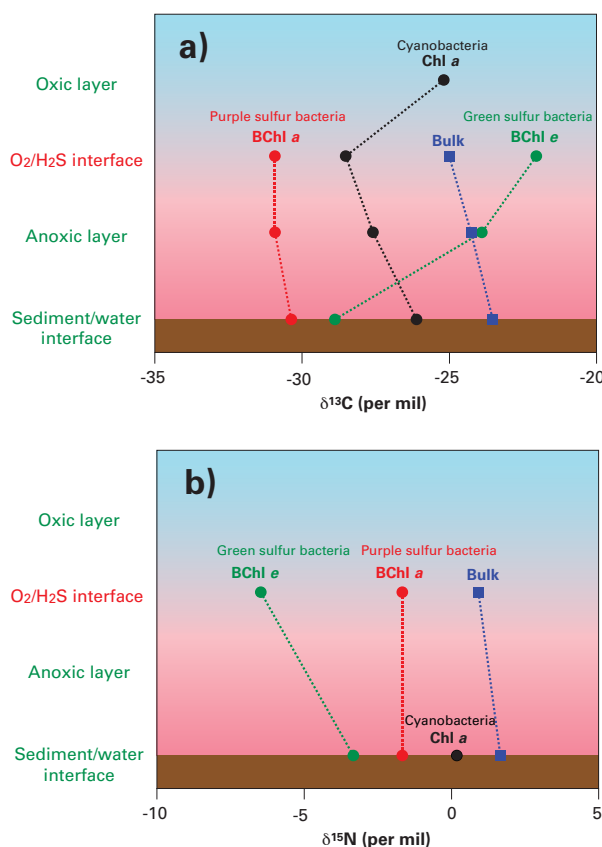


Fig.34 Distribution of (a) carbon and (b) nitrogen isotopic compositions of chloropigments and carotenoids isolated from Lake Kaiike.

1.2. High-resolution analysis for Cretaceous black shales

Research addressing the Cretaceous "Greenhouse Earth" is essential for understanding near future global warming. We have collected sedimentary rock samples from the Vocontian Basin, SE France, deposited in the hemipelagic environment during the middle Cretaceous. We have constructed a detailed geological column and analyzed total organic carbon (TOC), its stable isotopic compositions, and major elements with a non-destructive elemental mapping technique using TATSCAN for the black shales of Goguel (OAE 1a, ca. 120 Ma), Paquir, and Kilian levels (OAE 1b, ca. 110 Ma).

The sediments in the Vocontian Basin mainly consist of massive marl with about 40wt% calcium carbonate. Laminated black shale intercalate within the marls. The lamina preserved in the black shale have a thickness of several 10 to 100 μm , composed of light-

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colored laminae containing foraminifera and dark laminae enriched with clay minerals and organic matter. These lamina couple to form several mm to cm-scale rhythmic laminated intervals. These laminated intervals are intercalated at faintly laminated intervals and at massive marls in several cm to several tens of cm.

The maximum TOC content of the black shale is ca. 4wt%, which is four times higher than that of the upper and lower marls. The isotopic composition of the TOC indicates a negative excursion of about 6‰ in clay interval within the Goguel level, confirming that the level is correlated with the OAE Ia event. On the other hand, the idea that large methane release by collapse of gas hydrate as a trigger for the black shale formation should be rejected because the negative excursion of the carbon isotope record is found after the initiation of the black shale deposition.

TATSCAN analysis revealed asymmetric variation of Ca and Al content on three scales, variation of several mm, several cm, and several tens of cm. Based on the microscopic observation of thin sections, the increase of Ca content corresponds to foraminifera-bearing laminated intervals. The increase of Al is found in clay-rich intervals with less abundant foraminifera. The three sedimentary rhythms are estimated as several 10 years, several 10^3 years, and several 10^4 years cycles under the assumption of a linear sedimentation rate for the Goguel level.

Preliminary results suggest several new aspects for the mechanism of black shale formation. Although the ocean circulation during the OAEs was generally stagnant, the depth of the redox boundary in the water column, primary productivity, and terrigenous input would be more variable during the formation of black shales. We also found three levels of sedimentary regime during black shale formation. First, massive, bioturbated light bluish grey marl containing less organic matter would have been deposited under high primary production and a less anaerobic bottom water condition where benthic biota were active for bioturbation. Second, massive dark marl containing abun-

dant organic matter would have been deposited under low primary production and moderate anaerobic environment without benthic biota. Third, well-laminated black shale or massive black marl would have been preserved in a strong anaerobic condition without benthic biota and with accumulating iron sulfide in the water column. In December 2003, we performed continental drilling at Les Sauzeres in the Vocontian Basin in collaboration with Hokkaido and Kyushu Universities (Fig.35). We succeeded in recovering 62 m of continuous sedimentary sequence, including the Goguel level.

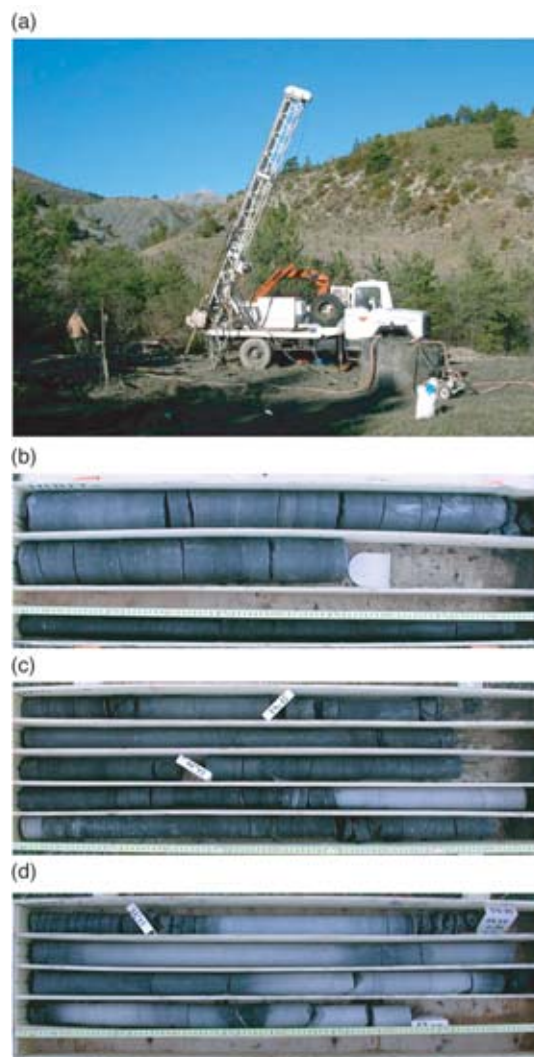


Fig.35 The OAE (Ocean Anoxic Events) Drilling in Dec. 2003. (a) Drilling at Les Sauzeres (SE France). (b) Goguel level (OAE Ia) in 51.7–54.15 m depth, (c) 54.15–58.50 m level, and (d) 55.50–62.00 m level.

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1.3. Investigations of benthic foraminifera adapting to a euxinic environment

Most eukaryotic organisms adapt and are able to live in oxic environments. This means that both a low concentration of oxygen and the existence of hydrogen sulfide should not be suitable for them. However, some protists, single-celled eukaryotes, have been known to live in anoxic and/or euxinic environments. We found that the benthic foraminiferal species *Virgulinitella fragilis* (marine protists) is distributed in the meromictic Lake Namakoike, where a euxinic environment is developed at the lake bottom. Both δ -proteobacteria, which may be identified as sulfur oxidizing bacteria, and kinetoplast particles, which may have originated from the diatom species *Chaetoceros socialis*, are housed in a foraminiferal cell (Figs.36a, b, c). It is probable that these particles play some role for the protist in adapting to a euxinic environmental condition.

Virgulinitella fragilis is ubiquitously distributed in euxinic bottom environments, from Japan to New Zealand, Australia, the coastal upwelling areas of the Arabian Sea and Namibia, to the Cariaco Basin. How does this organism adapt to euxinic environments? How does it migrate from one euxinic environment to another? Is there any gene flow among the remotely separated populations? To answer these questions, we are investigating this species using morphological, molecular genetic, and anatomical techniques. By doing so, we may contribute to an evolutionary theory in which evolution of eukaryotes from prokaryotes takes place by bacterial endosymbiosis. We also would like to point out that a euxinic environment may play a key role in accelerating eukaryotic evolution throughout the history of life.

2. Research for the Cenozoic Icehouse Earth

2.1. Sedimentary processes at the slope basin of continental margins with high sedimentation rate

We have been investigating both sedimentary processes and material cycling in central Sagami Bay as a modern analogue for understanding sedimentary

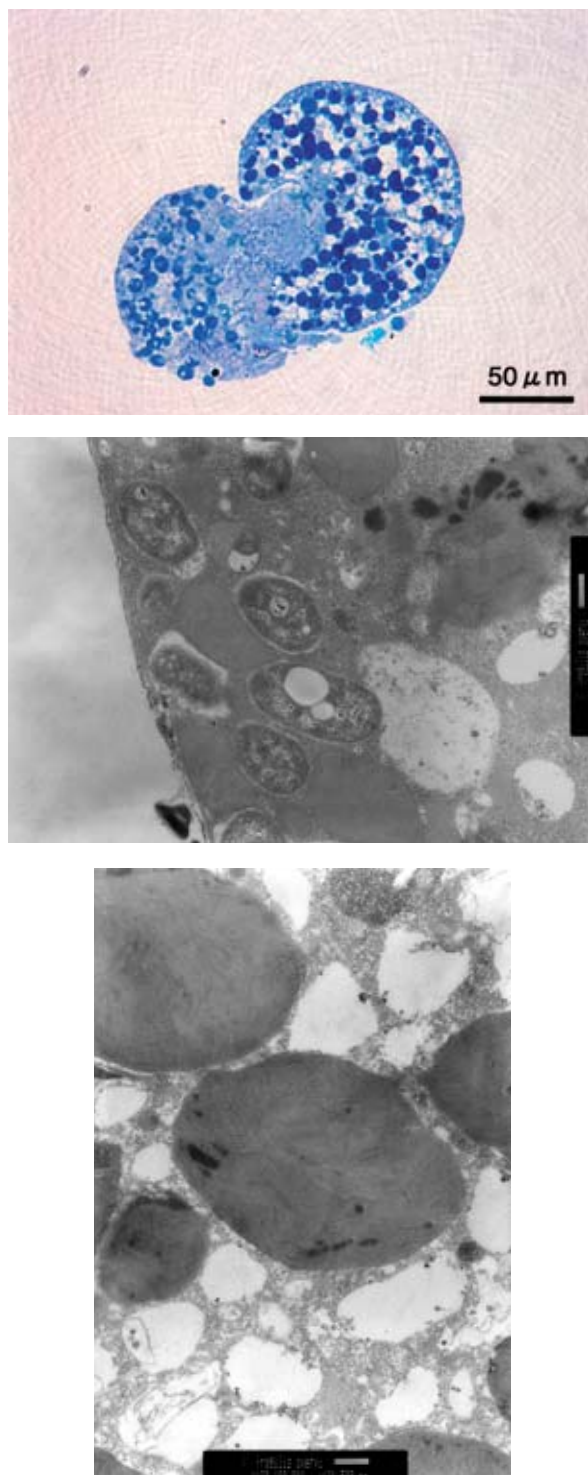


Fig.36 (a) Microscopic photograph of *Virgulinitella fragilis*. Tangential section against the growth axis. (b) TEM photograph shows endosymbiotic bacteria which are gathered in the surficial part of the cell. Each bacterium is covered with a thick membrane. (c) TEM photograph showing kinetoplastic particles in the central part of the cell. These particles may be derived from those of diatoms. The membrane does not clearly cover the particle.

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processes in the continental margin, where rapid accumulations of both organic and inorganic materials take place. We have already reported an overview of these sedimentary processes in Kitazato *et al.* (2003).

Among the material cycles in the basin, benthic processes at the sediment-water interface should be important. For the FY2003, we attempted to quantify the material cycle at the sediment-water interface through two different approaches. We measured micro-environmental gradients at the sediment-water interface, with both a 2D-optode and a sensor micro-electrode assembled on an Elinor-type lander system owned by the Marine Biological Laboratory, University of Copenhagen. We kept this lander system in an adequate position and location at the sea floor by using the ROV "Hyperdolphin". We succeeded in drawing out a precise profile of dissolved oxygen (DO), with both the 2D-optode and the sensor micro-electrode (Figs.37, 38). The results show that the pen-

etration depth of DO in the Sagami Bay sediments dynamically changed from 1 to 8 mm. We plan to observe long-term changes in DO profiles at the sea floor in order to better detect variabilities in the physicochemical properties between sediments and bottom water.

Organic matter produced in the surface ocean reaches the sea floor and is ingested by benthic organisms. To calculate the carbon budget at the sea floor, we made in situ culture experiments at the deep-sea permanent station in the central part of Sagami Bay. We supplied two types of ^{13}C -labeled food materials, *Dunaliella* and *Vibrio*, on the sea floor with *in situ* culture devices. Two devices were recovered with the ROV on deck at two days intervals. Uptake rates of organic matter were measured with a mass spectrometer for each species of meiobenthos. We found that benthic foraminifera quickly responded and consumed fresh organic material. This strongly suggests that

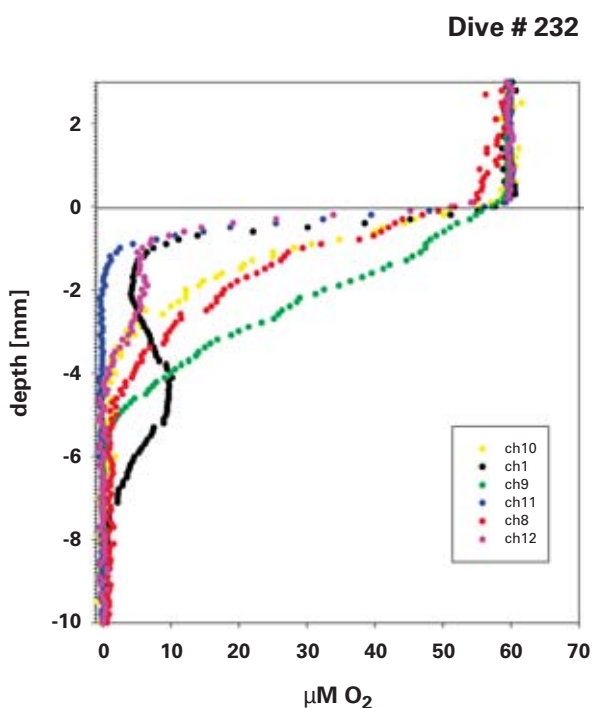


Fig.37 Oxygen profiles at the sediment-water interface measured with a sensor oxygen microelectrode. The profiles are different between sites, indicating that oxygen penetration depths are heterogeneous even in a small area (courtesy from Dr. F. Wenzhöfer, Max Planck Institute for Marine Microbiology, Bremen, Germany).

Data examples from Sagami-cruise 2003
(only rough calculations - to be treated)

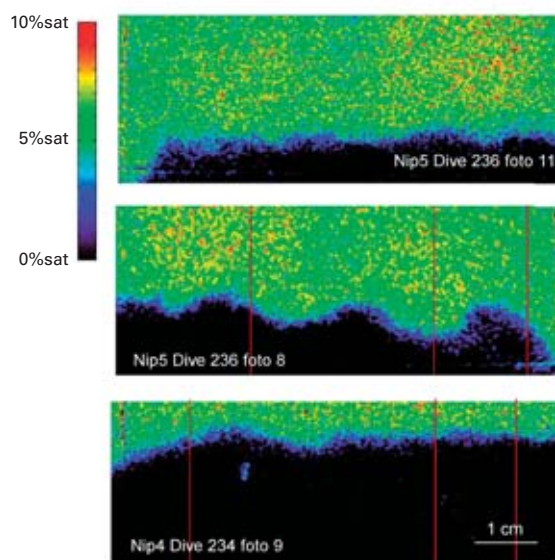


Fig.38 Two dimensional images of oxygen concentration at the sediment-water interface taken with 2D-planer optode system. Oxygen penetration depths are 2-8 mm in depth (courtesy from Dr. R. N. Glud, Marine Biological Laboratory, Copenhagen University, Denmark).

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benthic foraminifera play an important and primary role as consumers within the benthic ecosystem (Nomaki *et al.*, 2005). We calculated the carbon budget on the sea floor using the uptake rate, the respiration rate, and biomass data. It is striking that benthic foraminifera remineralize as much as 30% of the organic matter sinking to the sea floor. In total, 100 mgC m⁻² day⁻¹ of organic carbon is calculated to be deposited in the sediments (Kitazato *et al.*, in prep.). Inorganic materials rapidly supplied from adjacent land areas may also play a role in accelerating the burial of organic materials into the sediments.

Chemosynthetic colonies of *Calyptogena* and other benthic organisms are distributed on the sea floor in strong relation to cold seepage. An upward flux of both methane and hydrogen sulfide from the sediments in cold seepage should originate from organic matter that has been buried in the sediments. Buried organic matter should decompose by subsurface bacterial activities and then be recycled to the sea floor. Material cycles should extend from water column to the sediments and then deep into the sediments.

2.2. Abrupt climate changes recorded in the sediments from Sea of Okhotsk

Research exploring the Cenozoic "Icehouse Earth" is essential for understanding the globally abrupt climatic changes in the cold Earth system. We have investigated sediment core MD01-2412 recovered from the Sea of Okhotsk by International Marine Past Global Environmental Changes Study (IMAGES) WEPAMA 2001 cruise of R/V *Marion Defrens*.

Based on the AMS ¹⁴C dating of the foraminiferal shell, oxygen isotope stratigraphy, and tephro chronology, the mean sedimentation rates of MD01-2412 were estimated to be as high as 115.5 cm kyr⁻¹ during the interglacial and as low as 41.2 cm kyr⁻¹ during the glacial. Based on the alkenone unsaturation ratio, we found rapid shifts of sea surface temperature (SST) with millennial timescales including the D-O cycles, the Younger Dryas and Bølling-Ållerød events. We

reconstructed sea ice history during the last 120 kyr based on the content of ice-rafted debris in the sediments. The sea ice in the Sea of Okhotsk rapidly increases at the stadial intervals in the millennium-time scale. The expansion of sea ice corresponds to the intervals of strong polar circulation recorded in the Greenland ice core, GISP2. This implies that the polar circulation intensity forces the expansion of sea ice in the Sea of Okhotsk. From another perspective influenced by micropaleontology, we proposed that the formation rate and composition of Okhotsk Sea Intermediate Water has had a great impact on North Pacific Intermediate Water during the last 120 kyr. The alkenone-based SST and salinity records indicate that a warm, fresh water mass existed in the Sea of Okhotsk during interstadial intervals, resulting from large water discharge from the Amur River. Modern observation has shown that warm (20°C) fresh water discharges in the autumn when the drainage basin of the Amur River has a large precipitation. Furthermore, saline water from the Soya Strait should have been cut off or very weak during the low sea-level stand in the glacial periods. The combined effect may have resulted in warm, fresh water mass during the interstadial. We also found abrupt negative excursions of up to 3‰ in carbon isotopic composition of benthic foraminifera during the last 120 kyr. As many as 10 excursions were found, mainly in interstadial periods. The reason for these excursions is currently being studied, based mainly on the microstructure, isotopic, and elemental compositions of the foraminiferal shell.

Our research products should continue to effectively meet the main scientific objectives for the IODP proposal associated with the Okhotsk and the Bering Seas, a proposal now under planning that involves drilling by IODP-SAS.

V. Center for Data and Sample Analysis

Research Overview:

One task of the Sample Analysis Division is to conduct comprehensive analyses focusing on the chemical

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composition and physical properties of rock and fluid samples. For this, the Sample Analysis Division has developed effective and analytical techniques and has gathered accurate and precise geochemical data. This has enabled them to decode the geochemical characteristics (major and trace elements, isotopic compositions, and radiometric dating) of solid samples such as igneous rocks, sedimentary rocks, and fossils, as well as fluid samples such as pore water.

The Pacific Data Network Division has developed a database system for storing geophysical data recorded through the operation of the Pacific region geophysical observation network. It also has developed a new technique for analyzing both seismological and electromagnetic data. The Seismic Data Processing Division is currently constructing a crustal structure database. It has developed a data-publication web site in order to broadly disclose this data. The Seismic Data Processing Division is also developing an integrated imaging method for MCS (Multi-Channel Seismic) and wide-angle reflection data.

1. Sample Analysis Division

1.1. A state of the art apparatus, maintained and organized by well-trained scientists and technicians, has been installed in the Center and at the collaborative universities

- (i) Electron Probe Microanalyser (EPMA): We have developed an improved method that enables the decoding of major-element compositions in particularly small regions, in both minerals and volcanic glasses.
- (ii) Thermal Ionization Mass Spectrometer (TIMS): We have developed new techniques for analyzing Sr, Nd, Pb, Os and Ru isotopic ratios for rock samples.
- (iii) Quadrupole ICP Mass Spectrometer (QP-ICP-MS): We have established new techniques for analyzing ultra-trace elements and platinum group elements for rock samples using QP-ICP-MS.
- (iv) X-ray Fluorescence Spectrometer (XRF): We

have enabled the quantification of major elements (SiO_2 , TiO_2 , Al_2O_3 , Fe_2O_3 , MnO , MgO , CaO , Na_2O , K_2O , P_2O_5) by using a multi-channel simultaneous XRF and the quantification of trace elements (Rb, Ba, Th, Nb, Pb, Sr, Zr, Y, Ni, Cu, Zn, S) by using a wavelength dispersive XRF in rock/sediment samples.

- (v) Noble gas mass spectrometer: A new noble gas mass spectrometer is being used for noble gas isotope analyses and K-Ar dating of rock/mineral samples.
- (vi) Micro-drill: We have established a method for in-situ measurement of Sr isotopes in minerals (mainly plagioclase) through micro-drill sampling.
- (vii) Clean room: Clean rooms are used for the pre-treatment of rock samples, pretreatment including the decomposition of powdered rock samples and the separation of target elements. These clean rooms allow us to handle samples under very clean conditions.

1.2. Evolution of early continental crust

Well-preserved oceanic sedimentary rocks in Archean greenstone belts provide insight into the ancient oceanic environment and the evolution of continental crust, if it existed, during the early history of the Earth, in that eroded continental crust would have contributed to the chemical composition of Archean seawater. Here we report on Re and Os isotope analyses of the Archean Marble Bar cherts from the Pilbara Craton, NW Australia. These cherts provide evidence for the existence of early Archean continental crust. Re-Os isotopic data of the Marble Bar cherts form an isochron with an age of $3.45 \pm 0.88 \text{ Ga}$ (2σ). The initial $^{187}\text{Os}/^{188}\text{Os}$ ratio is 0.932 ± 0.074 (Fig.39), which is extremely high compared with that of 3.45 Ga chondritic mantle (0.105). Continental crust generally possesses high $^{187}\text{Os}/^{188}\text{Os}$ ratios (present-day average is 1.0-1.3) and other geochemical reservoirs could not have easily obtained such high Os isotope ratios, especially by early Archean times. Therefore,

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the high Os isotope ratio implies that a significant amount of continental crust material contributed to the isotopic composition of the Marble Bar cherts, which leads us to conclude that evolved continental crust already existed as early as 3.45 Ga.

1.3. In-situ Sr isotope measurements of mineral

Most previous geochemical and isotopic studies on igneous rocks have been conducted on a "whole-rock" basis. In-situ geochemical and isotopic analyses of phenocryst are required in order to decode the dynamic processes involved, from magma generation to solidification, including magma mixing. Therefore, we have established a method for the in-situ measurement of Sr isotopes in minerals (mainly plagioclase) through micro-drill sampling followed by TIMS measurements. This method has been applied to the in-situ analysis of plagioclase Sr isotopes from the Zao Volcano, NE Japan (Fig.40). As a result, we have found that Sr isotopic compositions are variable within the rim and core of the mineral, and within the ground mass and whole rock. This work has been in collaboration with the Institute for Geothermal Sciences, Kyoto University.

2. Pacific Data Network Division

2.1. Computation of theoretical seismogram

The Pacific Data Network Division has been developing a numerical technique to produce precise synthetic

seismograms for realistic 3D Earth model. By using the Spectral-Element Method on the Earth Simulator, this division has shown that it is possible to calculate synthetic seismograms accurate up to 3.5 sec and longer for realistic 3D Earth model. This technique was applied to the 2002 Denali fault earthquake in the United States (Fig.41). This study was awarded the 2003 Gordon Bell Prize for peak performance at the International Meeting for High-performance Computing, SC2003, which was held in Phoenix Arizona.

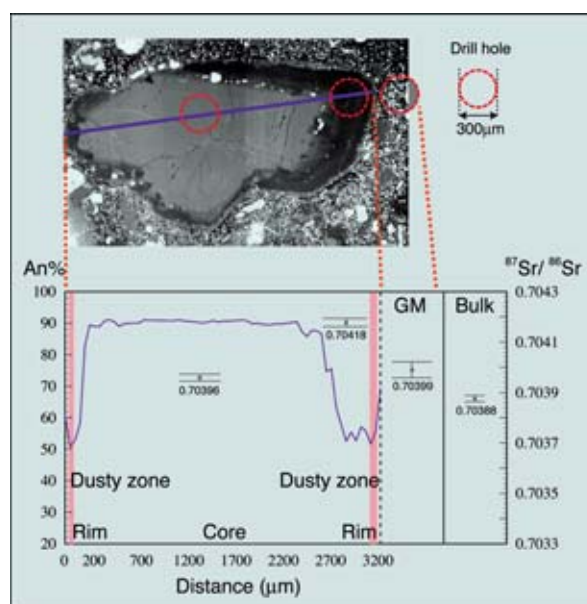


Fig.40 Sr-isotope Micro-Analysis.

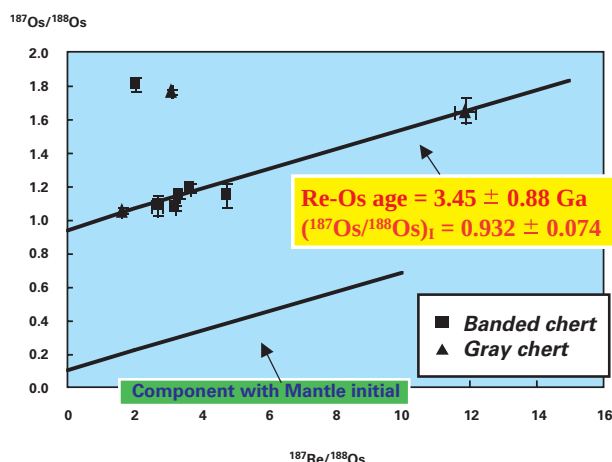


Fig.39 Re-Os isochron plot of Marble Bar cherts, Pilbara.

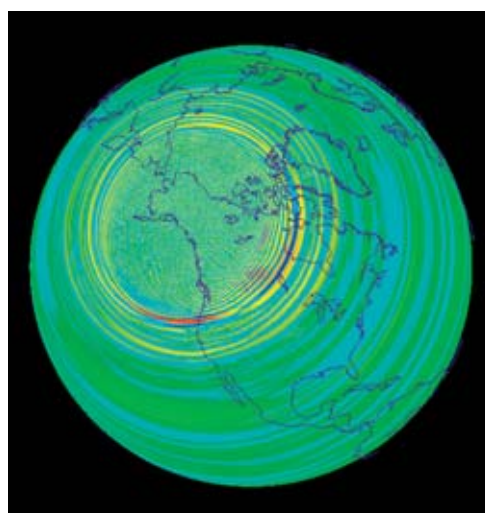


Fig.41 Snapshot of seismic wave propagation for the 2002 Denali fault earthquake in Alaska.

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2.2. Electromagnetic data distribution system

The Pacific Data Network Division developed a new unified electromagnetic field (EM) data distributing system, the service of which opened last August (service URL: <http://www.jamstec.go.jp/pacific21/index.html>). By using this system, data users can, in theory, access the EM data of several independent data centers using just one system. This reduces the effort previously needed to access data from each data center, thus increasing EM data usage.

From this year, multi data formats are supported, improving the usability of data by data users. In addition to a conventional OHP format, WDC 1-min, INTERMAGNET IMF V1.22, INTERMAGNET CD-ROM (supported by only simple search), IAGA2000, and IAGA2002 formats are supported, formats frequently used within various EM communities. When a data user requests to download data in one output format, a data server converts that data from the original OHP data format into the output format requested. The requested data files are then gzip-compressed and archived in a tar file. The data user can finally download a tar-archived data file via http port and can easily use it in the requested format.

The main feature of this development is the multi-thread processing involved in the conversion of data formats, processing that can drastically reduce the real-time process of data archive creation. We compared the performance of our system, the real-time process of data archive creation, with that of the EM data distributing

service by WDC Kyoto (<http://swdcwww.kugi.kyoto-u.ac.jp/index.html>), a service frequently used by EM data users. Our results indicate that our system is 2 to 5 times faster than that of WDC Kyoto, and that its performance is quite effective (Fig.42).

2.3. GPS database system

Network of Global Positioning System (GPS) stations function in the western Pacific region, as a part of the Ocean Hemisphere Project (OHP), ERI, University of Tokyo, to precisely measure plate motion and detect intraplate deformation. These stations, covering the area from the Kamchatka peninsula to Melanesia, have been operational since 1996. IFREE Center for Data and Sample Analysis developed, in collaboration with OHP, a database system for the distribution of this GPS data. A New Java enabled interface distributes this data through the internet using standard web-page viewers such as Microsoft Explorer or Netscape navigator. This system is called NINJA - New Interface for Networked JAVA Applications (Fig.43). Currently, DMC IFREE is distributing the data from 8 GPS stations located in the western Pacific region by this GPS NINJA system. This data can be accessed at <http://www.jamstec.go.jp/pacific21/>. GPS NINJA can use RINEX or Hatanaka formats to archive data. However, only the Hatanaka format is used for data distribution. The following information facilities also can be accessed from the web-browser: data availability or station changes by graphical representation, sta-

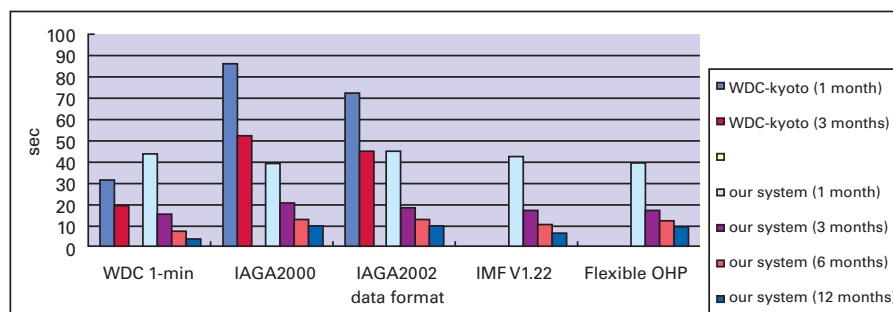


Fig.42 Measurement results of real time of data processing between data requests and download of various data formats, divided by number of months. The service of WDC-kyoto supports only WDC 1-min, IAGA 2000, and IAGA 2002 formats. The advanced search was used for our system.

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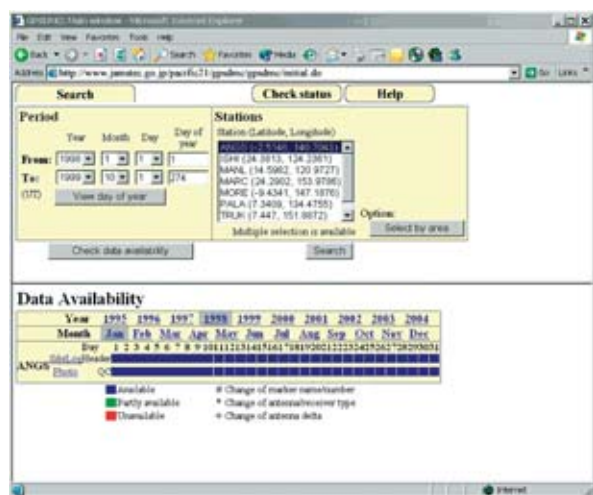


Fig.43 Interface of the GPS NINJA system allowing the analysis of data availability. The graphical interface shows additionally changes in the instrument and marker.

tion logs, station photographs, data quality checks as an output of the TEQC tool, and the data header. Data can be selected on a time basis, by station name or station location. Users can quickly evaluate data availability and quality without actually downloading the data. When selected, data can be downloaded in the background while the user further evaluates desired information or selects additional data for downloading.

The advanced features of GPS NINJA include the possibility of functioning while computer firewall protection is enabled. This feature is very important in protecting the data against unauthorized modification or damage. Both the data server and the dispatcher system can be protected by personal firewalls. The dispatcher system firewall has relaxed security measures to satisfy the functionality of the HTTP protocol between the client and the dispatcher while a separate firewall strictly protects the data server, increasing the security of the data. This system uses a tunneling algorithm, enabling Java RMI to transmit data between the data server and the dispatcher.

We are planning to implement GPS NINJA through the same mechanism in other international data centers in order to broaden the availability of GPS data and to speed up the process of international scientific data interchange.

3. Seismic Data Processing Division

3.1. Construction of geophysical database

To promote crustal studies at IFREE, the Seismic Data Processing Division is constructing a crustal structure database. A major objective of this database is to create an integrated model involving the different physical properties of rocks: density, magnetic susceptibility, velocity, reflectivity, acoustic impedance, resistivity, and so on (Fig.44). These physical properties can be derived by geophysical data that have been collected in structural studies using R/Vs Kairei and Kaiyo of JAMSTEC, as well as drillings by ODP and possibly drillings by IODP.

In 2003, we developed a data-publication web site in order to broadly disclose the data and to promote research in earth science. Currently available data for publication consist of seismic reflection and refraction data collected by R/Vs Kairei and Kaiyo of JAMSTEC. Those data are basically available after two years from each onboard survey. The publication-site is accessible on the home page of JAMSTEC through the Internet. This site also demonstrates several tectonic structural images clarified by seismic structural studies conducted since 1996.

The preparation of seismic reflection data is now complete and all data from 1996 to 2002 are available on the IFREE web site. The seismic refraction data obtained by Ocean Bottom Seismometers are now in the process of preparation. With regards to gravity and geomagnetic data, many data are collected along the

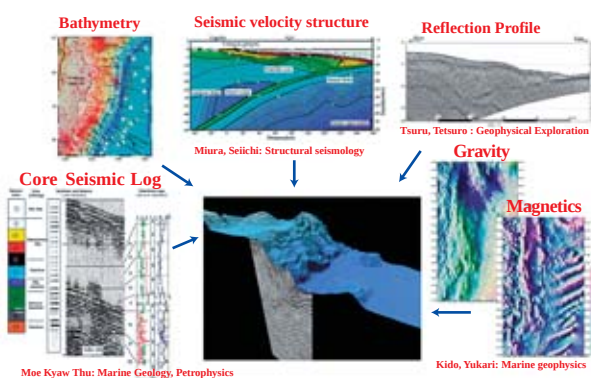


Fig.44 Integrated crustal structure model.

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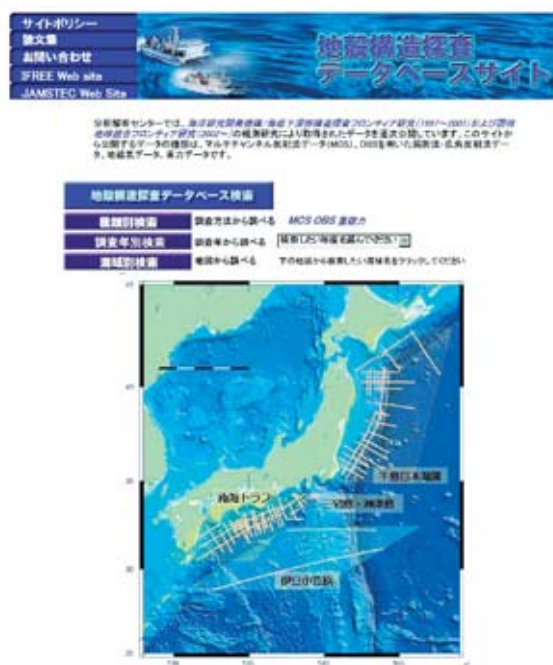


Fig.45 Data-publication web site of the crustal structure database.

2D seismic survey lines and some are collected spatially during the night-time survey. Therefore, we disclose the data that are spatially dense collected and other inventory information. According to a user's needs, the obtained data, such as raw data and a correction coefficient value, are also due to be offered. Furthermore, in addition to images, field data are available through the web site. Figure 45 shows the front page of the web site.

3.2. Seismic Data Analysis

The Seismic Data Processing Division conducts data processing of multi-channel seismic (MCS) reflection data obtained by IFREE's cruises. This Division also develops new techniques that facilitate efficient and sophisticated processing of the data used in crustal studies. In 2003, we started developing an integrated imaging method incorporating MCS and wide-angle reflection data in order to combine the advantage of each in subsurface imaging, hoping to more precisely figure out crustal structures. In general,

the MCS data can clearly delineate structures < 10 km in depth but are not appropriate in imaging of those > 10 km. On the other hand, the wide-angle seismic reflection data obtained by OBS have contrary characteristics in structural imaging. We have adopted the Kirchhoff integral method as the algorithm of prestack depth migration for integrated imaging. This method is often used in the migration processing of MCS data, however there are few application examples for that of wide-angle data.

Figure 46 shows an example of prestack depth migration applied to the wide-angle reflection data off Miyagi. The prestack depth migrated records of MCS data is overlaid on the top-right corner of the figure. The plate boundary in depths < 12 km is clearly visible on the MCS profile; it is however not recognized in depths > 12 km. On the other hand, the migrated records of the wide-angle data clearly demonstrate the plate boundary in 20-25 km depths. Interestingly, the depth where reflections become obscure on the wide-angle migrated records is nearly consistent with that of the upper limit of the rupture area of the interplate thrust earthquakes in the area.

Furthermore, we analyzed data in order to detect changes in seafloor topography and in the reflectivity of the plate boundary, which would have been caused by the Tokachi-oki earthquake on 26 September in 2003. Data were collected three years before and three months after the earthquake occurrence.

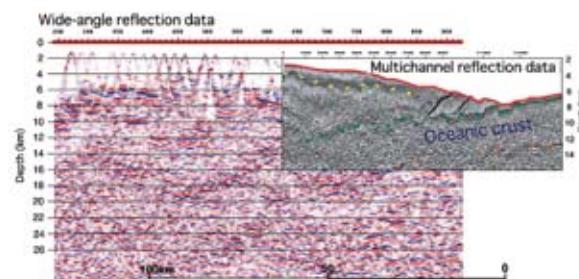


Fig.46 An example of prestack depth migration of wide-angle reflection data.

Research Activities

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Overall Activities and Events

Seven years has passed since Frontier Research System for Global Change (FRSGC) was established in October 1997. Since then, FRSGC has been conducting various research for elucidation and prediction of global change mechanisms. In 2001, before the end of the first five-year phase, external evaluation was conducted, after which five year mid-term plan was developed. In 2002, "Research Project for Sustainable Coexistence of Human, Nature, and the Earth" started under Ministry of Education, Culture, Sports, Science and Technology (MEXT)'s guideline. Three out of seven projects have been carried out by FRSGC. In addition, since starting of the Earth Simulator's operation in March 2003, many FRSGC researchers have started developing high resolution models in many subjects using the Earth Simulator.

There are two main events for the FY 2003. First is the appointment of Dr. Tatsushi Tokioka as Director of the Global Warming Research Program. The other event is that since June 2003, FRSGC became a domestic support body for Working Group 1 (WG1), toward the publication of the IPCC 4th Assessment Report in 2007 under the guidance of the Japan Meteorological Agency (JMA) and the MEXT. As every year, we have organized and participated in various international workshops and events. Followings are the summary of our activities for FY 2003.

1. Dr. Tatsushi Tokioka became a full time director of the Global Warming Research Program

Dr. Tatsushi Tokioka was appointed as Director of the Global Warming Research Program.

Dr. Taroh Matsuno, Director-General and Director of the Integrated Modeling Research Program, has served as Director of the Global Warming Research Program since November 2001, following the return of Dr. Shukuro Manabe to the United States in November 2001 after serving as director of the program since its establishment in 1997. Until 1 April 2003, Dr. Tokioka was Director of the Meteorological College. One example of his many notable research achievements is the development of an atmospheric general circulation model (AGCM). He served in an international role on the Intergovernmental Panel on Climate Change (IPCC).

2. FRSGC became a domestic support body for Working Group 1 (WG1) for the publication of the IPCC 4th Assessment Report

In order to make contribution for the publication of IPCC 4th assessment report in 2007, MEXT has arranged a domestic support and corporation body at Frontier promotion office of JAMSTEC. The purpose

of this support body is to promote coordination and corporation among research institutions and researchers conducting studies on global warming and climate change prediction. FRSGC/JAMSTEC was assigned as a focal point of this support body and has been promoting support and corporative activities accordingly. After IPCC domestic networking group was officially established, FRSGC started working as a domestic support body for Working Group 1 (WG1).

As a domestic support body of the IPCC WG1, a secretariat was established having researchers within the university and institutions, and operating a planning and organization of supportive activities. In addition, the support body has a role to give advices and opinions from researchers' point of view to the JMA and the MEXT, organizations in charge of IPCC/WG1. Some main works of the domestic support body of the IPCC WG1 includes handling of international conferences, studies on progress on domestic research, studies on international trends, organizations of workshops, and summary of related information, and so forth.

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3. Meetings for International Research Cooperation

(a) CAMP-FRSGC Collaborative Workshops

Two workshops were held at the Yokohama Institute for Earth Sciences on June 10 and November 5 of 2003 to discuss the collaboration between the CAMP (Climate of Arctic: Modeling and Processes, sponsored by NSF) and FRSGC. The first workshop was held on June 10, 2003 in order to identify possible collaborative projects and coordination mechanisms among various institutions. A particular focus of the workshop was collaboration on projects that make use of the Earth Simulator. The second workshop was held on November 5. The particular focus was on examining the progress in the Arctic processes using global model simulations. The participants made some important recommendations on how to improve and digest the modeling of the Arctic processes, such as the Atlantic Layer and dense water formation. Collaboration between IARC and FRSGC will continue with the ultimate goal being the use of a coupled model to address the role of ice/ocean anomalies in decadal-scale oscillation of the high-latitude atmosphere-ocean system.

(b) "Air Pollution in Asia and Our Life"

–UNEP ABC Open Public Symposium–

The Atmospheric Brown Cloud Asia (ABC) Open Public Symposium was held on September 23rd at U Thant International Hall/ United Nations University. The symposium titled: "Air Pollution in Asia and Our Life" was open to the general public and about 150 people joined this opportunity. In the opening, there were some words from the MEXT and JAMSTEC/ FRSGC as an introduction. three guest speakers for this special event were invited: Dr. S.C. Lonergan from United Nations Environment Programme (UNEP), Dr. V. Ramanathan from the University of California (also the co-chair of the ABC Science Team), and Dr. P. Crutzen, the winner of the 1995 Noble Prize for chemistry and also the former director of the Max-Planck Institute for Chemistry, Atmospheric Chemistry Division. They made presentations about "Air pollution, economic

activity and society in a Post-Johannesburg world", "Atmospheric Brown Clouds: S. Asian, Tropical & Global Impacts", and "The role of the tropics in atmospheric chemistry and climate" respectively.

After a break the panel discussion was conducted. Starting with Dr. Teruyuki Nakajima (CCSR/ Tokyo University)'s talk concerning "The influence of human activity to the climate", some discussions about the dilemma of development, economical growth and the air pollution, environment and poverty were made. In this discussion, it was reached a point that in order to cope with this problem, it is necessary to make a change in people's minds, and to do so, educating young people and also distributing information would be a very important factor. Some suggested the necessity of holding a symposium like this in China or in India too.

(c) FRSGC/FORSGC Symposium 2004: Seeking for the Knowledge on Extreme Weather

–Challenge for the Climate Change Prediction–

On 14th January 2004, in order to introduce our recent research activities for further understanding on climate change prediction, FRSGC and FORSGC jointly organize the above symposium at the National Museum of Emerging Science and Innovation in Tokyo, Japan.

Dr. Mohri, Director of the Museum emphasized difficulties of the climate change prediction, and encouraged us to further work on it. After Director Mohri's foreword, each presenter explained 1) elements to decide climate of Japan, 2) monsoon system, 3) role of the ocean to the climate, 4) atmospheric system respectively. There, system of the extreme weather events and effects of various climate systems on climate in Japan were introduced along with the recent research findings.

Then, the guest speaker Mr. Iwaya, weather caster of the Fuji Television's program "Super News Weekend", explained in detail the view points of media and weather forecaster about the climate change

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prediction. In his presentation, he insisted the timely and smooth information delivery of our research outputs to the public.

It is hoped that through this symposium, complexity of climate system and long-term weather prediction have been understood to the wide range of people.

(d) Workshop on Global Warming Prediction Research

From 18–19th March 2004, above workshop was held at Mahoroba Mines in Miura, Japan. The workshop was organized so that researchers in Japan would discuss the current progress and concerns regarding the research on global warming at the timing when various activities for IPCC-AR4 started. One of the main focuses of this workshop is to work in detail about the methods to producing outstanding output regarding the numerical experiments using the world's fastest vector parallel computer, the Earth Simulator. This workshop was organized as part of the supporting and cooperating activities for IPCC AR4, working under the MEXT's guidance. Current situation and future tasks of various numerical models on global warming experience were introduced during the mid-term report of the global warming prediction. During the discussion about important issues on global warming prediction, many research subjects were introduced as large elements of uncertainties, such as turbulent diffusion in the ocean, sea ice, air turbulence at atmospheric boundary layers, upgrading of various physical process parameterization including clouds. In addition, various opinions were exchanged regarding the observational and process studies on carbon cycles on land, ocean, and the atmosphere. Current progress and future plan of Integrated Earth System Model, currently developed at FRSGC was also shared.

(e) FRSGC/FORSGC Annual Symposium 2004

On 23–24 March 2004, FRSGC and FORSGC jointly held the Annual Symposium 2004 at Miyoshi Memorial Auditorium, JAMSTEC Yokohama Institute for Earth Sciences. Based upon the results of the

questionnaires of our past annual symposiums, the symposium this year had divided into two to make each of them more substantial and productive; one for public (held on 14 January 2004) and the other for researchers. This Symposium was about the latter one, and it aimed to promote the further cross-cutting understandings on research accomplishments among researchers of FRSGC/FORSGC by providing a place to exchange information, and to discuss the direction of our future research plans after the JAMSTEC's transformation to an independent administrative institute from 1 April 2004.

More than 100 participants including not only FRSGC/FORSGC researchers but also many participants outside JAMSTEC, such as Meteorological Research Institute, Communications Research Laboratory, etc., joined the Symposium, and had actively exchanges of opinions among them.

4. Participation in International Events

(a) 23rd General Assembly of the International Union of Geodesy and Geophysics (IUGG2003)

The 23rd General Assembly of the International Union of Geodesy and Geophysics (IUGG2003) was held from 30 June to 11 July in Sapporo, Japan. It was a first time that the Assembly was held in Asia, and more than 5,000 participants from about 100 countries joined the Assembly.

As JAMSTEC was one of the main sponsors of the Assembly, FRSGC made an active contribution including participation of more than 100 researchers. Furthermore, in the JAMSTEC's exhibition booth with two main themes (Toward the Prediction of Global Change, Toward the Monitoring and Prediction of Crustal Deformation and Related Hazards), we have introduced our research activities under the theme of "Toward the Prediction of Global Change" along with the FORSGC, Earth Simulator Center and the Ocean Observation and Research Department. The exhibition booth was set parallel to the sessions, and more than 50 related companies and organizations participated to

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promote communication among researchers and technicians, research development, and release of research outputs to the world.

More than 1,000 people visited our exhibition booth. Among them, there were many specialists, friends of FRSGC who already know our research activities and researchers themselves. Moreover, we had several offers for joint researches with other organizations, and many people requested to have direct contacts with specific researchers. We thus strongly felt the need for returns of research results to the society, as well as research collaboration in many fields. Since we were able to introduce our newest research outputs to the various specialists from all over the world, we successfully disseminated our activities for the further promotion of our researches.

(b) Intergovernmental Panel on Climate Change (IPCC) Twenty-first Plenary Session and Working Group I-9th Session

IPCC convened its twenty first plenary session in Vienna, Austria from 3 to 7 November. 126 countries, 13 international organizations and non-governmental organizations (NGOs) for a total of 485 people participated in the session. Many ministries and agencies in Japan also attended it. From FRSGC, Dr. Tatsushi Tokioka, Director of the Global Warming Research Program (one of the lead authors of the First Assessment Report) and Dr. Hiroki Kondo, Research Supervisor of the Integrated Modeling Research Program (one of the Japan's representative of the Third Assessment Report) also joined in the session. Both of them currently make research activities to contribute to the AR4.

The plenary session was aimed to discuss outlines and guidelines of various reports, procedure for the election of a new IPCC bureau, work schedule and budget for AR4. During the session, each working group held working group session to discuss mainly outline of each working group report. The result was reported in the last day of the plenary session. As one

of the key issue of the twenty first session, the pros and cons of preparation of the synthesis report were actively discussed.

5. Award

Not only domestic awards, but also FRSGC received various international honors. The American Meteorological Society (AMS), one of the leading professional societies for atmospheric and related sciences in the United States, bestows the prestigious life-long title to a few scientists who have made the outstanding accomplishment on researches on atmosphere and ocean, as well as meteorology-related researches, which contributed greatly to the development of meteorology. Taroh Matsuno, Director-General was selected as a Honorary Member of the AMS. Furthermore, Dr. Toshio Yamagata, Director of the Climate Variations Research Program received Sverdrup Gold Medal "for his outstanding accomplishments in the study of ocean and climate dynamics, especially with respect to El Niño and air-sea interaction over the Indian Ocean" from AMS. Sverdrup Gold Medal is one of the AMS' highest honors, which is given to researchers who made outstanding contributions to the scientific knowledge of interactions between the oceans and the atmosphere. Within Japan, Dr. Michio Kawamiya, Sub-Leader of Integrated Modeling Research Program received the 2003 Okada Prize from the Oceanographic Society of Japan (OSJ) for the subject "Study on lower trophic production in the North Pacific by numerical ecosystem modeling". Other FRSGC participants also received various honors both domestically and internationally.

Research Program

1. Climate Variations Research Program

The Climate Variations Research Program (CVRP) studies climate variations from seasons to decades and related oceanic phenomena in the Asia-Pacific sector including the Indian Ocean, polar and subpolar oceans. To understand fundamental processes of those climate

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variations, our research is conducted using ocean and atmosphere models of various degrees of freedom as well as various analysis methods. We also conduct predictability and application studies on the influence of the global climate variability upon regional atmospheric and oceanic phenomena. Main accomplishments in FY 2003 are summarized in the following.

a. Model Group

a-1. Climate Variability in the Tropical and Mid-latitude Regions

The process studies in the Indo-Pacific sector are continued using a coupled general circulation model (CGCM) and observational/reanalysis data. The SINTEX-F1 CGCM developed under the EU-Japan collaborative framework was successfully integrated for 220 years on the Earth Simulator. Results from the last 200 years show model's remarkable skill in simulating ocean-atmosphere conditions related to the Indian Ocean Dipole (IOD) and El Niño Southern Oscillation (ENSO). As in the observation, more than 70% of the simulated IOD events are not accompanied by ENSO in the Pacific. Composite and partial correlation analyses of the model results confirmed the observed independent nature of the IOD. In addition, it turned out that the subsurface equatorial long Rossby waves, which are associated with the IOD rather than the ENSO, play a major role in strengthening Sea Surface Temperature (SST) anomalies in the central and western parts of the basin during the positive IOD events. The ENSO influence is only apparent south of 100S.

The seasonal structure of the barrier layer in the Indian Ocean simulated by SINTEX-F1 is found to be in good agreement with observation. It is also found that the barrier layer variability is controlled by intraseasonal and interannual variability of the Wyrtki jet off Sumatra and that equatorial shallow salinity stratification in the IOD years has a positive impact on the dipole amplitude.

The results of the SINTEX-F1 and a series of the experiments using the stand-alone FrAM AGCM are

used to clarify the influences of the IOD events on the global climate variability. The results indicate the large impact on the East African short rains and the Australian rainfall during the austral winter as well as the effects on the wide area between Europe and the southeastern/eastern Asian countries.

The SINTEX-F1 also well simulated the variability in the Pacific on various time scales. In a collaborative research with researchers from the University of Tokyo, it is found that the salient features of annual ENSO are reproduced by the model; such as the classical El Niño that triggers an air-sea interaction in the eastern equatorial Pacific, a westward expansion of sea surface temperature anomaly, and a westward propagation of sea surface height anomaly along 5°N. The results also demonstrate that the South Pacific subsurface temperature acts as an external thermal source to discharge/recharge the tropical ocean, thus, inducing decadal fluctuations of the ENSO-like phenomenon. Besides, the model reproduces a high lagged-correlation between the global land surface temperature and the decadal Niño3 SST. Despite the model biases, this suggests a potential prediction skill of the global warming based on the ENSO-like decadal variation. A non-hydrostatic model for the global domain is developed and applied to a study of the water exchange between the Red Sea and the Indian Ocean. The model successfully reproduced the seasonal variation of the outflow of the dense Red Sea water over the sill located at the exit of the Red Sea. The model will be used as an important component of the global climate model to reproduce the local processes affecting the basin-scale ocean circulations.

a-2. Japan Coastal Ocean Predictability Experiment (JCOPE)

For better understanding of the Kuroshio variability and its predictability south of Japan, we have developed a Japan Coastal Ocean Predictability Experiment system, which consists of a high-resolution nested-grid

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ocean model of the North Pacific and a relatively simple assimilation scheme that incorporates the observed data into the model. In FY 2003, we have achieved near-operational forecasting of ocean conditions around Japan by assimilating almost all available data: sea surface height (SSH) anomaly, SST, and temperature/salinity profiles from 0 m to 400 m depth, including the data obtained by ARGO floats. It is shown that the system has a forecasting skill of about one month for the Kuroshio path variation south of Japan during the operational experiment for the year of 2003. In particular, the system has successfully predicted a small meander propagating eastward along the Kuroshio south of Japan during March-May, 2003 (figure 1).

a-3. Collaboration with the Earth Simulator Center

As a continuation of a 50-year integration of the OGCM for the Earth Simulator (OFES) driven by a climatological monthly forcings conducted during the last year, we have successfully finished a hindcast simulation from 1950 to 2003 with the daily-mean NCEP/NCAR reanalysis data as the forcings. The extensive analysis of the output from the fifty-year climatological experiment and the preliminary analysis of the hindcast results are carried out. Comparison of the results from the climatological run and the hindcast simulation clearly shows that meso-scale eddy activities in the latter simulation become more realistic than those in the former. In particular, we notice that

the global distribution of SSH variability and the frequency of eddy shedding at the loop current are much improved in the hindcast simulation. The ENSO and the IOD phenomena are well captured in the simulation as the basic climate variability at the interannual time-scale. The degree of the coincidence of the timing and amplitude of Niño3 SST index for the ENSO and the dipole mode index for the IOD are more than expected. The OFES results also show that the subsurface variability and wave propagation in the Indian Ocean play the important role in the evolution and the phase reversal of the IOD events as suggested in the SINTEX-F1 results.

In addition, the development of another high-resolution model Princeton Ocean Model for the Earth Simulator (PFES) has finished, and a test integration with the climatological forcings is underway.

b. Climate Diagnostics Group

b-1. Variability in the Extratropical Atmosphere

Through our collaboration with Columbia University and our predictability group, we have extended our analysis to an interannual seesaw between the intensities of the Aleutian and Icelandic Lows (AIS) simulated in the ECHAM4 AGCM. In 24-member hindcast simulations for 50 recent years, the AIS forms in each of the external and internal modes of variability through eastward propagation of a stationary Rossby wave train emanating from the AL anomalies. Our particular

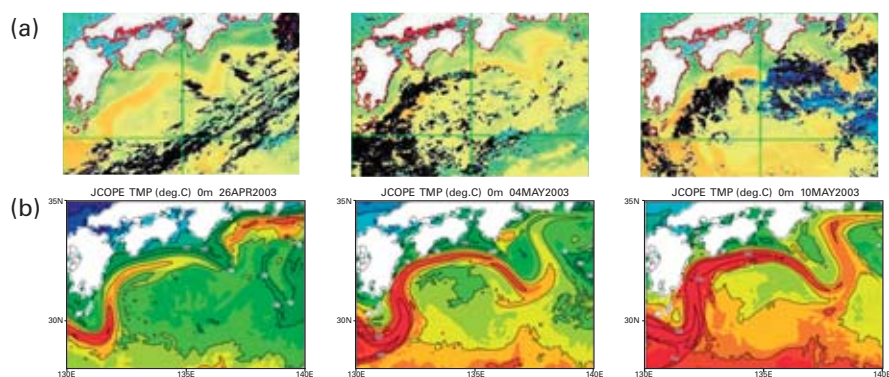


Fig. 1 Snapshots of sea surface temperature from 26 Apr., 2003 to 9 May, 2003. (a) Observation from the NOAA satellites provided by the Japan Coast Guard and (b) forecasting results of the JCOPE system initialized on 16 Apr., 2003.

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emphasis is placed on the AIS-based predictability of late-winter anomalies over the Euro-Atlantic sector. The midwinter development of North Pacific anomalies is found to be a necessary but not sufficient condition for the AIS formation. The persistence of the Pacific anomalies beyond one month appears to augment the probability of the AIS formation (figure 2), by sustaining the wave-activity emanation.

For deepening our understanding of the variability of the East Asian winter monsoon, we are also studying dynamics of the Siberian High. Through a composite analysis of the observed data, we have found, at every location over Siberia, a surface high is found

to amplify associated with a formation of a blocking ridge aloft. The blocking formation is found quite different between the east and west of the climatological upper-level trough over the Far East. To the west, a blocking ridge forms in association with a wave train propagating eastward across the Eurasian continent, whereas to the east, it forms in association with a westward extension of anticyclone anomalies from the North Pacific. In either type of blocking formation, the surface high amplifies through enhanced cold advection by anomalous surface wind induced by the blocking.

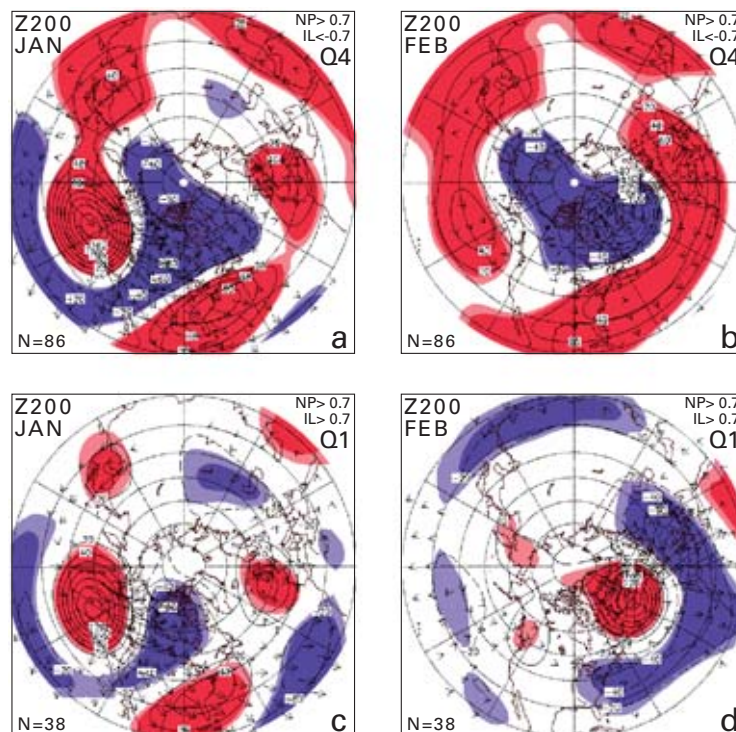


Fig. 2 Composite maps for Z_{200} (m) for (a) January and (b) February in the internal component of variability, for the case of formation of the positive phase of the AIS (i.e., positive Z_{200} anomalies over the North Pacific in January and negative IL anomalies over the North Atlantic in February). (c) and (d): As in (a) and (b), respectively, but for composite maps based for the case of formation of in-phase relation between the AL and IL (i.e., positive Z_{200} anomalies over the North Pacific in January and positive IL anomalies in February). Areas of light and heavy shading indicate where the difference from the ensemble mean is significant at the 95% and 99% confidence levels, respectively. Arrows indicate the horizontal component of the wave activity flux ($\text{m}^2 \text{s}^{-2}$; scaled as at the bottom) formulated by Takaya and Nakamura (2001, J. Atmos. Sci.). Note that the Pacific anomalies are more persistent during the AIS formation than in the formation of the in-phase anomalies. Based on Honda et al. (2004, submitted to J. Climate).

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b-2. Variability in the Extratropical Coupled Atmosphere-Ocean System

The climate diagnostic group has been analyzing a high-resolution marine observation data archive and high-resolution OGCM output including that of OFES, to examine the mechanism of decadal oceanic variability inherent to the midlatitude North Pacific and its coupling with the extratropical atmospheric variability. We have revealed that decadal-scale SST anomalies observed in the North Pacific subarctic frontal zone control the anomalous heat release to the atmosphere. We have also found that high-resolution OGCM, including OFES, can reproduce the decadal variability reasonably well, with respect, for example, to the concentration of thermal anomalies into the subarctic and Kuroshio Extension frontal zones.

b-3. Collaboration with the Earth Simulator Center (ESC)

As our continuous contribution to ultra-high resolution simulations of the global atmosphere with AFES, we have carried out ensemble hindcast experiments with 20-km horizontal resolution (T639) and 48 vertical levels for reproducing upper-level cutoff low over Europe in August 2002 and for rapid cyclogenesis in November 2002 over the Northeastern Atlantic. Despite the lack of sophisticated data assimilation, the model can predict the target cyclogenesis reasonably well in each of the cases. Filamentation of high-PV air associated with breaking of a propagating Rossby wave train appears to be of particular importance in triggering the cyclogenesis. We have also been contributing to the development of a high-performance coupled model CFES in the ESC.

c. Predictability Research Group

c-1. High Resolution Predictability Experiment: Impact of Emanuel Scheme on the Simulated Precipitation Field

Some of the most important processes that govern the climate system are moist convection and associat-

ed precipitation formation. Unfortunately, currently available computers cannot resolve these processes in the context of the global climate simulation, requiring parametric representations of these processes. Most of the parameterization schemes for moist convection in climate models are extremely crude and are not based on solid physical theories, rendering climate changes predicted by such models essentially meaningless. A relatively new scheme developed by Kerry Emanuel is based on a more physical ground and has been implemented in an AGCM, with a slight modification that allows the scheme to represent the effect of the background flow shear on some microphysical parameters. With the new scheme, the AGCM has generated more realistic precipitation patterns overall, particularly when the horizontal resolution is high.

c-2. Statistical Characteristics of the Earth Climate System as a Nonlinear Forced Dissipative One

In order to understand statistical characteristics of the climate system, relative stability among multiple steady states of the oceanic thermohaline circulation is investigated with GCM experiments. It is found that the thermohaline circulation tends to change its state to a state with a higher supply rate of available energy when the system is subject to small perturbations. This maximisation of the available energy supply, which is frequently observed in a variety of non-linear dissipative systems, is shown to be explained by positive feedback growth of perturbations that feed on available energy supplied from the surrounding system.

c-3. Potential Predictability of the Extra-tropical Atmosphere

The seasonal predictability of the atmosphere is investigated with an ensemble of 50-year AGCM Atmospheric Model Intercomparison Project (AMIP) like simulations. It has been known that the potential predictability, which is defined as the ratio of the external variance to the total variance, is low in the extra-tropics, compared with that in the tropics. Our

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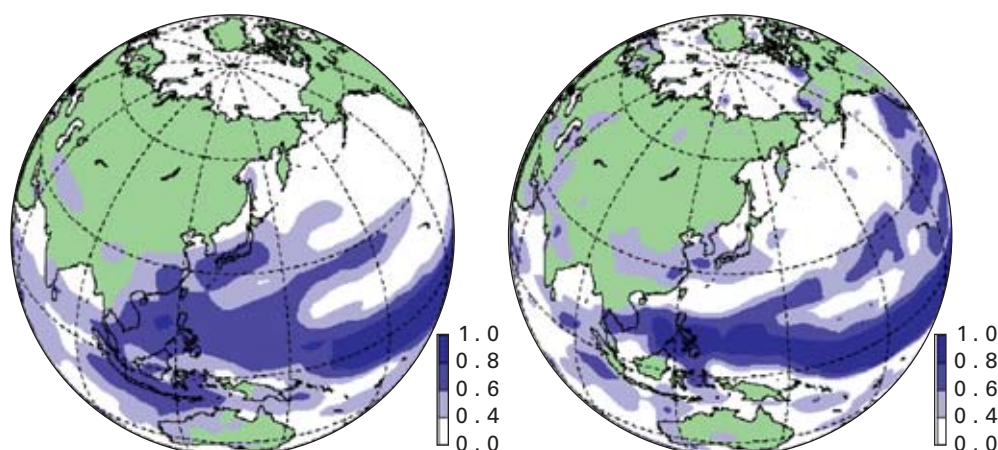


Fig. 3 Potential predictability of wintertime precipitation (left panel) and correlation coefficients between the interannual variability of the observed wintertime precipitation and the simulated one for a period of 1980-2000 (right panel).

results show a relatively high predictability around the area of South Japan in winter (figure 3). It is found that the interannual variability of the tropical SST contributes to this high predictability.

2. Hydrological Cycle Research Program

Very essential and urgent issues for us living in monsoon Asia may be how the hydrological cycle, including precipitation, evaporation and land-surface hydrological processes change and vary due to anthropogenic and other external forcings (e.g., ENSO, NAO etc). How regional and river basin scale hydro-climate and water resources vary associated with these large-scale forcings is also an important issue.

Based upon the comprehensive hydro-meteorological data and modeling, we will target these issues and to provide physical basis for the prediction of hydrological parameters on a seasonal through to interannual time-scale.

a. Group for Large-scale Hydrological Processes

This group focuses on the impact of climate change and variability on continental and regional scale hydrological cycle and their feedbacks to climate variability, based on global scale reanalysis data, satellite-remote sensing data and in-situ measurement data. Validation of hydrological processes obtained from

simulations by General Circulation Models (GCM) and regional climate models is also being carried out by using observational data mentioned above. In FY 2003, the following studies were conducted.

a-1. Variations of Global, Continental, and Regional-scale Energy and Water Cycle

Continental-scale surface energy and water budgets were compared and evaluated particularly over Eurasian region by using GAME reanalysis data, GAME-AAN surface in-situ data and satellite-based data for the recent several years. The results showed that precipitation from GAME reanalysis and the AAN in-situ data are generally more powerful and more effective for estimating seasonal-scale water and energy budgets over this region.

The east-west seesaw of summer-time surface and atmospheric water balance was found as a continental-scale dipole mode with 6 to 8 year period (Fukutomi et al., 2003). We further demonstrated that this seesaw is associated with the seasonal storm track activities accompanied by a quasi-stationary planetary to synoptic scale wave variability over the continent, as shown in figure 4. The structure of storm track activities and pressure wave patterns have also strongly suggested to play an important role in the feedbacks and mechanisms of this seesaw-type continental-scale oscillation.

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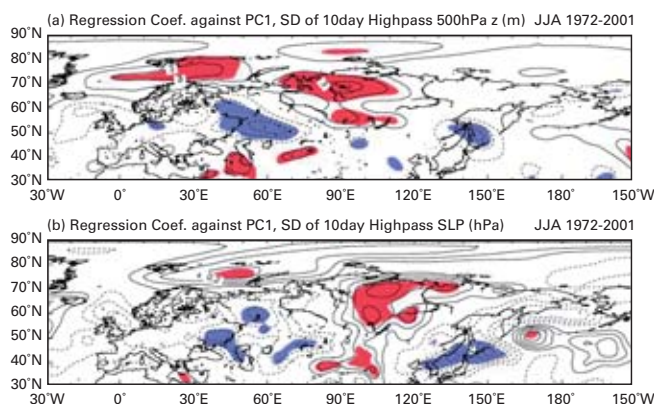


Fig. 4 (a) regression coefficient of standard deviation of 10-day high-pass filtered 500 hPa height with the east-west seesaw mode for JJA 1972-2001. Solid (dashed) contours show positive (negative) values. Zero contours are omitted. Contour interval is 1 m. Shaded regions show statistically significant at 95% level. (b) Same as Figure 4 (a) except for sea level pressure with 0.05 hPa interval. (Fukutomi et al., 2004).

a-2. Land Surface (snowcover, soil moisture, vegetation)-atmosphere Interaction and Climate Variability over Eurasia

The sub-decadal covariability relationship between continental snow cover extent and the dominant atmospheric circulation modes, e.g., the Arctic Oscillation (AO) or the North Atlantic Oscillation (NAO), were explored for the period 1971-2001. On the seasonal time scale, the winter AO is found to be significantly correlated with the preceding autumn Eurasian snow cover (SNC) throughout the observed period. Consistent with this finding, SNC variability led the AO variability on the sub-decadal time scale in the early half of the record. However, starting in the mid 1980s, the AO and SNC vary in phase as shown in Figure 5. Analyses of the seasonal relationship and persistence of snow and atmospheric variables illustrate a phase shift in the sub-decadal variability between the AO and SNC due to the loss of autumn-winter SNC autocorrelation, replaced by a significant winter-spring persistence and the emergence of a concurrent SNC-AO connection in winter and spring. Similar analysis shows that the sub-decadal NAO variation is mostly described by the fluctuation in summer North American snow cover.

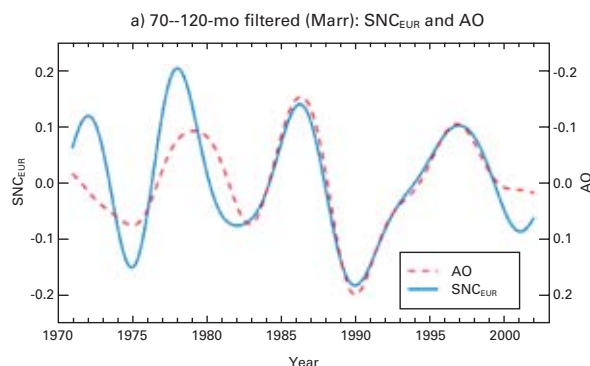


Fig. 5 70-120 month bandpass filtered monthly anomaly time series of Eurasian snow cover (solid; SNC) and the AO (dashed; scale at right). (Saito et al., 2004)

a-3. Climate Variability and Energy and Hydrological Processes in China

Xu and Haginoya (2001) used a multi-layer soil model with input data derived from routine meteorological data to estimate heat and water balances over Tibet in 1997. The same method was applied to estimate heat and water balances for 1998 and the results of these two years were compared. GAME-Tibet intensive observation period (IOP) data were used to verify calculation results. Observed longwave radiation flux agrees well with calculations. Surface air temperatures were higher in 1998 than in 1997. Western Tibet was drier, and eastern Tibet was wetter, in 1998 than in 1997. Evaporation (E) was small (less than 100 mm/year) in western Tibet and large (about 400 mm/year) in eastern

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Tibet. The wetness index (WI) distribution agrees well with the distribution of the normalized difference vegetation index (NDVI) from satellite data. Thus, the datasets of daily and seasonal variations of heat and water balances were established for 1997 and 1998.

The surface radiation balance over China for the recent 30 years (1971-2000) was estimated using the routine meteorological station data. The sunshine duration data were used to estimate downward surface solar and long-wave radiation fluxes. Downward surface long-wave radiation flux was estimated from the surface air humidity, temperature, and calculated downward surface solar radiation. The influence of topography or high altitude was also considered. Calculations were checked against in situ observations. Daily mean values of downward surface solar and long-wave radiation fluxes ranged from 140-240 W/m² and 220-380 W/m², respectively. Decreases occurred only at Hotan and Lushi. Surface solar radiation decreased in large cities. Surface air temperature has increased at all 31 stations over the past 30 years; vapor pressure has increased at most stations. The estimated solar radiation was compared to a satellite-based surface radiation budget (SRB) dataset. The two datasets show good agreement in rural areas. In large cities, the estimated surface solar radiation is less than the SRB data. Over the Tibetan Plateau, the estimated data have greater values than do the SRB

data. These systematic differences between the estimated and the satellite-observed data suggest the impact of urbanization and anthropogenic change of atmospheric turbidity on the radiation balance in China.

b. The Hydrological Process on Land Group

Hydrological Process on Land Group are clarifying the detailed processes of the energy and water cycle as well as modeling the entire processes of the water cycle over the land, in order to predict future water resources in various basins in Asian continent; namely, basins located in the regions underlain by permafrost, whose variation mechanisms still remain unclear, basins with biospheres (i.e. tropical rain forests, tropical monsoon forests etc), and those in the mid-latitudinal arid zones in Asia.

Hydrological model studies were carried out for Selenge River basin, Mongolia. This basin is located in a semi-arid region and basin area is about 280,000 km², while mean annual precipitation is only 300 mm. The hydrological model was able to simulate the hydrographs at four hydrological stations of the Selenge River from 1988 to 1992. Both of the seasonal and year-to-year variations of the estimated discharge agree well with the observation.

Year-to-year variation of the snow cover in Japan are also investigated. Figure 6 shows the difference in winter precipitation (from December to March) between in

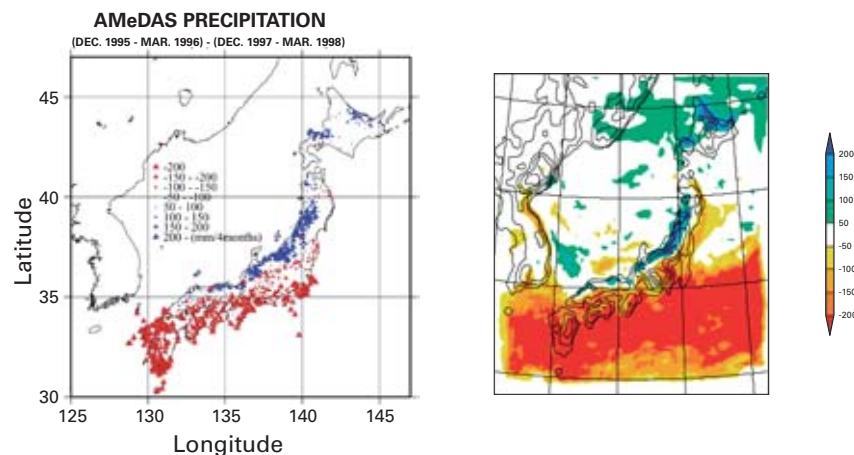


Fig. 6 (a) Difference in precipitation between winters (DJFM) in 1995/96 and 97/98, which are a typical heavy snowfall and a light snowfall winter, respectively. (b) Same as (a), but simulated precipitation using a cloud resolved regional climate model. The model simulates the difference between two years correctly.

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1995/96 (one of typical heavy snow year) and in 1997/98 (less snow year). The left panel (a) of Figure 6 indicates the difference in observed precipitation at Japan Meteorological Agency (JMA)-AMeDAS sites. The right panel (b) is that of calculated precipitation simulated by hi-resolved Regional Atmospheric Modeling System (RAMS). The model simulates the difference correctly in distribution of precipitation between two years. It has been well known that the precipitation including snowfall in the mountainous region strongly depends on the elevation of the rain gauges. The rain gauges almost always locate in a narrow valley in the mountainous regions because of the limitation of mountainous. These facts make difficult to estimate the total water resources including snow cover over the mountains surface. The high spatial resolved climate model combined with a land surface model helps not only to estimate precipitation and snow cover in the mountain areas but also to predict future variation of water resources after the global warming.

c. Clouds and Precipitation Process Group

c-1. Improvement of Parameterization Schemes of

Microphysics and Radiative Properties of Clouds

We developed and improved our hybrid (Lagrangian and Eulerian framework) microphysical cloud model to advance the study of the aerosol-cloud interaction, that is, indirect effect of aerosols. The proposed parameterizations are used in GCM models to evaluate the indirect effect of aerosols.

c-2. Development of 3D-Radiation Model

We are developing a new radiative transfer model so as to take into 3D structure of clouds, which does not require horizontally homogeneous assumption (figure 4). A generalization ability of this method was examined, and a high performance was demonstrated.

c-3. Improvement of Cloud-resolving Models and Numerical Experiments

Our mesoscale-convection-resolving model

(MCRM) was able to simulate rainfall distributions and other features of the typhoon much better than other models. Although it is desirable to improve the MCRM further in coming years, it appears that the performance of the model has nearly attained a reasonable level with respect to parameterization (or implicit representation) of the effects of cumulus convection which is of the subgrid-scale in a model having horizontal grid sizes of 5~20 km.

c-4. Understanding the Physical Processes of Mesoscale Convective Systems

We tried to simulate meso-scale cloud systems that develop within cold-air outflows, Baiu frontal system and typhoon system. For simulation of these cloud systems, we have been developing a cloud resolving model, "CReSS". Since parallel computation and huge memory are necessary for this type of simulation, CReSS is optimized for the Earth Simulator and run on it. Since the Earth Simulator enabled us to perform wide domain size ($\sim 1000 \text{ km} \times 1000 \text{ km}$) with small grid size (0.5 km – 1 km), we successfully simulated the hierarchical structure and interactions between multi-scale disturbances of the organized meso-scale cloud systems (figure 7).

c-5. Cooperation with IARC

We joined the Arctic cruise of the research vessel "MIRAI" in 1999, 2000, and 2002. Main purposes of our study are to understand formation and organization processes of marine boundary layer clouds and mesoscale cloud systems, precipitation mechanism, aerosol-cloud interaction, and to make ground truth data of many remote sensors. Usually sensible and latent heat fluxes near the sea surface were very small. However, both upward turbulent heat fluxes and downward CO_2 flux increased very large when the cold air outbreak occurred. Using a 95 GHz cloud-radar and a C-band Doppler radar, we studied mesoscale features of precipitation cloud systems and vertical distribution of precipitation over the Arctic Ocean.

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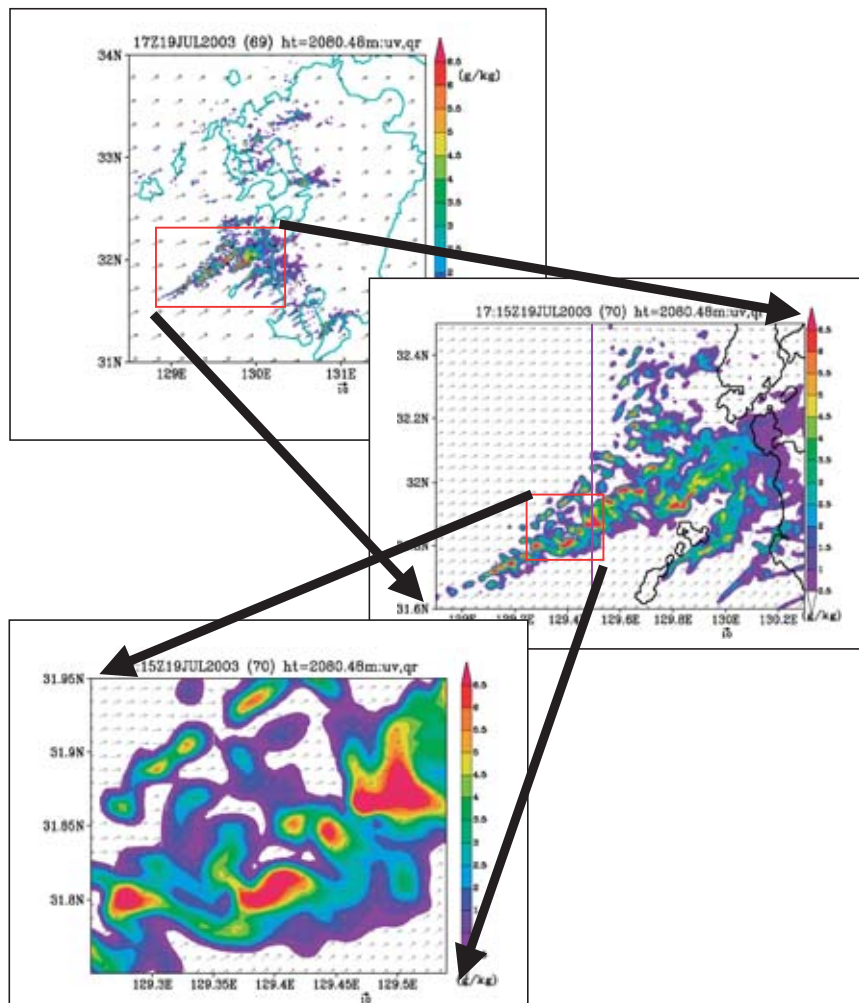


Fig. 7 Multi-scale structures of a rainband simulated by CreSS.

3. Global Warming Research Program

The main goal of the global warming research program is the projection and predictive understanding of global warming. The program consists of three research group projects, which conduct study on global warming, carbon cycle and paleoclimate. One of the topics of the program during the last fiscal year is that the carbon cycle group obtained the first successful results of a global biogeochemical oceanic general circulation model coupled with an ecosystem model. The model will be applied for many studies in future including marine carbon cycle problem, simulation of marine ecosystems and relationship between climate changes and changes in marine ecosystems. Another topic is numerical experiments on the response of the

Atlantic thermohaline circulation (THC) to higher atmospheric CO_2 concentrations with a climate model of relatively coarse resolution. Processes which govern time evolution of changes in THC are studied in detail. Here, selected research accomplishments including these topics are briefly described.

a. Global Warming Research Group

a-1. Climate Sensitivity and Cloud Phase Parameterizations

The estimated range of the equilibrium response of global mean surface temperature to the doubling of atmospheric carbon dioxide has not decreased substantially over the last decade and remains between 1.5°C and 4.5°C . The large range in the estimated sensitivity of surface temperature is attributable mainly to

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our inability to reliably determine the influence of cloud feedback upon the radiative damping of the surface temperature anomaly.

Tsushima and Manabe (2001) analyzed cloud feedback in GCMs and found that solar cloud reflectivity increases significantly with the increase of surface temperature, in contrast to the observation, on a global scale. Regional analysis showed that this increase in the models seems to be related to the change in cloud water distribution in the layer between -15°C and 0°C where ice and water cloud coexist. Based on this finding, Emori (2003) modified the cloud parameterization so that liquid cloud "melted" from ice cloud becomes rain and falls directly to the surface. Ogura (2003), changing the form of cloud water phase function, showed that the climate is very sensitive to such a small change in a GCM. The climate sensitivity decreased by as much as about 3°C .

a-2. A quick Look of Tropical Cyclone Climatology of an AGCM of 20 km Resolution

A super-high-resolution atmospheric GCM is being developed under the Category 4 of the 'Kyosei Project' (MEXT Research Project for Sustainable Coexistence of Human, Nature and the Earth). During FY 2003, Yoshimura investigated tropical cyclone climatology with the use of outputs from an atmospheric GCM of 20 km resolution, in collaboration with researchers at MRI and AESTO. The number of simulated tropical cyclones is 73 in a year and is compared well with the climatological value. Frequency distribution of tropical cyclones as a function of maximum wind speed at 850 hPa (Figure 8) is also appropriate.

b. Carbon Cycle Research Group

b-1. Development of a Global Biogeochemical Oceanic GCM Coupled with an Ecosystem Model

With the use of an oceanic GCM coupled with a new coupled ecosystem-biogeochemical cycle model, which was developed in the last fiscal year and is called NEMRO, we discussed the role of seasonal ver-

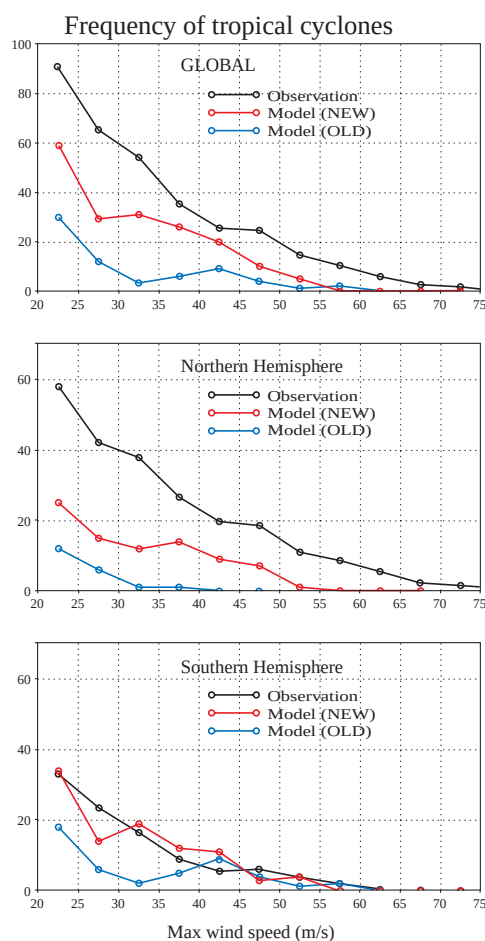


Fig. 8 Frequency distribution of tropical cyclone occurrence, shown as functions of maximum wind speed. Tropical cyclones are counted every 24 hours.

tical migration of copepods, one of popular zooplankton, in the marine ecosystem in the subarctic region (Aita et al., 2003, Fisheries Oceanogr.). Since the global total downward flux by the vertical migration of copepods is estimated to be 5-10% of that by settling particle, marine snow, at the 1000 m depth, the migration would be needed for more realistic simulation of the marine biological cycles. We conducted the historical run from 1948 to 2002 by daily forcing provided by NCEP, to study interannual/decadal variability of biological production and oceanic CO_2 uptake. Our preliminary result simulates the climate shift in 1970s associated with the Pacific Decadal Oscillation (PDO) index well (Figure 9). The primary production in 1980s decreases in the subtropical and increases in

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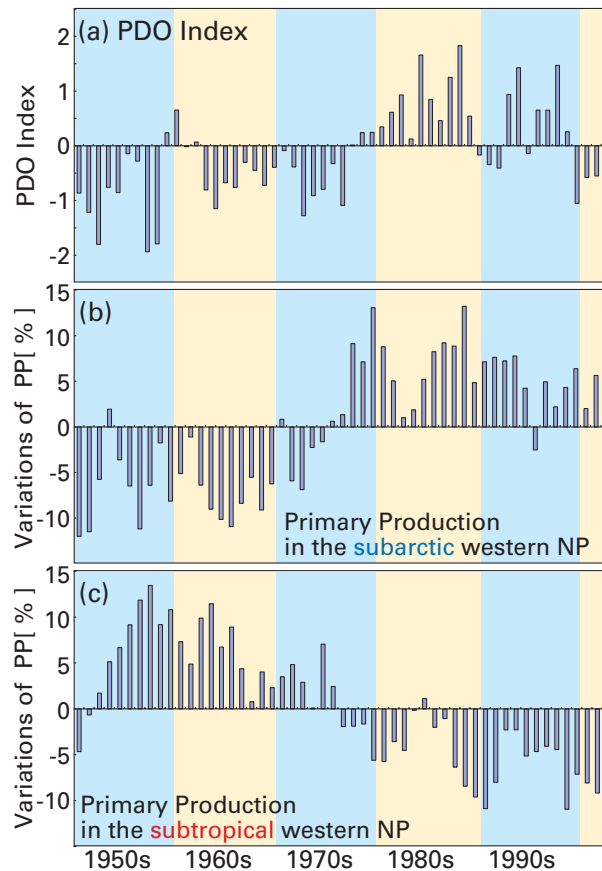


Fig. 9 Time series of (a) Pacific Decadal Oscillation (PDO) index, (b) primary production in the subarctic, and (c) primary production subtropical regions of western North Pacific from 1948 to 2002.

the subarctic regions of western North Pacific compared with that in 1960s, which is consistent with a mechanism suggested by Chai et al. (2002).

b-2. Tracer Study with an Eddy-resolving Oceanic GCM

Sasai et al. (2004) investigate oceanic chlorofluorocarbons (CFCs) uptake using an eddy-resolving high resolution model with $1/10 \times 1/10$ degrees on the Earth Simulator, to understand effects of mesoscale eddies on the CFCs distribution. The estimation of global CFC-11 inventory in the model is 5.1×10^8 mol in 1994. This value is within the estimated range from World Ocean Circulation Experiment (WOCE) CFC-11 concentrations (Willey et al., 2004). The model successfully reproduces the CFC-11 distribution in the deep layer ventilated by the Antarctic Bottom Water

(AABW) from the Weddell Sea and the Ross Sea (Figure 10). The model clearly shows two pathways of CFC-11 spreading from the western Weddell Sea to the section along the Greenwich Meridian (AJAX). One pathway is over the South Scotia Ridge into the Scotia Sea and continues eastward with the Antarctic Circumpolar Current (ACC) to the AJAX section. The other pathway is eastward in the northern Weddell Gyre along the South Scotia Ridge. Our model results demonstrate that global models with super high resolution are potentially useful for studying local distributions such as those observed in one time cruise.

c. Paleoclimate Research Group

c-1. Numerical Experiments for Paleo-climate and Global Warming Using Fully Coupled GCM

In FY 2003, the coupled atmosphere and ocean

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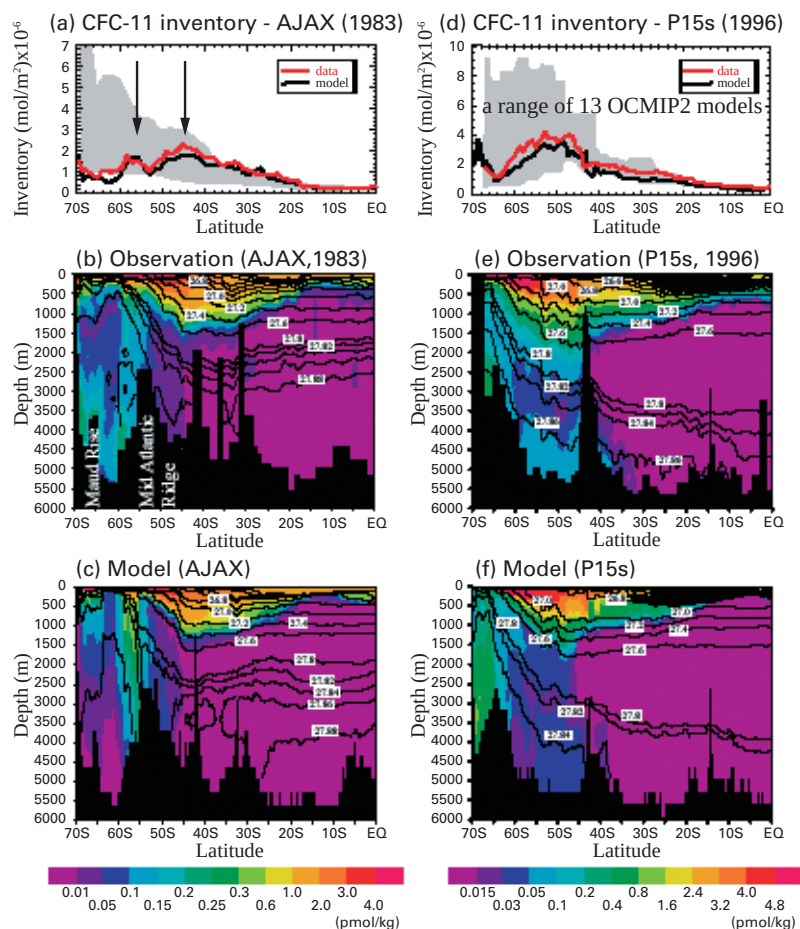


Fig.10 CFC-11 inventories (mol/m^2) and comparison of the CFC-11 concentrations (pmol/kg) from observation and model with potential density (solid line) along (a)-(c) Greenwich in the South Atlantic (1983) and (d)-(f) 170°W in the South Pacific (1996). Shaded area is a range of 13 models from Dutay *et al.* (2002).

GCM, which is planned to be used for the new global warming studies in the IPCC frame work, was developed in collaboration with the Ecosystem Change Research Program of FRSGC, CCSR and NIES approved as *Kyosei* Project under the MEXT. The coupled atmosphere and ocean model without the so-called 'flux adjustment' with an intermediate resolution (about 250 km for atmosphere and 50 to 100 km for ocean) was developed, tuned and tested against observational data. Several transient experiments with CO_2 increase and decrease as well as simulations for 6000 years BP (Before Present) and 20000 years BP (Last Glacial Maximum) were performed by the latest model versions for about 1000 years integration.

c-2. Development of a Climate Model of Intermediate Complexity

In order to help planning and/or interpreting the GCM results, development of an atmosphere-ocean-icesheet climate model of intermediate complexity continued through FY 2003 for paleoclimate studies and some preliminary attempts of paleoclimate experiments have begun.

c-3. Quantifying the Uncertainties in Climate Models Using the Ensemble Kalman filter

Uncertainty in climate forecasts is largely due to uncertainty in model parameterizations (at least for a specified forcing scenario) so probabilistic climate forecasting is essentially a problem of probabilistic

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multivariate parameter estimation in a nonlinear model. Using the ensemble Kalman filter, we have developed an efficient probabilistic parameter estimation system which is designed to enable objective optimal probabilistic ensemble forecasting with fully coupled AOGCMs. We demonstrate its effectiveness by application to a low resolution coupled 3D ocean - 2D atmosphere Earth System Model, and present some forecasts of anthropogenically forced climate change. Using this method we were able to improve this low resolution model to the extent that its performance is, in some respects, as good as or better than state-of-the-art GCMs.

c-4. Some Sensitivity Studies to Understand the Role of Ocean in Paleoclimate

(i) Response of the Atlantic Thermohaline Circulation to Higher Atmospheric Carbon Dioxide Concentrations

Several experiments are performed using a GFDL climate model (R15 resolution in the atmospheric component, $4.5^\circ \times 3.75^\circ$ in the oceanic component), whereby CO_2 concentrations are set to four times that of the present, with and without ice sheets in the polar regions (named $\text{CO}_2 \times 4$ and $\text{CO}_2 \times 4\text{nis}$ run, respectively) and to eight times that of the present, with ice sheets intact ($\text{CO}_2 \times 8$ run).

For the $\text{CO}_2 \times 4$ run, time evolution of the North Atlantic THC intensity (see figure 11) is divided into 4 stages. The first is a very rapid decrease within the first 200 years. This is followed by a minimum of 2-3 Sv, after which a gradual recovery takes place over approximately 1,000 years (2nd stage). Thirdly, within a century, the intensity increases rapidly, and finally, the mean intensity appears to reach an equilibrium value, slightly larger than that of a control run, and exhibits a much larger variability.

During the THC recovery, warming continues in the sub-surface and deep layers in the low latitudes. Warm saline water, at depths of 1000-1500 m, extends northward from the low latitudes. The change in density due to warmer water at these depths in high latitudes

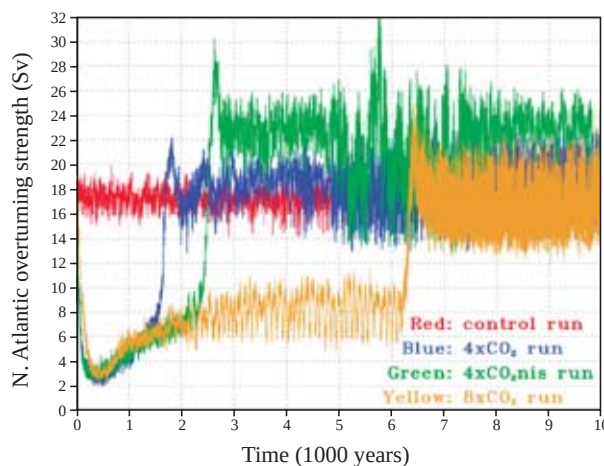


Fig.11 Time series of the meridional overturning strength in the North Atlantic Ocean for 4 cases: control run, $4 \times \text{CO}_2$ run (CO_2 concentration set to 1200 ppm), $4 \times \text{CO}_2\text{nis}$ run (CO_2 concentration set to 1200 ppm, ice sheets removed) and $8 \times \text{CO}_2$ run (CO_2 concentration set to 2400 ppm)

eventually leads to convective instability and resumption of a strong THC.

(ii) Coupled Ocean-atmosphere Multi-decadal Oscillation in the Southeast Pacific Basin Simulated by a Climate Model

A natural period and related spatial pattern are estimated from a control run of the model stated in (i) over 10000 years. A common regionalized multi-decadal period of approximately 35 model years, in and around the Southeast Pacific Basin, is close to periods estimated from climate proxies of tree-ring, ice core, and deep-sea sediments. Composite analyses are performed in order to figure out the mechanism of the oscillation, which use band-pass filtered model variables for the period range of 22 to 66 years. Fields of sea-ice thickness and sea-level pressure show strong coupling feature through evolution of the oscillation in the basin. Atmospheric surface wind plays the role of restoring factor of the coupled oscillation, which is regionalized due to closed contours of vorticity f/H .

(iii) Effects of Stopping the Mediterranean Outflow on the Southern Polar Region

The sensitivity of the climate in the southern polar region to the stopping of the Mediterranean outflow is investigated by use of the coupled model stated in (i).

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Large responses in the SST due to the stopping are found in both the northern North Atlantic and the Southern Ocean. The greatest changes are found between latitudes 50°S and 60°S in the Pacific Ocean sector with a maximum SST decrease of about 1.5°C. A smaller decrease in SST of up to 0.7°C is found at a similar latitude in the Indian Ocean sector. The largest decreases in SSS (Sea Surface Salinity) are seen in the same two locations.

The meridional overturning in the Antarctic bottom water exhibits little change in structure, but reduces by 2.6 Sverdrups (20%) in intensity, brought about by the decreasing difference in density between the polar and equatorial regions, resulting from salinity anomalies.

(iv) Switching of Deep Water Source from the North Atlantic to the North Pacific due to Opening of the Panamanian Gateway in a Coupled Atmosphere-Ocean-land Surface Model

Switching of deep water source from the North Atlantic to the North Pacific is found in a climate model experiment whereby the Panamanian Gateway is opened. THC collapses in the Atlantic within 500 years and develops in the Pacific within 1000 years due to salt transport from the Atlantic to the Pacific through the open gateway.

4. Atmospheric Composition Research Program

Increase of emissions of greenhouse gases and air pollutants accompanying with the economic and population growth is exerting heavy burden to global and regional environment in various part of the world. The atmospheric composition change caused particularly by Asian emissions is a serious problem from the point of sustainable development of this region as well as from the point of global environmental change. The mission of Atmospheric Composition Research Program is to elucidate the mechanism of regional and global scale air pollution in Asia Pacific Region, and to study the influence of atmospheric composition change on climate and vice versa by developing advanced chemical transport model and chemistry-climate model.

To clarify the relationship between regional and global atmospheric composition change, physical and chemical processes of emission, transport, transformation and deposition of atmospheric trace constituents are studied focusing on Eurasian Continent, and global chemical weather maps are drawn. Three categories of atmospheric species studied in this program are long-lived greenhouse gasses (CO₂, CH₄, N₂O, etc.), short-lived reactive gaseous species (O₃, CO, NO_x, VOC, SO₂, OH, HO₂, etc.) and aerosols.

Important processes such as inter-continental long-range transport of air pollutants, tropospheric photochemistry, aerosol composition change are modeled. Source and sinks of greenhouse gases are discussed with an inverse modeling technique. Temporal and spatial variability of concentrations and carbon/oxygen isotope ratios of greenhouse gases are analyzed by using a global transport model for clarifying source and sink processes including the biosphere. Further, prediction of air quality change by ozone and aerosols in Asian Pacific Region, and elucidation of relationship of regional air quality and climate including chemistry-climate feedbacks are targeted in this program.

Contribution to international programs will be made through Atmospheric Brown Cloud-Asia (ABC) under United Nations Environmental Program (UNEP), Global Emission Inventory Activity (GEIA) under IGBP, Intercontinental Transport and Chemical Transformation (ITCT)/IGAC/IGBP, and TransCom, an international program of Intercomparison of inverse modeling for evaluating source and sink of CO₂.

a. Global Chemical Transport Modeling Group

Using the FRCGC/UCI Chemical Transport Model we have investigated the outflow of ozone and its precursors from Europe and North America and quantified their impacts at measurement sites in Siberia and in Japan. Figure 12 shows their impacts for O₃ and CO over Japan. Transport and chemical processing lead to the largest European impacts in spring, and although impacts on surface O₃ in Japan are rather small, aver-

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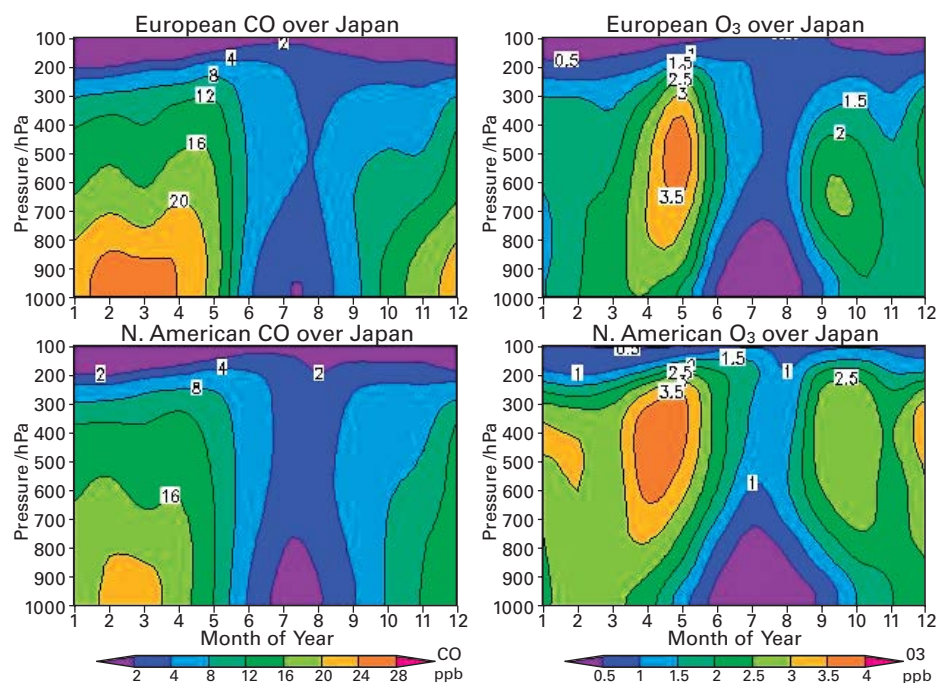


Fig.12 Impacts of European (upper panels) and North American (lower panels) sources over Japan for CO (left) and ozone (right).

aging 2.5 ppbv, they occur at a time when O₃ over Japan is already close to the 1-hr O₃ environmental standard (60 ppbv), and may thus have a significant effect on attainment of air quality standards. North American sources have a smaller effect on surface O₃ and CO over Japan than those from Europe, but have a larger effect on O₃ in the mid troposphere. This is due to more efficient lifting by convection and cyclonic systems, followed by faster transport at higher levels in the troposphere, where the chemical lifetime of O₃ is longer. Outflow from Europe generally occurs at lower altitudes, where O₃ production is less efficient and the lifetime is shorter.

Chemistry-climate interaction was studied on feedback of global warming on tropospheric ozone using our newly developed chemistry coupled climate model CHASER. We performed future simulations of important pollutants such as ozone and sulfate aerosol with the IPCC scenarios. In the simulations only with changes in emissions of ozone precursors, significant increases in surface ozone are calculated in eastern Asia in response to enhanced chemical ozone produc-

tion with the expected emission increases. However, our study suggests that these increases in tropospheric ozone with emission changes can be modulated by future climate change (warming). With climate change, the emission-induced increase of lower tropospheric ozone is reduced due to increased chemical loss of ozone associated with the water vapor increase. On the other hand, the model shows enhanced increase in upper tropospheric ozone in the low-mid latitudes due to the enhanced ozone input from the stratosphere accompanying with the climate change. This is caused by the enhancement in the stratospheric and tropospheric circulation with climate change, and positive feedback of tropospheric ozone is suggested.

We evaluated transport characteristics of the CCSR/NIES AGCM by comparing the modeled mean age of the air in the stratosphere with estimations from in situ and satellite observations of CO₂ and SF₆. The numerical experiment was performed for 10 years by using the Earth Simulator. Further, photochemical interactions between VOCs and reactive halogen species in the marine boundary layer was studied by a

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box model, SEAMAC. Model calculations revealed that the oceanic emissions of acetaldehyde and alkenes are important for regulating reactive halogen chemistry by promoting the conversion of Br atoms into HBr or more stable brominated intermediates in the organic form.

b. Regional Chemical Transport Modeling Group

We investigated the seasonal variation of boundary layer ozone over East Asia by a regional scale air quality modeling system, RAQMS. RAQMS is able to reproduce the observational surface ozone features over East Asia with daily and seasonal variations. The ozone seasonal distribution is controlled by the seasonal evolution of East Asian monsoon system in combination with photochemical production activity. In the simulated results, we find that there is a high ozone band between 35°N~45°N from 70°E to 130°E in summertime as shown in Figure 13. In polluted regions, to the east of 110°E, the high ozone is mainly controlled by photochemical production, which corresponds to ozone export region. But in the west of 110°E, high ozone band is caused by transportation with weak photochemical destruction. In the west of

110°E region, the high ozone is transported from eastern/central China, South/Central Asia, and even from Europe. Above results can give a reasonable explanation for the distinct seasonal variation features of surface ozone at Waliguan station (WMO/GAW), northeast edge of Qinhai-Tibetan plateau, which shows summer maximum and winter minimum in contrast to spring maximum and summer minimum observed at most of remote sites in the northern hemisphere.

c. Greenhouse Gases Modeling Group

A new, higher resolution inverse model for atmospheric transport has been developed. Spatial resolution of the inverse model increased to 64 regions, the land area by about 4 times (42 regions) and twice for the 22 ocean regions in a time-dependent inverse (TDI) model, compared to that used in TransCom-3. In addition to the increase in resolution, we have used inter-annually varying meteorological fields from the NCEP/NCAR reanalysis dataset. Analysis of CO₂ fluxes indicates that the terrestrial ecosystem and oceanic uptake during the 1990s were about 1.15 ± 0.14 and 1.88 ± 0.18 Pg-C yr⁻¹, respectively. Figure 14 shows the anomaly in total ocean and land CO₂ fluxes. Our

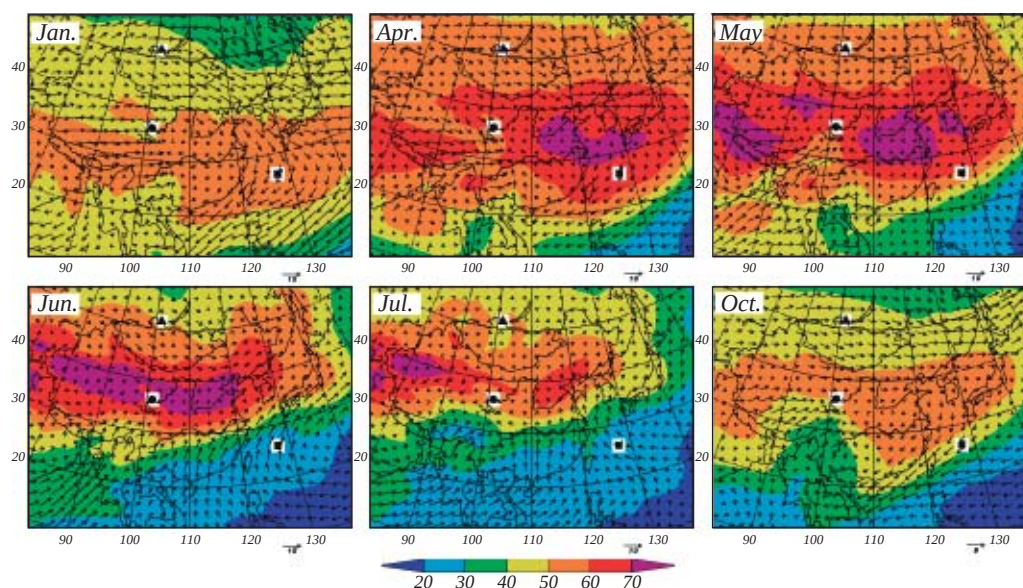


Fig.13 Monthly mean ozone mixing ratios (in ppbv) and wind vector (in m/s) in the boundary layer (~1 km) in January, April, July and October 1996. The locations of Waliguan, Okinawa and Mondy are shown as black circle, square and triangle, respectively.

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results suggested that forest fires have contributed largely to the enhanced CO₂ source (sink) from all land regions, mainly in the tropical latitudes, during the El Niño (La Niña) events. Simulated positive flux anomaly from the boreal Asia also correlates well with fire inventories. The total-ocean fluxes show opposite variability to the land regions during El Niño/La Niña. The oceanic CO₂ flux anomalies appear to be closely correlated with the primary modes of climate variability such as the Pacific Decadal Oscillation (PDO), El Niño/Southern Oscillation (ENSO), North Atlantic Oscillation (NAO) and Arctic Oscillation (AO). Thus, we believe the inter-annual variability in global and regional fluxes are captured more realistically in this work since the information from a greater set of observational stations utilized efficiently in the higher spatial resolution inverse model.

A higher resolution inverse model, designed to estimate annual average fluxes from 432 land/ocean regions, was developed and applied to the comparative analysis of several proposed designs of GHG observations from space which are under consideration for future planned missions, such as Greenhouse gas Observing SATellite (GOSAT). To reduce surface flux uncertainty for terrestrial regions, total column observations over land and including the Planetary Boundary Layer (PBL) appear to be necessary.

Using daily CO₂ fluxes simulated by a process-based ecosystem model, Biome-BGC and NIES/FRSGC global atmospheric transport model, we conducted model analysis of the influence of climate perturbations on the biospheric activities, and their contributions to the inter-annual variations of atmospheric CO₂ concentrations for the period 1960–2002. The results show that global Net Ecosystem Exchange (NEE) is negatively correlated with temperature anomalies but positively with precipitation, while the regional NEE responses are not necessarily similar to the global anomalies. For example, during the 2002 El Niño year, Boreal Asia became a carbon sink (~0.2 GtC/yr) due to enhanced Net Primary Production

(NPP) as a response to highly positive temperature anomalies and negative precipitation ones, while on a global scale the ecosystems act as a carbon source (~1.4 GtC/yr) due to a extremely large decrease in NPP over a decrease in soil respiration that leads to large increase of atmospheric CO₂ concentration. Climate-induced NEE variability accounts for a significant part of the anomalies of atmospheric CO₂ concentration as shown in Figure 14. The model experiments show that inter-annual variability in the atmospheric transport correlates with the CO₂ anomalies in the northern hemisphere, especially in the northern higher latitudes, while the transport variability has less influence in the southern hemisphere.

The observational GHG database has been updated for analysis of spatial/temporal variability in GHG and for validation and comparison with model simulations. From analysis on the observed CO₂ from the aircraft measurements over Japan, it is found that the observed vertical gradient of atmospheric CO₂ over Japan has inter-annual variability that is apparently correlated

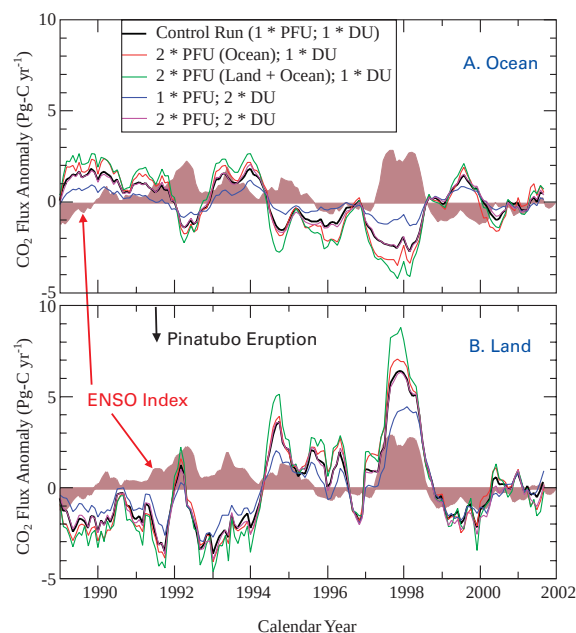


Fig.14 Variability in CO₂ flux anomaly for (A) ocean and (B) land in the period 1989–2001 as derived from the TDI model of atmospheric CO₂. Several case studies by varying the starting prior flux uncertainty (PFU) and estimated data uncertainty (DU) are shown (see legend), and the ENSO index is plotted as the background.

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with ENSO events, and gradually increasing trend (~ 0.02 ppm/yr in lower troposphere).

d. Atmospheric Composition Data Analysis Group

Four atmospheric composition observatories have been established in East Asia with a support from MEXT Research Revolution 2002 project. These observatories focus on long-term change of ozone and carbon monoxide. Three of the monitoring sites are remote mountains but located in the rapidly developed and highly populated region of China, and one of them is a background site in a remote mountain of East Siberia. During spring and early summer of 2003, we found the evidence of extremely high ozone episode at Mt. Taishan in eastern China, maximum at ca. 80, 120 and 160 ppbv in April, May and June 2003, respectively.

The OH and HO₂ radical concentrations during the intensive field campaign performed at Rishiri Island in September 2003 were simulated in a box model based on the tropospheric chemistry mechanism and were compared with the observed concentrations in order to test our current understanding of the tropospheric chemistry. The model runs were performed with the

concentrations of the important OH/HO₂ precursors and the reaction partners and the key parameters (J values, temperature) fully constrained to those observed simultaneously at the island. The comparison, shown in Figure 15, indicates that the model significantly overpredicts the midday HO₂ concentrations, by 89% on average. The model also overpredicts the midday OH concentrations by 35%, but the overestimation of OH did not occur if the model was constrained to the observed HO₂ concentration levels. This analysis suggests that some loss processes for HO₂ are missing from our current understanding of the daytime photochemistry at the coastal site. We raise two possibilities on the missing sink of HO₂, 1) heterogeneous loss of HO₂ on the aerosol surfaces, and 2) the perturbation from iodine chemistry.

Carbon monoxide total column amounts observed in the high latitude Northern Hemisphere (30°-90°N) between January 2002 and December 2003 based on the analysis of infrared spectra recorded with spectrometers has been compared to ground-level CO mixing ratios and to the total column amounts measured from space by the Terra/MOPITT instruments. In comparison to the unperturbed 2000-2001 period,

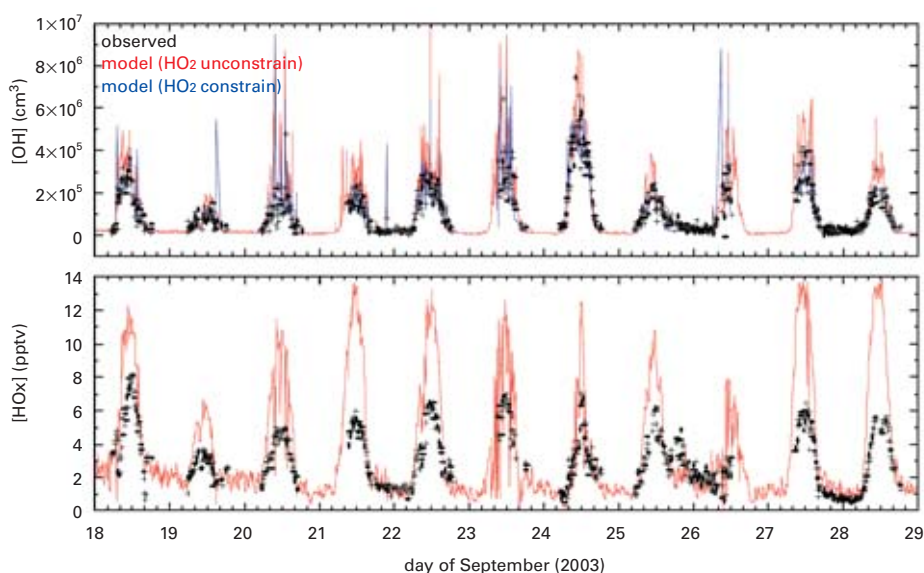


Fig.15 The observed OH and HOx (= OH + HO₂) concentrations (+) and those simulated by the model (red lines). The OH concentrations were also simulated with the HO₂ concentrations constrained by the observed ones (blue line).

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all these databases reveal increased CO abundances in 2002-2003 summer-autumn period with maximum anomalies observed in September 2002 and August 2003. Using a simple two-box model, the corresponding annual CO emission anomalies have been found equal to 98 Tg in 2002 and 142 Tg in 2003, thus close to those for 1996 and 1998. It is most likely that strong boreal forest fires induces the increased CO burdens.

d-1. Emission Inventory Sub-group

The emissions of SO₂, NO_x, CO, BC, OC, and other species, from fuel combustion activities for 1995 and 2000 in China have been estimated. The total annual amount for SO₂, NO_x, CO, BC and OC emissions for 2000 are 20.8, 10.7, 70.5, 0.88, and 2.8 Tg, respectively. Generally, our results are consistent with the results of other regional inventory, such as RAINS-ASIA and Streets et al. However, we can find the relatively large differences between our regional inventory and the global inventory EDGAR, particularly for SO₂. It is considered that the major causes of those discrepancies are the differences in the emission factor (sulfur content in fuels) and the emission control level.

Based on results of field measurements of NO_x emissions from soils, a non-linear mixed model was developed to describe the influences of soil organic carbon (SOC) content, soil pH, land cover type, climate, and nitrogen input on NO_x emission. The statistical results indicate that NO_x emissions are positively correlated with SOC content and negatively correlated with soil pH. Soils in dry or temperate regions have higher NO_x emission potentials than do soils in cold or tropical regions. Agricultural and savannah soils have high NO_x emissions, in sharp contrast to those of wetland and forest soils. The annual NO_x emission from global soils was calculated to be 6.88 Tg N, which decreased to 4.79 Tg N after canopy reduction. The global pre-industrial (as of 1900) NO_x emission from soils (above-canopy) was estimated to be 3.17

Tg N yr⁻¹ by considering changes in land use and nitrogen input, but the estimate could be less than 2 Tg N yr⁻¹ when changes in soil acidity were considered. Mapping of simulated global annual soil NO_x emission (after canopy reduction) in 1995 with a grid size of 0.5 by 0.5 degree.

Emission database for atmospheric trace components from animal farming in South, Southeast, and East Asia was updated to 2000. These emissions were 4.7 TgNH₃-N, 0.51 TgN₂O-N, and 29.9 TgCH₄ in 2000. As for estimations of NH₃ and N₂O emissions, original emission factors were applied taking into account the detailed N-exclusion values for some livestock species in Asia. This experiment gave substantially lower emission values than previous studies, which suggested that the previous studies overestimated Asian NH₃ and N₂O emissions from animal farming. Gridded data sets of the NH₃, N₂O, and CH₄ emissions with a 0.5 degree grid in 2000 were constructed by means of the weighting by high-resolution land cover data sets.

5. Ecosystem Change Research Program

Ecosystems play a vital role in climate and environmental changes, however, data and information on ecosystem structure and functions are insufficient to model ecosystem mechanisms and to simulate their changes in the future. The objective of the Ecosystem Change Research Program (ECRP) is to investigate the mechanisms by which climate and environmental change affect ecosystems, and conversely, how ecosystem change affects climate and the environment, and to model these mechanisms so that we may simulate future changes in ecosystems. In particular, the research focuses on observations of the spatial distribution of ecosystem parameters, including biological species, biomass, primary production, and carbon fluxes, and on modeling of material flows and interactions within ecosystems, and between ecosystems and the atmosphere.

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The following four research groups are organized in this program.

- a. Ecosystem-Atmospheric Interaction Model Group
- b. Ecosystem Architecture Model Group
- c. Ecosystem Geographical Distribution Model Group
- d. Marine Biological Process Model Group

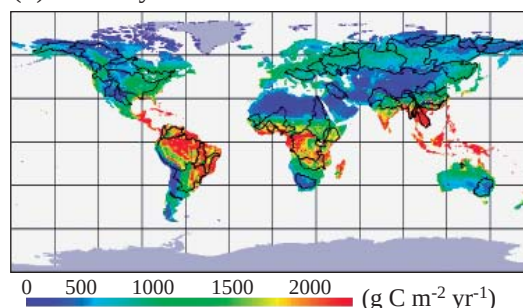
a. Ecosystem-Atmosphere Interaction Model Group

This group focuses on model development and application with respect to atmosphere-ecosystem exchange of carbon dioxide, which plays a key role in the global carbon cycle and climate system. In this fiscal year, the terrestrial ecosystem model, Sim-CYCLE was used for global, landscape, and plot-scale studies.

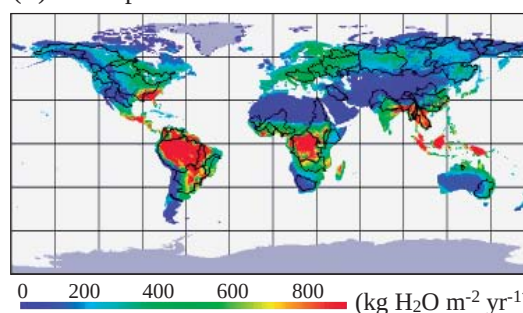
a-1. Water-Use Efficiency (WUE) of the Terrestrial Biosphere

Because there are intimate interactions between the carbon cycle and water cycle in terrestrial ecosystems, hydrological information is useful for examining accuracy of carbon cycle models. Here, water-use efficiency (WUE; photosynthetic CO_2 assimilation per unit transpiration water loss) was investigated with a global-scale model; Sim-CYCLE was performed under a long-term average climate condition at a spatial resolution of $0.5^\circ \times 0.5^\circ$. Total annual gross primary (photosynthetic) production was estimated as $130.2 \times 10^{15} \text{ g C yr}^{-1}$ with a remarkable geographic variability (Figure 16a). On the other hand, total transpiration was estimated as $41.5 \times 10^{15} \text{ kg H}_2\text{O yr}^{-1}$ (Figure 16b), and then the biosphere-average WUE was estimated as $3.13 \text{ g C (kg H}_2\text{O)}^{-1}$. Because of differences in C_3/C_4 composition, canopy structure, and stomatal properties, the model simulation (Figure 16c) revealed that the WUE distributes heterogeneously across the land surface ($1 \sim 10 \text{ g C (kg H}_2\text{O)}^{-1}$). For example, arid regions dominated by C_4 species show apparently higher WUE values than humid forests. The grid-based simulation result was aggregated and analyzed for the world's major river basins, to validate the model simulation with hydrological data (e.g., runoff discharge).

(a) Photosynthesis



(b) Transpiration



(c) WUE (= a/b)

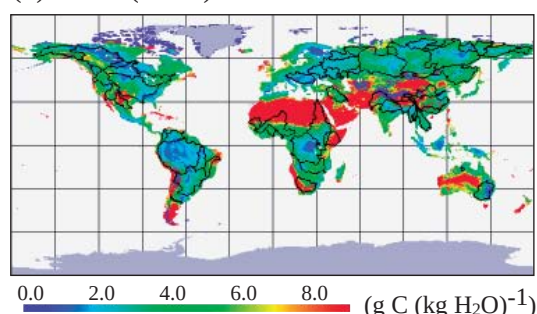


Fig.16 Simulation result of the global $0.5^\circ \times 0.5^\circ$ model. (a) Gross photosynthetic carbon assimilation, (b) water loss by transpiration, and (c) water-use efficiency (WUE) defined as carbon uptake per unit water loss.

a-2. Interannual Variability of Biomass Burning in East Siberia

A coupled carbon cycle and fire regime model was developed and applied to a Siberian larch forest near Yakutsk, Russia, which is a fire-prone ecosystem. The model is composed of a 10-compartment carbon cycle scheme and a grid-based fire regime scheme; fuel accumulation and biomass burning connect these schemes interactively. Using a time-series meteorological data from 1996 to 2003, interannual variability of net CO_2

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exchange including biomass burning was simulated. The fire-related processes (ignition, expansion, extinction, and combustion) were sensitive to environmental conditions, and a substantial magnitude of seasonal and interannual variability emerged in the model simulation. The simulation indicated that the forest released carbon intensively in severe fire years (e.g., 2002), and sequestered the comparable amount of carbon in other years to compensate for the carbon loss. Accordingly, fire regime change can alter the carbon budget of the Siberian larch forest, and so it is necessary to elucidate the regulation mechanism of fire regime for predicting the carbon budget under changing environments.

a-3. Net Ecosystem CO₂ Exchange at Flux Measurement Sites

In many sites in the world, atmosphere–ecosystem CO₂ exchange is continuously measured with the eddy-covariance method. The present study developed a process-based model to account for the observed net ecosystem CO₂ flux in a context of carbon cycle. The model contains a short-term scheme (biochemical photosynthesis model and sun/shade canopy model) and a long-term scheme (12-compartment carbon cycle model including allocation, litterfall, and decomposition). Here, the model was applied to a cool-temperate deciduous broad-leaved forest near Takayama, central Japan (1998–2000). The short-term scheme (30-min step) captured diurnal and seasonal changes in net CO₂ exchange as observed with the eddy-covariance method. The long-term scheme (daily step) captured interannual and decadal changes in carbon cycle, such as forest growth and disturbance impact. The model simulation suggests that over half of the net carbon sequestration (about 200 g C m⁻² yr⁻¹) was attributable to the disturbance impact in 1960s; atmospheric CO₂ increase and climatic change in recent years played an ancillary role. Thus, this model allowed us to retrieve both short-term and long-term processes at the flux measurement site, and will be applied to other sites to examine model applicability to a wide variety of ecosystems.

b. Ecosystem Architecture Model Group

The purpose of this group is to forecast long-term changes in forest ecosystems, which form the largest terrestrial organic carbon pool, in response to climate and environment change, through modeling ecological processes at various scales paying attention to three-dimensional ecosystem architecture.

b-1. PipeTree Simulator

This shoot-scale physiological-process-based model has been revised and presented in a symposium of annual assembly of the Botanical Society of Japan in September 2003. Particular progress during the year was the explicit expression of root (below-ground) systems. Root system is reservoir of organic carbon, playing roles of water/nutrient absorbing function, and tree-anchoring function. Water/nutrient competition occurs locally between trees. Explicit water potential calculation allows us to relate height-specific shoot-growth change. Figure 17 shows the root system presentation of a model tree.

b-2. Stand-level Models

Stand-level response of forest systems to disturbances such as windstorm and drought was parameterized based on permanent-plot census data, and dynamic models were constructed. Target forests cover tropical peat-swamp forest and cool-temperate subalpine coniferous forest.

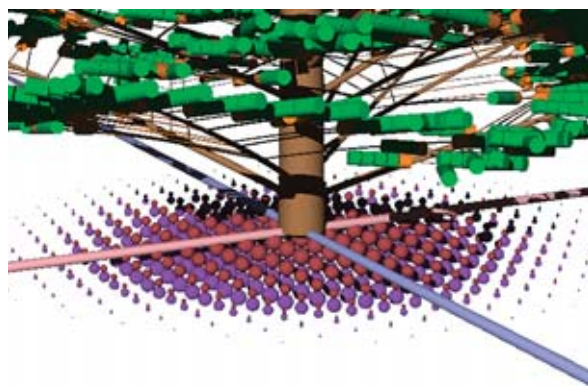


Fig.17 Spatial distribution of root system in a PipeTree simulator. Root mass is subdivided into active absorbing root with short life and anchoring root with long life.

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In a freshwater peat-swamp forest of Central Kalimantan, Indonesian Borneo, undulating microtopography influenced tree survival in contrasting way during the severe drought (1997-98) and the post-drought (1998-2000) periods. In a coniferous forest of the Shiretoko Peninsula, our model for vegetation dynamics demonstrated that the forest landscape ultimately changed with frequency and severity of disturbances by windstorms and landslides. These results showed that natural disturbances, such as drought, windstorms, and landslides had a great impact on ecosystem processes and population dynamics. While we have some mechanistic understanding of tree regeneration in forests based on large-scale and long-term monitoring, we know little of the processes controlling tree responses to changes in resource availability caused by natural disturbances. Networks of plot data in East Asia along latitudinal gradients from equatorial to boreal areas are allowing us to estimate more precise parameters in order to apply the vegetation model to changing disturbance regimes with global warming.

b-3. Global Modeling of Vegetation Dynamics

As a component of integrated global model, this group contributed to develop a Dynamic Global Vegetation Model (DGVM), which is a hybrid of physiology-based Sim-CYCLE model (Ito and Oikawa) and individual-tree based forest model.

This DGVM can simulate changes in ecosystem functions (ex: carbon and water flux) as well as ecosystem structures (ex: distribution and composition). It links several modules, which have different computation time steps. Some of the modules are functions of environmental factors, letting the model simulate ecosystem responses according to environmental changes. Because spatial hetero-structure plays a central role in vegetation dynamics, this model explicitly treat forest 3D structure using individual-basis modeling approach (Figure 17). Simulation will be conducted on the T42 global grid (128×64), each of which includes 10 replication forest stands. Thus,

assuming 1/3 of the earth surface is terrene, about 27,000 independent forest stands will be independently simulated. To date, this would be the most complex ecosystem model that have ever made. It should be noted that the vast computation power of the Earth Simulator capacitates this project.

In FY 2003, coding of one-point simulator was almost completed. We are currently estimating parameters through test running of the program. After vectorize, parallelize, and tuning, we will conduct simulation experiment on global grid within FY 2004.

c. Ecosystem Geographical Distribution Model Group (EGDM)

The Ecosystem Geographical Distribution Model (EGDM) Group uses remotely sensed satellite observations in combination with conventional data sources to analyze and model terrestrial ecosystems and their interaction with the climate system. Research activities in 2003 focused on three major themes: 1) satellite-based modeling of photosynthetically active radiation (PAR) and terrestrial carbon cycle studies, 2) linking remotely sensed satellite data to ecosystem process modeling, and 3) vegetation-climate relations and ecohydrology in northern Asia. The research provides new knowledge and insight regarding ecosystem functions and dynamics, and has generated new environmental and biophysical data for terrestrial carbon cycle modeling. The results achieved in FY 2003 were presented at numerous domestic and international conferences and workshops, and published in two international peer-reviewed journals (one article each by Dye and Suzuki). Additional journal publications are in preparation.

c-1. Satellite Monitoring of Photosynthetically Active Radiation (PAR) for Terrestrial Carbon Cycle Studies

This research focused on developing the knowledge base for implementation of a new satellite-based method for modeling PAR on a global basis. Analysis of *in situ* PAR data resulted in new information and

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understanding of the effects of clouds on the spectral composition of diffuse PAR. Application of these results to a canopy photosynthesis model demonstrated that accurate modeling of terrestrial primary production requires accounting for the spectral shift in PAR associated with scattering by clouds. An empirical model was derived to account for this effect. The results are immediately useful to the carbon cycle modeling community and will enable improved model accuracy.

An additional investigation was undertaken to examine the spatial and temporal variability in global and diffuse PAR in the Amazon forest region of South America. Results from this study indicated that a decline in diffuse PAR coincident with a reported decreasing trend in cloud cover over recent decades might have reduced rates photosynthesis and CO₂ uptake in the Amazon region. These results contradict simpler modeling studies that do not account for the effects of diffuse PAR, and highlight the need for further research to clarify the role of a changing radiation regime on the terrestrial carbon cycle. Such research is now underway in the EGDM Group.

As key step toward modeling PAR with satellite observations, the CCSR radiation model, FSTAR5 was modified to compute spectral fluxes of diffuse and direct beam PAR. Research is ongoing to test the model with data on cloud and aerosol properties from the MODIS sensors on the Terra and Aqua satellites.

c-2. Linking Remotely Sensed Satellite Data to Ecosystem Process Modeling

This activity is aimed at developing a diagnostic model of the terrestrial cycle that assimilates remotely sensed satellite observations of vegetation properties. The research is performed in collaboration with scientists at University of Tokyo/Institute of Industrial Science (U. Tokyo/IIS) and the FRSGC-ECRP Ecosystem-Atmosphere Interaction Group. Major progress was achieved in the collaboration with U. Tokyo/IIS. Initial development and testing was completed for a modified version SimCYCLE that

assimilates MODIS LAI data through a model "nudging" technique. Model-based analysis with PAR data from research in Theme 1 provided motivation and a scientific basis for incorporating a "sun-shade" type of canopy photosynthesis model into the SimCYCLE model.

c-3. Vegetation-Climate Relations and Ecohydrology in Northern Asia

Interannual variation in vegetation over a large area may be expected to induce variation in the land-atmosphere water budget through the process of evapotranspiration (ET). This research examined interannual changes in vegetation and ET over northern Asia. Remotely-sensed vegetation index (NDVI) data were acquired from Pathfinder AVHRR land dataset. Actual ET was estimated from assimilated atmospheric data of NCEP and precipitation data from the CPC Merged Analysis of Precipitation. Calculations were made on a monthly basis from 1982 to 2000 (19 years) over northern Asia (Figure 18). The correlation coefficient of the 19-year time series of ET and NDVI anomalies showed the annual maximum correlation occurs in June over most vegetated areas. Since the vegetation in this region is most active in June, it is considered that vegetation interannual variability contributed significantly to ET through its transpiration activity.

In addition, a diverse set of field observation data collected within the Lena River Basin in eastern Siberia by the GAME-Siberia project and FORSGC were compiled into a single dataset for public dissemination. The dataset includes hydrological, meteorological, glacial and physiological data measured through year 2000 from various platforms, such as towers, masts, aircraft and balloons. The dataset also contains other related datasets, many of which were obtained from the operational observatory network in and around the Lena River Basin. The combined dataset was published on CD-ROM and widely distributed among the participant scientists and other researchers.

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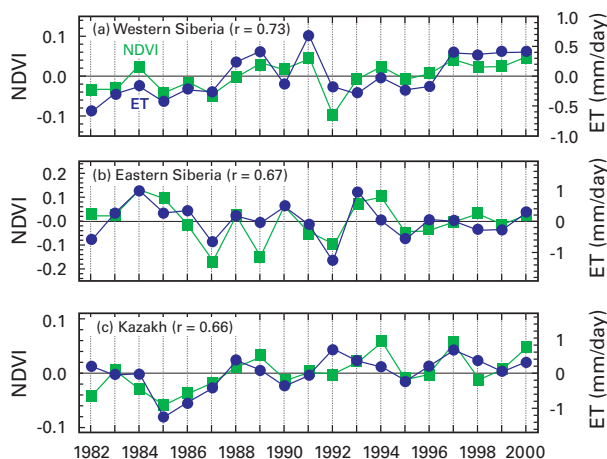


Fig.18 Interannual variation of NDVI and ET anomalies averaged in three selected regions of north Asia; (a) Western Siberia, (b) Eastern Siberia and (c) Kazakh. The correlation coefficient is denoted by "r" in each panel.

d. Marine Biological Process Model Group

In order to facilitate model development, we aim at discovering functional relationship of the lower trophic level ecosystem change in the North Pacific to the global climate variation. Possible feedback to the global environments through changes in ocean carbon cycles as results of the observed ecosystem change is also to be examined. Retrospective approaches have been taken for the two target oceanic regions, the Oyashio and the Japan Sea based on the field observation data sets collected from the 1970s to 1990s. In both regions, we found the ecosystem change processes related to the decadal to multi-decadal scale climatic variations. We will start regional comparison of the ecosystem change processes in the whole area of North Pacific Ocean.

d-1. Multi-decadal Scale Trend in the Lower Trophic Level Productivity in the Oyashio

The Oyashio Water locating along the western edge of the North Pacific subarctic circulation is one of the most productive regions of the world oceans. In the conventional view, extensive phytoplankton spring bloom occurs when the surface water becomes stratified to form a stable, shallow mixed layer with sufficient nutrients supplied during winter. Zooplankton

production is sustained by the large amount of phytoplankton in spring. However, we observed a sign of alteration of physical, chemical and biological environments of the water column in the Oyashio for these 3 decades.

Wintertime subsurface dissolved oxygen (DO) linearly decreased, implying the reduction of water exchange between the subsurface and the surface layers. Freshening of surface water was considered to be the cause of the increased stratification and subsequent attenuation of vertical water mixing. Net community production (NCP) estimated from the phosphate consumption from February through August, decreased for the same periods. Decreases in average spring-time diatom abundance and Chl-*a* concentration were consistent with the multi-decadal decreasing trend of NCP. Total spring zooplankton biomass, presumably dominated by *Neocalanus* copepods also decreased. The attenuation of winter-time vertical water mixing might limit iron entrainment from subsurface to surface reduced winter-summer NPC, and zooplankton biomass for these 3 decades (Figure 19). As annual vertical carbon export by the ontogenetic migration of the *Neocalanus* copepods were estimated to account for 18% of the new production in the subarctic North Pacific, the observed multi-decadal scale change might have largely affected the efficiency of biological carbon pump in the Oyashio.

d-2. North-South Comparison of Variation in the Lower Trophic Level Ecosystem in the Japan Sea: Light-limited vs. Nutrients-limited

The Japan Sea is so-called a "miniature ocean" because it has some characteristics of a major ocean despite its small size and semi-closed boundaries. By studying this smaller scale system, we expect to gain insights on the climate-ecosystem interaction in the subarctic and subtropical gyres of the North Pacific. The particular interest was toward the regional comparison of the mechanisms between northern, subarctic region and southern, Tsushima Current region

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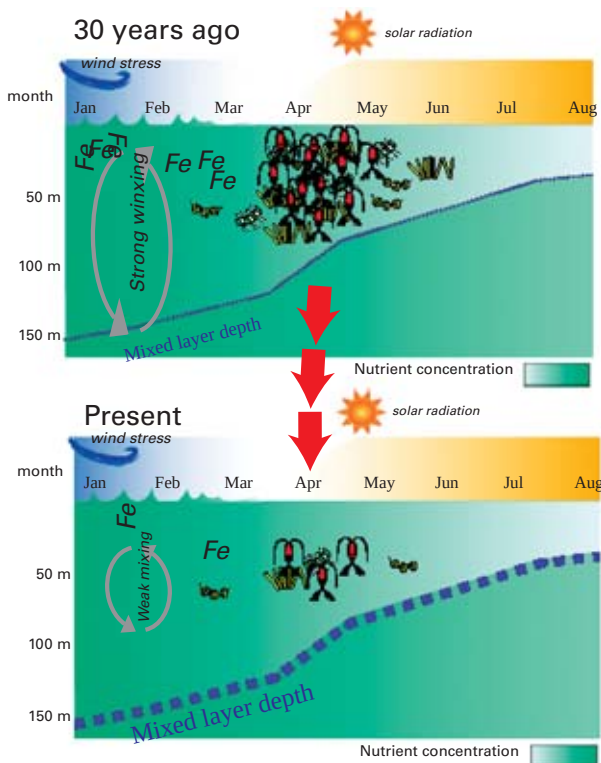


Fig.19 Schematic diagram of the physical-biological processes 30 years ago (upper) and in the recent years (lower) in the Oyashio. 30 years ago, active wintertime mixing supplied iron from the subsurface to the upper layer allowing massive phytoplankton bloom to occur, and zooplankton biomass was high. In the recent years, iron supply was limited due to attenuation of vertical water exchange, and both primary and secondary productivity were low.

using zooplankton biomass data sets.

We found a decadal scale variation in phytoplankton and zooplankton abundances both in the northern and southern regions. However, mechanisms and timings of the variations differed between the north and south regions. Springtime mixed layer shoaled and stratification increased due to surface water warming after the late 1970s, the regime shift years, in the north, and after the early 1980s in the south. Responding to the stratification increase, springtime abundances of phytoplankton and zooplankton increased in the north, while these decreased in the south. In the north, spring phytoplankton production might be enhanced by increase in light availability due to the mixed layer stabilization. In the south, on the other hand, stratification increase was likely to limit

nutrients supply to the surface layer, resulting in decrease in phytoplankton production. These results were consistent with the theories that light availability is the most important limiting factor for primary production in the subarctic region where rich nutrients are derived by wintertime deep mixing, and that nutrient availability determines spring primary productivity in the subtropical regions where the surface water weakly stratified even during wintertime. As there was a significant positive correlation between variations of phytoplankton and zooplankton abundances, bottom-up control was likely in the spring lower trophic levels both in the north and south. This study demonstrates that regional comparison of mechanisms of long-term scale variation is indispensable to understand how a common climatic forcing could differently alter regional ecosystems.

6. Integrated Modeling Research Program

Introduction

The mission of the Program is to develop "new" climate models, global environmental models and ocean data assimilation systems to be run on the world's fastest "Earth Simulator" which was completed in March 2002. The following are the present targets of development:

- (i) Spectral atmosphere model with a horizontal resolution T213 and 50 layers in the vertical, world ocean model with 0.1 horizontal resolution and 50 layers in the vertical, and a coupled A-O GCM consisting of the two. An objective is to carry out long-term global warming experiments with eddy containing oceans.
- (ii) Atmosphere model with a horizontal mesh size of 5 km or less by which tropical cloud clusters and other meso-scale atmospheric systems can be represented explicitly. Similarly, eddy resolving world ocean model are being developed. As the coordinate system to cover the globe cubic-grid and icosahedral-grid (quasi-uniform grids) are adopted.

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- (iii) Development of global environmental models to include new elements such as atmospheric chemistry aerosols effects on clouds, terrestrial and ocean carbon cycles and so on, on the basis of currently existing climate models cooperating with other research programs.
- (iv) In addition to the above described model development, ocean data assimilation systems are also developed in this program. Four-dimensional variational data assimilation systems, which incorporate satellite and in-situ observational data into numerical models, are the target of development. These can provide realistic initial conditions for adequate prediction and also useful re-analysis datasets for accurate estimation of ocean circulation processes.

Within FY 2003, the first version of the high-resolution coupled model was completed and global warming experiment started. So the group moved to the Global Warming Prediction Research Program in FY 2004.

a. Coupled Model Development Group

Since FY 1999 this Group has been engaged in the development of a very high resolution coupled atmosphere-ocean model to be applied to global warming experiments by use of the Earth Simulator in collaboration with the CCSR and the NIES. A coupled AOGCM originally developed by the CCSR and NIES was adopted as the basis and a high resolution version model was developed by the FRSGC group. In FY 2002 and 2003 this activity was done as the FRSGC's part (a sub-theme) of the *Kyosei* Project 1 which is the joint research project of CCSR, NIES and FRSGC to conduct numerical experiments of global warming with the world's highest resolution CGCM by use of the ES to contribute to the IPCC 4th Assessment Report.

In FY 2003, the final version of the model was completed. The resolution of the AGCM is T106/L50 and that of the OGCM is $1/4^\circ$ long. $\times$ $1/6$ lat. and L46.

The poles of the spherical coordinate of the OGCM is shifted to locate over Greenland and Antarctica.

In parallel with the final tuning of the model, various test calculations were carried out to check the performance of the models and also to investigate mechanisms of some interesting phenomena. Among them the two interesting results will be reported subsequently.

First, equatorial wave modes and intra-seasonal oscillation appearing in the AGCM. Recently equatorial wave modes coupled with convective activity were detected in the spatio-temporal variations of OLR in the tropical regions (Takayabu, 1944; Wheeler, 1999). The same analyses were applied to the results of numerical experiments of the atmospheric GCM with prescribed SST.

Figure 20 shows the spectral intensity of the OLR variations as functions of the zonal wavenumber (x-axis) and frequency (ordinate), for symmetric (upper panels) and antisymmetric (lower panels) components with respect to the equator. In figure 20, (a) and (e) are the zonal wavenumber-frequency spectra of the observed OLR variation, (b) and (f) are the same as (a) and (e) but for the results of T106 experiments, (c) and (g) are those but for T42 experiments and (d) and (h) are the results of T106 experiments but without the trigger effect which acts to suppress the occurrence of convection. Apparently the dispersion relation for the eastward and westward moving equatorial waves are well reproduced by the T106 and T42 models including the intensity, while in the case of removing the trigger in convective parameterization ((d) and (h)) the power intensity is significantly weaker in comparison with the other cases. The fact implies that without the trigger control convection occurs easily so that larger-scale conditions (equatorial waves) do not modulate convection occurrence as in the other cases or observation. This result confirms the conjecture that the trigger control is needed to the realistic simulation of wave-convection coupling.

The second result is Hawaiian lee counter-current

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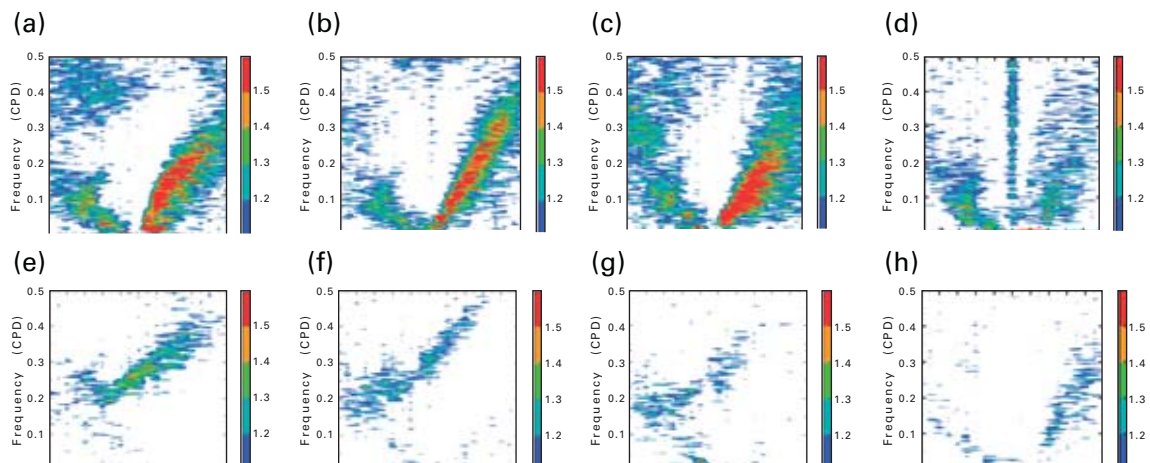


Fig.20 Temporal-Spatial spectra of daily OLR distribution. The zonal wavenumber is taken as the abscissa and the frequency is the ordinate. (a)~(d) are spectra of the symmetric component about the equator while (e)~(h) are for the antisymmetric component. For further detail see the text.

appearing in CGCM. In a recent paper, Xie et al (2003) reported that under the existence of background easterly winds (trade winds), a narrow band of convergent wind and associated upward motion (cloud band) is generated in the lee of Hawaiian Island which in turn produces a narrow eastward ocean current with higher sea surface temperature through a unique coupling mechanism between the atmosphere and the ocean, and that this system extends as far as 3,000 km or longer away from the Island (see Figure 21 (a)).

They have shown this phenomenon from the observational data and discussed the generation mechanism by use of either atmosphere or ocean model by prescribing the structure of the system in the one side and giving it as the forcing to the other side.

In our coupled AOGCM with a very high resolution (about 20 km) ocean component the coupling mechanism worked automatically and consequently the Hawaiian lee current system was naturally formed in the model as seen in Figure 21 (b). As a contrasting experiment we performed another simulation by removing Hawaiian Island. In this case, the lee system is completely missing as shown in Figure 21 (c).

b. Next-generation Model Development

b-1. Next Generation Atmospheric Modeling Group

(i) Purpose

The aim of this project is to develop super-high resolution atmospheric general circulation models. We intend to run the model with a few-kilometer grid interval in the horizontal directions using the Earth Simulator. With such a high-resolution simulation, we aim to explicitly calculate cloud motions. To achieve this goal, we are developing new models based on quasi-uniform grids, which are suitable for the Earth Simulator.

(ii) Development of a Global Cloud Resolving Model

Up to the last year, we have developed the dynamical core of the new atmospheric model. This model is based on nonhydrostatic equations and the icosahedral grid (Figure 22). We call it Nonhydrostatic ICosahedral Atmospheric Model (NICAM). The main objectives of FY 2003 are to run a 3.5 km-grid global simulation using the dynamical core of NICAM on the Earth Simulator and tune up the computational performance of NICAM, and to implement various physical processes and make preparation for global cloud resolving calculations.

We have done a dynamical core experiment of life cycle of extratropical cyclones proposed by Polvani et

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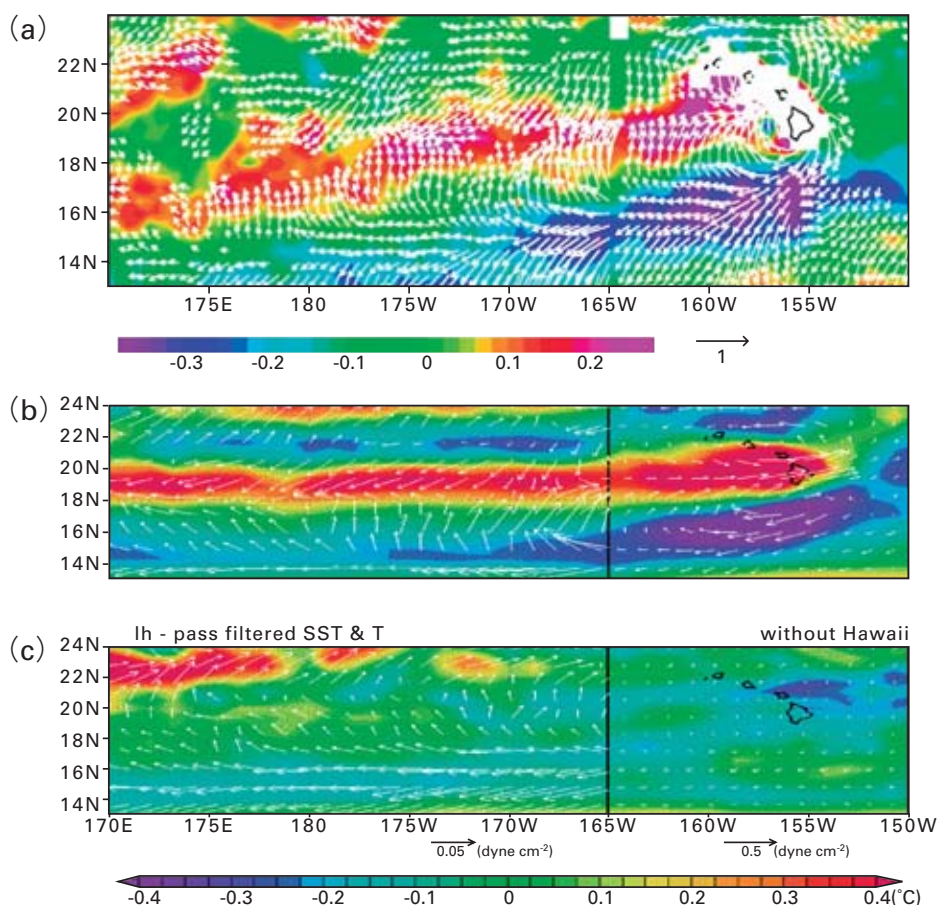


Fig.21 The SST distribution and winds near the sea surface to show Hawaiian lee current system. (a) Observation (b) Simulation (c) Simulation but without Hawaii Island.

al. This is a deterministic experiment for about 10-days integration and is suitable for a high resolution simulation. We performed this experiment using different grid intervals: 120, 60, 30, 14, 7, and 3.5 km. Figure 23 shows the results from the 3.5 km-grid simulation: the global distribution of temperature near the surface at day 10. The surface temperature distribution shows very sharp fronts associated with cyclones. Fine structure of the cyclones is more evident as the grid interval becomes smaller. We also found that the maximum speed of vertical velocity becomes stronger as the resolution becomes finer, though the nonhydrostatic effect is not appreciable (not shown here).

The second objective of the atmospheric modeling is implementation of physical processes: cloud physics, radiation, and boundary layer turbulence schemes are investigated. To evaluate properties of

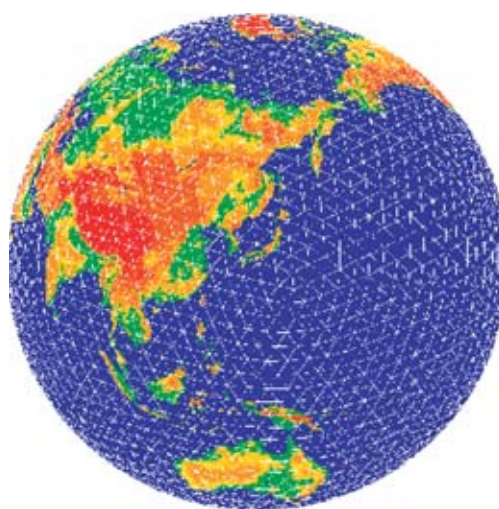


Fig.22 Icosahedral grid.

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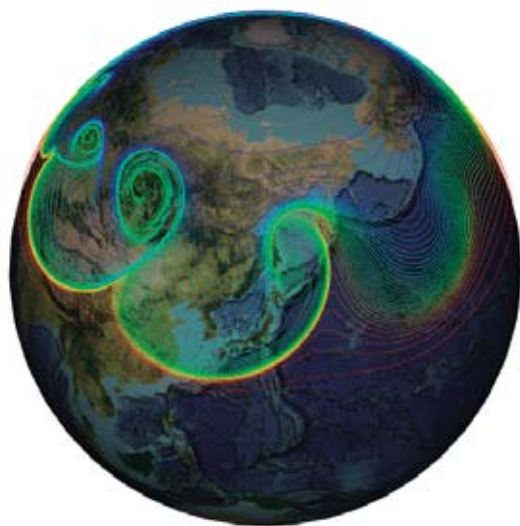


Fig.23 Global distribution of temperature near the surface obtained from 3.5 km-mesh model for the life cycle experiment of extratropical cyclones at day 10.

various physical processes, we need to test them using a cloud-resolving simulation, i.e., a few kilometers resolution. Since NICAM is a global model, we devised the following two methods: a stretched grid model and a small planet model. We also use a Cartesian coordinate model which has the same numerical scheme as NICAM and is separately developed. By concentrating grid mesh in a particular region, we run a squall line experiment, which is proposed as an intercomparison experiment and has been further investigated in terms of resolution. We investigate dependency on physical schemes, particularly on cloud microphysics, and also study cloud-radiation interaction. We tested cloud microphysical schemes from the Kessler-type simple warm rain bulk scheme to 5 categories cold rain scheme including cloud water, cloud ice, rain, snow, and graupel. The results are almost comparable to the previous studies.

Another experiment is a statistical run including moist processes: direct calculations of radiative-convective equilibrium on a uniform sea surface temperature. This experiment is a first step to evaluate climate sensitivity of the global model. Although integration time is 5 days, mean temperature is about 265 K, and precipitable water is about 40 kg/m², which are relatively

smaller than those of typical values in the tropics. This difference might come from the fact that the configuration of the everywhere-tropics planet does not take account of the mean large-scale ascent associated with the Hadley and Walker circulations. We are now in a position to run a global cloud resolving experiment on the real size of the earth, in which cloud-scale motions and large-scale circulations co-exists.

b-2. Next Generation Ocean Modeling Group

An ocean circulation model with high physical and computational performance is being developed. The purpose of this project is to develop a new ocean model on the Earth Simulator to study physics of mesoscale eddies in the world ocean. In this fiscal year, we developed a three dimensional dynamical core, based on the shallow water model developed last year. In order to increase time-step-width and realize high computational performance, we decided to employ a homogeneous cubic grid system for the new model. This grid system is quadrilateral so that it is relatively easier to introduce schemes used in conventional ocean models. In addition, the cubic grid is structured one so that high computational performance on the Earth Simulator is expected by utilizing its vector-parallel processors efficiently. Last fiscal year, the characteristics of the cubic grid was studied by developing a shallow water model and we had confidence to apply this grid system for the new ocean circulation model. This fiscal year, we have extended it to a three dimensional dynamical core. Figure 24 shows the sea surface height calculated using the three dimensional dynamical core. The grid size used in this calculation is about 100 km and there are 30 levels in the vertical. Wind forcing at the sea surface is the annual-mean wind stress of Hellerman and Rosenstein and thermal and freshwater forcing at the sea surface is imposed by restoring to the sea surface temperature and salinity of Levitus. The model is integrated for 1000 years.

In parallel to this development, eddy resolving simulations of the Southern Ocean using a conventional

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ocean model are carried out to study the dynamics of the Antarctic Circumpolar Current (ACC) before studying the physics of the world ocean mesoscale eddies using the new model. The model used for this study is the Center for Climate System Research Ocean Component model. The ACC in the Southern Ocean flows eastward without land barriers and the activities of the mesoscale eddies in this current is very high. These eddies are believed to play a central role in both the dynamical and thermodynamical balances of the ACC. Therefore, it is important to calculate these eddies explicitly without parameterization to understand the dynamics of the ACC. Figure 25 shows the calculated transport (Sv) which is caused by eddies

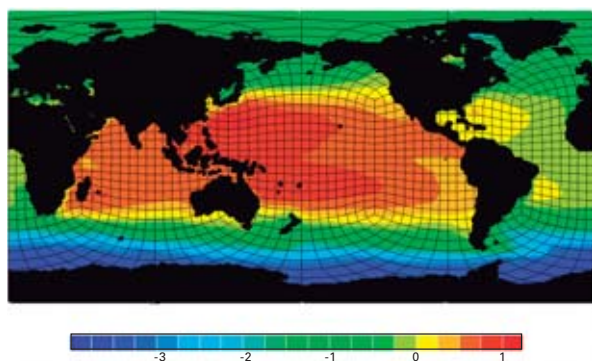


Fig.24 The calculated sea surface height field (m) after 1000 model year integration. The model was spun up with Hellerman and Rosenstein wind stress and Levitus sea surface temperature and salinity field.

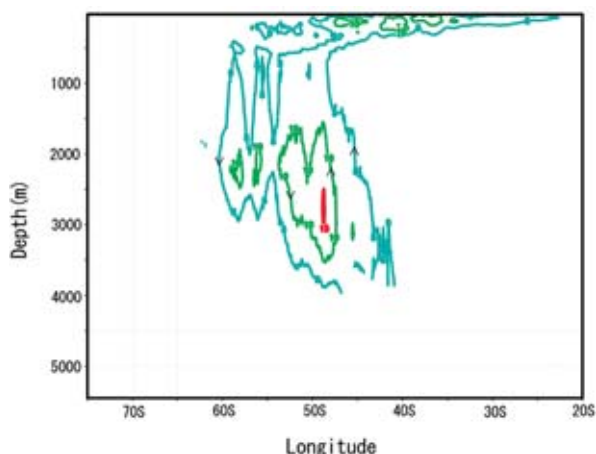


Fig.25 The calculated transport (Sv) caused by eddies in the ACC. The horizontal resolution is 1/8 degree in longitude and 1/12 degree in latitude. There are 85 levels in the vertical.

in the ACC. The horizontal resolution is 1/8 degree in longitude and 1/12 degree in latitude. There are 85 levels in the vertical. It is clearly shown that eddy induced transport tends to decrease the slope of the density surface.

c. Development of an Integrated Earth System Model for Global Warming Prediction

Climate change, such as global warming, is an outcome of complex interactions among climate, terrestrial and oceanic ecosystems, and chemical composition of the atmosphere. The purpose of this project is to develop an integrated earth system model that can simulate these interactions, and provide reliable predictions for the change of global environment.

In current studies of climate change due to increase of greenhouse gases, specifically CO₂, the atmospheric CO₂ concentration is first calculated using CO₂ emission scenarios and simple models of terrestrial and oceanic carbon budgets. The calculated CO₂ concentration is then substituted into climate model, and predictions of the future climate are made. However, this approach do not consider any feedbacks between climate and carbon cycle; while increase of atmospheric CO₂ concentration would cause global warming, global warming could in turn affects process of CO₂ release and uptake by terrestrial and oceanic ecosystems and by the sea water. For example, global warming would enhance decomposition of terrestrial organic matters, and thereby accelerating CO₂ increase. Moreover, climate change could also affect concentration of troposphere ozone, which is another greenhouse effect gas. Therefore, for providing reliable predictions of global warming and climate change, it is strongly required to develop an integrated earth system model combining climate, carbon cycle, and chemical composition of the atmosphere and to use it for global warming prediction. In this project, we are developing an integrated earth system model, and planning to conduct simulation experiments on the Earth Simulator.

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This is a project originally planned as the third target of the model development at the Integrated Modeling Development Program. The project team was organized by participation of members from many other programs of FRSGC. The project started from FY 2002 as Subject 2 of the MEXT project for Sustainable Co-existence of Human, Nature and the Earth (*Kyosei* Project). For details, see the report of this project.

d. Data Assimilation Group

d-1. Improved Estimates of Dynamical State of Ocean Circulation during 1996-2002

For the purpose of providing greater information content and forecast potential for climate variation to science community, an oceanic component of our 4-dimensional variational (4D-VAR) coupled data assimilation (DA) system has been applied to a reanalysis experiment for better descriptions of a global ocean state during 1996-2002. This experiment assimilated all the observational data available (e.g., water temperature, salinity, and sea surface height anomaly data, recent ARGO float data) into an OGCM. Our OGCM has been already confirmed to be a good platform for the use of the 4D-VAR adjoint model. The horizontal resolution of the OGCM is 1 degree in both latitude and longitude with 36 vertical levels.

An optimal synthesis of observational data and model results provides a dynamically self-consistent database capable of offering greater information and forecast

potential for seasonal to interannual climate variation than do models or data alone. For example, Figure 26 shows the time series of SST along the Pacific equator during the period of 1996-1999. Comparison of the maps among the observation, simulation, and assimilation results reveals that the 1997/1998 El Niño event, which was biggest in the 21st century, is better reproduced by our 4D-VAR DA system.

In addition, the rmd difference between the observed time-evolution of Niño 3 SST and the assimilated one is 0.69 K during 1996-1998, while the difference for the simulation case is 1.60 K. This much improved reproduction of the evolution of Niño 3 SST in the assimilation run gives us confidence in the validity of our dataset for climate variability in this region.

d-2. Impacts of ARGO Float Data on Description of Subsurface Circulation

Using the reanalysis dataset described above, we have investigated the impacts of subsurface data derived from the ARGO drifter. The ARGO float, which has been most recently deployed in order to cover the entire ocean, has been designed to provide higher quality subsurface information than earlier methods, and hence its detailed assessment is required.

Our reanalysis dataset exhibits realistic subsurface water mass distributions. For example, the North Pacific Intermediate Water characterized by a subsurface salinity minimum is successfully reproduced.

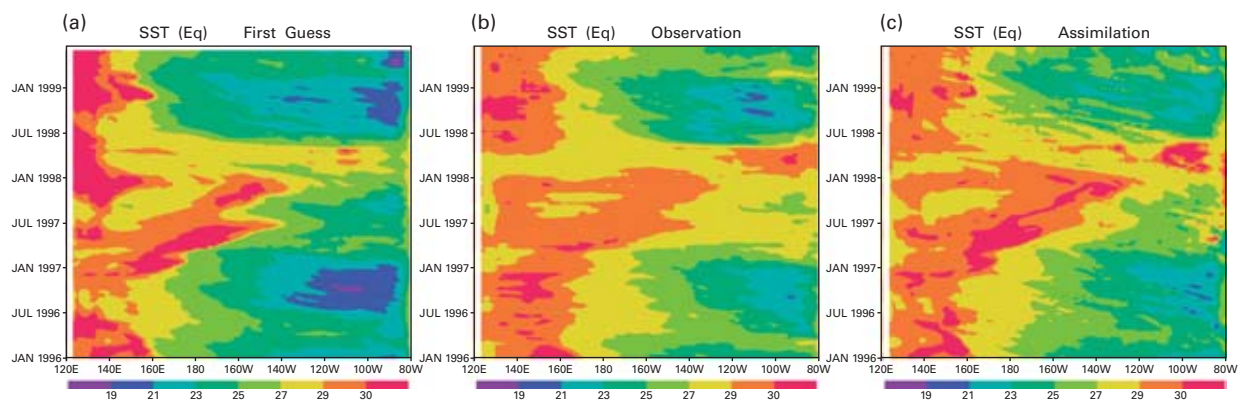


Fig.26 SST along Pacific equator from January 1996 to June 1999.

(a) Simulation. (b) Observation. (c) Assimilation.

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Salinity different at lon 330 as-as_clim t=91

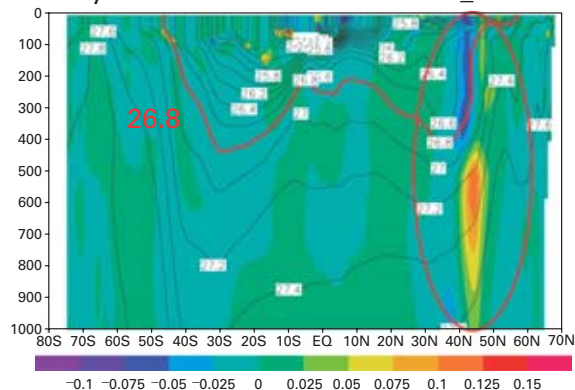


Fig.27 Impact of ARGO subsurface observations on correction of ocean circulation (vertical cross section along 30°W). Color shade denotes salinity difference between the results of assimilation experiment with and without ARGO data.

Another evidence of significant impacts of ARGO data on the improvement of ocean circulation is shown in Figure 27, which demonstrates that the correction of the inter-gyre process is striking, particularly in the North Atlantic Ocean and the Bering Sea. These results suggest that assimilation of ARGO subsurface data allows us to better define the ocean state via the mold dynamics.

7. International Pacific Research Center (IPRC)

The Frontier Program for the International Pacific Research Center (IPRC) at the University of Hawaii in Honolulu is fully integrated into the research activities of the IPRC. The IPRC is a climate research center that was conceived under the "U.S.–Japan Common Agenda for Cooperation in Global Perspective." Receiving funds from Japanese and US research agencies, it operates under an agreement between JAMSTEC and the University of Hawaii. Research at the IPRC is divided into four themes focused on understanding the air-sea (and at times land) processes that affect Asia-Pacific climate and the impacts of global climate change. Since IPRC research work requires intensive use of data sets covering a wide variety of time and space scales, the Asia-Pacific Data-Research Center (APDRC) was established as a part of the IPRC in 2001. The following summary highlights some (but by no means all) of

our accomplishments during the past year in each of the Themes and the APDRC. During FY 2003, our researchers published 66 articles in peer-reviewed scientific journals and received acceptances for 31 articles. Our biannual newsletter and annual report as well as the IPRC website (<http://iprc.soest.hawaii.edu>) feature the IPRC research activities in greater detail.

a. Indo-Pacific Climate

Research under this theme investigates the ocean's role in climate and climate variability. Research projects fall into three broad areas: ocean processes, *air-sea interaction* (or coupling), and climate variability. In air-sea interaction research this year, we continued to study the role of mountain ranges on air-sea interactions. A well-known, but so far unexplained feature, is that the ITCZ in the eastern tropical Pacific is displaced to the southern edge of the Pacific warm pool during boreal winter. Studies with the IPRC Regional Model (IPRC-RegCM) attribute this phenomenon to the presence of the Central American mountain ranges, which block the northeast trades, thereby causing subsidence and dry conditions on the Pacific (lee-ward) side. Analyzing summertime satellite observations in this region, we noted that the strong wind jets passing through gaps in these mountains lower SST significantly (Figure 28). One such oceanic response, the Costa Rica Dome, in turn affects the atmosphere, punching a distinct, and previously undocumented, hole into the summer ITCZ. Together with colleagues at other institutions, we have noted a similar interplay between air, sea, and mountain ranges in the South China Sea and the Arabian Sea.

In another study, we noted that around the globe between 40°S and 40°N, the air-sea pattern near ocean fronts is characterized by *positive* SST-wind speed correlations, opposite to the negative correlation often observed at large scales. A key process seems to be that warm SST destabilizes the planetary boundary layer and the resulting vertical mixing strengthens the surface winds. Modeling this air-sea interaction associated with

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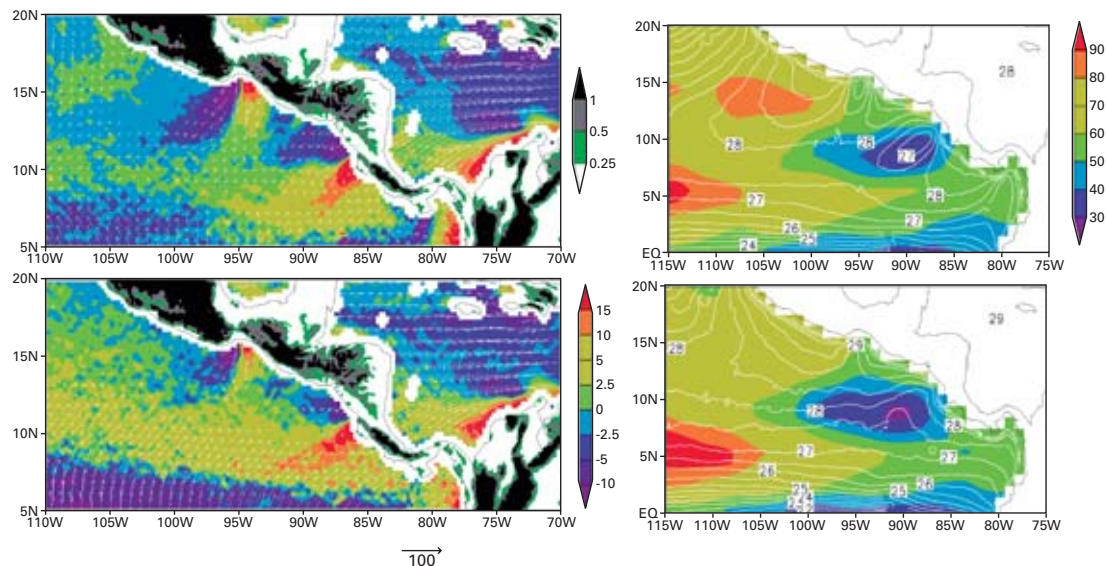


Fig.28 (Left panels) QuikSCAT pseudo wind stress (vectors in m^2s^{-2}) and Ekman pumping velocity (shade in 10–6 m/s) climatology (top) annual mean, (bottom) July–October. Mountain height (km) is plotted in color shading. (Right panels) SST climatology (contours at intervals of 0.5°C) and the 20°C isotherm depth (color in m): (top) annual mean, (bottom) July–October.

the equatorial front and Tropical Instability Waves in the eastern equatorial Pacific revealed that changes in atmospheric pressure also affect this adjustment.

In studies of *climate variability*, we explored intraseasonal SST variations in the Indian Ocean, climate impacts of the IOD, and processes underlying the Pacific Decadal Oscillation. Work on the IOD, for example, suggests it affects land temperatures over remote subtropical regions in both the Northern and Southern Hemispheres as a result of changes in the Walker Circulation (associated with the east-west SST gradient of the IOD) and stationary Rossby wave trains originating in the eastern Indian Ocean. Atmospheric-model experiments suggest that the IOD and El Niño affect Indian monsoon rainfall differently: A cold eastern Indian Ocean results in excessive rain over India, whereas El Niño results in drought. An increase in the frequency of IOD events then may account for the lower ENSO-monsoon correlations noted in recent years.

In studies of *ocean processes*, we considered the dynamics, forcing, and variability of near-surface currents and their heat and salt transports, as well as the parameterization of ocean mixing.

b. Regional Ocean Influences

Research under this theme focuses on the marginal seas adjacent to Asia, the Oyashio, Kuroshio, and low-latitude western boundary currents, and Indonesian Throughflow. These circulations are known to impact the climate of Asia and Japan through ocean-atmosphere interactions, the mixing of water properties, and the transport of heat and salt. In this theme we aim to describe these major oceanic transport pathways, understand the processes that maintain them and account for their variability, and determine their influence on Asia-Pacific climate.

With regard to the *low-latitude western boundary currents*, we focused this year on the connection between variability in the western boundary currents and the South China Sea. A combined analysis of observations and model simulations, including the OFES, and the use of 4-dimensional variable data-assimilation techniques suggest that such a connection exists *via* transport through the Luzon Strait. Water entering through the Luzon Strait surfaces 5–7 months later in a cyclonic gyre east of Vietnam. The transport is strongly affected by ENSO, approaching its maxi-

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mum (minimum) strength during El Niño (La Niña) and appears to play a key role in conveying Pacific conditions to the South China Sea.

Consistent with previous work on the *Kuroshio meander*, we found that the impact of high-frequency wind on the Kuroshio path was due to a nonlinear response of an anticyclonic eddy within the Shikoku recirculation gyre. It appears that the high-frequency, high-wavenumber wind perturbs the thermocline depth of the eddy through local Ekman pumping. In another project, analyses of historical hydrographic observations of the *subtropical North Pacific circulation* showed that 3 subsurface fronts are primarily the result of water masses with low

potential vorticity just north of the fronts.

The *production of enhanced datasets of oceanographic variables* for use in climate studies is a very important part of research under this theme. Our development of a combined mean, surface-current and sea-surface-height data set, with a resolution high enough to capture the fine-scale structure of the flow field, has been plagued by the poorly defined geoid. This year we included data from the NASA GRACE mission in our analyses, which greatly improved the estimate of the geoid. Figure 29 provides several examples from the data set. The detailed structure of the flow field is apparent even when averaging over a 10-year period.

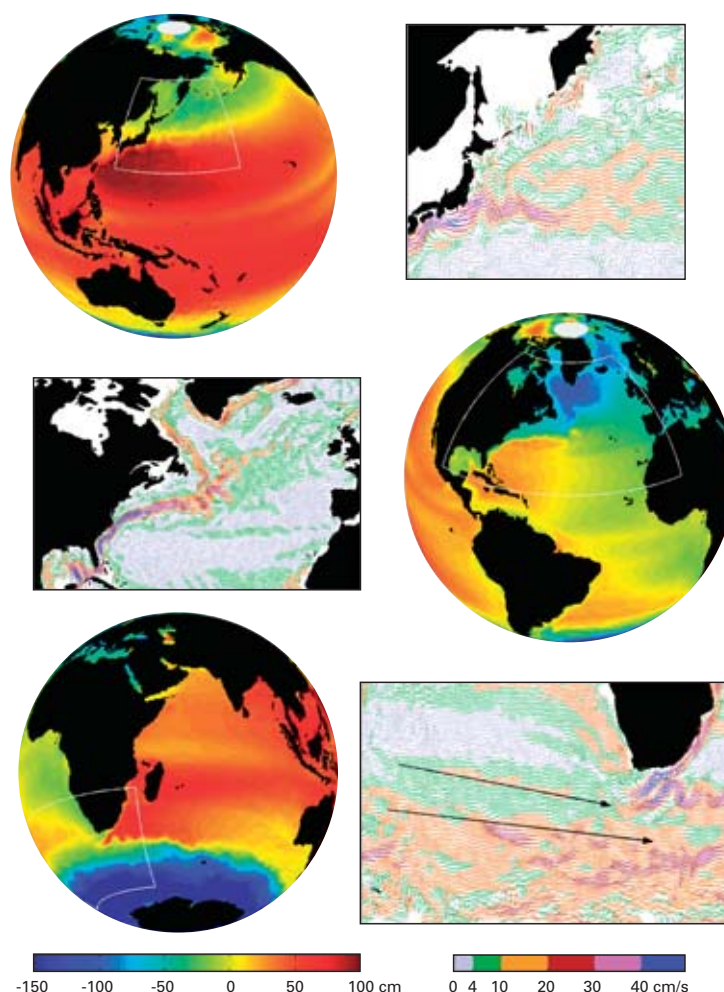


Fig.29 Maps of hybrid 1992–2002 mean sea level (globes) and mean surface velocity (rectangles) in the three strongest western boundary currents: Kuroshio, Gulf Stream, and Agulhas. Black arrows show branches of the South Atlantic Current. Velocity vectors in color are proportional to their magnitude and shown only where drifter data are available.

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Indeed, some jets, such as the Azores Current in the North Atlantic, have never been so clearly identified before. Other jets, such as a branch of the South Atlantic Current, do not follow previously proposed pathways. We will use the new dataset to explore upper-ocean dynamics and to compare it with output from high-resolution ocean models such as OFES.

c. Asian–Australian Monsoon System

Research under this theme is directed toward understanding the processes responsible for climate variability and predictability of the Asian–Australian monsoon system.

We have made significant progress in understanding the role of ocean–atmosphere coupling in the *Madden Julian Oscillation* (MJO) and the *monsoon intraseasonal oscillation* (ISO). A theoretical model successfully simulated the main characteristics of the MJO, pointing to the importance of friction-induced moisture convergence in the boundary layer in linking surface heat exchange, the motion of free tropospheric waves, and heating due to condensation. A series of experiments with a hybrid coupled model developed at the IPRC suggests that air–sea coupling is necessary for the realistic rainfall simulation of the summer ISO. In addition, implementation of a better convection scheme in a popular atmospheric GCM also improved ISO simulation. A third study revealed that the summertime ISOs over India, Indochina, and the South China Sea are not distinct components but interact with each other strongly.

Despite the climatic importance of *stratocumulus clouds* over such areas as the subtropical eastern Pacific Ocean, these clouds are poorly represented in most global atmospheric GCMs, and this deficiency may account for the models' failure to simulate the region's atmospheric and SST conditions realistically. This year's successful representation in the IPRC–RegCM of the complex physical processes and feedbacks that maintain this thin cloud deck and their sharp temperature inversion cap points to improvements for such cli-

mate models.

Studying *tropical cyclones* in the western Pacific, we verified in high-resolution satellite data two formation processes: a Rossby wave train induced by energy dispersion of a previous tropical cyclone, and energy accumulation of easterly waves in the confluence region between the monsoon westerlies and the easterly trades. Our ability to also simulate these two formation processes in a 3-dimensional cyclone model indicates we have a sound understanding of the physics underlying these cyclone formations. The findings are relevant to forecasting tropical cyclones.

Land-surface degradation alters the overlying atmosphere and may thus impact regional climate. We, have, therefore, been studying desertification and deforestation. China's efforts to replant desertified lands with forest and grasslands successfully depend on increase in rainfall, especially in its frequency. In a modeling study to investigate the effects of large-scale vegetation restoration, we found increased vegetation increased net radiation at the surface, total heat flux from surface to atmosphere, ascending motions over the test area, and moisture to the atmosphere. Rainfall, however, increased mainly in intensity, not frequency, indicating it will be difficult to maintain a vegetated surface in these regions without irrigation.

d. Impacts of Global Environmental Change

This theme centers on identifying the relationship between global environmental change and Asia Pacific climate. This year our projects have included investigations of climate sensitivity to radiative and land-surface perturbations, studies of global influence over regional climate variability, and development of high-resolution global atmospheric modeling. Much of this research is done in collaboration with other IPRC research teams and with colleagues at JAMSTEC and elsewhere.

To investigate *climate sensitivity* to temperature changes we are looking at the response in coupled models to changes in levels of solar radiation. Using

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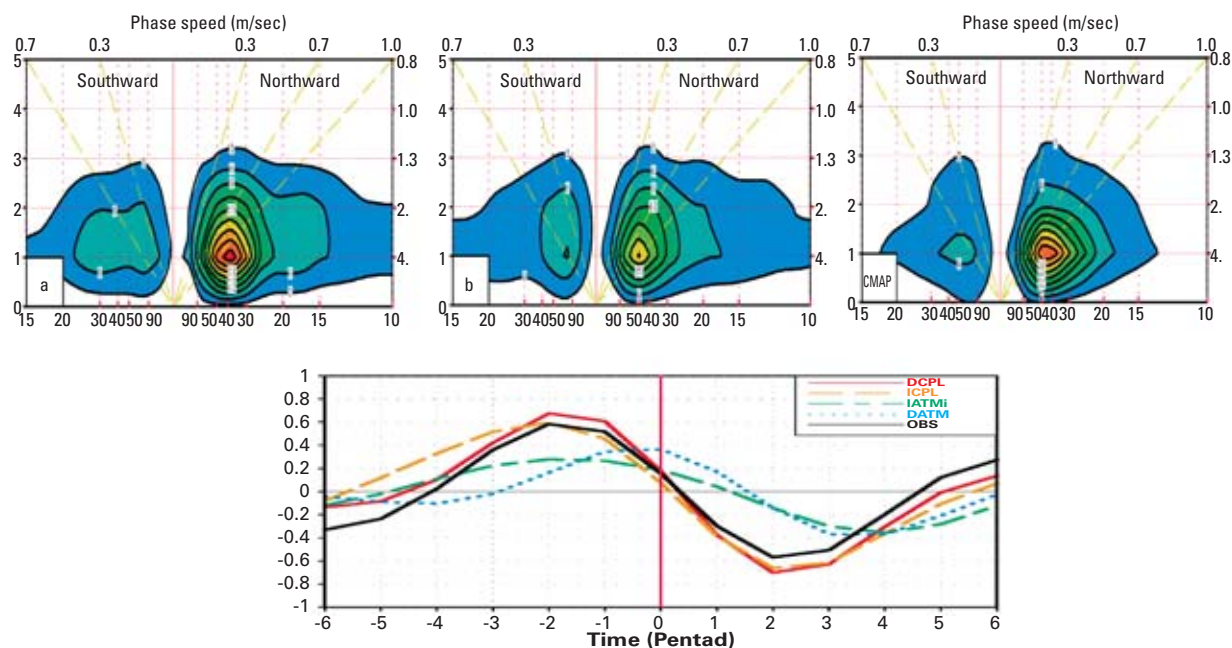


Fig.30 Plots from a coupled-model simulation of the Asian summer monsoon wet and dry spells.

Top panel: Rainfall variance [in (mm/day)²; contour interval = 3; red = 30; blue = 3] averaged over 65°E–95°E for north-south waves, ranging from about 1,300 km (wavenumber 3) to 4,000 km (wavenumber 1) and propagating within 10°S–30°N (left - coupled IPRC hybrid ocean-atmosphere GCM; middle - atmospheric GCM using sea surface temperature (SST) specified daily from the coupled model outputs; right - CMAP observations.) *Bottom panel:* Lagged-correlations between SST and rainfall anomalies at for observations (black, CMAP rainfall/Reynolds SST), coupled runs (red and yellow), and atmospheric GCM runs using SST specified as above (blue and green). The coupled model simulates realistically both the rainfall characteristics and the time relationship between SST and rainfall. Its superiority to the stand-alone atmospheric model points to the important role of ocean-atmosphere interaction.

NCAR's CSM1.4 coupled system, we varied the solar constant from its current value to a maximum increase of 45% (Figure 31). At roughly a 25% increase in the present-day solar constant, the model climate became unstable, warming indefinitely. Detailed diagnostics of the top-of-atmosphere radiative fluxes revealed that the main contributor to this "runaway" climate response is the decrease in shortwave albedo associated with low clouds. Currently, we are comparing long control and perturbed integrations with the NCAR CSM2 with results from similar integrations of two versions of the Canadian Climate Center coupled model. In another climate sensitivity project, we are studying the effects of global warming on tropical cyclone climatology in the western Pacific. Specifically, we are using the IPRC-RegCM to assess how a warmer climate will affect tropical cyclone occurrence in the eastern Pacific.

In a study of *global influence*, we have been analyzing results from a global atmospheric GCM and observations to determine the effects of stratospheric interannual variations on the wintertime, Northern-Hemisphere surface circulations. This work has successfully simulated the Northern Hemisphere circulation anomalies in response to the large 1991 Mt. Pinatubo volcanic eruption. Recently we included the quasi-biennial oscillation (QBO) in the tropical stratosphere. We now plan to simulate the effects of the QBO on the seasonal mean tropospheric circulation and to compare these effects with long-term observations.

Regarding the development of *high-resolution atmospheric models*, colleagues at the Earth Simulator Center have conducted a series of simulations at different resolutions with the AFES. We are collaborating on analyzing these integrations to document wind

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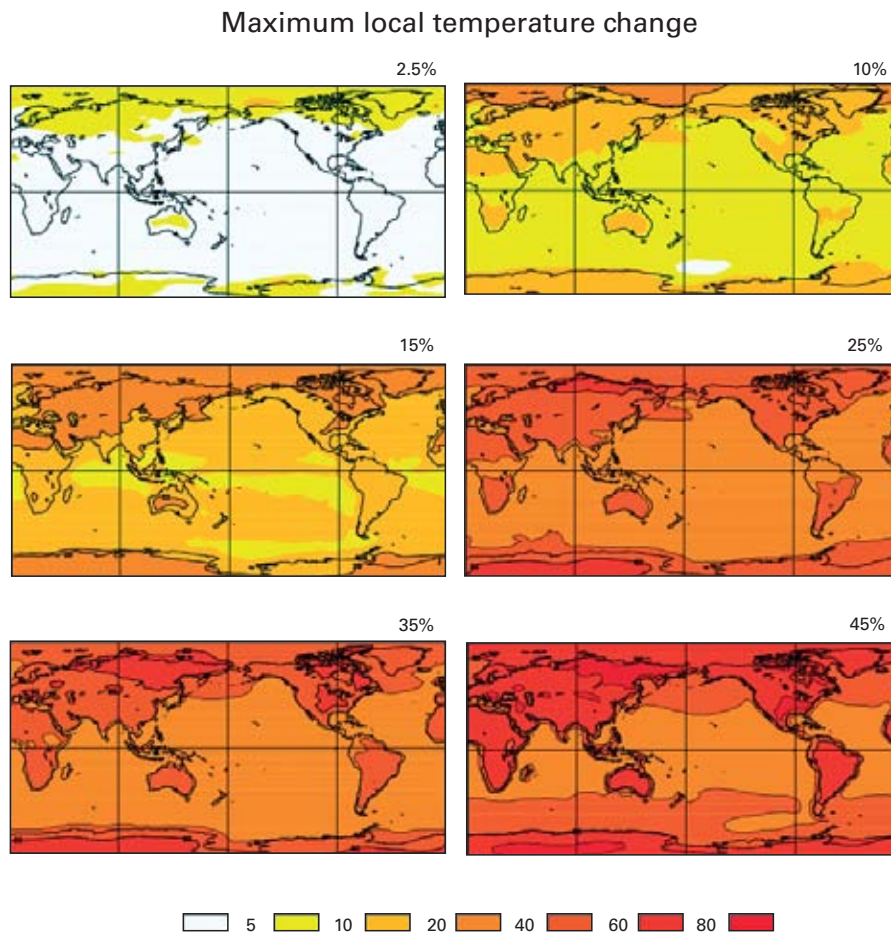


Fig.31 The warming of the annual mean surface temperature in a series of six global warming experiments performed with the NCAR Climate System Model Version 1.4. Each experiment is run with the incident solar flux increased over the actual value (by 2.5%, 10%, 15%, 25%, 35% and 45%). The color bar is labeled in °C.

and temperature variance spectra, and the dependence of these spectra on the model's vertical resolution, horizontal subgrid-scale diffusion, and moist convection parameterizations. Results show that AFES can simulate a realistic spectrum over three decades of horizontal wavelengths, including the shallow mesoscale regime that has been observed in the real atmosphere at horizontal wavelengths less than about 500 km. We are now analyzing implications of the high-resolution results for subgrid-scale parameterization in more modest resolution models.

e. The Asia-Pacific Data-Research Center (APDRC)

One goal of the APDRC is to provide easy access to climate data and products. This year, the APDRC has

progressed in its ability to handle and serve extremely large data sets from large-scale, high-resolution models (*e.g.*, OFES), and to serve data from various sources and with different formats (gridded and non-gridded data, *in situ* and remote observations, *etc.*).

We have increased APDRC data holdings in three areas: (1) extremely large ocean model data sets, which includes several OFES products at 0.1° resolution (restricted for use only within the IPRC) served through the GrADS distributed data-system server, and daily output from the 1/16° NLOM "nowcast" and "forecast" runs; (2) *in situ* oceanographic data, which includes JAMSTEC Argo data, WOCE *in situ* data, and FNMOC/GODAE profile data; software to search specific atlases and display results, such as the Java

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Ocean Atlas, HydroBase2 and Ocean Data Viewer, are all now available at the APDRC; (3) atmospheric data, which includes satellite observations of rainfall (TRMM, GPCP, *etc.*), SST (NOAA) and lightning (LIS), as well as historical measurements of *in situ* rainfall at various stations in Asia. We have also added high-temporal resolution ECMWF data, ERA-40, to the data-center archive.

The server capabilities now provide straightforward access, subsampling, comparison, and analysis of data. For example, for comparison purposes, one can easily make plots of the August mean SST and upper-layer velocity from OFES and of August 2003 mean conditions from the NLOM.

As part of the MEXT's, *Kyosei* project and the Integrated Modeling Research Program of FRSGC (under Professor Toshiyuki Awaji), the APDRC staff

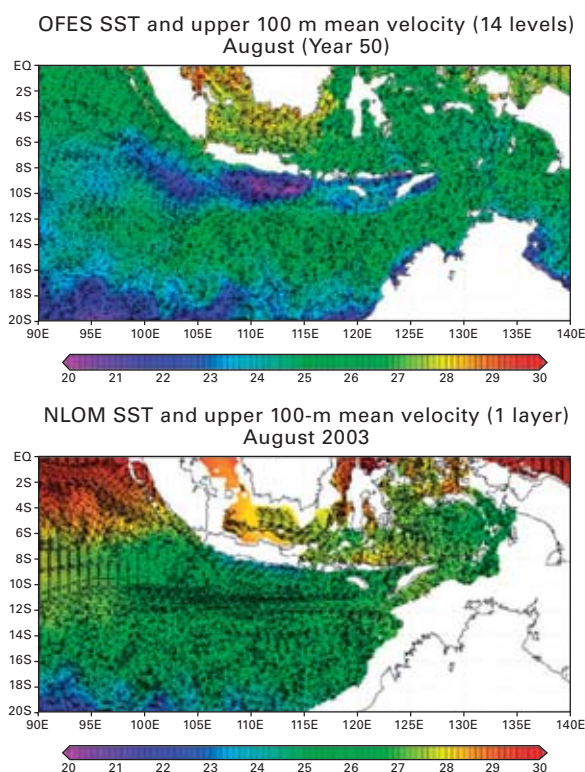


Fig.32 This figure was made using the APDRC GDS and shows a comparison of simulations of the Indonesian region in two global ocean models. Both panels show upper-ocean (surface to 100 m) flows and temperatures (shading). The upper panel is from the OFES for the mean of August, and the lower panel is from the Navy Layered Ocean Model (NLOM) for August 2003.

assisted with setting up an international data network for the project by identifying and collecting global ocean, atmosphere, and land-surface data, by providing quality control and value-added information, and by conducting data analyses. Among other things, we have given technical assistance to our Japanese partners in setting up FRSGC servers in Yokohama as server sisters. A "sister server" system among servers at Frontier, the APDRC, and the US GODAE Monterey now gives the ability to access huge data sets that are distributed among these servers as if they were on a single server.

8. International Arctic Research Center (IARC)

a. Ocean-Ice-Atmosphere Coupled Climate System

a-1. Ice-Ocean model development

In 2003, Model development research activities has been carried out in both IARC and Yokohama Institute for Earth Sciences. We developed close relationship between IARC and Earth Simulator research groups.

By using an ideal ocean-sea ice model, detailed processes of transport and dispersion of brine produced on continental shelf has been examined in order to have better understanding of the processes and better parameterization of bottom boundary layer in GCM. An example of the results from basic simulation is shown below (figure 33).

The model domain is 300 km × 300 km with water depth from 30 m to 300 m. Salt flux was introduced at

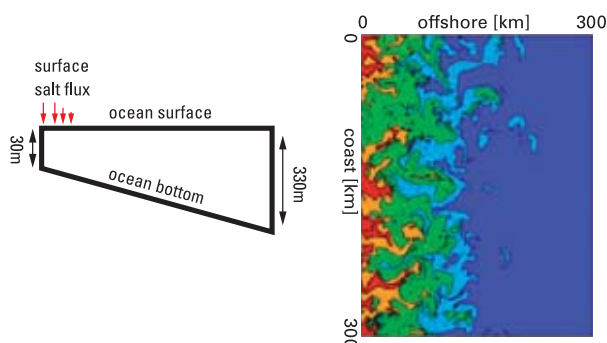


Fig.33 Horizontal salinity of bottom layer in case of surface salt flux ($110.0 \times \exp(-4) \text{ kg/s m}^2$) forcing at day 100. Red (blue) corresponds to high (low) salinity.

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30 m water depth region in order to express brine rejection during sea ice formation. Instability and meandering induced by brine was studied by using idealized modeling. In this study, turbulence due to salt from brine was spread up to 150 km offshore. The mean diameter of meanders was about 10 km (figure 34). Meso-scale movement of sea ice (especially due to tidal forcing) and deformation were observed by using GPS positioning system in sea ice field. By analyzing results and model simulation, better parameterization has been studied for internal stress in multi-year

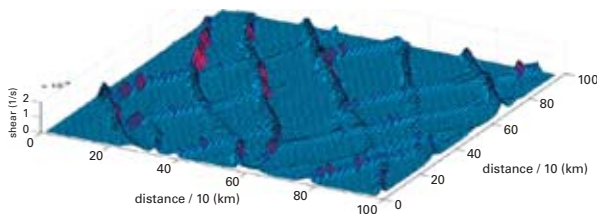


Fig.34 Internal shear obtained from idealized sea ice deformation model.

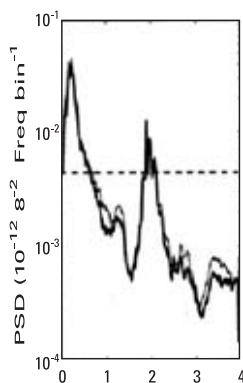
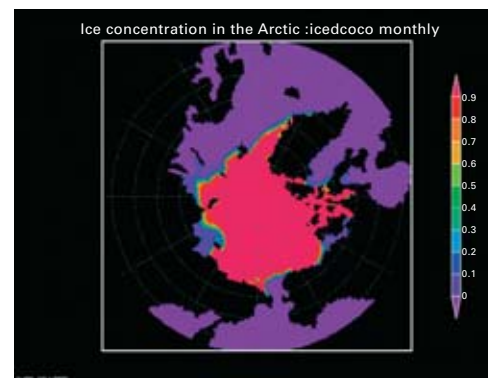


Fig.35 Comparison between observation and model with inertia.



March



September

Fig.36 Sea ice distribution in March and September from model calculation.

ice (figure 35).

Arctic atmosphere-ice-ocean coupled model developed at IARC has been successively introduced into Earth Simulator and has been producing various test results. Although validation and further tuning have to be carried out, at a glance sea ice distribution in March and September from model calculation is in reasonably good agreement to the observation (figure 36).

a-2. Mechanism and Prediction of Multi-decadal Climate Variability

By using hydrochemistry data, temporal and spatial change in fresh water distribution and abundance has been studied. The relationship with atmospheric forcing is identified to study for better understanding of ocean and atmosphere interaction. At first, we developed to differentiate fresh water from its sources by using alkalinity and salinity relationship. The result is in very good agreement to the conventional isotope technique. Hydrochemistry data atlas compiled at IARC under the close collaboration with AARI, Russia, has been analyzed and river water and sea ice melt water (negative values represent water removal due to sea ice freezing) portions in sea water have been obtained. In the figure 37, the averaged distributions for last 60 years are shown. We plan to examine the distribution change in AO and NAO regime changes in the next fiscal year.

In Barents Sea, the position of sea ice edges has

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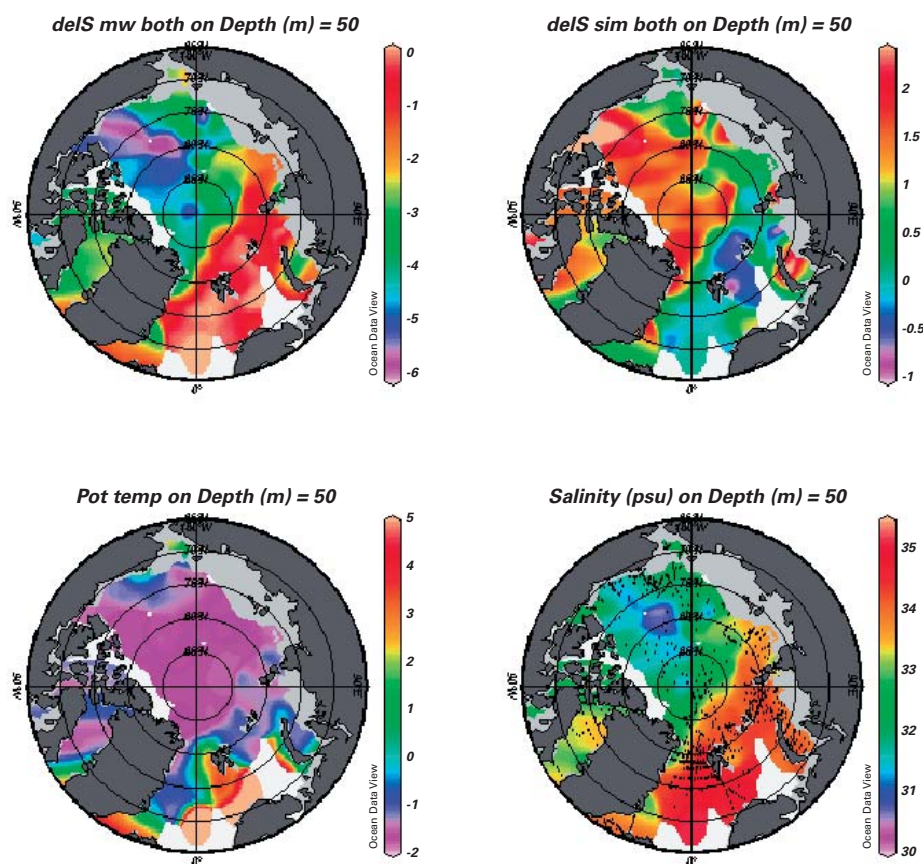


Fig.37 Mean distribution of river and sea ice melt waters in the last 60 years in Arctic Ocean (the data source is IARC hydrochemistry atlas)

been observed since early 1900s. we compiled these historical data and analyzed for temporal change. the preliminary results showed northward shift of the edges, indicating warming of the region. Long-term variation similar to the atmospheric temperature was also identified.

In Arctic Ocean, the observation data has been very limited. We developed the data assimilation technique by using limited current and hydrographic data in order to obtain consistent distributions of temperature, salinity and current from ocean circulation dynamics (figure 38). This technique has great potential to provide data set to examine Arctic ocean response to the climate in theoretical manner.

The above figure 39-A shows observed April mean temperature and current (red arrows) from drifter buoys at 40 m water depth in Barents Sea. In figure 39-B, Temperature obtained from the data assimilation

technique is shown. In figure 39-C, current distribution obtained from this method and mooring current meters (red arrows) are shown. It clearly shows that current meter results from limited position have very limited information to obtain regional mean current field. At present, by using this technique, mean sea surface height is tried to reconstruct.

b. Arctic Physical-ecosystem Coupled Model Development

In order to simulate ecosystem at high resolution in Bering Sea, MITGCM has been introduced. The maximum horizontal resolution is 4.4 km. Number of vertical layers are 38 including 4 layers with 6 m thickness in the surface. In the simulation, Hibler-type sea ice model is employed and NCEP reanalysis data is given as atmospheric forcing of the model.

Figure 40 shows sea water temperature at 9 m water depth on April 1. The temperature values are quite

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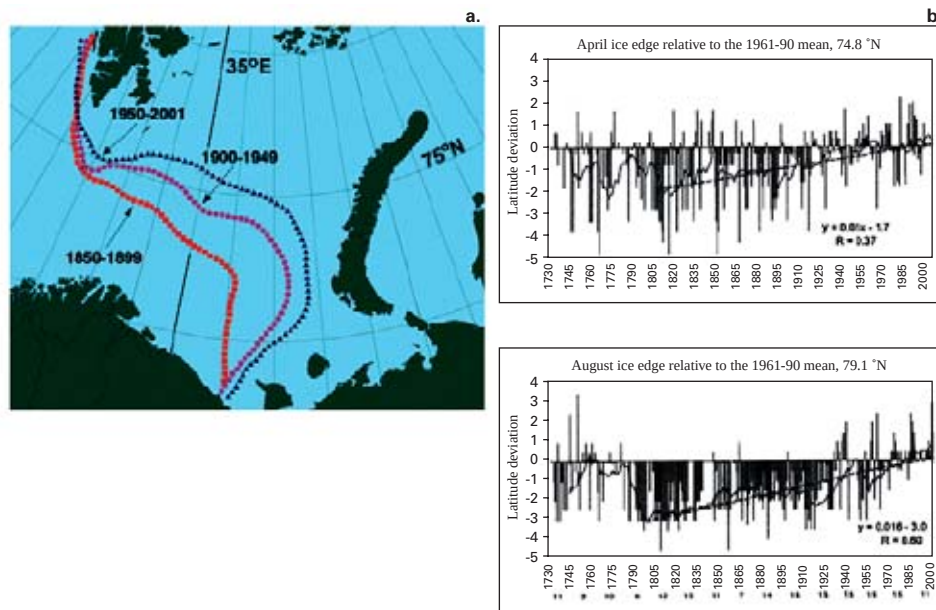


Fig.38 Sea ice extent exhibits variability on multiple time scales – the annual cycle, interannual and decadal variability, and long-term variability. (a) 50-year averages of late winter (April) ice edge position in the Barents Sea. (b) Latitude of late winter (April) and mid-summer (August) ice edge in the neighborhood of 35°E longitude. Annual positions have been smoothed by a 15-year filter.

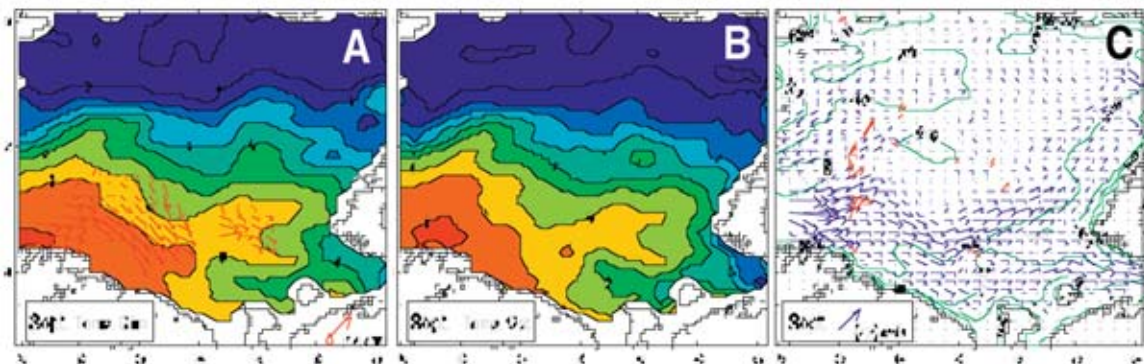


Fig.39 A: observed April mean temperature and current (red arrows) from drifter buoys at 40 m water depth in Barents Sea. B: temperature obtained from the data assimilation technique C: current distribution obtained from this method and mooring current meters (red arrows).

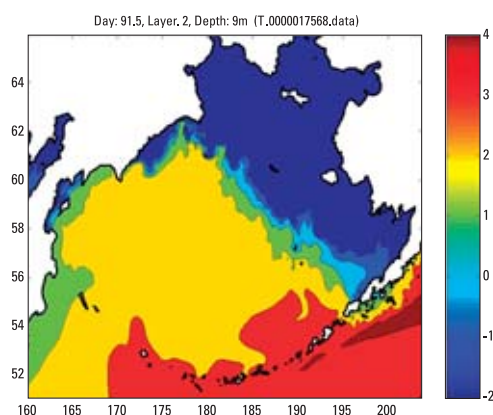


Fig.40 sea water temperature at 9 m water depth on April 1.

normal and meanders on shelf and shelf edge are well reproduced.

Current distribution at 112 m depth in Bering sea (figure 41 left) and sea ice distribution (figure 41 right) on April 1 are also very good agreement with the observation. By coupling above physical model to ecosystem model developed at IARC, chlorophyll a, phytoplankton and zooplankton distribution are simulated. The validation site for this simulation is selected at NOAA mooring station in south of Bering shelf. In this simulation, the meteorological data observed by

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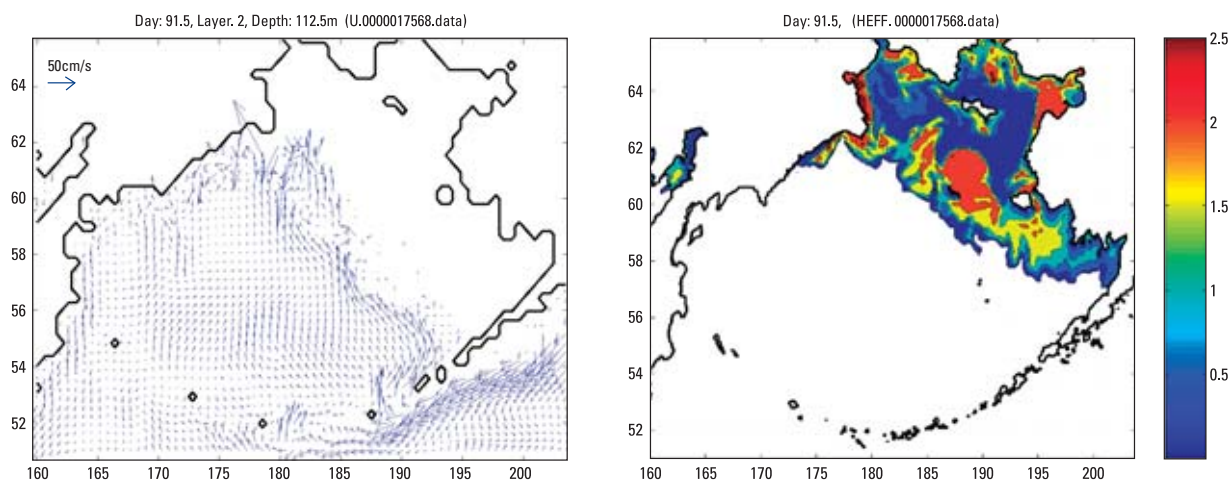


Fig.41 Current distribution at 112 m depth in Bering sea (above left figure) and sea ice distribution (above right figure) on April 1.

the mooring is employed for forcing the model.

The results shown in figure 42 shows plankton blooming in spring time is well reproduced by the model, although the start of the blooming is somewhat earlier in the model simulation. The model failed to reproduce the third blooming peak but showed fourth blooming in the late summer season. The reason for failing to catch third peak is believed that zooplankton grazing pressure is too strong in the model. It is obvious that the field evaluation of zooplankton grazing pressure has to be carried out.

Research Project for Sustainable Coexistence of Human, Nature, and the Earth

Since 2002, Ministry of Education, Culture, Sports, Science and Technology (MEXT) started new strategies to promote science and technology. The "Research Project for Sustainable Coexistence of Human, Nature, and the Earth", shortly called *Kyosei* project is included in the area of "Environment" as larger new initiative of the MEXT named "Research Revolution 2002 (RR2002)". The period of the Project is 5 years. Among seven subjects of the Project, FRSGC has been carrying out the whole or part of the following three subjects.

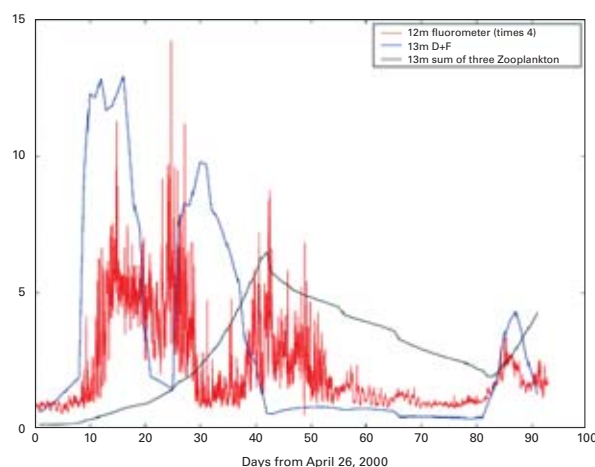


Fig.42 Plankton blooming in spring time reproduced by the model.

Subject 1: Future Climate Change Projection using a High-Resolution Coupled Ocean-Atmosphere Climate Model

The aim of this project is to conduct a series of future climate change projection experiments using a high-resolution coupled ocean-atmosphere climate model on the Earth Simulator, for reducing and understanding the uncertainty of the projection. The project team consists of members of Center for Climate System Research of the University of Tokyo (CCSR), National Institute for Environmental Studies (NIES), and Frontier Research System for Global Change (FRSGC), and directed by Prof. Sumi of CCSR. The climate model used is called MIROC and has been

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collaboratively developed by CCSR, NIES and FRSGC. The advantages of a high-resolution coupled model include better representation of atmospheric disturbance, which is relevant to extreme events such as heavy precipitation, and better representation of complex current system of the ocean, especially that over the northern North Atlantic related to the thermohaline circulation. The experiments to be performed include a control run, an idealized climate change run with 1%/year CO₂ increase, a run for reproducing 20C climate, and some 21-22C scenario runs. The project includes the following four subjects:

- a. Development of a high-resolution coupled ocean-atmosphere climate model,
- b. Designing future climate change projection experiments based on IPCC SRES scenarios,
- c. Development of component models for the climate model, and
- d. Advancing the climate model of Hadley Centre, UK.

Since the members of FRSGC are, in principle, involved in the first subject, the activity of only that part is introduced herewith.

a. Sub Group for the Development of a High-Resolution Coupled Ocean-Atmosphere Climate Model

The resolution of our model is T106 (approximately 1.1°), 56 levels for the atmospheric part and approximately 1/4° × 1/6°, 48 levels for the oceanic part. To complete major experiments in time for the first lead-author meeting of IPCC 4th assessment report (September 2004), our work in the fiscal year 2003 has been devoted mainly to the improvement and evaluation of the high-resolution coupled climate model, whose pilot version has been developed in the fiscal year 2002.

(i) Zero-order Experiments with the High-resolution Coupled Model

After a few serious problems in the pilot version coupled model being fixed, a 56-year control experiment with constant CO₂ concentration and a 40-year climate

change experiment with CO₂ concentration increased by 1%/year compounded have been performed. It has been shown that the model, which does not use 'flux correction', can be integrated stably for tens of years without any serious climate drift, though some SST errors to need improvement are identified. The response of the model to increased CO₂ concentration is qualitatively reasonable. Quantitatively, however, increase in global mean 2 m temperature by 1.5 K in 40 years seems to be too high compared with the other existing model results.

(ii) Improvement and Evaluation of the High-resolution Oceanic Model

Since the horizontal resolution of the oceanic model is not sufficient to resolve meso-scale eddies in higher latitudes, a thickness-diffusion parameterization (Gent-McWilliams) has been introduced only in high latitudes. It suppressed the wrongly represented eddy activities in the higher latitudes, resulting in better representation of stratification, sea-ice formation and bottom water formation especially around the Antarctica. The turbulence closure scheme has also been improved, resulting in a more realistic distribution of surface mixed layer and SST.

(iii) Modification of Cloud Processes Related to Climate Sensitivity

The version of the atmospheric model used in the zero-order coupled model runs has very high climate sensitivity (~10°C). We have modified the liquid/ice partitioning of cloud and revised the treatment of melted cloud ice (the melted cloud ice should be large particles and should turn into rain rather than small cloud water particles). Then, the climate sensitivity is successfully reduced to a reasonable value (~3.7°C). There is actually a very large uncertainty in the estimation of climate sensitivity and a very high value cannot be rejected by observational constraints. However, we have at least understood a part of the mechanisms that strongly affect climate sensitivity in our model.

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(iv) Evaluation of the High-resolution Atmospheric Model

An AMIP-type run (with the observed SST for 1979-1998) and a time-slice $2 \times \text{CO}_2$ run (with the same observed SST plus distribution of SST change due to $2 \times \text{CO}_2$ estimated by a lower-resolution coupled model) of the atmospheric model have been performed and analyzed. A good reproducibility of daily precipitation intensity, tropical cyclones and convective activity coupled with equatorial waves are confirmed. An enhancement of intense precipitation in a $2 \times \text{CO}_2$ climate is projected. It is also shown that some suppression mechanism of cumulus convection plays an important role in representing realistic intensity of precipitation.

(v) Analysis of the Hawaiian Lee Counter Current in the coupled model

The Hawaiian Lee Counter Current (HLCC) is clearly found in the model. It is analyzed as a good example of phenomena unique to a high-resolution coupled ocean-atmosphere model. When the mountains over the Hawaiian Islands are removed in the model as a sensitivity experiment, HLCC disappear. It suggests that the atmospheric response to the mountains is necessary to maintain HLCC.

Subject 2: Development of Integrated Earth System Model for Global Warming Prediction

a. Development of a Coupled Carbon Cycle – Climate Change Model

a-1. Terrestrial Carbon Cycle Model

The objective of this group is to develop a model that estimates carbon budget of terrestrial ecosystem, which may exert short- to long-term effects on atmospheric carbon dioxide concentration. This model will be built in the integrated earth system model and should allow us to predict the global climate change induced by the anthropogenic greenhouse effect gases. In the FY 2003, this group has conducted the following three subjects:

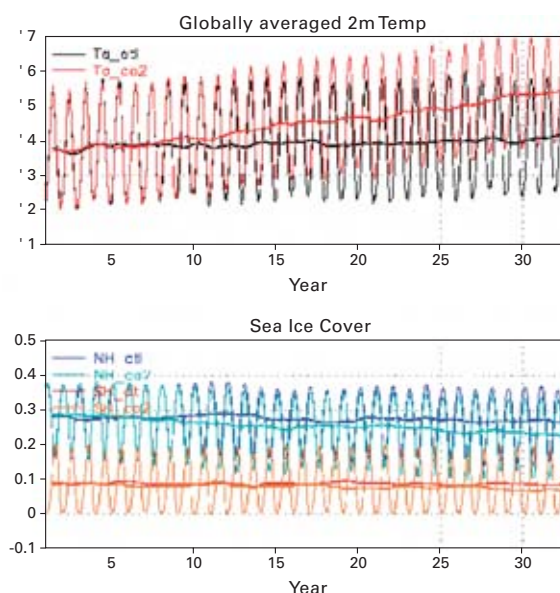


Fig.4.3 Global mean 2 m temperature (upper) and hemispheric mean sea ice cover (lower) in the zero-order control and climate change (1%/year CO_2 increase) runs.

(i) The Offline Assessments of the Sim-CYCLE

To investigate the response of terrestrial carbon budget to the future climate change, the offline simulations were performed, in which the Sim-CYCLE was forced by several climate scenarios (SRES A2 and B2) derived from GCM simulations. The results showed that plant biomass and soil carbon increased gradually in any GCM-scenario sets in the 20th century, however in the 21st century, terrestrial carbon responded significantly to global environmental change, with remarkable differences among the climate scenarios. Additionally in more detailed analysis, these differences were found to be originated by the differences in the temperature input data, derived from the climate models.

(ii) The Built-in of the Terrestrial Model to the AGCM

To integrate the terrestrial carbon cycle and the climate system, the Sim-CYCLE is combined with the CCSR/NIES GCM (including MATSIRO). Figure 44 shows the carbon dynamics of the global terrestrial ecosystem in the preliminary simulations with Sim-CYCLE-MATSIRO-AGCM coupled model. NEP showed adequate seasonal changes consistently with the GCM climate fields (Figure 44a). Applying the

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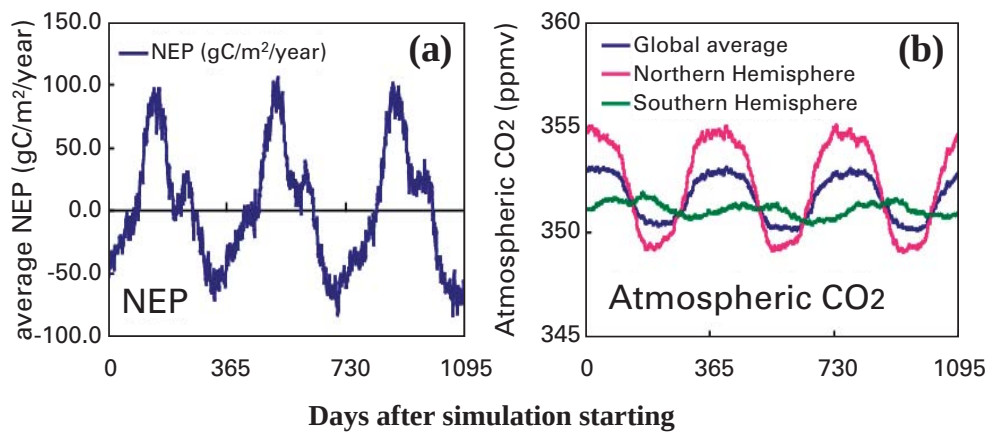


Fig.44 Carbon dynamics of the global terrestrial ecosystem in the preliminary simulations with Sim-CYCLE-MATSIRO-AGCM coupled model in (a) net ecosystem production (NEP) and (b) Atmospheric CO₂. Simulations are conducted in the integrated model run, after the 2000 years spin-up of the Sim-CYCLE run. Data are shown for the initial three years of the simulations.

land surface CO₂ budgets in the wind fields derived from the GCM outputs, atmospheric CO₂ concentrations present reasonable seasonal changes in the north hemisphere; summer increasing and winter decreasing (Figure 44b).

(iii) The functional expansion of the Sim-CYCLE for the participation to the integrated model intercomparison project

Interactions between climate and the carbon cycle have the potential to provide major feedbacks on climate change, but major uncertainties in the magnitude of these feedbacks persists. Several climate research institutes of the foreign countries promote the coupled climate-carbon cycle model intercomparison project (C⁴MIP) that aims to investigate the plausible sensitivity range of the climate-carbon cycle system by using a number of independent models driven by a common set of forcings. This group now proceeds the cording operation for that installation of the land use change components according to the guideline.

In the next fiscal year, this group will promote: (i) the validation of the Sim-CYCLE with the field and satellite measurement data for improving the parameterization, (ii) the interface maintenance and the vali-

dation of the integrated model for improving the affinity between Sim-CYCLE and MATSIRO-AGCM, and (iii) the development and simulation runs of the integrated model for the C⁴MIP.

a-2. Development of an Oceanic Carbon Cycle Model

Precedent to the inclusion of the carbon cycle to our coupled climate model, a preliminary experiment for future uptake of CO₂ by the ocean is carried out using an ocean-only model with carbon cycle processes. The model is forced with and without the effect of global warming using results from a coupled climate model. The CO₂ concentration is increased in both cases by 1%/year after 1990. The focus is on the differences in time evolution of the uptake between the two cases, which turn out to be small (Figure 45). The present result is not something that attracts many people's

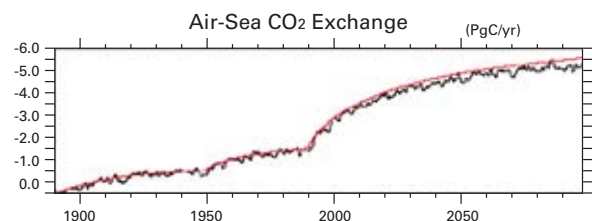


Fig.45 Model projection of future CO₂ uptake by the ocean under CO₂ increase of 1%/year after 1990. The red line represents the result where the model is forced without the effect of global warming, and the black line with it.

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attention in that it only confirms the result of past experiments reported in the IPCC Third Assessment Report, but it is meaningful for the project in that it assures that the model shows a plausible behavior.

Following the experiment with the ocean-only model, we have embarked on the incorporation of oceanic and terrestrial carbon cycle processes into our coupled climate model. A prototype of a coupled carbon cycle climate model is now completed. Parameter tuning, code tidying, and sufficient spin-up etc. will be further conducted to prepare for the "Coupled Carbon Cycle – Climate Model Intercomparison Project (C⁴MIP)" and contribution to the IPCC Forth Assessment Report.

a-3. Development of an Integrated Terrestrial Ecosystem Model for Global Changing Prediction

While climate condition can strongly influence terrestrial ecosystem, it can also affect the climate, particularly through changes in evapotranspiration, carbon cycle, and albedo. Thus, for providing reliable predictions for the change of global climate, integrated terrestrial ecosystem models that include biogeochemical processes and vegetation dynamics would be required.

To fulfill this need, we are developing a Dynamic Global Vegetation Model (DGVM) that can simulate changes in ecosystem functions (ex: carbon and water flux) as well as ecosystem structures (ex: distribution and composition). This model links several modules, which have different computation time steps. Some of the modules are functions of environmental factors, letting the model simulate ecosystem responses according to environmental changes.

Because spatial hetero-structure plays a central role in vegetation dynamics, this model explicitly treat forest 3D structure using individual-basis modeling approach (Figure 46). Simulation will be conducted on the T42 global grid (128 × 64), each of which includes 10 replication forest stands. Thus, assuming 1/3 of the earth surface is terrene, about 27,000 independent forest stands will be independently simulated.

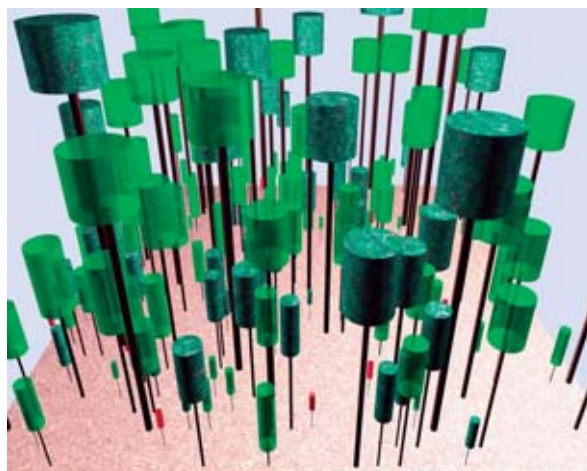


Fig.46 A snap shot of the simulated forest stand (30 m × 30 m of template mixed-forest). Individual tree is composed of top, stem, and root. Shape of crown and stem are approximated by cylinder. Simulation will be conducted on the T42 global grid (128 × 64), each of which contains 10 replication forests stands.

To date, this would be the most complex ecosystem model that have ever made. It should be noted that the vast computation power of the Earth Simulator capacitates this project.

By FY 2003, coding of one-point simulator was almost completed. We are currently estimating parameters through test running of the program. After vectorize, parallelize, and tuning, we will conduct simulation experiment on global grid within FY 2004.

b. Development of a Coupled Stmospheric Composition – Climate Change Model

b-1. Accurate Estimate of Feedbacks on the Global Warming through Interactions in the Cloud –Aerosol –Radiation System

The subgroup "coupled atmospheric composition-climate model" aims at simulation and prediction of atmospheric chemistry (involving tropospheric/stratospheric ozone) and aerosol processes and their interaction with climate change and ecosystem change in the framework of the FRSGC integrated model, Kyosei Integrated Synergetic System Model of the Earth (KISSME). This fiscal year, we started developing a chemistry-aerosol coupled climate model on the

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Earth Simulator using a global chemistry model CHASER (Sudo et al., 2002) and aerosol model SPRINTARS (Takemura et al., 2000) which are both based on the CCSR/NIES AGCM. Since the chemistry component in CHASER, including 53 chemical species and 140 photochemical reactions in its present configuration, requires much computational time relative to the default AGCM, optimization of the CHASER code is also our critical issue in view of our planned long-term simulations on the Earth Simulator. This fiscal year, we tuned the code of the CHASER chemistry component prior to coupling the aerosol component of SPRINTARS with CAHASER. Owing to our tuning, the total CPU time required for the all processes in CHASER (including dynamics and physics) decreases by 35% on the Earth Simulator. We have also performed future simulations of tropospheric ozone with CHASER, focusing on the impacts of future climate change on tropospheric chemistry. Our simulations show that future tropospheric ozone distributions and budgets can be modulated significantly by climate change influences such as water vapor increases and large scale atmospheric circulation changes. In addition, we have evaluated the transport process (especially in the stratosphere this fiscal year) in the CCSR/NIES AGCM. We calculated distribution of age of air, a good measure of cross-tropopause and stratospheric transport, and evaluated it with the observation derived age distribution. The observed air age is well reproduced by the model in the tropics, but is underestimated in the extra-tropics.

b-2. Global Warming – Precise Assessment of Feedback between Cloud, Aerosol Particles and Radiation

The assignment of this group is to develop the parameterization estimating the indirect radiative forcing of aerosol particles for GCM. Two kinds of parameterization (Abdul-Razzak et al., 1998 and Kuba, 2003) to predict the number of cloud droplets are installed to the CCSR/NIES/FRONTIER AGCM with SPRINTARS

(Takemura et al., 2000, 2002). The global distributions of annual mean of cloud droplet effective radius are compared between model results and satellite data. The lack of knowledge about the performance of organic carbon particles as cloud condensation nuclei (CCN) leads to the underestimation of cloud droplet number. To improve the parameterization, the cloud resolving global/regional model is needed. To develop the cloud resolving global model, cloud microphysical model (bulk method) and radiation model (MSTRNX) are installed to NICAM. Besides, to develop the cloud resolving regional model, cloud microphysical model (2 moment bin method) is being installed to Cloud Resolving Storm Simulator (CReSS).

c. Development of a Cryospheric Climate System Model Sub – Group of Cryosphere Modeling

In order to investigate the influence of Global warming upon the Cryosphere, such as ice sheet and sea ice this group has worked on (1) an ice sheet model called ICIES (Saito and Abe-Ouchi, 2004) and (2) a GCM which is a coupled ocean-atmosphere-seaice model called MIROC, developed cooperatively with *Kyosei-1* and been running on the Earth Simulator. The ice sheet model, which is forced by temperature and precipitation was applied to the two major ice sheets, Antarctica and Greenland ice sheet. It has a resolution of 20 km to 40 km and successfully simulates the modern shape, flow and temperature of both ice sheets. The GCM which has a resolution of 2.8 degree latitude- longitude for atmosphere and 1 to 0.5 degree for ocean part, was used to estimate the change of temperature and precipitation over these polar regions as well as the sea ice distribution and it was forced with 1% per year compound CO₂ increase for 140 years followed with constant CO₂ level which is 4 times of present level (1380 ppm). It is shown that over Greenland, temperature increase due to doubling of CO₂ and quadrupling CO₂ were 4 and 8 degree C, respectively and they already cross the threshold that more than half of the ice sheet melts down after several hundred years. Over Antarctica, on

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the other hand, precipitation increase seems to cancel out or overcome the melting due to the warming. Since the result must be dependent on the climate sensitivity of GCM and also the expression of the North Atlantic Deep Water, we will repeat the analysis with other versions of our GCM which is now under investigation and also run our ice sheet model with the outputs of GCM as the next step. Also the work to couple directly the ice sheet model to GCM is in progress.

d. Improvement of the Physical Climate System Model

This sub-group aims at improvement of an AGCM used as a basic component of the 'Integrated Model'. The AGCM is based on the CCSR/NIES/FRSGC AGCM version 5.7b, which has been developed for the IPCC assessments, i.e., a main objective of 'Subject 1 of the *Kyosei* Project'. In order to predict long-term changes in chemical composition, e.g., stratospheric ozone, the model has been extended to include the middle atmosphere (up to about 80 km).

There has been a prominent shortcoming in the previous version of the AGCM. Temperatures near the tropopause had a large cooling bias by about 10 K, so that distribution of moisture and clouds was quite unrealistic. In order to look for causes of such biases, Mini-Project for Physical Process Intercomparison (MIPPI) was conducted as a cooperative effort with

Japan Meteorological Agency (JMA) and UK Hadley Centre. As a result, it was found that radiative heating rate near the tropopause was significantly underestimated in the previous version of our radiative transfer code "mstrn-8" (see Nakajima et al. 1995).

Very recently, a new version of radiation code "mstrn-X" was released by CCSR radiation group (please refer Ph.D thesis for University of Tokyo; Sekiguchi 2004), in which following improvements were made; 1) an update of HITRAN database for atmospheric absorption, 2) a replace of a program calculating continuum absorption (from LOWTRAN7 to MT_CKD_1), 3) a substantial increase of bands for calculations of atmospheric absorption, 4) a change in optimization method for a selection of integration points. The cooling biases near the tropopause and in the lower stratosphere are significantly reduced when the new radiation code is used (Figure 47). It is also found that appropriate tuning of orographic gravity wave drag parameterization is important to improve the temperature fields near the tropopause.

Other efforts performed in this fiscal year are an implement of a non-orographic gravity wave drag parameterization and an estimation of gravity wave source distribution by using a very high resolution version of the AGCM. The non-orographic gravity wave drag parameterization is required for a better simulation of

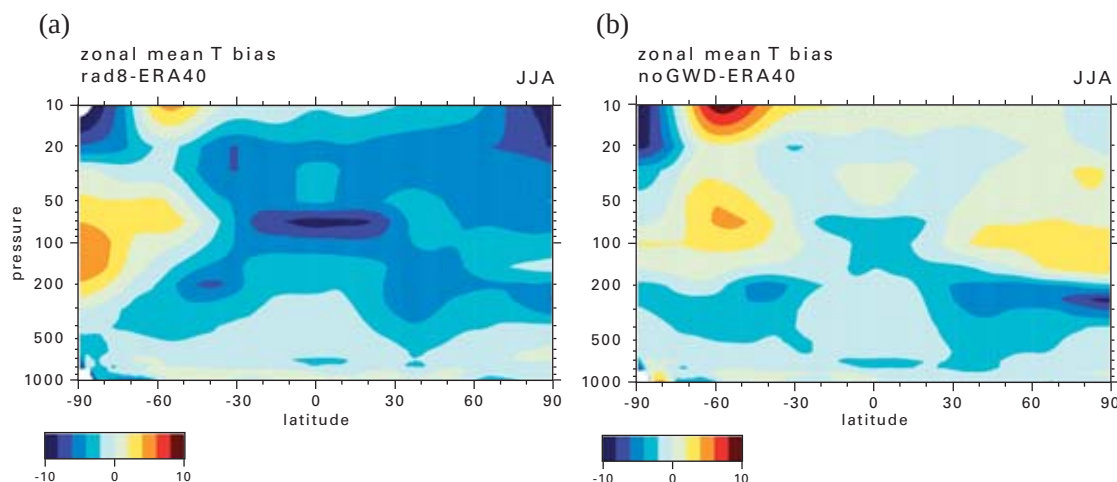


Fig.47 Zonal mean temperature biases [K]. T106L56 simulation using mstrn-8 (a), and mstrn-X without orographic gravity wave drag parameterization (b). See text.

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the middle atmosphere, because it represents effects of unresolved waves which accelerate/ decelerate large-scale wind fields. A "Doppler-spread" parameterization proposed by Hines (1997) is employed, because it has been well tested by various modeling groups.

Global distribution of horizontal RMS winds associated with small-scale (horizontal wave length: 250-1250 km) gravity waves are obtained from a T213L250 AGCM simulation. The RMS winds and propagation directions are derived using a hodographic method around 70 hPa, and averaged over a month.

Realistic characteristics of gravity waves are realized; 1) large wind variances and a dominance of westward propagation over storm tracks, and some localized maxima over mountainous regions in mid latitudes of winter hemisphere, 2) broad maxima corresponding to large-scale precipitation patterns in the tropics and mid latitudes of summer hemisphere, which reflect importance of source distribution, 3) minima in high latitudes of both hemispheres. By use of this source information with the Hines parameterization, realistic circulations in the tropics are realized with a middle resolution version (T42L78) of the model (not shown).

Subject 7: Research Development of Advanced Four-Dimensional Data Assimilation System Using a Coupled Atmosphere-Ocean-Land Surface Model Toward the Construction of High-Quality Reanalysis Datasets for Climate Prediction

The main objective of our project is to construct an innovative four-dimensional data assimilation system capable of providing a high-quality comprehensive dataset. Synthesis of observation data and state-of-the-art GCMs by the variational approach has the ability to produce a dynamically self-consistent 4-dimensional dataset. Such reanalysis datasets are extremely required for more accurate seasonal to inter-annual (S-I) prediction and for a better description of the dynamical state of the global warming and hydrological cycle. For example, CLIVAR in all its planning documents identifies data assimilation as a tool needed to

synthesize basin and global climate datasets as the basis for climate dynamics studies. This effort often referred to as "reanalysis" is focused on defining the time-varying state of the global climate through the assimilation of in situ and remotely sensed data such that the resulting fields are dynamically consistent with one another and with the model dynamics.

For this purpose, we have been striving to construct the 4-dimensional variational (4D-VAR) adjoint data assimilation (DA) system on a coupled atmosphere-ocean-sea ice-land surface model, which is designed to be a platform capable of providing greater information and forecast potential than earlier models.

In 2003, we (1) improved the coupled model, (2) completed the DA system, and (3) started experiments by the full-coupled data assimilation. In our assimilation system, the coupled model for the Earth Simulator (CFES), whose atmospheric component model originates from the CCSR/NIES model, is used as a numerical model. By conducting many modifications and tunings of the CFES, its physical performance is considerably improved. As a result, the familiar gross features of the global climate and its variability are reproduced very well. Using this improved coupled GCM, we have developed each adjoint model, particularly for ocean and atmosphere elements. Consequently, our climatological DA experiment exhibits more realistic features of climate variabilities than simulation experiments can do. These results confirm that our 4D-VAR coupled DA system is a powerful tool for the understanding and prediction of S-I phenomena.

In the following, the result of each sub-theme is briefly summarized.

a. Coupled Model Development

This group has successfully developed the CFES. For example, the IARC ice model is incorporated for more realistic reproduction of subduction processes. Also, the model incorporates the land parameterization scheme, MATSIRO, instead of the current one layer model so called "bucket model". Furthermore, many

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modifications and tunings of the CFES have been added in order to enhance the physical and computational performance. Figure 48 shows one example of the successful results. In many coupled models, it is well known that the precipitation over the tropical Pacific Ocean is too symmetric about the equator (so called "Double ITCZ") as is shown in Figure 48a. In contrast, such a "Double ITCZ" structure is significantly weakened in our result (without assimilation).

Another good example of the improved CFES can be confirmed in Figure 49 which demonstrates that both the spatial pattern and intensity of S-I variations in simulated SST are close to those of observations.

As for the land surface model, Figure 50 shows the spatial distributions of the Bowen ratio over land areas obtained in offline experiments using (a) the commonly-used Bucket model and (b) the new MATSIRO, for which the Global Soil Wetness Project (GSWP1) product was used as atmospheric forcing data. The value of Bowen ratio using the MATSIRO is much

larger than that using the bucket model and is similar to previous reports, suggesting a notable improvement in reproducing land surface processes by our system.

It should be noted that the 4D-VAR assimilation approach needs to be used in conjunction with sophisticated numerical models because the accuracy of the product obtained from the adjoint calculation greatly depends on the performance of the models. The above simulated results underline that the improved CFES is a good basis for the 4D-VAR coupled DA system.

b. Assimilation Experiments Using Each Component model

In 2003, we have constructed the adjoint code for each component model. Figure 51 shows the results of our 4D-VAR experiment for atmosphere in which the one-month averaged SSM/I sea surface wind speed data are assimilated. The difference between the observed wind speed data and the corresponding simulated values (Figure 51a) is considerably reduced in

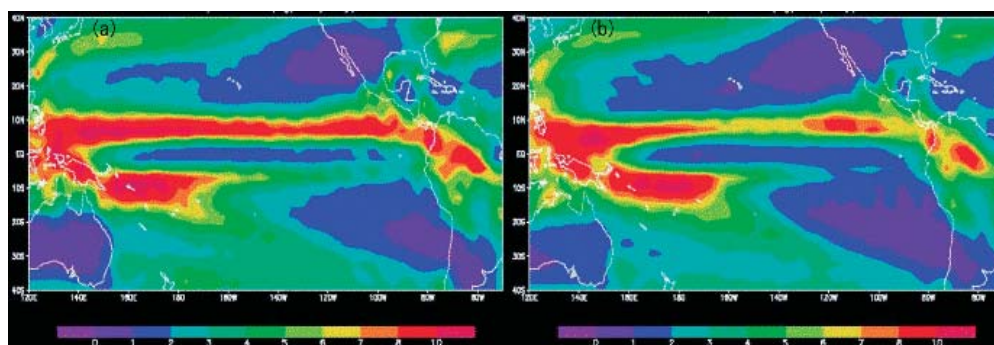


Fig.48 Precipitation over tropical Pacific Ocean from the CFES. (a) Before tuning. (b) After Tuning.

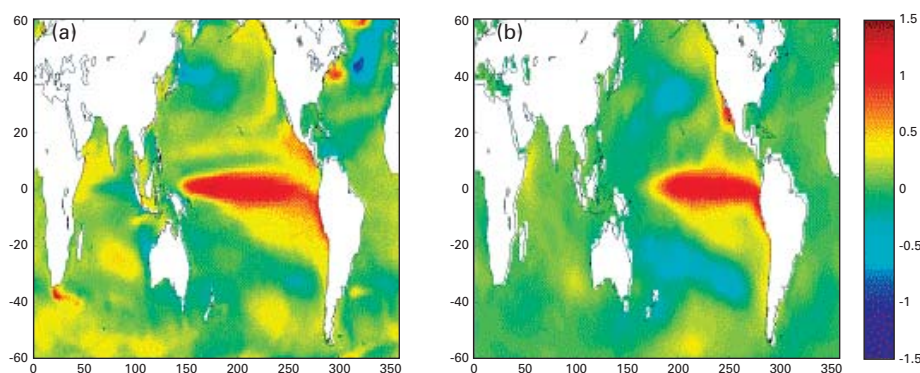


Fig.49 Linear regression of SSTs at each grid box against Niño 3.4 SST anomalies.
(a) From CFES. (b) From the observation (ERSST).

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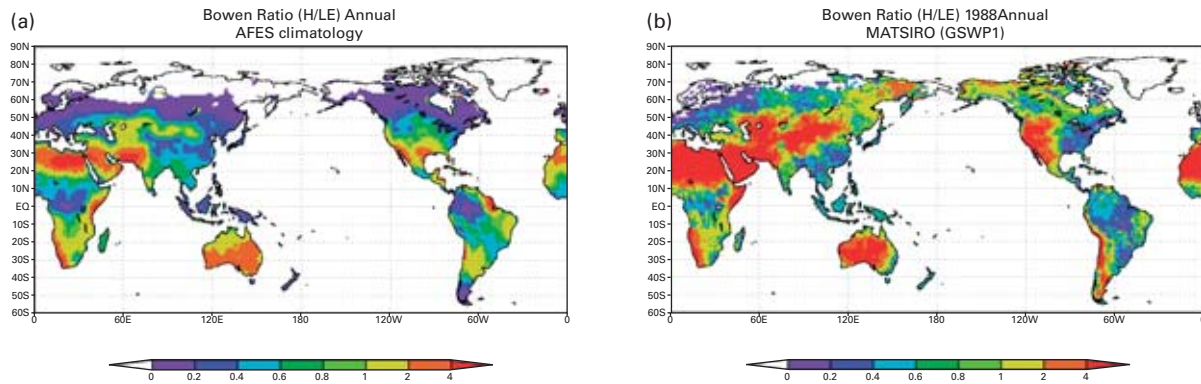


Fig.50 Annual mean climatology of Bowen Ratio over land areas.

(a) Bucket model case. (b) MATSIRO case.

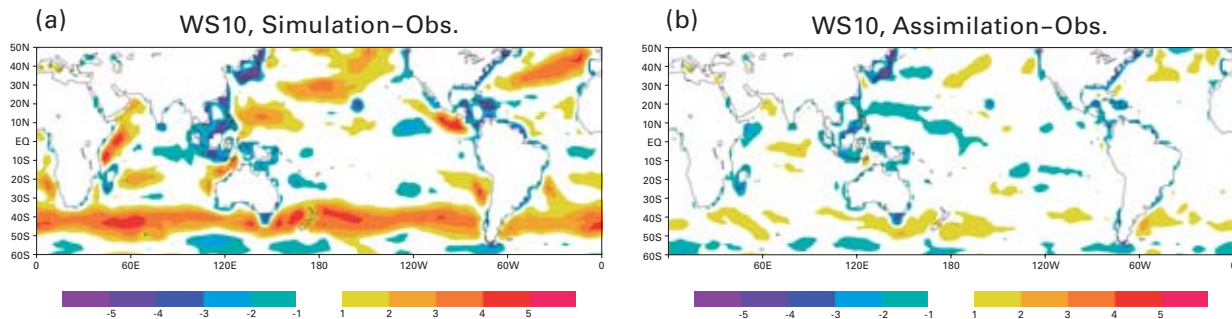


Fig.51 The difference of the 10m wind speed between (a) simulation and observation and (b) assimilation and observation.

the assimilation experiment (Figure 51b). This fact demonstrates that our atmospheric DA system can effectively correct the monthly-mean (beyond weather-mode) wind field.

Next, using the oceanic component of our DA system, we have performed a reanalysis experiment to define a global ocean state during 1996-2002. The assimilated elements in this experiment are water temperature, salinity data, and sea surface height anomaly data. In addition to these data, the ARGO float data recently available are used. Horizontal resolution of the ocean model is 1 degree in both latitude and longitude, with 36 vertical levels. The obtained reanalysis dataset shows good dynamical consistency with previous knowledge of important climate events. For example, the root mean square difference value between the observed time-evolution of Niño3 SST and the assimilated one is 0.69 K during 1996-1998, while the difference is 1.60 K (Figure 52) for the simulation case. This much improved reproduction of the evolution of

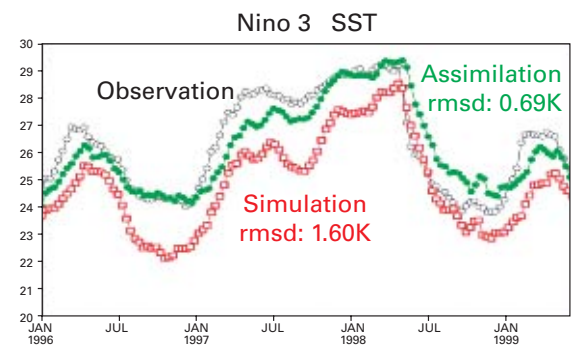


Fig.52 Time change of the NINO3 SST. Result from observation (black), simulation (red), and assimilation (green).

Niño3 SST gives us confidence in the validity of our dataset of the S-I variability in this region. Further, our dataset exhibits realistic subsurface water mass distributions. For example, the North Pacific Intermediate Water characterized by a subsurface salinity minimum is successfully reproduced. Such good correspondence is attributed to the realistic interplay of the subduction process and the subsurface circulation in our DA experiment. These results illustrate that the ocean state derived from our DA has greater information content

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and forecast potential for climate variability than do models or data alone.

c. 4D-VAR Coupled Data Assimilation

By making the adjoint model for the coupler and by unifying all the component models described above, we have constructed a prototype of a 4D-VAR coupled data assimilation system (CDA). This CDA system has been applied to a test experiment in which the bulk parameters for air-sea fluxes (momentum, heat and freshwater) and the initial condition for ocean circulation alone were used as the control variables. The

cost function consists of the sum of the difference from the WOA data for an ocean part, that from the monthly mean 10 m wind speed data for an atmosphere part, and the periodicity of model variables. Our preliminary result shows significant reduction of the cost function value, suggesting goodness of our CDA system. For example, Figures 53 and 54 exhibit much improved reproduction of precipitation and zonal sea surface wind fields (particularly in the tropics), respectively, compared with those obtained by the simulation run. These are attributed to the good optimization of the air-sea fluxes by our CDA approach.

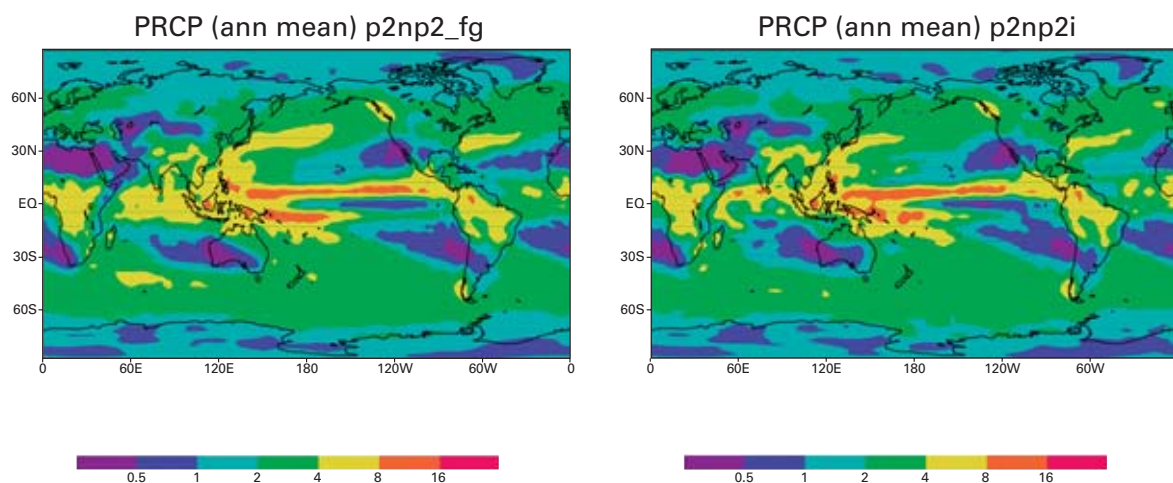


Fig.53 Annual mean precipitation. (left): first guess, (right): assimilation).

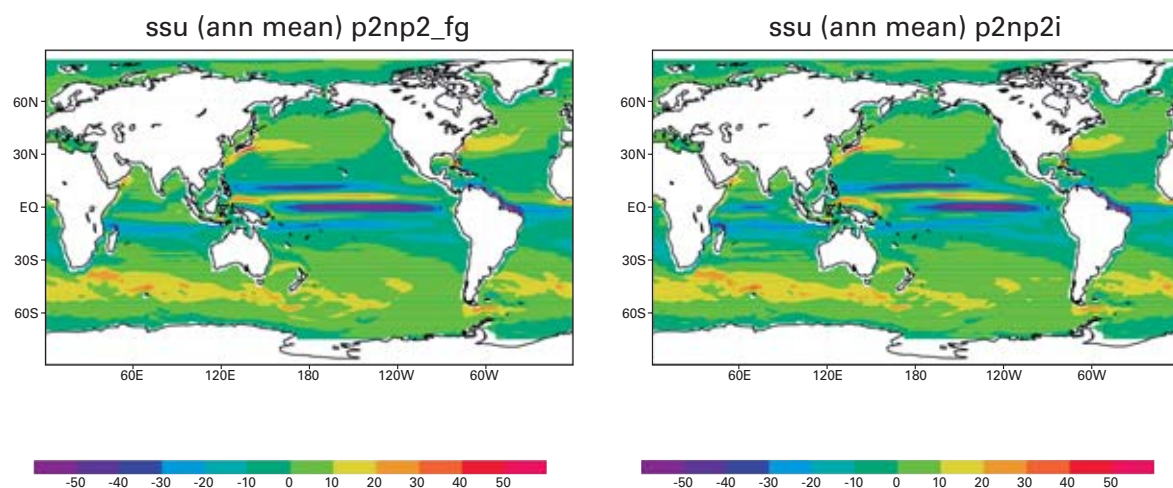


Fig.54 Zonal sea surface velocity. (left): first guess, (right): assimilation).

Research Activities

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Overview of Research Activities

The Frontier Observational Research System for Global Change (FORSGC) aims to contribute to the realization of the reliable prediction of global change and the fight against global warming in collaboration with the Earth Simulator (supercomputer operation) and the Frontier Research System for Global Change (model studies). Scientists have highlighted the critical need for high-precision, large-scale and long-term observation data in the development of a next-generation high-resolution integrated global model for predicting global environmental variability. However, because of a lack of related data, it is essential to establish a new observational research framework that enables flexible and intensive observational research through the efficient use of existing facilities and close cooperation with existing research projects, and domestic and overseas research organizations. FORSGC undertakes observational research aimed at contributing to the elucidation of large-scale (both in time and space) climate change phenomena, the acquisition of global observational data essential for model studies, and the establishment of a global observational system for data assimilation. Under the leadership of excellent supervisors, we will achieve these objectives through the temporary researcher employment system, close cooperation with affiliated ministries, national research institutes, universities and private sector organizations, and the effective use of observational research support staff. FORSGC was established in August 1999, and Dr. Nobuo Suginoara assumed office as the third Director-General in October 2002. The Interim Evaluation Committee meeting was held in May, 2003. As described in the Evaluation Report, the observational research plan has been proceeding very well, and the remarkable outcomes are being produced. On July 1, 2004, the FORSGC will be combined with the Ocean Observation and Research Division, and a new research institute called "Institute of Observational Research for Global Change" will be established. At this new institute, sticking to the original principles of the FORSGC, the FORSGC's research activities will be succeeded and developed.

Climate Variations Observational Research Program

The purpose of the Climate Variations Observational Research Program is to elucidate the mechanism of climate variations with years to decades time scale, through observations by three groups in three key regions; i.e. the warm water pool region of the tropical Pacific Ocean and the Indian Ocean, the western boundary current "Kuroshio" in the Pacific Ocean, and the subsurface and the middle layers of the ocean. The first two groups aim at improving accuracy of model predictions through the more precise observations than ever. The latter group aims to develop a system that enables large-scale and continuous observations in order to elucidate the variation mechanism.

(I) Air-Sea Interaction Group

The Air-Sea Interaction Group aims to elucidate air-sea interaction process associated with the climate

variation in the tropical western Pacific Ocean and Indian Ocean, mainly focusing on intra-seasonal oscillation, El Niño and southern oscillation and Indian Ocean Dipole Mode Oscillation. The group consists of two sub-groups, the Palau sub-group and the Indian Ocean sub-group.

(a) Palau sub-group

Around the western tropical Pacific (Palau) region, surface weather observations were undertaken continuously from November 2000. In this fiscal year, we intensified the observations targeting rain formation processes by using a newly installed disdrometer, which observes size distribution of raindrops, micro-rain-radar, etc. During the Intensive Observation Period (IOP) from February to March 2004, aviation observations using Gulfstream II were carried out to reveal the structure of the convective system and its environmental condition over the warm water pool, south of Palau

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in collaboration with the R/V Mirai MR04-01 cruise. We carried out flight missions three times within the Doppler radar observation range of the R/V Mirai. In the case of cloud cluster development on 10 March, 8 drop-sondes were launched from the aircraft (Fig. 1). Significant drops in temperature correspond to the passage of squall-lines were recorded on weather sensors onboard R/V Mirai (Fig. 2). In order to understand the detailed upper air conditions, we requested the National Weather Service of Palau to increase the frequency of the routine radiosonde observations to 4 times a day during the IOP.

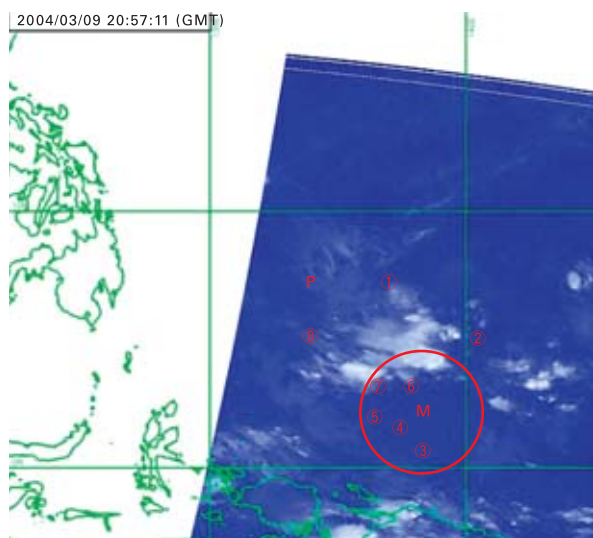


Fig. 1 Satellite cloud image superposed by radar observation range (circle) of R/V Mirai (M), Palau Islands (P), and drop-sonde points (numbers from 1 to 8).

(b) Indian Ocean Observation sub-group

Warm surface water pool in the tropical eastern Indian Ocean is known as an important factor that controls the global climate variability through coupled processes between the atmosphere and the ocean. In order to clarify important processes and mechanisms involved in the variability in the tropical Indian Ocean and to contribute to accumulation of the in situ data of the upper-layer conditions, we have been conducting the following observations. They include (1) an ADCP mooring at 90E on the equator, (2) VOS XBT/XCTD lines, (3) wide area XBT/XCTD observations, (4) hydrographic observations by the R/V Mirai (Fig. 3).

In FY2003, we participated in the MR03-K03 cruise of the R/V Mirai to replace the ADCP mooring in the eastern equatorial Indian Ocean, and we have obtained about 3 years of upper-layer velocity data since November 2000. The preliminary analysis of these data confirms that energetic intra-seasonal variability both in zonal and meridional currents, found in the data obtained in the first year, can be seen through the observed period with year-to-year modification in its typical period and amplitude (Fig. 4). We also observed the spatial structure of the temperature, salinity, and velocity along the cruise track, using XCTD, CTD, and the ship-mounted ADCP.

In addition, we continued to maintain two VOS XBT/XCTD lines; one in the northern Indian Ocean

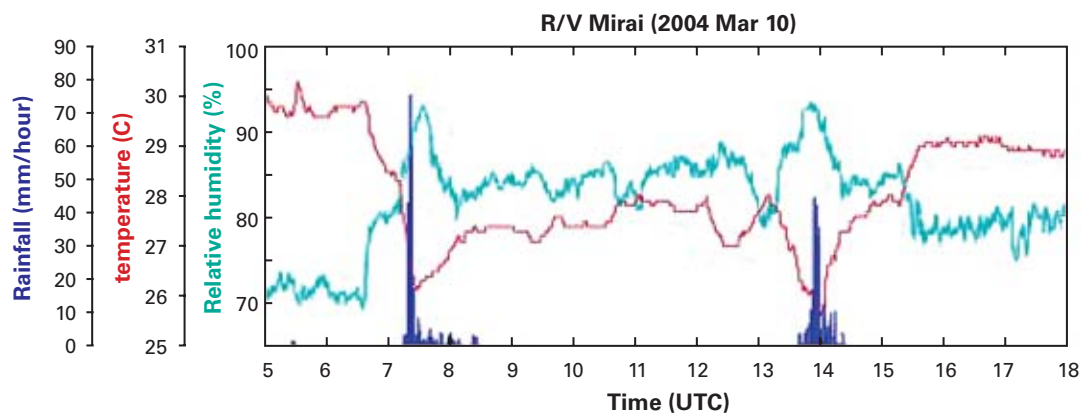


Fig. 2 Time series of temperature (red line), relative humidity (light blue line), and rainfall (blue bar) recorded on R/V Mirai corresponding passages of squall-lines.

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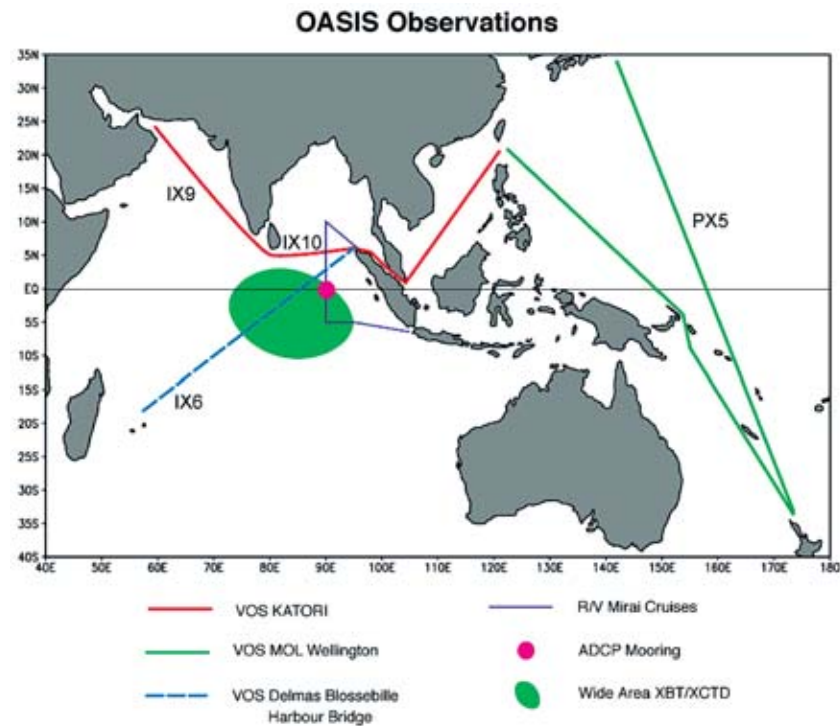


Fig. 3 Summary chart of the Indian Ocean observations.

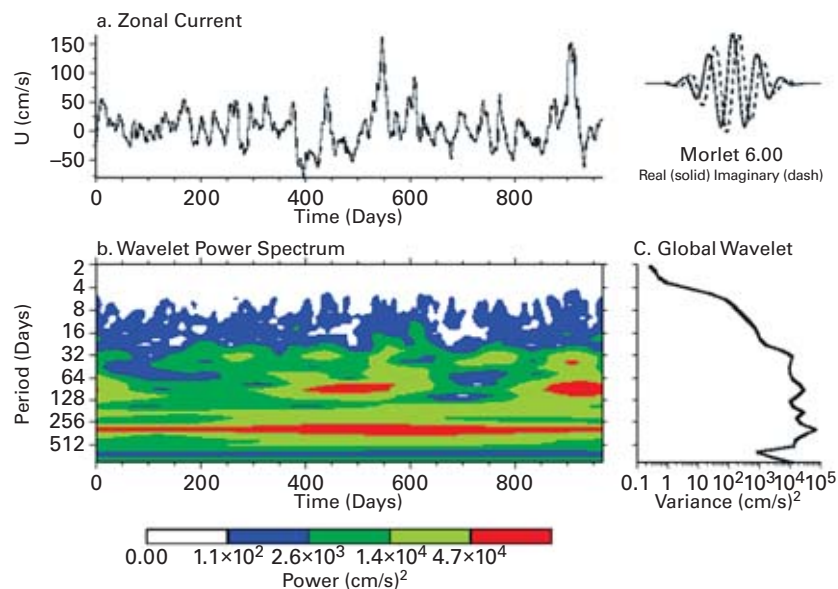


Fig. 4 Observed zonal current at 40 m depth at 90E on the equator from November 2000 to July 2003. (a) Time series of the zonal current, (b) wavelet power spectrum of the zonal current, and (c) global wavelet for the whole observed period.

and the other in the western tropical Pacific Ocean. The subsurface temperature and salinity data along the two lines are continuously being accumulated for studying the inter-annual variability in the tropical Indo-Pacific sector. We also continued wide area

XBT/XCTD observations using fishing vessels. These XBT/XCTD observations are being operated in collaboration with Japan Meteorological Agency and National Research Institute of Far Seas Fisheries.

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(II) The Subsurface and the Middle Layer Ocean Variation Research Group/ Argo Group

Our group aims to elucidate the subsurface and the middle layer ocean variation mechanisms influencing climatic changes with seasonal to decadal temporary scales in the North Pacific Ocean. Along these lines, we have been deploying Argo floats jointly with the JAMSTEC Ocean Observation and Research Department since on FY 2000.

We have deployed 97 Argo floats in FY2003 in the North and South Pacific, the South Indian and the Southern Ocean in collaboration with JAMSTEC (Mirai and Yokosuka), Japan Meteorological Agency (Ryofu-maru and Keifu-maru), Japan Coast Guard (Takuyo), National Polar Research Institute (Sirase), Tokyo University (Hakuho-maru) and Tokyo University of Marine Science and Technology (Umitaka-maru) as shown in Fig. 5a, 5b and 5c. The Beatle 2003 cruise of R/V Mirai in which 28 JAMSTEC's floats were deployed was very useful to fill the blank region of Argo float deployment in the South Pacific and South Indian Ocean. As of the end of March 2004, 1,121 Argo floats are active in the world oceans among which 208 Argo floats are Japanese.

It is very important for the Argo Project to maintain the quality of float measurements on a high level.

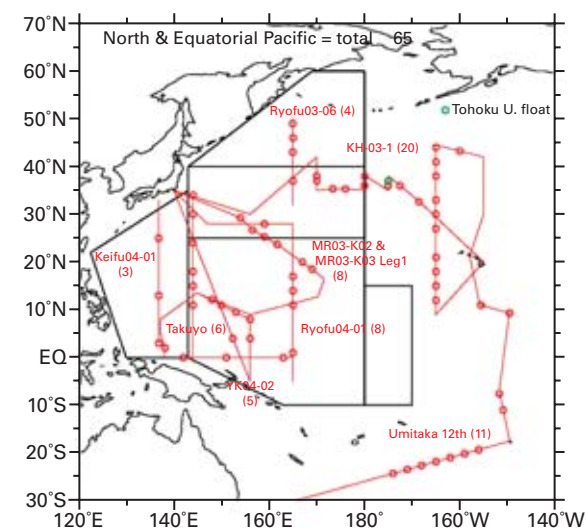


Fig. 5a Launching locations of Argo floats deployed in the North and South Pacific.

Comparing salinity measurements of floats with local climatological ones especially in deep layers is one of the most realistic methods for examining measurement accuracy, and a new method was developed and adopted as an Argo standard. Our experiments clarified that the standard method has the sufficient potential to correct float salinity measurements within ± 0.01 psu, only when the suitable climatological datasets are used (Fig. 6). Thus, we produced a reference dataset necessary to cor-

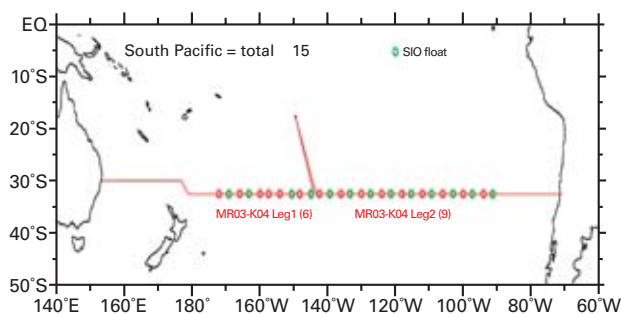


Fig. 5b Launching locations of Argo floats deployed by Mirai in the South Pacific. red circles: JAMSTEC floats, green: US floats.

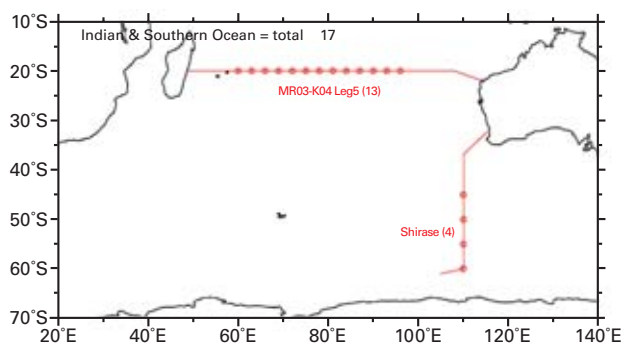


Fig. 5c Launching locations of Argo floats in the South Indian and Southern Ocean.

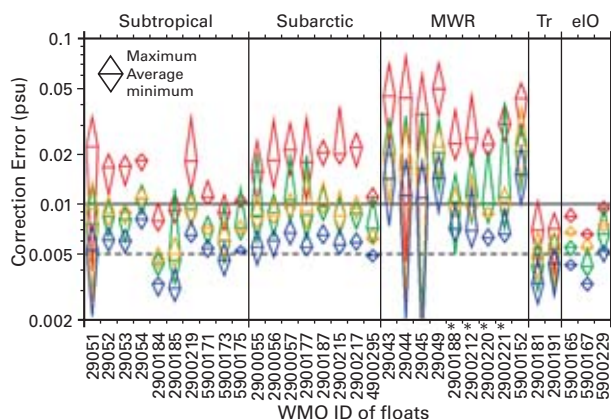


Fig. 6 Correction error of salinity.

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rect Argo salinity measurements in the Pacific, which is named as the Selected Hydrographic Dataset (SeHyD) and available from the Japan-ARGO web site. When Argo floats measure profiles from a constant depth of 2000 dbar, most of the quality-controlled salinity measurements agree with the most reliable values obtained by nearby shipboard CTDs within ± 0.01 psu.

The mixed layer structure and properties in the formation region of the North Pacific Subtropical Mode Water (STMW) east of Japan in the late winter of 2003 were examined using temperature and salinity data primarily from Argo profiling floats. The formation region extends south of the Kuroshio Extension, between 30°N and 35°N and as far east as 175°E (Fig. 7). It is characterized by a mixed layer with depths greater than 200db and merid-

ionally uniform temperature between 16.5°C and 18.2°C, associated with a mixed layer front at its southern edge. The mixed layer in the formation region becomes colder, fresher, and denser toward the east, leading to the formation of warmer, saltier, and lighter STMW in the western part of the region. The spatial variation of the mixed layer depth in the formation region corresponds well with the underlying permanent thermocline depth.

A 4DVAR data assimilation system consisting both with a dynamic oceanographic model and with observational data has been developed to create a 3-dimensional grid dataset from sparsely measured Argo data. Assimilation experiments were carried out using the Argo data from 2001 to 2002 and a global ocean model with the resolution of 1°x1° in horizontal and 36 levels in vertical. A comparison of the simulated and assimilated ocean states reveals that temperature and salinity fields are improved fairly well by use of Argo data (Fig. 8). Further examination on the physical performance as well as the operational use of this assimilation system is left to the future study.

We held the First Argo Science Workshop cosponsored by JAMSTEC and NOAA in Tokyo in November 12-14, 2003. This was very successful to demonstrate the early achievements of Argo and the present and likely future value of Argo for a wide range of applications. More than 200 scientists and

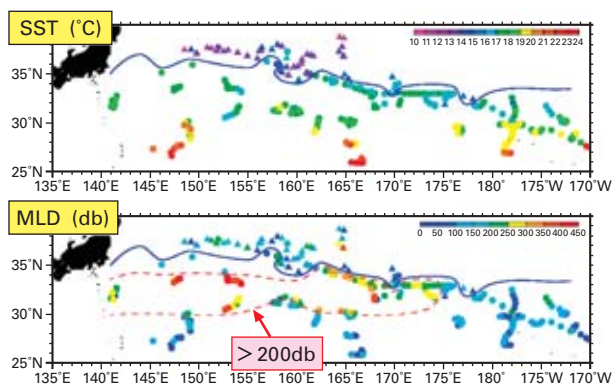


Fig. 7 Distribution of sea surface temperature and mixed layer depth measured Argo floats in February and March, 2003.

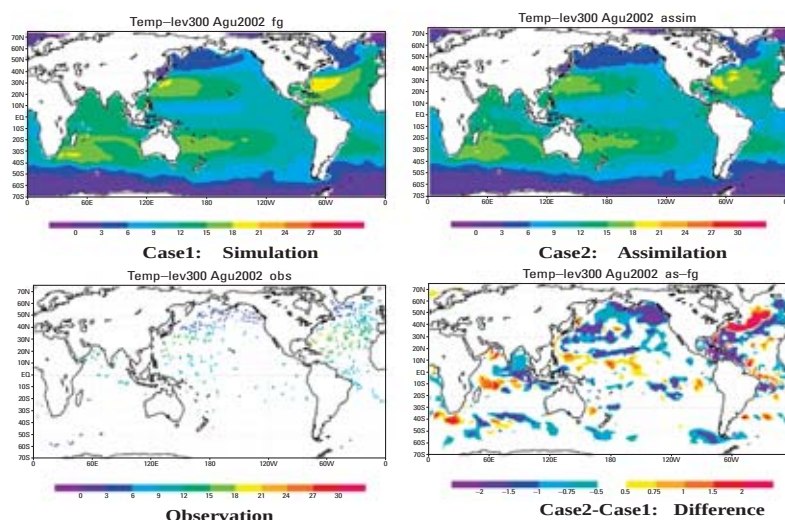


Fig. 8 Distribution of sea surface temperature and mixed layer depth measured Argo floats in February and March, 2003.

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engineers attended this workshop including 99 attendees from 22 foreign nations.

(III) Japan Coastal Ocean Predictability Experiment

The Kuroshio Extension region is one of the major areas where the heat flux from the ocean to the atmosphere is very large. By transporting to this region a large amount of heat, the Kuroshio south of central Japan plays an important role in the global climate change. Our goal is to improve the accuracy of numerical prediction models for global climate change by observational study on the variation mechanism of volume and heat transports of the Kuroshio south of central Japan.

It is believed that the northward current (Ryukyu Current System) in the southeast of Nansei Islands and the Kuroshio in the East China Sea meet south of Kyushu, and form the Kuroshio to the south of central Japan. However, due to the mesoscale eddies coming frequently from the east, there are still several open questions on the Ryukyu Current System. For examining its mean state and seasonal variation, and elucidating the effects of mesoscale eddies and bottom topography on its driving and variation mechanism, we have been conducting intensive surveys in the southeast of Nansei Islands since 2000.

In the JFY 2003, moored instruments observations and ad-hoc hydrographic observations have been continued in the southeast of Amami-Oshima Island, Okinawa Island, and Miyakojima Island, and in the East China Sea Kuroshio region through collaborations with the Nagasaki Marine Observatory (NMO) of Japan Meteorological Agency, Nagasaki University, Kagoshima University, the University of Rhode Island and Ocean Observational Research Division of JAMSTEC. During the cruise in August 1 - 9 on board of the R/V Chofu-Maru, we conducted the recovery and deployment of two PIEs (Pressure gauge equipped Inverted Echo Sounder) in the southeast of Amami-Oshima Island together with the CTD (Conductivity, Temperature and Depth Recorder)/ LADCP (Lowered Acoustic Doppler Current Profiler) observations in the

south of Kyushu (TK-, TA-, AA-, and AE-lines in Fig. 9), as a part of co-operative research with the NMO. During the cruise in August 7 - 17 on board of the R/V Kaiyo of JAMSTEC, we recovered and deployed five mooring arrays with a current meter and one mooring array with an ADCP (MADCP) in the southeast of Miyako-Jima and Okinawa Islands together with XBT (Expendable Bathythermograph) observations along MY-line in Fig. 9. During the cruise in August 17 - 23 on board of the T/S Kakuyo-Maru of Faculty of Fisheries, Nagasaki University, we carried out other CTD/LADCP observations in the southeast of Amami-Oshima and Okinawa Islands on the OS-, E-, and AE-lines in Fig. 9.

While we intended to recover and deploy not only current meters but also PIEs in the mid August, we could not do the works due to the attack of typhoon, which forcing us to conduct other two cruises on board of the T/V Kagoshima-Maru of Faculty of Fisheries, Kagoshima University, in November and the R/V Kaiyo in December. However, due to wrong weather condition again and other problems, we could recover only four PIEs and deploy six PIEs during these two cruises. All the current meters and PIEs in the sea

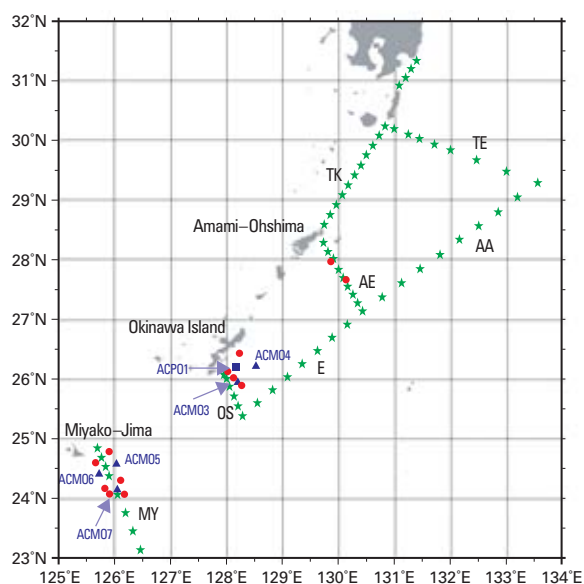


Fig. 9 Map showing the locations of CTD/LADCP or XBT observations in August 2003 (★), and moored instruments at the end of March, 2004 (■: MADCP, ▲: Current meter, ●: PIEs).

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southeast of Miyakojima and Okinawa Island at the end of JFY2003 will be recovered in August 2004. During the cruise from February 24 to March 11 on board of the R/V Kaiyo-Marui of National Research Institute of Fisheries Science, Fisheries Research Agency, we carried out CTD/LADCP or XCTD (Expendable CTD) observations in the Kuroshio Extension region to obtain marine meteorological and hydrographic data for estimating the amount of heat flux in winter season.

By analyzing the data of these mooring and hydrographic observations in JFY2003, we have obtained the following results:

- 1) By the moored current-meter observations from December 2002 to August 2003, we successfully obtained at the first time the time series of current vector southeast of Miyakojima Island shown in Fig.11, together with those southeast of Okinawa Island (see Fig. 9 for their locations).
- 2) Using the empirical relation between geostrophic transport calculated from PIES data and the sea surface height difference during the PIES observation period from November 2000 to August 2001, we have derived a 9-year long time series of volume transport of the Ryukyu Current System southeast of Okinawa Island (Fig.12). We found that its 9-year mean is 4.5 Sv with the pronounced period

from 106 to 160 days and a quasi-biennial period.

- 3) Comparing the data obtained by moored current meter, PIES and CTD from May to December 2002 in the southeast of Amami-Oshima Island, we have confirmed that also the PIES observation can detect the sub-surface northeastward current core at 200 - 500 m depth which has been measured by moored current meter and CTD observations.

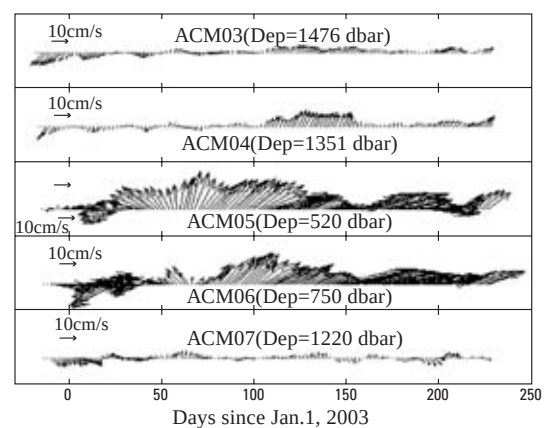


Fig.11 Current vector stick diagrams in the southeast of Okinawa Island (ACM03 and ACM04) and Miyakojima Island (ACM05, ACM06, and ACM07). Upward points the north. Comparing the current vectors at ACM07 with those at ACM03 and ACM04, it is obvious that the variability of current vector southeast of Miyakojima Island is much stronger than southeast of Okinawa Island suggesting that there is no stable current in the southeast of Miyakojima Island while the eddy activity is very large in the shallow stations of ACM05 and ACM06.

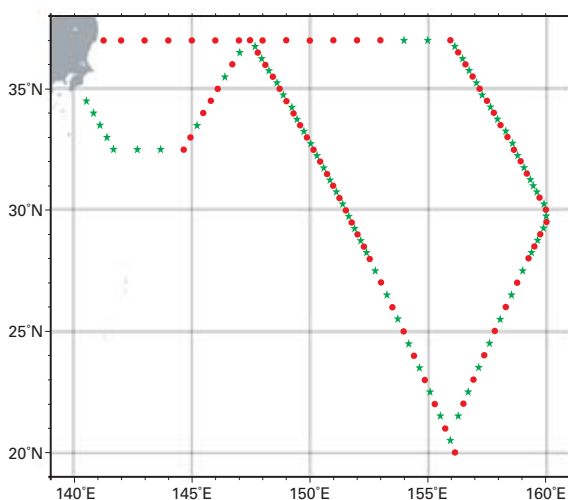


Fig.10 Map showing the locations of CTD/LADCP or XCTD observations in the Kuroshio Extension on board of R/V Kaiyo-Marui from February 24 to March 11, 2004. ★: CTD, ●: XCTD.

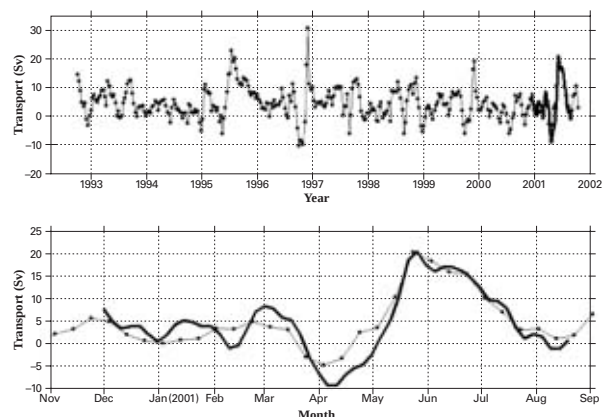


Fig.12 Top: 9-year long time series of volume transport of Ryukyu Current System southeast of Okinawa Island derived from sea surface height difference across the current with an empirical relation. Bottom: geostrophic transports calculated from PIES data (thick line) and those estimated from sea surface height difference with an empirical relation (thin line).

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Hydrological Cycle Observational Research Program

The overall objective of this program is to clarify the seasonal to long-term variation of the regional characteristics of water cycle including the influence of global warming and the physical processes related to it, and to contribute to the integrated model needed for future prediction, through the development of observation system/observation network on the Eurasia Continent and the surroundings including the Asian monsoon region.



Fig.13 The observation network of this program is shown on Fig.13.

(I) Land-Surface Hydrological Cycle and Processes Group

The direction of the study of the Land-Surface Hydrological Cycle and Processes Group is to clarify the surface processes and atmosphere-land surface interactions of the cold continental regions, and to understand the role of these regions in the regional/global hydrological cycles. The research objectives are as follows.

- Clarify the land water and the energy cycle of the cold regions such as the Eastern Siberia, Tibet and Mongolia, and the influence of snow cover, frozen ground and vegetation to these processes.
- Develop high quality data-sets on the water and energy cycle.
- Develop physical models of the water and energy cycle and validate these models.

In order to fulfill these objectives, the following observations were made in 2003.

(i) Observation on the surface heat/water exchange at the various sites and the various spatial scales in the Eastern Siberia, such as tundra (Tiksi) and taiga (Yakutsk).

(ii) Installment of observation network and start of research work on water/heat balance and drainage study in Northern Central Mongolia.

(iii) Further data accumulation on the solid precipitation evaluation and the role of drifting/blowing on surface water/heat exchange at Barrow.

In 2003, the stress was laid on initiation of Mongolian observation site (ii), and the study on Tibetan Plateau has been basically terminated. Data accumulation at discontinuous permafrost zone (ii) will make it possible to conduct comparative study of the characteristics of land hydrological cycle in discontinuous and continuous permafrost zone. Initial analysis has been made for Mongolian site and the behavior of heat/water exchange in relation to snow cover and grass growth, and the water accumulation above the sub-surface ice layer has been clarified (Fig.14, 15). Further data accumulation has been done

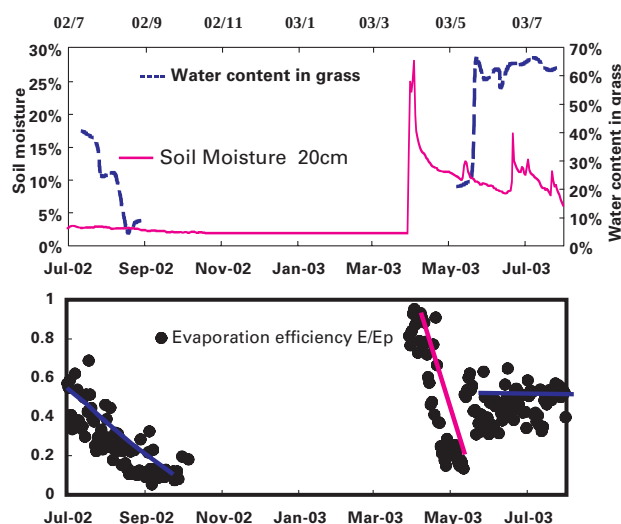


Fig.14 Evaporation efficiency (Below: Ratio of actual evapotranspiration to potential evaporation) and 20cm depth soil moisture (Above, red line) and amount of water content inside the grass (Above, blue line) at flat grass surface in the research basin east of Ulanbaatar.

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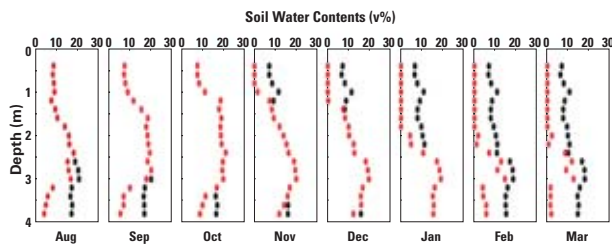


Fig.15 The total water amount (Black dot, and red dot at depth without black dot) and liquid portion (red) at plot in the drainage research basin. The amount between two dots is amount of ice. Change of liquid water in autumn to ice in winter can be seen.

for the topic (iii) (Fig.16, 17). In this study snow particle counter is performing an important role. The group is participating in the CREST project related to water cycle and the role of structural and physiological characteristics of the vegetation, and this aspect will be studied in detail under that project.

During the past four years, observation network has been established and the preparation has been basically finished for the data collection for implementing objectives (a) – (c). So the main part of the activities will be shifted to continuous data accumulation for different years, the analysis of the obtained data, model application studies and integration of results. The group has been strengthening the cooperation with other projects, and held two joint symposiums; one for the Northern Eurasia Water Cycle and the other for the Changes of Terrestrial and Hydrological Conditions in Mongolia in December 2003.

(II) Cloud and Precipitation Processes Group

In order to clarify hydrological cycle in heat source regions of the Asia and the maritime continent, especially atmospheric hydrological cycle processes in these regions from the western tropical Pacific to the Baiu front, this group is carrying out multiscale observations on hydrological cycle processes of cloud clusters and elucidating roles of mesoscale cloud and precipitation systems in each process of atmospheric hydrological cycles. The results of the observations and analyses will contribute to the development and improvement of



Fig.16 Photograph of precipitation gauge correction study site at Barrow, Alaska. The large gauge is the Wyoming and DFIR type, and various small gauges used in each country are installed in front.

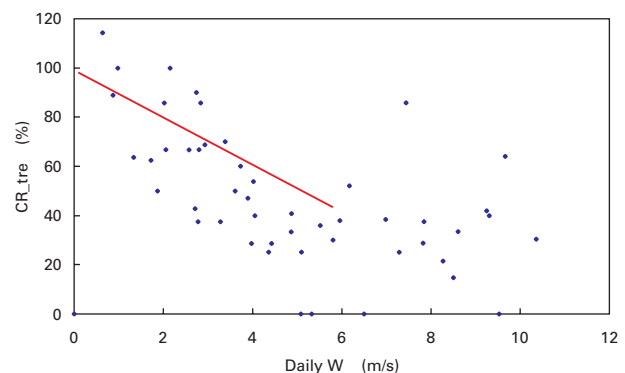


Fig.17 The relation between daily mean wind speed (W) and catch ratio, CR (ratio of amount caught by gauge to true precipitation) for Trechakov Rain Gauge (Used in Russia and other region) from measurement at Barrow. Red line is past result obtained by WMO Project. Large CR under strong wind is due to influence of blowing snow.

numerical models of global atmosphere.

This group is conducting observation of the structure and evolution of cloud and precipitation systems in the downstream region of the Yangtze River. It is also collaborating closely with the Air-Sea Interaction Group of Climate Variations Observational Research Program of FORSGC on the observation of cloud and precipitation processes in the western tropical Pacific region.

Intensified observations in the downstream region of the Yangtze River were performed in FY 2001 and FY 2002 by using Japanese instruments. In FY 2003, an observational network (Fig.18) consisting of Chinese Doppler radars, radio sondes, and surface observatories was used to observe the three-dimensional structure and evolution of precipitation systems along the Baiu front.

During the Baiu season of 2003, Baiu fronts and

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associated precipitation systems have been stationary frequently on the north side of the Yangtze River, where much more rainfall was observed (Fig.19). Compared with the rainfall of about 200 ~ 400 mm on the south side, the rainfall of over 600 mm was observed on the north side of the Yangtze River. The rainfall in some regions has exceeded 800 mm that was the average annual rainfall in these regions. On the north side of the Yangtze River, the rainfall was as three times as an average year. As a result, many places suffered from severe flood (Fig.20). Many precipitation systems that contributed to the formation of the flood have been observed by Doppler radars. The analyses of these precipitation systems have been advanced. Combined with the observations carried out in the previous years, observational data from this year provided a good opportunity for studying annual variations of the Baiu front and precipitation systems in the downstream region of the Yangtze River.

For the observation in the western tropical Pacific region, please refer to the items shown by Air-Sea Interaction Group of Climate Variations Observational Research Program.

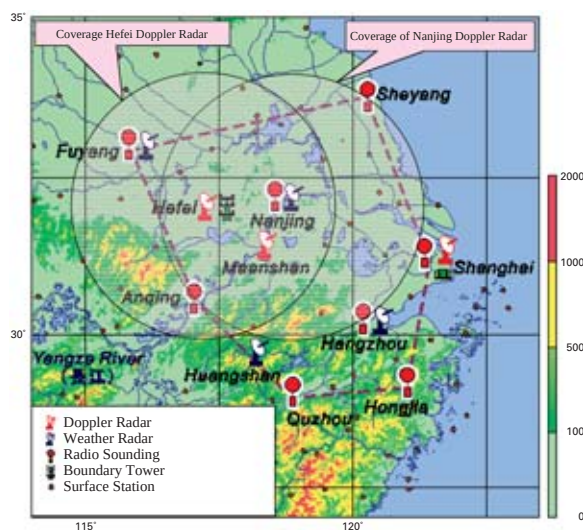


Fig.18 Observational network used in the intensive observation in 2003.

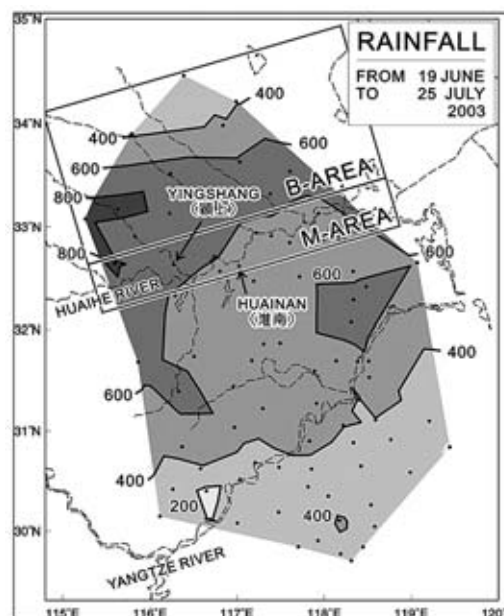


Fig.19 Horizontal distribution of the total rainfall observed in Anhui Province, China during the Baiu season of 2003.



Fig.20 A photograph showing a village suffered damage from the flood.

(III) Large-scale Hydrological Cycle and Processes Group

In FY2003, the Large-scale Hydrological Cycle and Processes Group continued observations in Indonesia, Thailand, Tibet and Siberia, with the aim of elucidating the large-scale energy and water cycles in Asian monsoon region. The results, obtained since the establishment of this group in 1998, have been published in international journals and presented at international meetings. An overview of our activities and achievements is as follows:

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(a) Diurnal, intraseasonal, seasonal and interannual variability of precipitating cloud systems and energy/water cycles over the Indonesian maritime continent

At Kototabang, in West Sumatra, Indonesia, the major base of observations, continuous measurements of precipitation characteristics, sensible and latent heat fluxes, lower-atmospheric winds, rainfall amounts in the surrounding area and so on have been carried out automatically. Rawinsondes (meteorological balloons) were launched intensively (4 or 8 times per day) for 7 weeks in total in this fiscal year. In addition, standard meteorological observations have been continued also at Padang in the west coast and at Siberut Island off the coastline. Furthermore, onboard observation of convective activity over the eastern Indian Ocean has been carried out by using Doppler radar and rawinsondes equipped with the R/V Mirai (Fig.21). Based on analyses of the data obtained so far as well as various meteorological satellites data, we have shown a diurnal land-sea rainfall peak migration and its interaction with local circulations over Sumatra Island and the eastern Indian Ocean, differences of rainfall characteristics (e.g. rainfall types, radar echo top height, atmospheric instability, vertical wind shear, and cell organization) between active and inactive phases of intraseasonal variation over the eastern Indian Ocean. Furthermore, regional characteristics

of diurnal rainfall variation between the mountainous and coastal areas over Sumatra Island in relation with large-scale disturbances have also been analyzed in detail by using the automatic rain gauge network data.

(b) Diurnal variations of moisture and heat transport processes in Indonesia, Thailand and the Tibetan Plateau

Based on the finding during the previous fiscal year on diurnal variation in precipitable water vapor estimated from GPS (Global Positioning System) data at Kototabang (the mountainous area of western Sumatra, Indonesia), mechanism of the diurnal moisture variation has been investigated by numerical experiments using a regional atmospheric model. The numerical study suggested an existence of climatological diurnal variation of moisture transport around western Sumatra dominated by the thermal effect of the mountain range. The paper on this numerical study was accepted for publication in an international journal.

Continuous observations of moisture in Siberut Island, at Pontianak, at Balikpapan in Kalimantan, Indonesia and at Chiang Mai, Bangkok and Phuket in Thailand have been successfully made by GPS (Fig.22). Mechanism of drastic diurnal variation in moisture over the southeastern Tibetan Plateau, which was confirmed by GPS data analyses during the previous fiscal year, has been clarified by numerical experiments using a

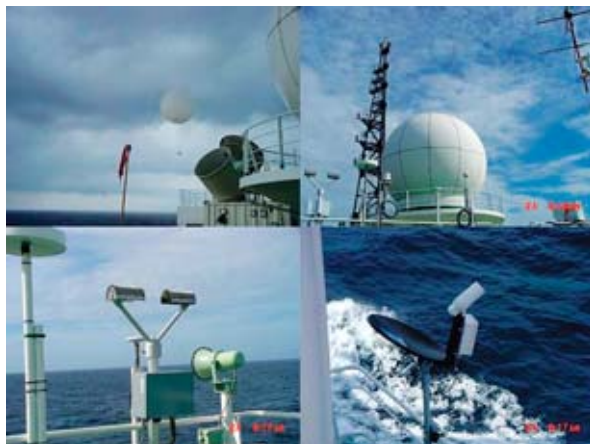


Fig.21 Atmospheric observation over the eastern Indian Ocean by rawinsonde (top left), Doppler radar (top right), disdrometer (bottom left), and micro rain radar (bottom right) during R/V Mirai cruise.



Fig.22 GPS receiver and automatic weather station at Balikpapan, Indonesia.

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regional atmospheric model and the paper on the results was published in an international journal.

Diurnal variations in moisture and precipitation during a monsoon season at Naqu in the eastern part and at Gaize in the western part of the Tibetan Plateau are under investigation by GPS data analyses and numerical experiments, and the results are also prepared for publication.

(c) Asian Network for Stable Isotopes in Precipitation

Since 2000, the Stable Isotope Group of Frontier Observational Research System for Global Change has been observing stable water isotopes of river, lake, groundwater, fallen snow, and precipitation (Fig.23) all over the Asia (Siberia, Tibet, Nepal, Thailand, Indonesia, and Palau). The importance of this dataset was recognized by the International Atomic Energy Agency (IAEA) meeting in May 2002 as a short-term observation (daily sampling) in Monsoon Asian region.

Daily variability of Oxygen isotope ratio of rainwater observed in Thailand and Indonesia during 2001 was well reproduced and their origins were estimated by the Isotope Circulation Model (Yoshimura et al., 2003). The daily variability in origin of rainwater at three stations in Thailand was observed during 2001. The precipitable water evaporated from Indian Ocean (IDO) was dominated during Asian Monsoon period (May to October) at all stations. Also, the precipitable

water evaporated from IDO and Java Sea were dominated on the western and eastern coasts of Sumatra Island of Indonesia, respectively. These results were presented several International scientific symposiums and submitted to the international journals.

The studies of (a) and (c) were carried out in collaboration with Kyoto University and University of Tokyo, respectively.

Atmospheric Composition Research Task Team Variability of tropospheric ozone in Asia and its impact on global warming

This research which was initiated as a sub-sub-theme of RR2002, aims at atmospheric chemistry observation related to tropospheric ozone in Asia, for the purpose of verification and development of high precision global chemical transport model. The research subject of this study includes:

- (a) Continuous measurements of tropospheric ozone (O_3) and carbon monoxide (CO) in China, Siberia and Central Asia to obtain spatial and temporal variation of their concentration.
- (b) Intensive campaign including direct measurement of HOx (OH and HO_2) radicals to verify tropospheric photochemistry theory.
- (c) Future projection of emission inventories of ozone precursors in Asia up to 2020.

In the FY 2003, following research has been conducted for each of the above subjects.

- (a) Under the Implementing Arrangement with Institute of Atmospheric Physics, Chinese Academy of Sciences, the observation of O_3 and CO was initiated at three mountain stations in China, Mt. Taishan, Mt. Huashan and Mt. Huangshan. Among these stations first observational data at mountain sites in China was obtained at Mt. Taishan where the instruments for continuous measurement of O_3 , and CO were installed in the previous fiscal year. The obtained data showed for the first time that the maximum ozone concentration in April, May and June in 2003



Fig.23 Rainwater samples for stable isotopes collected at Makassal meteorological station, Indonesia.

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were as high as 100, 120, and 160 ppbv, respectively, indicating that ozone pollution is in serious situation even in the rural mountain area of China.

- (b) Using the Laser Induced Fluorescence (LIF) instrument for the measurement of OH/HO₂ radicals, whose detection limit had been improved to be the same level as other world top instruments, intensive campaign at Rishiri, Hokkaido, and measurement in Tokyo was performed. Comparing the data of OH/HO₂ obtained at Rishiri with those of calculated one by a box model, it was revealed that theoretical prediction overestimates the observed values both for OH and HO₂ radicals exceeding the estimated error limits. However, if the calculated values of OH radicals are constraint with the observed values of HO₂ radicals, the calculated OH radical concentrations agreed well with the observation, indicating that the cause of disagreement would most probably be due to the unknown missing sink of HO₂ in the ambient air.
- (c) Activity data that are necessary for the future prediction emission inventory in China were obtained from Qinghua University in Beijing, and methodology for improving the accuracy of evaluation was developed.

Observation and research at International Arctic Research Center

The International Arctic Research Center (IARC) aims to understand natural and anthropogenic variations occurring in the Arctic region and predict their impacts. Its FY2003, carried out are (a) study for understanding

coupled ocean-ice-atmosphere system and (b) study on multi-disciplinary climate related processes.

(a) Coupled Ocean-Ice-Atmosphere System Group

The Coupled Ocean-Ice-Atmosphere System Group aims to elucidate interaction among the ocean, sea ice and atmosphere so as to shed light on the complex Arctic Ocean climatic system. In FY 2003, the following observations were undertaken in parts of the Arctic Ocean for understanding fate of inflows from Atlantic and Pacific Ocean.

- (i) NABOS2003 Laptev Sea cruise (Russian Ice-breaker Kapitan Dranitzyn)
(ii) JWACS2003 Canadian Basin cruise (Canadian Ice-breaker Louis S. St-Laurent)

By using Russian Icebreaker Kapitan Dranitzyn, NABOS2003 observation was carried out in Laptev Sea from August 26 to September 17, 2003. During this cruise, one mooring deployed last year was retrieved and CTD hydrocast, water sampling by conventional CTD-RT, plankton and fish sampling with vertical and horizontal nets were carried out. Ice buoys from COREL, Germany, England and Russia were also deployed during the cruise. One mooring was redeployed at the same location. One additional mooring was also deployed within Russian exclusive economic zone (EEZ) for the first time. Observation stations and mooring stations are shown in Fig.24. Schematic diagram for the mooring is given in Fig.25.

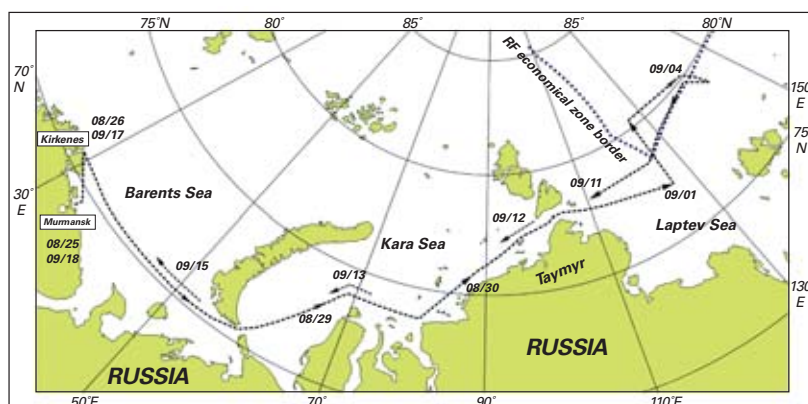


Fig.24

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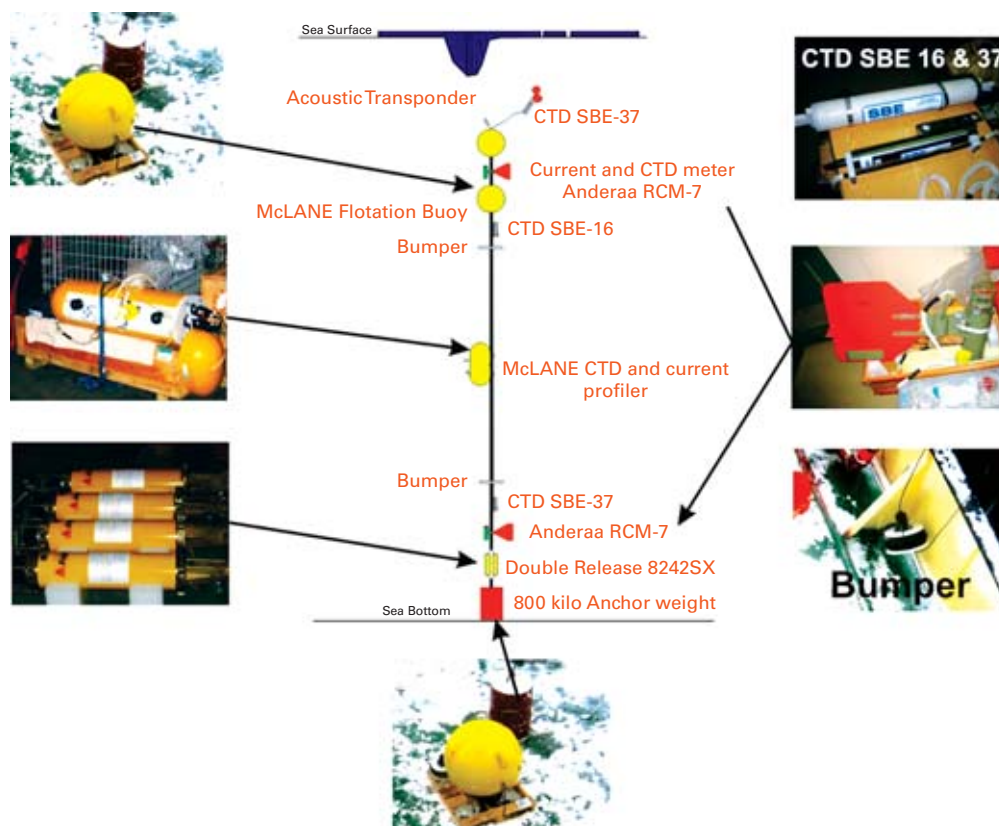


Fig.25

Basically, one MMP (McLane Mooring Profiler) and two CDT for the MMP calibration at upper and bottom part of the mooring put on the mooring system. In Fig.25, typical cross sections for temperature and salinity from the continental margin to the offshore in Laptev Sea are given. Relatively warm Atlantic layer between 150 and 500 meters is distinctively identified. There is startling stepwise structure in temperature profiles. Temperature captured by MMP also show the stepwise structure, which persisted more than 3 months duration (Fig.26). This feature seems very wide in space and long in time. The temperature maximum in the Atlantic layer has unique density of $\sigma_\theta = 27.9$ (Fig.27a). Temperature distribution of isopycnal plane at $\sigma_\theta = 27.9$ showed distinctively high temperature and low temperature areas (Fig.27b). It is also found the stepwise temperature feature was only exist in relatively high water temperature region, northwest area in Laptev Sea.

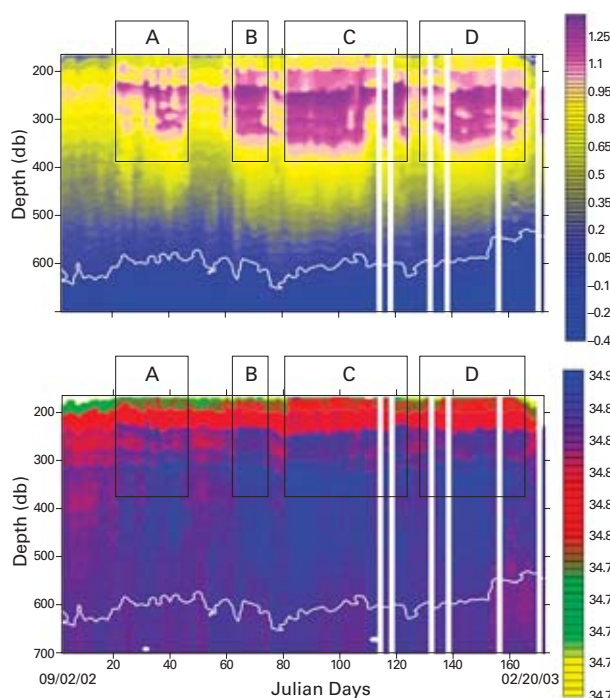


Fig.26

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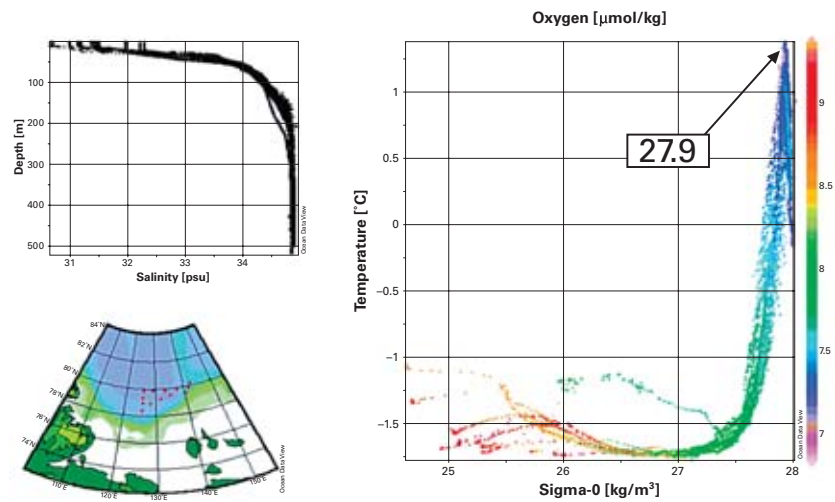


Fig.27a

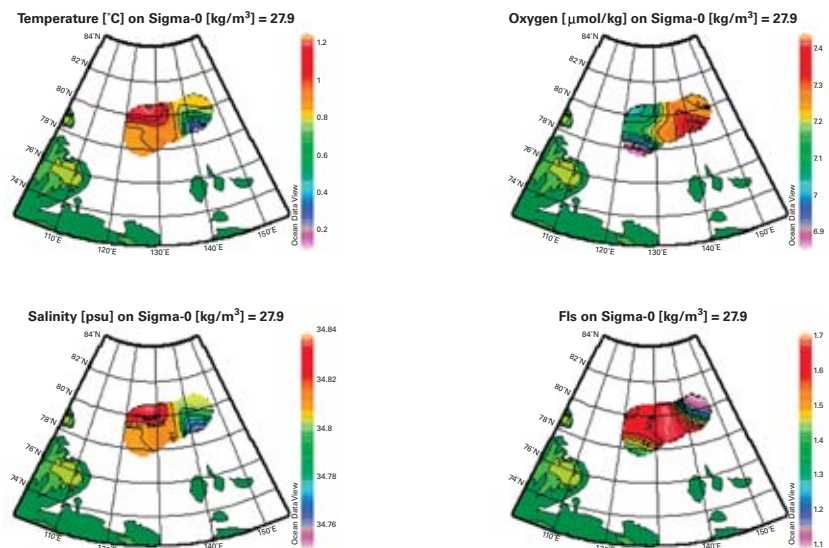


Fig.27b

During the almost same period of NADOS2003 cruise, JWACS2003 research cruise has carried out and we participated the cruise. JWACS is a joint research program between IOS, Canada and JAMSTEC. Two scientists was joined the cruise and collected 540 isotope analysis samples and 277 CDOM samples. One MMP mooring near McKenzie estuary was retrieved and redeployed. Cruise track chart is given in Fig.28. Based on preliminary analysis of MMP data, a distinctive middle layer meander has been found (Fig.29). Since this kind of meanders is impossible to detect by satellites and conventional

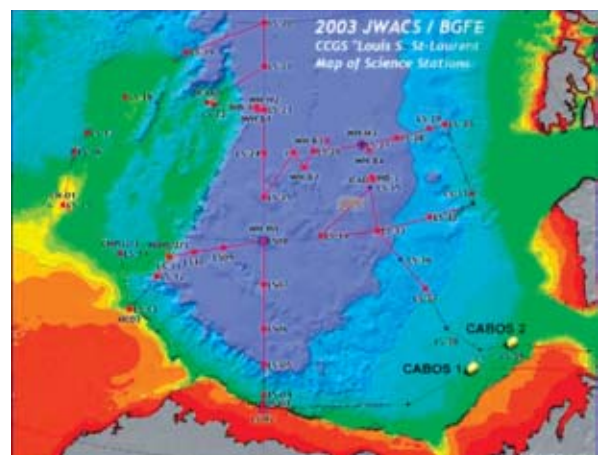


Fig.28

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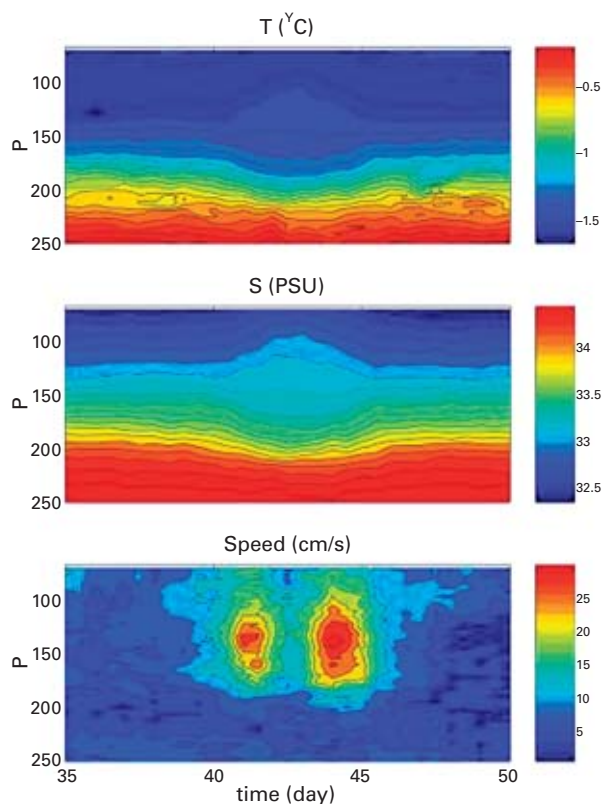


Fig.29

ship observations, the retrieved data could be very valuable to obtain better insight of Arctic Ocean circulation.

(iii) Fresh water distribution study in Arctic Ocean by using chemical tracers

The variation of abundance and distribution of fresh

water in Arctic Ocean is closely related to ocean circulation, sea ice formation, etc and consists of one of major climate control factors. By using data compiled in Hydrochemistry Atlas in the collaboration between IARC frontier program and AARI, Russia, a novel technique to differentiate river water and sea ice melt water in Arctic sea water has been developed. In this development, we utilized past alkalinity data, which is abundant in the Hydrochemistry Atlas. The results from this technique are well comparable to the results obtained by the conventional water isotope method (Fig.30). In Fig.31, abundance of river water and sea ice melt water at 50 m water depth in Arctic Ocean obtained by this method is shown. This is averaged one last 50 years data. We are going to analyze the results in terms of the relation to major climate regime shift in Arctic and uncover fresh water rule in Arctic climate system.

(b) Multi-Disciplinary Group

The Multi-Disciplinary Group mainly aims to clarify the impact of bio-geochemical processes on climate and environmental changes. Marine biological activity beneath ice is a unique bio-geochemical process characterizing sea ice zones, and its contribution to global warming is not yet well-known. Following polar dawn, regular observations of bio-production (abundance of plankton), biomarkers, dimethyl sulfide

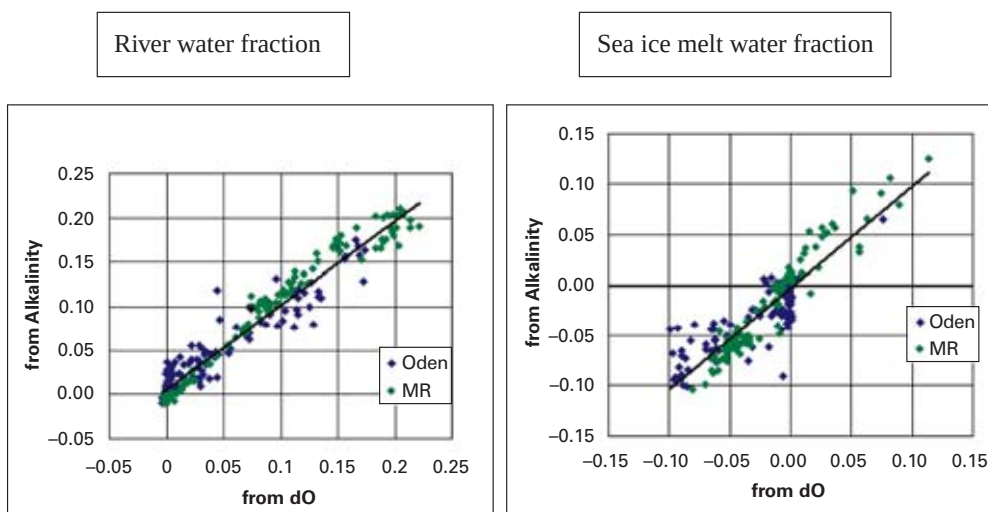


Fig.30

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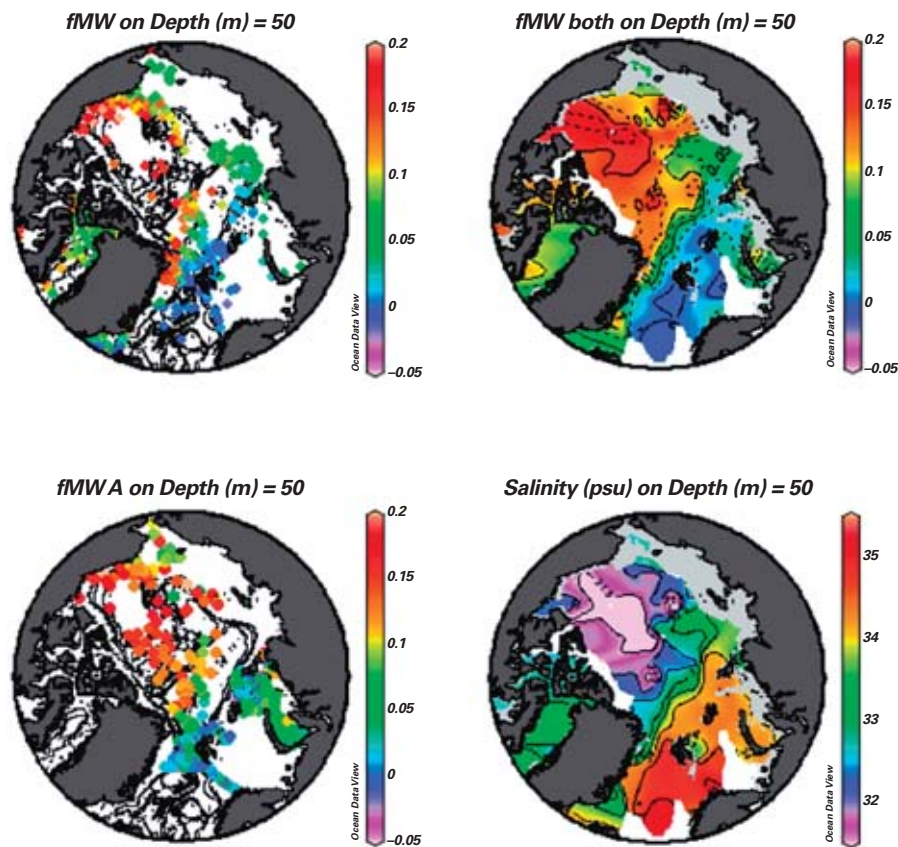


Fig.31

(DMS) and dimethylsulfoniopropionate (DMSP) were made at Point Barrow. The measurement of the opto-environmental condition including solar radiation, observation of sea ice composition, meteorological parameters, etc. were also carried out in collaboration

with other organizations studied this year. In the FY2003 field activity, we especially focused on in situ incubation study for production and decomposition of DOC and POC.

Research Activities

OD21 Program Department

Outline of Ocean Drilling in the 21st Century (OD21)

Ocean Drilling in the 21st Century (OD21) is the ultimate project, seeking to comprehensively understand the entire global system, and it establishes a new era in earth and life science by verifying the mechanisms of crustal movement, elucidating the dynamic evolution of the global environment, and exploring the unknown deep biosphere. This analysis is accomplished by studying core samples, monitoring the boreholes, and drilling into seismogenic zones, which are thought to cause major impacts, such as earthquakes and tsunamis. With existing platforms, it is almost impossible, or quite difficult, to drill directly into these zones. The OD21 intends to build and operate the unique deep-sea drilling vessel "CHIKYU", which is the first scientific drillship to be equipped with a riser system, and has the most advanced scientific drilling capability in the world.

Meanwhile the Ocean Drilling Program (ODP) led by the U.S. achieved outstanding results in the late 20th century, such as the substantiation of plate tectonics, elucidation of the dynamic evolution of the global environment and discovery of the new deep biosphere. The ODP has been integrated with the OD21 into the Integrated Ocean Drilling Program (IODP) under the co-leadership of Japan and the U.S. since October 2003. The IODP is an international project that mainly uses two drilling vessels: one is the riser drilling vessel "CHIKYU", to be provided by Japan, and the other is a riserless drilling vessel, to be provided by the U.S.

The IODP is an international project to achieve significant advances in the geoscience and life science for the 21st century. Scientific accomplishments from the IODP can contribute to the elucidation of the earthquake mechanism, resolution of environmental and energy problems, and so on. The IODP greatly anticipates resolving some of the pressing issues human beings face today. Japan Marine Science and Technology Center (JAMSTEC: the present Japan Agency for Marine-Earth Science and Technology) is the overall coordinating and promoting organization for the IODP in Japan. The OD21 Program Department in JAMSTEC is responsible for the construction of "CHIKYU" and the development of associated technologies, the setup of the "CHIKYU" operational structure, and arrangement of domestic/international support structures.

The OD21 Program Department was integrated with the Center for Deep Earth Exploration (CDEX) in July 1, 2004.

1. Development of Technologies for Exploration of the Earth's Deep Interior

(1) Construction of an Ultra Deep-Water Drilling Vessel

The ultra deep-water drilling vessel "CHIKYU" (Figure 1, 2), to operate in OD21, is a riser drilling vessel, and is the first scientific drilling vessel to apply mud circulation, a technology commonly used for petroleum exploration. "CHIKYU" aims to penetrate to a depth of 7,000 meters in the ocean floor up to a water depth of 2,500 meters (4,000 meters in the future) all over the world, except in icebound seas. "CHIKYU" is equipped with facilities to collect continuous cylindrical core samples of sedimentary rocks or igneous rocks by drilling, to conduct various physi-

cal and chemical measurements in boreholes, to analyze obtained core samples and to interpret data on geological formations. The standard outer diameter of core samples obtained in the drilling is approximately 60 mm, comparable to that of the Ocean Drilling Program (ODP). Table 1 shows the major specifications of "CHIKYU".

As the objective of "CHIKYU" is scientific drilling, it must be able to drill the seafloor of sea areas worldwide. To achieve this, severe conditions are set for the vessel's structural design. Design conditions for wind velocity are 51.5 m/s, and for a significant wave height equivalent to that expected once every 100 years, in the long-range wave data of the Global Wave Statistics (published by the British Maritime

OD21 Program Department

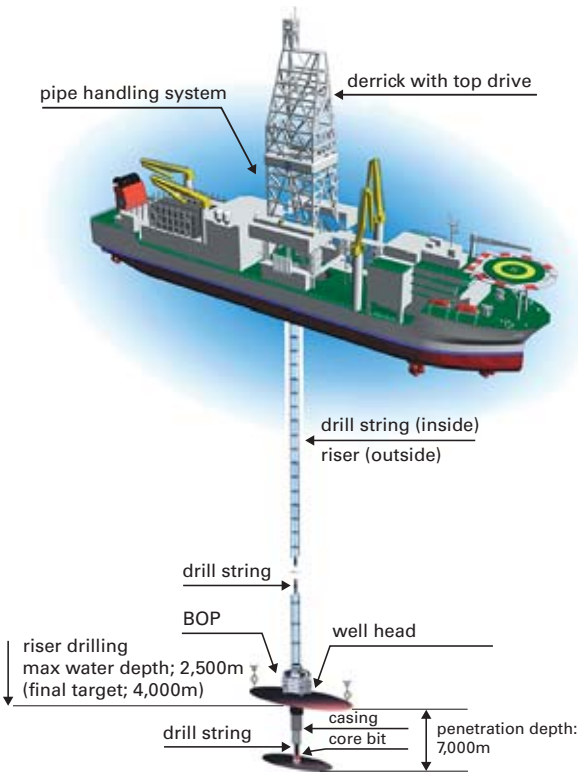


Fig. 1 Conceptual Drawing of "CHIKYU"

Technology). "CHIKYU" is also designed to carry out drilling safely and effectively under harsh meteorological and oceanographic conditions, and incorporates automatic or laborsaving features in drilling operations.

"CHIKYU" is equipped with six azimuth thrusters for its dynamic positioning system (DPS) to keep it efficiently in position. To determine the vessel's exact location, it has a global positioning system (GPS) and an acoustic positioning system. The vessel's dynamic positioning system is also designed to minimize the riser's upper and lower angles to prevent it from being damaged.

"CHIKYU" is designed for high workability and living comfort, considering the expected long-term sea stays for drilling and research. Its design provides sufficient allowance for variable loads, considering ultra-deep-drilling on ultra-deep seafloors in remote sea areas. Furthermore, from the viewpoint of marine environment conservation, "CHIKYU" will be equipped with facilities to reduce the volume of



Fig. 2 Appearance of "CHIKYU"

Table 1 Principal Particulars of "CHIKYU"

Length	210m
Width	38m
Depth	16.2m
Draft	9.2m
Gross tonnage	57,500ton
Variable load	Approx. 25,500 tons
Service Speed	Approx. 10 knots
Accommodation	150 persons
Classification	NK NS*, "Deep Ocean Drillship", MNS*(M0), DPS-B

drilling waste such as cuttings and waste mud generated by drilling operations, and to hold the waste instead of dumping it into the sea.

Effective data uses on various core samples and geological formations obtained through "CHIKYU's" operation are expected to promote understanding of the mechanisms of global warming and the initiation of earthquakes, mantle materials and deep biospheres in the earth's crust. "CHIKYU" will contribute significantly to advancing earth and life sciences.

Construction of "CHIKYU" began at the end of FY 1999, with the main contract for construction awarded to Mitsubishi Heavy Industries, Ltd. At the beginning of FY 2003, hull construction was completed at the Tamano Shipyard of Mitsui Engineering and Shipbuilding Co., Ltd and sea trials on the hull were conducted. After that, "CHIKYU" was shifted to the Nagasaki Shipyard of Mitsubishi Heavy Industries,

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Ltd., and structure modules of the vessel's drilling components -- such as its drillfloor -- were installed. Also, the vessel's drilling components such as a derrick, pipe-handling and mud-circulation equipment and drilling control system were installed, and an operational test of these equipments was conducted.

2. Activities related to the Deep Earth Exploration Vessel

(1) Center for Deep Earth Exploration (CDEX)

The Center for Deep Earth Exploration (CDEX) was established in October 2002 as the operator of "CHIKYU", the Deep Earth Exploration Vessel in the Japan Marine Science and Technology Center (the present Japan Agency for Marine-Earth Science and Technology). Its main roles are (1) to take responsibility of "CHIKYU" operation, including drilling planning, (2) staffing of scientists and their support teams, (3) scientific support for core analysis and logging, and (4) to conduct engineering site surveys.

In FY2003 CDEX was prepared for crew training cruises in FY2005 and international operation of "CHIKYU" commenced in FY2006.

(2) Pre-drilling site surveys

To achieve its scientific goals, "CHIKYU", a Deep Earth Exploration Vessel, will be able to perform deep/ultra deep drilling under several different conditions, such as through hydrocarbon-bearing and/or complicated geological structural zones, which were almost impossible to drill with the Ocean Drilling Program (ODP)'s riserless drilling vessel.

Using the same drilling method as the ODP's with sea-water, "CHIKYU" however, will be equipped with 30 inches of conductor pipe, 20 inches of casing pipe and a BOP (Blow-out Preventer) will be set, before the riser pipe is connected. As drilling will be carried out with sea-water until approx. 500 m below the seafloor, there would be any possibility of uncontrollable conditions when "CHIKYU" encounters shallow gas and water flow. At the same time, we

have to consider the influence of water currents upon the riser pipe and "CHIKYU" herself.

To ensure safe and efficient drilling in such locations, it is mandatory to conduct pre-drilling site surveys collecting accurate information, about weather and sea conditions, sea-floor topography, underground structures etc... The survey will particularly concentrate on determining underground geo-hazards, which could become hugely troublesome while drilling, and only using such information to plan detailed drilling programs makes it possible to perform drilling safely and efficiently.

In FY2003, JAMSTEC/CDEX conducted further studies to select riser drilling sites during the "CHIKYU" training cruise. There, a series of site surveys consisting of single-channel seismic surveys, side-scan sonar surveys/Sub-bottom profiling were conducted. Piston corings were also conducted based on the results of Side-scan sonar survey/ Sub-bottom profiling.

(3) Construction of the "Management System for the Deep Earth Exploration Vessel Operation"

During "CHIKYU's" operation, scientific goals must be achieved under several extreme conditions, such as deep-sea, ultra-deep drilling, remote locations and/or long durations. Even under these operating conditions, JAMSTEC must drill efficiently and provide scientific services safely, while preventing pollution and preserving assets. To achieve its mission, it is necessary to construct a "Management System" based on the functions and specifications of "CHIKYU", as well as responding to on/offshore organization/structures, including contractors.

Last year (FY2002), JAMSTEC started developing the "CHIKYU" Operation Management System as an IODP RISER drilling operator and started establishing basic policies for Safety, Health and Environment appropriate for the system including a CDEX HSE-MS Manual and a draft manual for RISER Drilling Procedures. This year, the basic

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preventive maintenance system (PMS) was finalized, which plans scheduled maintenance of all onboard equipment as well as monitoring storekeeping.

(4) Preparation of the Science Services System

The Science Services Group of CDEX has a responsibility to prepare all scientific measurement and analytical equipment that will be installed on "CHIKYU". Based on suggestions and recommendations from the IODP scientific community, CDEX is preparing to operate "CHIKYU" and a shore-based laboratory newly established in May 2003. The shore-based laboratory is implemented by JAMSTEC and Kochi University under the MOU.

The database software prototype for managing all data produced by onboard research was completed, and an external evaluation was performed. The database software was named "J-CORES (JAMSTEC CORE Systematics)" (Figure 3).

A preliminary assessment on a long-term borehole experiment is performed. A basic design and operation procedures are considered and from this, future development needs are extrapolated.

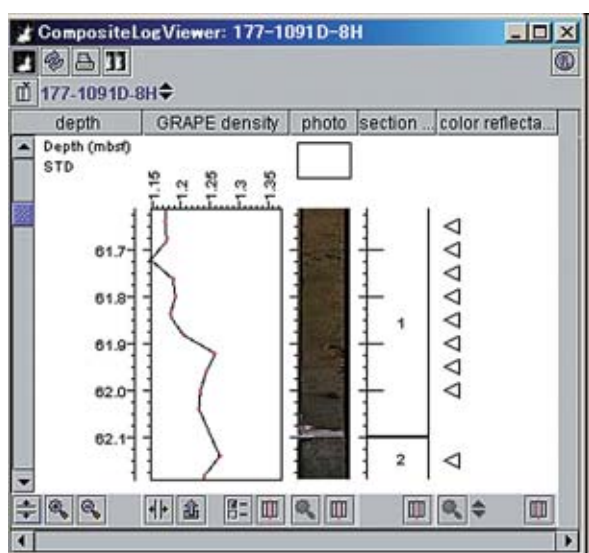


Fig. 3 A screen dump shows an example of J-CORES prototype database software that reads stored data and displays depth with various data items.

3. Activities of the Ocean Drilling in the 21st Century (OD21) for the Integrated Ocean Drilling Program (IODP)

(1) OD21 International Activities for the IODP

Ocean Drilling in the 21st Century (OD21), advocated by JAMSTEC, will advance to the Integrated Ocean Drilling Program (IODP) under international cooperation and funding. The IODP formally started October 1, 2003 with the conclusion of a memorandum between the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the U.S. National Science Foundation (NSF) on April 22, 2003.

The IODP is an international scientific program that mainly utilizes two drilling vessels: the riser-capable vessel "CHIKYU", to be provided by JAMSTEC, and a riserless vessel to be provided by the NSF.

The European Consortium for Ocean Research Drilling (ECORD), in which 12 nations in Europe participate, signed the memorandum, and has formally participated since March 2004. JAMSTEC has been working to build up the collaborative, cooperative and operational structure with IODP member countries through various activities at the international level, such as the International Working Group (IWG) and interim Science Advisory Structure (iSAS). As the IODP has formally started, the IWG/IODP meeting was over with its last meeting in Capri (Italy) in June 2003, and most of the roles have been taken over by the IODP council. The first IODP councils were held in San Francisco in December 2003.

Continuing from last fiscal year, JAMSTEC provided staff to the IWG Support Office (IWGSO) established in Washington D.C. with the cooperation of Japan and the U.S. to support the IWG and other related activities. JAMSTEC had hosted the iSAS office in the Yokosuka Headquarters until September 2003 to support iSAS activities, such as recommendations on the Science Advisory Structure (SAS), promotion of proposal submission and evaluation of proposals. After that, the office had been hosted until preparation of the IODP-MI (IODP Management International

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Inc.) was completed, which would assume control of the Central Management Office (CMO) (the so-called "tSAS office"). IODP-MI was established in February 2003 and it has been determined that major functions, such as science support and planning, would be implemented by the office in Sapporo, Japan (inside of Hokkaido University).

As the overall coordinating and promoting organization for the IODP in Japan, JAMSTEC has entrusted the business with promoting IODP-MI's management structure to the Advanced Earth Science & Technology Organization (AESTO). For the promotional and public relations activities of IODP, JAMSTEC provided an exhibition booth at the International Union of Geodesy and Geophysics (IUGG) in June 2003 in Sapporo, the OCEANS in September 2003 in San Diego, and the Annual Meeting of American Geophysical Union (AGU) in December 2003 in San Francisco.

(2) OD21 Domestic Activities for the IODP

For successful implementation of the IODP/OD21, the OD21 Program Department has been constructing the scientific riser-drilling vessel, "CHIKYU", which is one of the program's core capabilities. The Department is also setting up its operational structure and scientific research system in close collaboration and with the support of governmental agencies, uni-

versities and research institutions.

To promote domestic research, OD21 has entrusted administration of the IODP Japan Science Planning Committee to Advanced Earth Science & Technology Organization (AESTO) in FY2003. Through the activities of its seven panels and working group, the Committee has developed a domestic strategy for scientific research, planned concrete research objectives for the IODP, helped the IODP Science Advisory Structure (SAS), and recommended the onboard scientists of the IODP cruise. In collaboration with Japan Drilling Earth Science Consortium (J-DESC), in March 2004 the Committee published the "Strategy for IODP Science Activity in Japan –Science Plans towards Realizing Drilling Proposals (1)–" which serves as a concrete guide for the science promotion in Japan. The Committee has also managed the IODP Japan mailing list to spread related information.

The Department has continuously maintained the OD21 HP for promotional activities and public relations, published OD21 Newsletters (vol.15, in both English and Japanese). The Department provided an exhibition booth to the 2004 Japan Earth Planetary Joint Meeting, the 110th Conference of the Geological Society of Japan and Fall meeting of the Seismological Society of Japan, and held the IODP Inauguration Symposium to enhance support for the IODP/OD21 from both domestic and international scientists.

Research Activities

International Continental Scientific Drilling Program

The international Continental Scientific Drilling Program (ICDP) is an international joint-research program that began in 1996, with participation by Germany, the United States and China.

In 2000, JAMSTEC was assigned as Japan's representative to the project. In October 2000, JAMSTEC signed a memorandum to participate in the project with Germany's ICDP representative, the GeoForschungsZentrum (GFZ) of Potsdam. The OD21 Program Department serves as the secretariat office to support domestic activities, publish newsletters (vol.5-6 in FY2003) and maintain the HP for the ICDP.

In FY2003, at the 2004 Japan Earth Planetary Joint Meeting and the 110th Conference of the Geological Society of Japan, the Department held a town meeting about continental drilling, to enhance continental drilling support, including the ICDP. Moreover, the department helped organize the 8th ICDP AOG (Assembly Of Governors) meeting in Nagasaki, in which 22 representatives of each member country participated.



Fig. 1 Participants in the 8th ICDP AOG at the Unzen Scientific Drilling Project site.

Research Activities

The Earth Simulator Center

On Research Development and its Policies

The Earth Simulator Center has been operating "The Earth Simulator", the world's fastest vector parallel supercomputer (as of March 31st, 2004) along with promotion of large-scale simulation research. Its research plans are aimed for quantum leap in unraveling and projecting the global phenomena such as El Niño effect, to regional phenomena like local severe rain in the city area. Greatly expected is the significant contribution to mankind, moreover development of new materials and products resulting in striking economical growth.

(1) Selection for the Earth Simulator Research Project for FY 2003

In accordance with "Mission and Basic Principles of the Earth Simulator", the Earth Simulator is to be used in an open environment, and the usage plan is to be formulated by the Mission Definition Committee.

Based on its Mission and Basic Principles, the 3rd Mission Definition Committee held on March 5th, 2003 has formulated a plan for details like allocation of its computational resources in each field, such as ①Atmosphere and Ocean, ② Solid Earth, ③ Computational Science, and ④ Epoch making Simulation.

From 12th to 30th March 2003, the Earth Simulator Collaboration Project for FY 2003 was publicly sought. On 10th of April 2003, 57 projects applied were deliberated at the 3rd Selection Committee, and as a result, 34 projects were selected as the Earth Simulator Collaboration Project for FY 2003. Full listing of the Collaboration Projects for FY 2003 is shown in Table 1.

On 10th and 11th of January 2004, the Annual Meeting for Collaboration Projects for FY 2003 was held.

(2) Detailed Research Results using the Earth Simulator

1) Predictability of heavy rainfall over Europe in August 2002

Heavy rainfall flooded many parts of central Europe in August 2002. The storm was predicted only a few days before the event. In order to investigate its poor predictability simulations were conducted. Figures 1 and 2 are the infrared image observed at the time of

the event by a satellite and the corresponding simulated results from the initial condition at 3.5 days before, respectively. Those figures show that the storm over the Mediterranean Sea and its associated cloud pattern are well reproduced in the simulation. Further investigation implies a remote influence of a tropical cyclone off the east coast of North America.

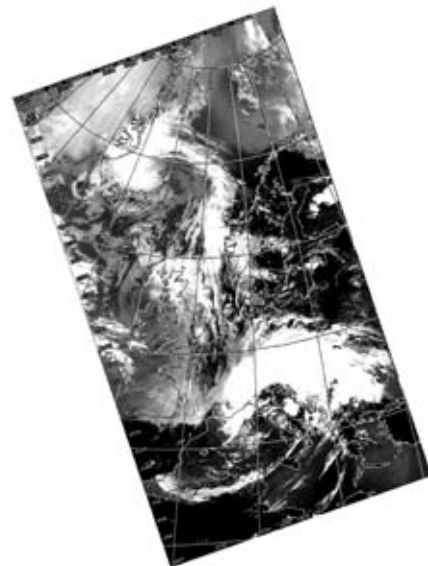


Fig. 1 Observation from Satellite



Fig. 2 Simulation Results

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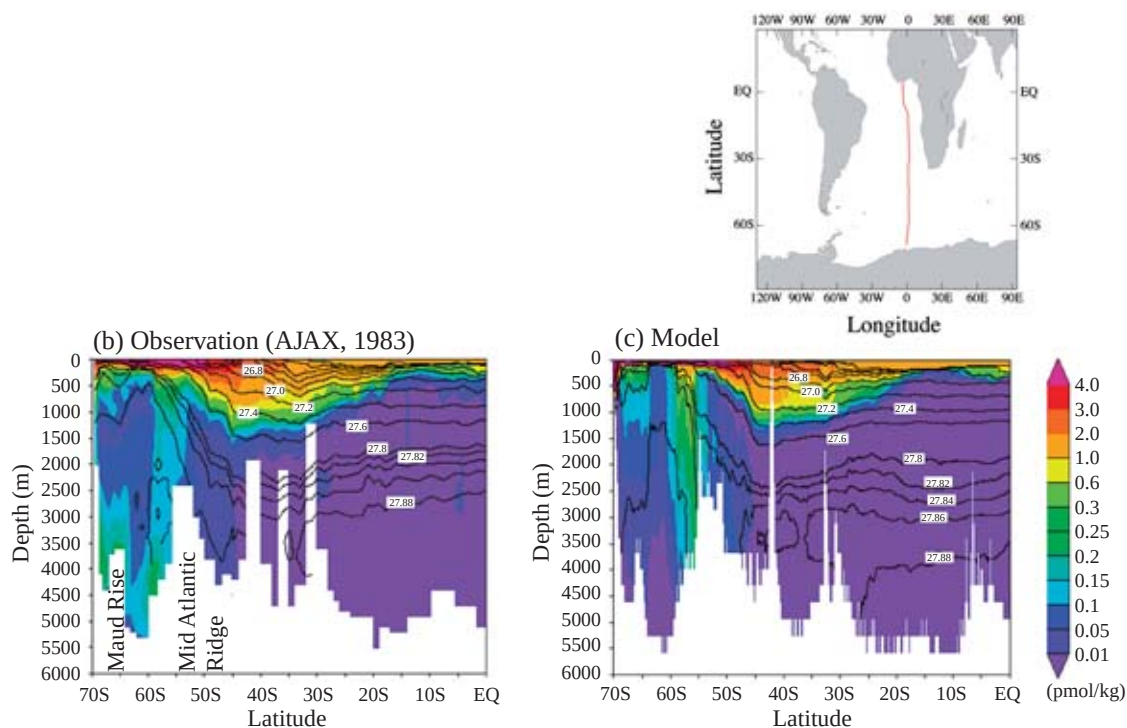


Fig. 3 CFC-11 concentrations (pmol/kg) with potential density (solid line) along 0°E in the South Atlantic (1983).

2) Chlorofluorocarbons Simulation using High Resolution Global Oceanic Simulation Code OFES (OGCM for the Earth Simulator)

Chlorofluorocarbons (CFCs) which are inert anthropogenic materials are absorbed at the ocean surface and carried with the oceanic circulation. The distribution of CFCs in the ocean provides information on not only the oceanic circulation but also the uptake and accumulation of chemical tracers.

The model simulates well the observed CFC-11 concentration along the AJAX section in the South Atlantic very well (Fig. 3). The high CFC-11 concentrations down to 1000m at 45S and in the deep layer at 55S are reproduced by the model. Fig. 4 shows the CFC-11 concentration in the deep North Atlantic simulated by the model. The CFC-11 distributions clearly capture the realistic pathway of the western boundary deep current in the Western Atlantic. Our realistic results seems to owe much to the employed high-resolution that resolves the bottom topography in a realistic fashion and hence improves the ocean circulation.

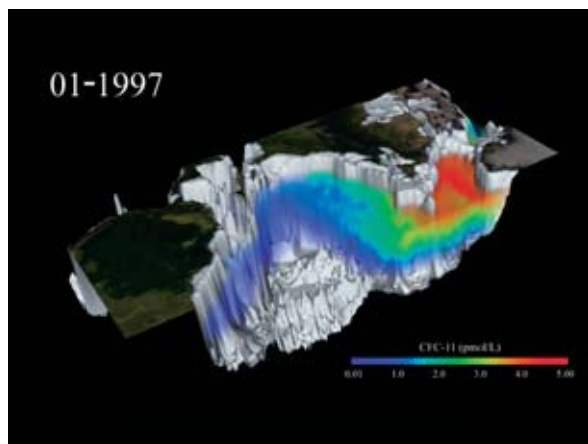


Fig. 4 Distribution of CFC-11 in the Deep North Atlantic Ocean around 2000m depth.

3) Mantle Convection Simulation Using "Yin-Yang Grid System"

In order to make the best use of the Earth Simulator, we have developed a new spherical grid named 'Ying-Yang grid'. The Ying-Yang grid is a kind of overset on chimera grid that is composed of two identical component grids (see Fig. 5; left). Based on this new grid system, we have developed a new simulation code for the study of slow and large-scale spherical

The Earth Simulator Center

connection of Earth's interior called mantle. Fig. 5. (middle and right) shows convection motion of the mantle: Red indicates hot and rising region, green does cold and sinking one.

We analyzed these three dimensional structure of the mantle convection in stationary and symmetric states. We used our virtual reality system 'BRAVE' for

the three dimensional and interactive data visualization. We found that the stationary mantle convection is organized by a set of cells of the torus (of doughnut) shape. The structure of the torus cells in the stationary mantle convection is an interesting binding on the basic native nature of the mantle convection.

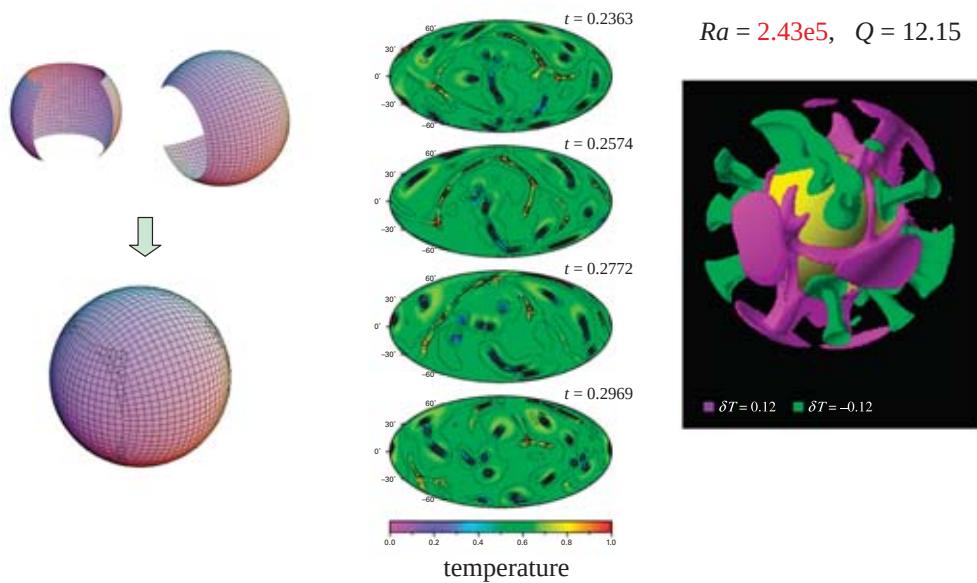


Fig. 5 Ying-Yang grid and its application to spherical mantle convection

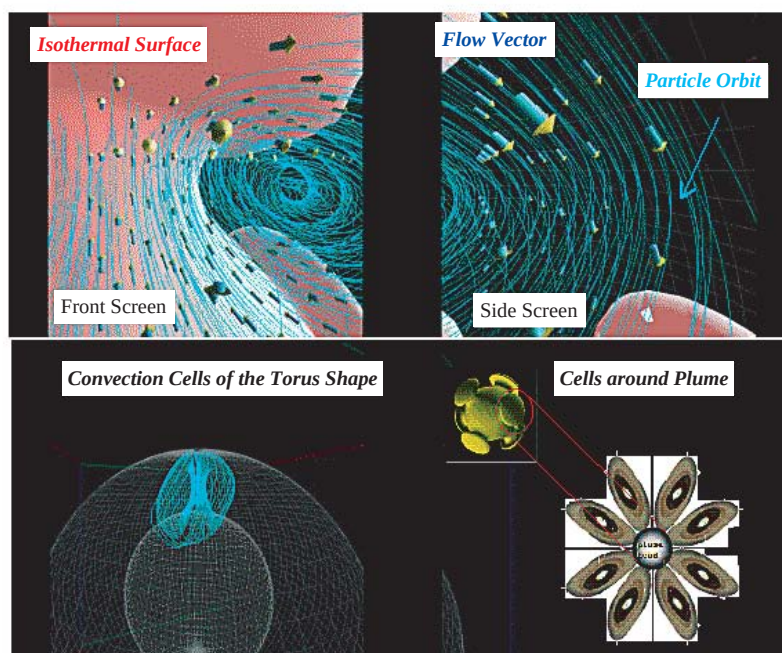


Fig. 6 Structure of the mantle convection

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4) Development of 3-D Data Visualization System 'BRAVE' and Related Softwares

The Earth Simulator Center installed 3-dimensional data visualization system 'BRAVE' in 2002.

The BRAVE is a room-sized, projection-based, and cubic shaped virtual reality system (CAVE-tape). The BRAVE has four screens (front, right, left and floor). Stereo, color images are projected onto these screens in the seamless way. Wearing a pair of "stereo – shuttle" glasses, researchers can observe and analyze their simulation data in stereo in the BRAVE room. We have developed various softwares to render the simulation data by the BRAVE system. An example of the BRAVE visualization is shown in Fig. 7. When the summer closes in, antagonism between Warm-moist air from South with Dry air from North constitutes Baiu front, which causes rain in the Eastern Asia. The figure indicates timely changes of amount of cloud water occurred alongside of seasonal Baiu front around Japan, analyzed by the BRAVE. The silhouette of a researcher in the BRAVE room can be seen in Fig. 7. (lower right).

(3) Introduction of MDPS

The simulation data produced by the Earth Simulator often exceeds 1 TB (1,000GB). Since the Earth Simulator had only the cartridge tape library as a mass data storage system at the beginning, users used to consume not only a lot of time but also CPU resource of the Earth Simulator for handling a huge

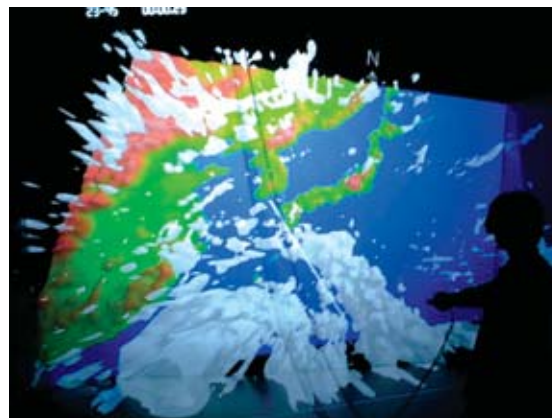


Fig. 7 Cloud water in Baiu rain analyzed by BRAVE.

simulation data. The new storage system called Mass Data Processing System (MDPS) was introduced in October 2003, so that users can handle the simulation results without using the Earth Simulator itself, and the input/output loads of the whole Simulator system is drastically reduced.

(4) Collaborations with other domestic and international institutions

Domestically, the Earth Simulator Center made an agreement on collaboration with Mitsubishi Heavy Industry, Ltd. in relation to "Primary Characteristics and Parameterization of Coupled Model for Wide-area Water Circulation Prediction System".

Regarding the international collaboration projects, the Earth Simulator Center has exchanged Memorandum of Understanding (MOU) with 9 institutions as listed in Table 2.

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Table 1 Collaboration Projects for FY 2003

Ocean and Atmosphere

	Title	Name	Affiliation
1.	Development of super high-resolution atmospheric and oceanic general circulation models on quasi-uniform grids	Yukio Tanaka	FRSGC, JAMSTEC
2.	Atmospheric Composition Change and Its Climate Impact Studied by global and Regional Chemical Transport Models	Hajime Akimoto	FRSGC, JAMSTEC
3.	Development of High-resolution Cloud-resolving Regional Model and its Application to Research on Mesoscale Meteorology	Fujio Kimura	FRSGC, JAMSTEC
4.	Process Studies and Seasonal Prediction Experiment Using Coupled General Circulation Model	Toshio Yamagata	FRSGC, JAMSTEC
5.	Future Climate Change Projection using a High-Resolution Coupled Ocean-Atmosphere Climate Model	Akimasa Sumi	Center for Climate System Research, The University of Tokyo
6.	Development of high-resolution atmosphere-ocean coupled model and global warming prediction	Kouki Maruyama	Central Research Institute of Electric Power Industry
7.	Research on development of global climate model with remarkably high resolution and climate model with cloud resolution	Takashi Aoki	Japanese Meteorological Research Institute
8.	Research Development of 4-dimensional data assimilation system using a coupled climate model and construction of reanalysis datasets for initialization	Toshiyuki Awaji	FRSGC, JAMSTEC
9.	Development of Integrated Earth System Model for Global Change Prediction	Taro Matsuno	FRSGC, JAMSTEC
10.	Parameterization of turbulent diffusivity in the deep ocean	Toshiyuki Hibiya	Graduate School of Science, The University of Tokyo
11.	Mechanism and predictability of atmospheric and oceanic variations induced by interactions between large-scale field and meso-scale phenomena (AFES CFES OFES)	Wataru Ohfuchi	ESC, JAMSTEC
12.	Development of holistic simulation codes on non-hydrostatic atmosphere-ocean coupled system	Keiko Takahashi	ESC, JAMSTEC

Solid Earth

	Title	Name	Affiliation
13.	Global elastic response simulation	Seiji Tsuboi	IFREE, JAMSTEC
14.	Simulation study on the generation and distortion process of the geomagnetic field in Earth-like conditions	Yozo Hamano	IFREE, JAMSTEC/Graduate School of Science, The University of Tokyo
15.	Numerical simulation of the mantle convection	Yoshio Fukao	IFREE, JAMSTEC
16.	Predictive Simulation for Crustal Activity in and around Japan	Mitsuhiro Matsuura	Graduate School of Science, The University of Tokyo
17.	Numerical simulation of seismic wave propagation and strong ground motions in 3-D heterogeneous media	Takashi Furumura	Earthquake Research Institute, The University of Tokyo
18.	Simulation of Earthquake Generation Process in a Complex System of Faults	Kazuro Hirahara	Graduate School of Environmental Studies, Nagoya University
19.	Development of Solid Earth Simulation Platform	Hiroshi Okuda	Research into Artifacts, Center for Engineering, The University of Tokyo
20.	Simulator experiments of physical properties of earth's materials	Mitsuhiro Toriumi	Graduate School of Frontier Science, The University of Tokyo
21.	Dynamics of Core-Mantle Coupled System	Akira Kageyama	ESC, JAMSTEC

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Computer Science

	Title	Name	Affiliation
22.	Designing and implementation of parallel numerical computing library for multi-node environment of the earth simulator	Kenichi Itakura	ESC, JAMSTEC
23.	Performance Evaluation of Large-scale Parallel Simulation Codes and Designing New Language Features on the HPF (High Performance Fortran) Data-Parallel Programming Environment	Yasuo Okabe	Academic Center for Computing and Media Studies, Kyoto University

Epoch-making Simulation

	Title	Name	Affiliation
24.	Numerical Simulation of Rocket Engine Internal Flows	Hiroshi Miyajima	Japan Aerospace Exploration Agency
25.	Large-scale simulation on the properties of carbon-nanotube	Kazuo Minami	Research Organization for Information Science & Technology
26.	Development of the next-generation computational solid mechanics simulator for a virtual demonstration test	Ryuji Shioya	Graduate School of Engineering, Kyushu University
27.	Study of the Standard Model of Elementary Particles on the Lattice with the Earth Simulator	Akira Ukawa	Center for Computational Physics and Institute of Physics, University of Tsukuba
28.	Large-scale simulation for a Tera Hz resonance superconductors device	Masashi Tachiki	National Institute for Material Science
29.	Geospace Environment Simulator	Yoshiharu Omura	Radio Science Center for Space and Atmosphere, Kyoto University
30.	Particle modeling for complex multi-phase system with internal structures using DEM	Hide Sakaguchi	IFREE, JAMSTEC
31.	Development of Transferable Materials Information and Knowledge Base for Computational Materials Science	Shuhei Ohnishi	CAMP (Collaborative Activities for Materials Science Programs) Group
32.	Cosmic Structure Formation and Dynamics	Ryoji Matsumoto	Faculty of Science, Chiba University
33.	Bio-Simulation	Nobuhiro Go	Forum on the Bio-Simulation
34.	Large scale simulation on the atomic research*	Hiroshi Okuda	Atomic Energy Society of Japan

*Sub-theme under the large scale simulation on the Atomic research

Title	Name	Affiliation
Large-Scale Numerical Simulations of Complicated Thermal-Hydraulic Behavior in Nuclear Reactors Using Direct Analysis Methods	Kazuyuki Takase	JAERI
First Principles Molecular Dynamics Simulation of Solution	Masaru Hirata	JAERI
Direct Numerical Simulations of Fundamental Turbulent Flows with the Largest Grid Numbers in the World and its Application of Modelling for Engineering Turbulent Flows	Chuichi Arakawa	CCSE, JAERI
Research on structure formation of plasmas dominated by hierarchical dynamics	Yasuaki Kishimoto	JAERI
Large-scale parallel fluid simulations for spallation type mercury target adopted in the project of high-intensity proton accelerator	Chuichi Arakawa	CCSE, JAERI
Studies for Novel Superconducting properties and Neutron Detector Applications by Superconductor Nano-fabrication Techniques	Masahiko Machida	CCSE, JAERI
Electronic and atomistic simulations on the irradiation induced property changes and fracture in materials	Hideo Kaburaki	CCSE, JAERI
Large-Scale Simulation of Groundwater Flow and Radioactive Nuclide Transportation	Hiroshi Okuda	Research into Artifacts, Center for Engineering, The University of Tokyo
First-principles molecular dynamics simulation of oxide layers for radiation-tolerant SiC devices	Atumi Miyashita	JAERI

JAMSTEC : Japan Marine Science and Technology Center
 IFREE : Institute for Frontier Research on Earth Evolution
 CCSE : Center for Promotion of Computation Science and Engineering

FRSGC : Frontier Research System for Global Change
 JAERI : Japan Atomic Energy Research Institute
 ESC : The Earth Simulator Center

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Table 2 The collaborative researches with foreign institutions

Hadley Center for Climate Prediction and Research (HCCPR)
Centre for Global Atmospheric Modelling (CGAM)
Institut français de recherche pour l'exploitation de la mer (IFREMER)
Centre national de la recherche scientifique (CNRS)
Italian Aerospace Research Center (CIRA)
Scripps Institution of Oceanography (SIO)
National Energy Research Scientific Computing Center (NERSC)
The University of Texas, Center for Computational Visualization (CCV / ICES /UT)
Recherche Prevision Numerique, Meteorological Service of Canada (RPN / MSC)

Research Activities

Mutsu Research Group

1. Research project

"Time-series observational study in the North Pacific (HiLATS project)"**(1) Overview**

The importance of time-series observation has been recognized for better understanding of the ocean's role in the uptake of increasing atmospheric carbon dioxide (CO_2). However, repeatable observation by ordinary research vessels is demanding economically and physically. Although time-series sediment trap experiments has been a powerful approach to time-series observation, this instrument is usually moored in the deep sea and does not always provide sufficient information about seasonal and interannual variability in the biogeochemistry of the upper ocean.

To more precisely clarify the "biological pump", one of the principal mechanisms of CO_2 uptake, time-series observation in shallow and intermediate water is strongly requested using autonomous observation instruments. Under these circumstances, the North Pacific Time-Series Observational Study (HiLATS project), was initiated in 2000 as one of the research

programs at the Must Institute for Oceanography (MIO) of JAMSTEC. This program is also a joint program with the Joint Pacific Research Center (JPAC) of the Woods Hole Oceanographic Institution (WHOI).

(2) Research activity outline

Fiscal years 2000/2001 and 2001/2002 were devoted to the preparation of time-series instruments, such as automated incubation chambers, automated oceanographic samplers and CTD profilers. In 2002, the first mooring sets were deployed in the northwestern North Pacific. In fiscal 2003/2004, the second mooring system and data sets were recovered.

(3) 2003/2004 annual report (HiLATS)

During the KAIREI KR03-11 cruise (October/November 2003), time-series mooring systems (BGC mooring for the study of biogeochemistry and PO mooring for the study of physical oceanography) were recovered and samples/data were analyzed onshore.

Fig. 1 shows time-series variability in the depth of a depth sensor initially equipped at 50 m and the current

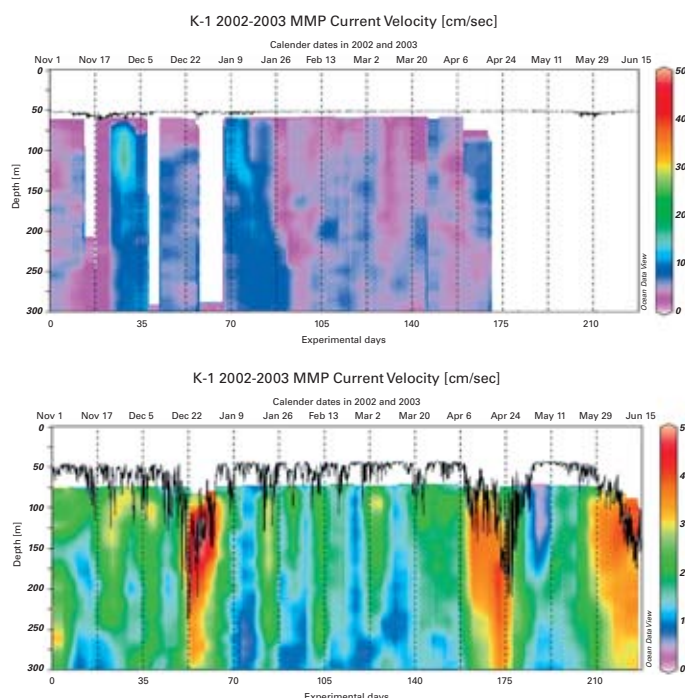


Fig. 1 Seasonal variability in the depth of a depth sensor (lines) initially equipped at approximately 50 m and the current velocity at depths down to 300 m observed by automatic elevating ACM (MMP) at stations (a) K-1 and (b) K-3.

Mutsu Research Group

velocity at depths down to 300 m observed by automatically elevating ACM (MMP) at stations (a) K-1 and (b) K-3. The depth of the sensor was relatively constant at station K-1, and current velocity was lower than 15 cm/sec. On the other hand, the depth sensor was dipped over 200 m in December 2003 and April 2004 at station K-3, and this was attributed to a strong current of higher than 40 cm/sec. In data analysis, samples during such periods were eliminated.

Fig. 2 shows seasonal variability in primary productivity (PP) at approximately 50 m at stations (a) K-1 and (b) K-3. PP at both stations were low in winter and high in summer/autumn. Average PP at station K-3 was higher than that at station K-1. Seasonal variability in daily light intensity (Dir) at SID-depths are also shown in Fig. 1. Dir at station K-3 was higher than at station K-1, supporting higher PP at station K-3. In addition, PP correlated well with Dir at station K-3 ($r = 0.7$).

To verify reliability of SID-PP values, these were compared with PP observed by traditional methods (*in situ* incubation) during previous North Pacific time-series observations (KNOT project). Although the pattern of seasonal variability differed, absolute values of

SID-PP were comparable to previous data indicating that SID-PP are reasonable.

In addition to the above mooring study, shipboard observation was conducted during several other scientific cruises (July and November 2003: Natsushima NT03-07 (12) cruise, March 2004: Mirai MR04-02 cruise) and seasonally variable data such as nutrients and natural radio nuclides were obtained. Compiling the above data, the precise mechanism of the biological pump in the northwestern North Pacific will be clarified in the future.

2. Research project

"Study on past marine environmental change"

(1) Overview

Past variation and changes in sea surface environment, biogeochemical cycle and thermohaline circulation recorded in marine sediment provide important information to predict future global climatic change. We focus on reconstructing the "natural" variability of global and regional climate recorded in the marine sediment during the late Quaternary. To clarify past environmental changes, we are investigating according to following themes:

- Changes in sea surface temperatures and current surface systems
- Changes in ocean biogeochemical cycles (Carbon cycles)

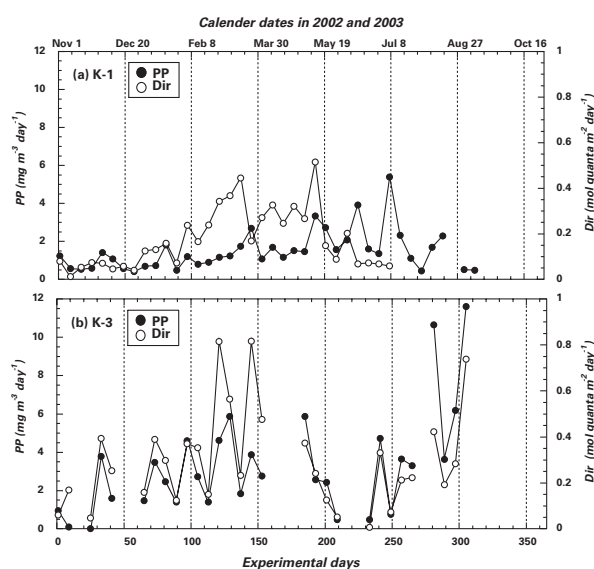


Fig. 2 Seasonal variability in primary productivity (solid circles) observed by the submersible incubation chamber (SID) and light intensity at SID-depth (open circles) observed by the optical sensor (BLOOM).

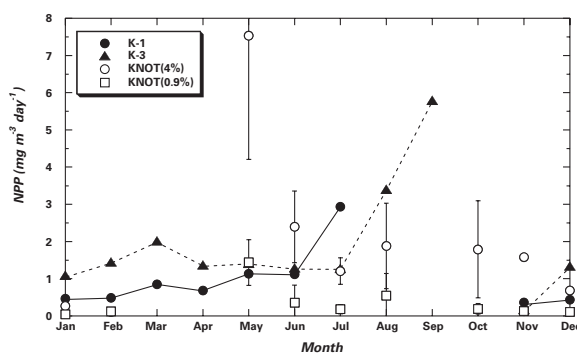


Fig. 3 A comparison of SID-PP (monthly average: solid circles for K-1 and solid triangles for K-3) with PP observed during time-series observation in the northwestern North Pacific (KNOT project) (open circles for PP at 4% relative light intensity and open squares for 0.9% relative light intensity).

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c) Changes in global thermohaline circulation

In addition, to reconstruct past climate changes more precisely, we also seek to find new paleo-proxies and develop them as follows:

- d) Chronology proxies (individual compound-specific radio carbon analysis and amino acid chronology)
- e) Proxies of nutrients and temperature (analysis of trace elements such as Cd, Mg, Ca contained in biogenic carbonate tests with culture experiments of foraminifera and coccolithophorid)

(2) Outline of research activities

This project has been conducted as one of the Mutsu Institute for Oceanography (MIO)'s research projects since FY2000. In FY2000–2001, analytical systems (carbonate device, ICP-MS, vacuum lines, preparation systems for compound-specific radio carbon measurement, etc.) of geochemical parameters recorded in sediment were developed and set up. Simultaneously, we collected sediment cores and living planktonic foraminifera in research cruises (MR00-K03, MR01-K03, and MR03-K04). Activities have been published as international journals, and in the following section, we introduce two major topics obtained in FY2003.

(3) Major topics in FY2003

a) Episodic methane release events from Last Glacial marginal sediments in the western North Pacific

According to recent observations of anomalous bottom-simulating reflections (BSR), the northwest Pacific marginal sediments around Japan's main islands bear a great abundance of methane hydrate. During the Last Glacial Age, direct and indirect evidence accumulated from geochemical data suggests that methane was episodically released from hydrate trapped in seafloor sediments. Despite the potential for large episodic releases of methane in the western North Pacific, the relationship between climate and hydrate instability in the region has been insufficiently studied, and little is known. In this study, to investigate relations with foraminifera carbon isotopic signals and methane release from the seafloor, biomarker compositions and their carbon isotopes have been analyzed in light of past methanotrophic bacteria activity in the oxic-anoxic interface of the overlying water column and/or surface sediment.

Analyzed piston cores (MR01-K03 PC4 and PC5, 41°07.10' N, 142°24.20' E, Fig. 4) at a water depth of 1366 m were retrieved from a single site in the eastern margin of the main Japanese island Honshu in the

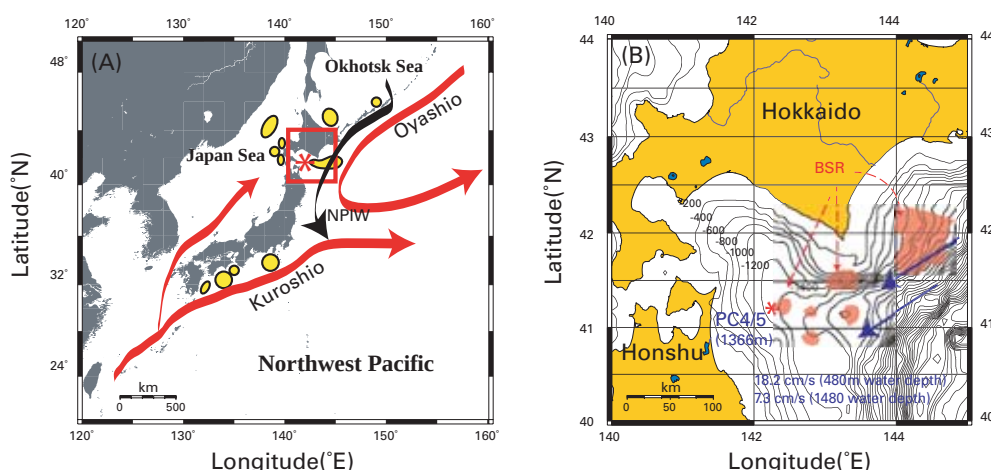


Fig. 4 Location of cored sites (MR01-K03 PC4/5) in the marginal sea off Honshu, the Japanese main islands in the Northwest Pacific. The yellow shaded areas on the map (A) show locations of anomalous bottom-simulating reflections (BSR) that suggest the occurrence of methane gas hydrates. Detailed site descriptions of BSR around the study site in map (B) were also found by preliminary investigation of the Center for Deep Earth Exploration, JAMSTEC. The arrays in the map (B) represent a prominent west-southwestward flow.

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northwest Pacific during the MR01-K03 cruise of the R/V *Mirai*. The carbon isotopic compositions of diploptene with planktonic and benthic foraminiferal test results are shown in Fig. 5. The carbon isotopic compositions of diploptene range between -41.0‰ and -27.9‰ (relative to PDB). In a horizon indicative of a contribution of methanotrophic bacteria, foraminiferal isotope signals were also found with highly depleted ^{13}C compositions of planktonic foraminifera ($\sim -1.9\text{‰}$, PDB) and benthic foraminifera ($\sim -0.8\text{‰}$, PDB), suggesting indirect records of enhanced incorporation of ^{13}C -depleted CO_2 formed by methanotrophic processes that use ^{12}C -enriched methane as their main source of carbon. From combined isotopic data of diploptene and foraminifera, the most prominent signal of methane release was detected in sediments deposited around 25.4 cal. kyr BP (ca. 100-year timespan), corresponding to the Interstadial 3. This is the first evidence of methane-hydrate instability in the open western North Pacific during the Last Glacial Age. Considering the region's glacial-interglacial hydrographic conditions, intermediate

water warming and/or lowering of sea levels may modulate the instability of methane hydrate. Our results suggest that the Northwest Pacific marginal regions may exert a profound effect on rapid global warming climate changes during the Last Glacial Age. (Uchida et al., 2004).

b) Characteristics of alkenones synthesized by a bloom of *Emiliania huxleyi* in the Bering Sea

Since it was first realized that alkenones were produced mainly by Haptophyte algae, the coccolithophores *Emiliania huxleyi* (*E. huxleyi*) and *Gephyrocapsa oceanica*, the alkenone unsaturation indices $U^{K_{37}}$ and $U^{K_{37}}$ derived from the relative abundance of methyl alkenones with 37 carbon atoms and 2, 3, or 4 double bonds, have been proposed as a proxy measure of water temperature. In addition, the $\delta^{13}\text{C}$ of alkenones has been used to estimate paleo- pCO_2 and growth rate of alkenone producers. However, neither the relationships between alkenone unsaturation and temperature, nor those between the $\delta^{13}\text{C}$ of alkenones, growth rate, and pCO_2 can be explained simply. Although the discrepancies of

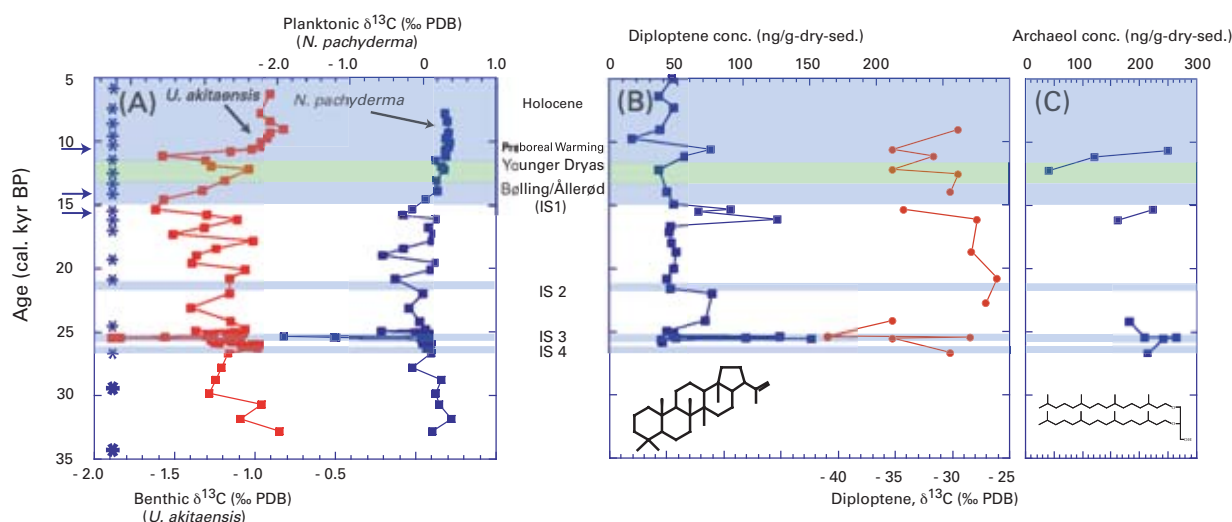


Fig. 5 Records of (A) the carbon isotopic composition of benthic (left) and planktonic (right) foraminifera in comparison with (B) the abundance (left) and carbon isotopic composition (right) of the methanotrophic bacteria and/or cyanobacteria biomarker diploptene (17-(H), 21-(H)-hop-22(29)-ene, structure shown) and (C) the abundance of the archaeal glycerol ether lipid archaeol (structure shown) in sediments. The arrays in (A) represent locations of the thin-laminated layers (10.3, 14.4, 15.5 cal. kyr BP), which likely correspond to the B/A period and the Pre-Boreal warming period. Light-blue and light-green shadings designate relatively warm interstadials and cold period Younger Dryas, respectively, which are evaluated through comparison with $\delta^{18}\text{O}$ data from the GRIP. Asterisks in (A) denote layers from which planktonic foraminifera were collected for AMS radiocarbon dating.

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biomarkers as paleo-proxies have been attributed to many reasons, the precise reasons are unclear. Especially under regional-level natural conditions, present information is insufficient to determine a relationship between alkenone abundance (and its unsaturation patterns) and environmental parameters such as nutrients and salinity. In this study, we discuss the relationship between alkenone content and nutrient levels, as well as the relationship between the $\delta^{13}\text{C}$ of alkenone, $[\text{CO}_2(\text{aq})]$, and bloom stages, to clarify the characteristics of alkenones synthesized by blooms in the eastern Bering Sea. Furthermore, the relationship between the relative content of $\text{C}_{37:4}$ ($\text{C}_{37:4}\%$) alkenones and temperature and salinity is discussed from the viewpoint of using $\text{C}_{37:4}\%$ as a possible indicator of salinity or temperature.

We investigated the characteristics of alkenones produced by a bloom of *E. huxleyi* in the eastern Bering Sea in 2000. Alkenones were detected in surface waters between lat 57°N and 63°N , where phosphate concentrations were low and the ammonium/nitrate ratio was high. The change in the stable carbon isotopic composition ($\delta^{13}\text{C}$) of $\text{C}_{37:3}$ alkenones could not be explained only by variation in $[\text{CO}_2(\text{aq})]$ in surface water, but also depended on the growth rate of *E. huxleyi*. The relative amounts of $\text{C}_{37:4}$ alkenone as proportions of the total alkenones (referred to as $\text{C}_{37:4}\%$) were high, ranging from 18.3% to 41.4%. Surface water salinities in this study area were low, and high $\text{C}_{37:4}\%$ values are common in such areas. The relationship between $\text{C}_{37:4}\%$ and salinity was linear (Fig. 6), suggesting that $\text{C}_{37:4}\%$ in the sediment may be an indicator of salinity (Harada et al., 2004).

3. Personal Research

"The particulate organic carbon fluxes estimated from ^{234}Th ."

The northern North Pacific Ocean, especially its western part, has been attracting the attention of biogeochemists because of its importance in global biogeochemical cycles of carbon and related substances.

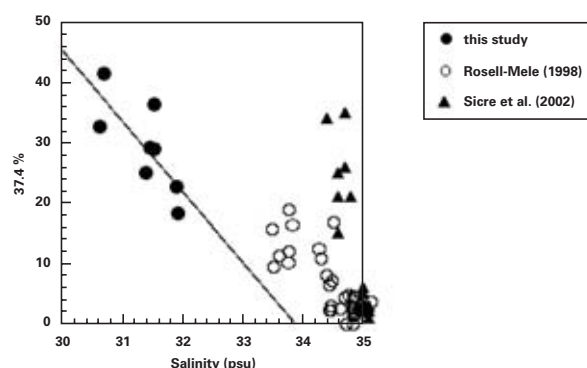


Fig. 6 The relationship between relative amounts of $\text{C}_{37:4}$ in total alkenones of suspended particulate samples and local salinity. Black circles indicate data analyzed in this study, open circles are from Rosell-Melé (1998), and solid triangles are from Sicre et al. (2002).

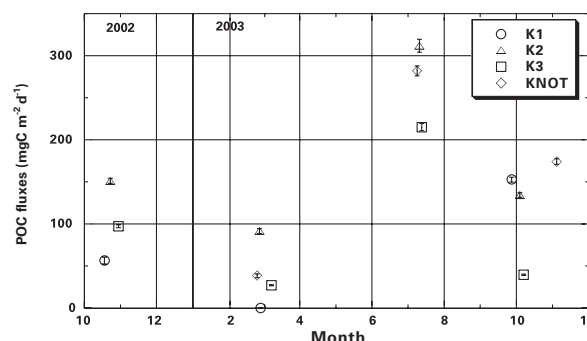


Fig. 7 Seasonal change of POC fluxes in the northwestern North Pacific.

It is well-documented that spring blooms, mainly consisting of diatoms, occur only in the western part of the subarctic Pacific. ^{234}Th , the short-lived (half-life = 24.1 days) natural radionuclide, has proven best in the euphotic zone for estimating particle exports. We determined POC fluxes using ^{234}Th in time-series stations K1 (51°N , 165°E), K2 (47°N , 160°E), K3 (39°N , 160°E) and KNOT (44°N , 155°), of the "North Pacific Time-Series Observational Study".

Samples were collected during the R/V Natsushima cruises; NT03-07 (Jul. 2003) and NT03-12 (Nov. 2003), the R/V Kairei cruise; KR03-11 (Sep.–Oct. 2003) and the R/V Mirai cruises; MR04-K02 (Mar.–Apr. 2004) in FY2003. POC fluxes showed wide seasonal variation in the northwestern North Pacific (Fig. 7).

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4. Personal Research

"The study of ecology and genetics of living calcareous plankton"

Planktonic foraminifera and coccolithophores, a group of free-floating marine protista, are distributed in the world ocean. Their morphology and chemistry are sensitive to ocean surface environmental changes. Their shells settle and deposit quickly in the sediment after death, therefore they are widely used for past-environmental investigations. In spite of their paleoceanographic importance, the relationship between their ecology, morphology and genetics are less known. It is very important to understand their ecology, life cycles, and relationship with surrounding ecosystems. The aims of this study are: 1) to understand the ecology of planktonic foraminifera and coccolithophores, 2) to establish cultivation systems in the laboratory, and 3) to develop methods for DNA analysis of calcareous plankton.

Living specimens were collected from the Tsugaru Strait (41°29' N, 141°14' E, water depth: 220 m, sample collecting depth: ca. 10 m below sea surface), northernmost part of Honshu, Japan. This area is located in the mixing zone between the Tsugaru warm current and Oyashio water.

In this FY, we focus on the accumulation of knowledge of the ecology of living species. We could successfully observe and describe some physiological phenomena (creating calcareous chambers, feeding processes, and gametogenesis) for some planktonic foraminifera, *Neogloboquadrina incompta* (Cifelli), *Globigerina bulloides* (d'Orbigny), and *Globigerinoides ruber* (d'Orbigny) (Figs. 8, 9) (Kimoto *et al.*, 2003). Molecular phylogenetic analysis was also conducted for some planktonic foraminifera. Moreover, a process-controlling system (EYELA, Tokyo) was installed in the incubator for continuous media flow in cultivation.

For the cultivation of coccolithophore, we developed the isolation technique. As a result, we succeeded in isolating *Gephyrocapsa oceanica* (Fig.10) (Kimoto *et al.*, 2003).

Now we plan to stock all digital images (still pho-

tos, movies and Scanning Electron Microscope (SEM) images) of living planktonic foraminifera in digital archives. These images will be open to the public and for educational use in the near future.

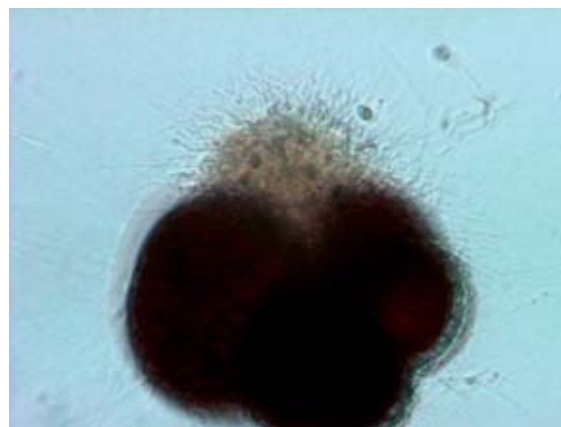


Fig. 8 Microscopic image of *N. incompta*, which was a creation chamber. The cytoplasm evacuated and radiated outward from the aperture. This image was an early (primary) step in the whole chamber-creating process.



Fig. 9 *G. bulloides* captured large zooplankton (*Artemia salina*).



Fig.10 *G. oceanica*, which was cultivated in isolation.

Research Support Activities

Computer and Information Service

(1) Activity overview

JAMSTEC has four functions: information activities consisting of collecting, managing and disseminating publications, and providing technical advice; data management activities consisting of data storage and quality control, and database development and operation for data dissemination; computer network activities consisting of managing computers ranging from PCs to the supercomputer, providing technical support to researchers, and network management and design; and promoting the use of information on environmental change consisting of digitization of information such as deep-sea images and research achievements, collection and dissemination of global environmental data, and providing access to facilities and equipment for researchers and the public. The main activities of JAMSTEC are as follows.

1) Information activities

- Collection, management, provision and storage of information relating to marine science and technology
- Technical consultation concerning marine science and technology
- Editing and publishing of publications

2) Data management activities

- Quality control management techniques such as enhancement of ocean observation data through correction, accuracy improvement, etc.
- Development and management of the various observation databases
- Management, storage, public release and provision of observation data

3) Computer network activities

- Management of computer systems and networks
- Computer-based data analysis and processing
- Investigation into the most advanced computer technologies

4) Promoting the use of information on environmental change

- Digitization of information such as deep-sea images and research achievements and reports held by JAMSTEC
- Collection, processing and dissemination of international ocean and global environmental data
- Providing access to facilities and equipment useful not just for researchers but for local residents and schools as well

This fiscal year, (2) and the following activities were carried out.

(2) Provision of research information

1) Collection, management and provision of books, periodicals and other publications

This fiscal year, as in the last fiscal year, JAMSTEC collected, managed and provided a wide range of material (books, journals, technical reports, conference material, etc.) relating to marine science and technology and earth sciences from Japan and overseas (Tables 1 and 2). Bibliographic information were provided inside JAMSTEC and outside, through the

JAMSTEC Library Search System and the National Institute of Informatics' National Center for Science Information Systems (NACSIS) database. The JAMSTEC Library Search System connects the three research centers of Japan Marine Science and Technology Center Yokosuka Headquarters, Yokohama Institute for Earth Sciences and Mutsu Institute for Oceanography over a network, allowing researchers at all three research centers to search and reserve books from their own computer terminals.

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Table 1 Library inventory (books)

Type	Inventory	New purchases
Japanese and foreign language books	18,882	7,094
Donated	7,620	1,468
Japanese and foreign language journals	2,920 titles	566 titles
Audio-visual materials	1,909	171

Table 2 JAMSTEC reports and periodicals

Type	Publications
Periodicals	14 titles
Consigned research reports	6 titles
Others	—
Total	20 titles

Library meetings were held periodically and attended by library committee members from each section. The library environment was improved to ensure better usability of books and materials for users and researchers, by carrying out an inquiry survey on books and magazines.

2) Collection of domestic and overseas information

(a) Domestic activities

- (i) We collected the latest information on library management by other domestic organizations and trends in electronic journals through the Japan Library Association and the Technical Library Council.
- (ii) We made efforts to improve reference room management and skills through participation in discussions at the Kanagawa Prefecture Data Research Society (KPDRS).

(b) International activities

- (i) The Intergovernmental Oceanographic Commission (IOC) was established to advance knowledge about natural marine phenomena and marine resources, and JAMSTEC has been receiving publications

since fiscal 1993.

- (ii) The International Association of Aquatic and Marine Science Libraries and Information Centers (IAMSLIC) was established to facilitate the exchange of marine science information, and JAMSTEC has been receiving publications since fiscal 1993.
- (iii) The Aquatic Sciences and Fisheries Abstracts (ASFA) is an integrated marine science and technology database run by the United Nations. JAMSTEC took part in Japanese ASFA committee meetings, and contributed through data input and the like.
- (iv) JAMSTEC continued gathering information on trends in international organizations and research programs.

3) Editing and publishing

This fiscal year, the periodical reports and journals listed in Table 3 were edited and published to disseminate JAMSTEC's research achievements and raise general awareness about the ocean. JAMSTEC developed a system for rapid issue of high-quality publications with expert staff and equipment for computerized editing and design.

4) Investigation and information services

JAMSTEC provides a broad range of information for both internal and external use.

(a) Books and journals

- (i) Inclusion of information about selected books in

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- the JAMSTEC Mail Newsletter.
- (ii) Introduction of electronic journals that are accessible over the intranet.
 - (b) Internal and external databases
 - (i) Provision of publication search services through the JAMSTEC Library Search System and external databases shown in Table 4. External databases were accessed 1,426 times by users.
 - (c) Current information
 - (i) Provision of an index of newspaper articles relating to the ocean on the JAMSTEC homepage under "Press releases".
 - (ii) Provision of information on ocean-related conferences and exhibitions as required on the JAMSTEC homepage.
 - (d) Reference service
 - (i) Registration of books, journals and other reference material held in the Cataloging System (NACSIS-CAT).
 - (ii) Provision of an advice and referral service for external enquiries on marine science and technology matters.

Table 4 External Databases Currently Available

Title	Content	
Report of JAMSTEC	Journal of academic theses on research achievements	Nos. 48, 49
JAMSTEC Journal of Deep Sea Research	Journal of academic theses on deep-sea research achievements	Nos. 23, 24
Blue Earth	Information magazines on the ocean and earth	Nos. 65, 66, 67, 68, 69, 70
JAMSTEC Annual Report (Japanese)	Business report	Fiscal 2002 edition
JAMSTEC Annual Report (English)	Business report (English)	Fiscal 2002 edition

Table 3 JAMSTEC publications

	Database title	Outline
1	JOIS	Information on literature and research themes on science and technologies (Japanese and English)
2	STN International	More than 200 international databases are available (English)
3	G-SEARCH	Contact point for Japanese/overseas databases (Japanese/English)
4	DIALOG	About 500 databases are available (English)
5	NACSIS	Database for supporting academic research activities (Japanese and English)
6	AIREX	System for management of literature on space by Japanese organizations and NASA (Japanese and English)
7	ASFA	International literature search system for fisheries
8	GEOREF	Literature database on earth science from sources throughout the world (English)
9	Medical and Pharmaceutical Proceedings full text database	Full-text PDF database of proceedings from about 200 societies

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5) Management of the JAMSTEC homepage

We updated JAMSTEC's research achievements and information for timely provision to the general public. The JAMSTEC publications were released as electronic files to enhance the quality of the contents. Also, new contents such as introduction pages for the cruise around the southern hemisphere BEAGLE 2003 were added this fiscal year.

(3) Data management activities

1) Oceanographic data management activities

To manage and disseminate observed data during oceanographic surveys and deep-sea surveys in accordance with the "guidelines on the release of observation data at JAMSTEC", a data management system has been developed for regular implementation of data quality control and accuracy improvement.

The quality control of observed data and the development of quality control techniques about a variety of data types and formats have been developed by expert staff in areas such as physical oceanography, chemical oceanography, geophysics and database technology. In addition, the sorting and archiving of deep-sea videos and slides obtained from research submersibles and the digitization and indexing of deep-sea images are performed. These activities are carried out in collaboration with the Global Oceanographic Data Center (GODAC) in Nago City, Okinawa Prefecture.

Observed data from the R/V Mirai is released by establishing the R/V MIRAI DATA Web (Fig. 1) through the Internet as soon as possible. There are many accesses from research institutes, universities and enterprises both inside and outside Japan.

2) Database development

JAMSTEC develops the databases necessary for the effective management and dissemination of observed data. Moreover, vast amounts of data are required for research into climate change and environmental issues on a global scale, and the efficient management of this

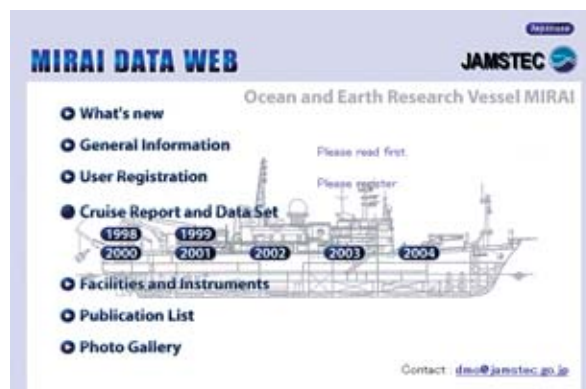


Fig. 1 R/V MIRAI DATA Web

data is absolutely crucial. In this light, there is a need to examine the framework for international data exchange and gather information on data exchange technologies so that researchers both from Japan and overseas can utilize the data held by JAMSTEC more effectively and efficiently.

We have been collecting information on distributed shared databases, which are being developed mainly in the U.S., and continued testing prototype systems based on DODS (Distributed Oceanographic Data System)/LAS (Live Access Server), which have only recently started to be used by oceanographic researchers.

3) Advanced processing of ocean observation data

JAMSTEC has been carrying out ocean observation to elucidate the mechanisms of ocean and meteorological change using the oceanographic research vessel MIRAI, mid-layer floating system ARGO floats, ocean observation buoy system TRITON buoys and other observation systems, and has accumulated vast amounts of data. While these data are made available through various databases, there is a need to process the data to make it more widely available and even more readily accessible to users. For this, we have been studying data assimilation methods.

One data assimilation method that has attracted attention over recent years is the statistics-based assimilation of observation data into numerical models. This can be used to draw up four-dimensional reanalyzed datasets, which is spatio-temporally homogenous.

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This fiscal year, we applied data assimilation based on optimum interpolation and nudging methods to the ocean general circulation model (MOM3) paralleled in JAMSTEC's supercomputer SC system, and examined advanced processing methods for ocean observation data obtained from MIRAI, ARGO floats and TRI-TON buoys. We then drew up reanalysis data covering the world's oceans for 2000 through 2002 after performing constant quality control upon the collected ocean observation data. From this we were able to clearly illustrate monthly variations in water temperature and salinity at various depths in the Pacific Ocean, and to reproduce more rationally major physical phenomena such as El Niño and La Niña that occurred during this period. At the same time, we were able to clarify future issues in preparing and providing high-quality four-dimensional reanalyzed datasets using more advanced data assimilation methods such as the adjoint method.

(4) Computer network management

1) Computer systems

(a) Supercomputer system

Understanding the various ocean phenomena through mathematical analysis and forecasting change through numerical models are pivotal to gaining a clear scientific grasp of global environmental issues. For the effective promotion of the research the power of a supercomputer with a large memory storage system is required.

JAMSTEC began using a supercomputer, the SX-4/20 system, on March 1, 1996, and replaced it with the SC system supercomputer in September 2001. This SC system is a 64-node-interconnected SMP server using AlphaServer ES40 scalar processors and has supercomputer performance. Peripheral devices include hard disk units connected by fiber channels, and a tape archival system expandable to 100 TB. The system also features a vector-type high-speed computation server to operate existing applications.

This fiscal year, as in the last fiscal year, the SC

system was used in explaining various ocean phenomena and predicting change through numerical modeling, and science and technology computation and data processing in reflection seismic surveys, genome analysis, and research and development projects.

(b) Shared computer systems

JAMSTEC has been operating the following shared computer systems. AlphaServer 4100 with VMS operating system upgraded from DEC7620 (Open VMS Alpha) VMS clusters at the end of September 1998, AlphaServer DS20E (Tru64UNIX) for use in data transfer to the supercomputer and small-scale computation, the SGI ONYX 3200 for image analysis and processing, and a file server, introduced in March 2003, to share and transmit research information and operation data.

2) Networks

(a) JAMSTEC network

In fiscal 1993 a local area network (LAN) based on FDDI was established at the Yokosuka Headquarters. In fiscal 1998, the branch LAN was upgraded to Fast Ethernet, and in fiscal 2002, the base was upgraded from FDDI to Gigabit Ethernet. The networks within the Yokohama Institute for Earth Sciences, Mutsu Institute for Oceanography and Japan Marine Science and Technology Center GODAC comprise Gigabit Ethernet base LAN and Fast Ethernet branch lines.

Figure 2 shows the network connection between JAMSTEC Headquarters and the research institutes. Mutsu Institute for Oceanography was connected to the Yokosuka area network in March 1996. In fiscal 2002, the leased 512 kbps connection to Yokosuka Headquarters was strengthened to a 3 Mbps wide-area LAN line to the Yokohama Institute for Earth Sciences. The Tokyo Branch was connected to the Yokosuka area network in 1994, and in 2002, the leased 128 kbps connection to the Yokosuka Headquarters was upgraded to a 3 Mbps wide-area LAN line to the Yokohama Institute for Earth Sciences. The Yokohama Institute for Earth Sciences

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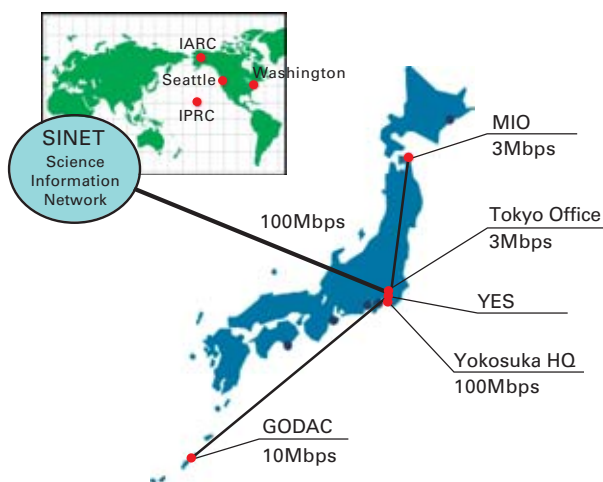


Fig. 2 JAMSTEC network

was connected to the Yokosuka Headquarters in March 2001 by a 100 Mbps ATM line, and in fiscal 2001, GODAC was connected by the JGN (Japan Gigabit Network). Following the end of the JGN project, the JGN connection was changed to a 10 Mbps wide-area LAN line in Feb. 2004. Now the center of the JAMSTEC network is at the Yokohama Institute for Earth Sciences.

(b) Internet

JAMSTEC first established its presence on the internet with a connection to TISN (Todai International Science Network) in January 1993. The connections to STAnet and IMnet were then established. In fiscal 2002, JAMSTEC was connected to SINET. The connection line was also changed from a leased line to an ATM line, and in 2002 to an Ethernet leased line. In fiscal 2001, the internet connection point was shifted from the Yokosuka Headquarters to the Yokohama Institute for Earth Sciences. GODAC was connected to the internet by leased line in fiscal 2001. The introduction of this high-speed link has enabled the effective use of image and video data, both of which require large bandwidth.

(c) Security

JAMSTEC installed a network firewall in fiscal 1996 at the connection point to the internet to ensure

the security of all network computers. The firewall system was doubled to make a stronger system against potential problems. In fiscal 2001, JAMSTEC upgraded the firewall and strengthened the countermeasures against the recent security intrusion.

Security monitoring through an intrusion detection system, regular network security and Web application tests, applying security patches, and updating network service applications ensure that a high level of security is maintained.

A virus-checking function was incorporated into the server in 1999 to detect and prevent viruses from spreading over the network.

(5) Promoting the use of information on environmental change (Global Oceanographic Data Center — GODAC)

In fiscal 2003, continuing from last fiscal year, we digitized information such as deep-sea images and research achievements and reports mainly held by JAMSTEC, and expanded the database. We also collected, processed and disseminated international ocean and global environmental data, and, as a feature of GODAC operations, provided open access to GODAC facilities and equipment as a part of its function of a dissemination center for oceanographic data that is of great value not just to researchers, but to residents and schools in the region, and also to the local tourism industry.

1) Digital archiving of image and bibliographical information

We digitized and made shot/panoramic processing of deep-sea images captured mainly from SHINKAI 2000 and SHINKAI 6500, constructed an image database and made it available to the general public over the internet (Table 5 and Figs. 3 and 4). We scanned publications such as "JAMSTEC Journal of Deep Sea Research" and "Report of Japan Marine Science and Technology Center", converted them into PDF format, and then split and linked the files according to size. We placed the information through OCR processing and proofing, and

Computer and Information Service

built up a publicly-accessible full-text search database providing not just bibliographical information, but whole text information as well (Table 6).

2) Disseminating global environmental data

We collected various forms of global environmental data online over the internet and offline through digital media provided by various research institutions, processed and entered the data into the database, dis-

seminated various datasets and operated a publicly-accessible data visualization system. We operated the global environment portal system, which is the point of access for this data, and connected to the JAMSTEC intranet through the wide-area Ethernet. This enabled us to provide these data to researchers, and also provide data visualized through the "Virtual Earth" for general users over the internet and the Nago local intranet, and maintain user registration data. (Figs. 5 and 6)



Fig. 3 Screen sample of viewing a shot image



Fig. 4 Sample of panoramic image

Table 5 Digital processing of image data (number of tapes processed)

Submersible/ ROV	Encoding (tapes)	Indexing (tapes)	Primary release (tapes)	Request for correction by researcher (tapes)	Secondary release (tapes)
SHINKAI 2000	813	53	29	4	4
SHINKAI 6500	687	100	20	0	0
DOLPHIN-3K	40	0	15	0	0
KAIKO	0	26	4	0	0
HYPER-DOLPHIN	7	5	0	0	0
DEEP TOW	0	0	0	0	0
Total	1,547	184	68	4	4

Computer and Information Service

Table 6 Digital processing of text data (regular publications)

Publication	Primary release		
	Edition	No. of issues	Pages
"Let's Draw Ocean Dream on Postcard" contest for children nationwide	Fifth and Sixth (*1)		410
Newsletter NATSUSHIMA	143-145, 203-216	17	56
Report of Japan Marine Science and Technology Center	1-14, 44-47	19	3,090
Cruise Report	NATSUSHIMA, KAIREI, YOKOSUKA, KAIYO	21	5,331
Technical Drawing	JAMSTEC Headquarters, Animal Simulator Building, etc.		176
Total		57	9,063

(*1) Prize entries in the fifth contest and top 17 prize entries in the sixth contest.

Publication	Secondary release		
	Edition	No. of issues	Pages
JAMSTEC Journal of Deep Sea Research	12, 14-20, 15II, 16II	10	2,235
Report of Japan Marine Science and Technology Center	1-3, 47	4	334
Total		14	2,569



Fig. 5 GODAC Web page (Top page)

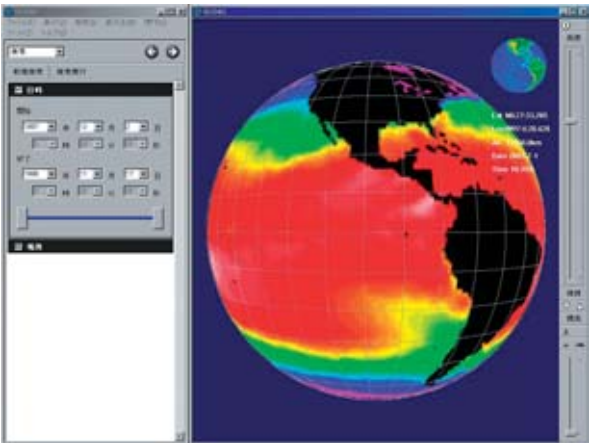


Fig. 6 Virtual Earth screen image

Computer and Information Service

(3) General use of facilities and equipment

We have developed displays and information for visitors to GODAC from within and outside the local region that will deepen their knowledge about and

interest in the global environment, deep-sea organisms, and global environmental change, and an integrated system that can be used in Period for Integrated Study at schools (Figs. 7, 8, 9, 10, 11, 12).

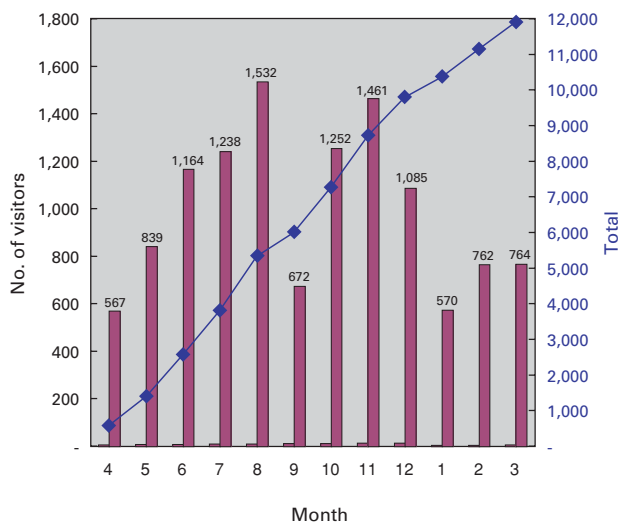


Fig. 7 Number of monthly visitors to GODAC in fiscal 2003



Fig. 9 Kindergarten children looking at the display (at National Lifelong Study Festival "MANABI-PIA Okinawa")

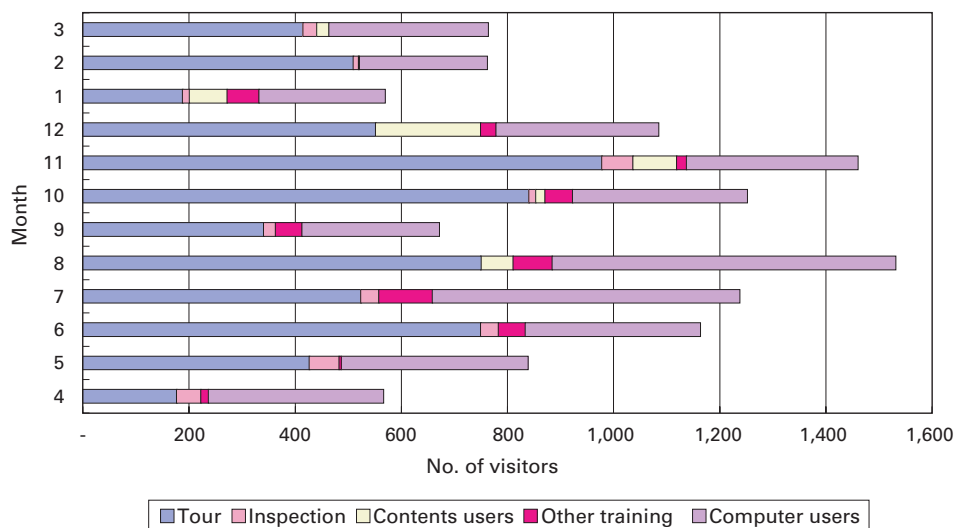


Fig. 8 Number of visitors to GODAC by purpose of visit in fiscal 2003

Computer and Information Service



Fig.10 Open terminals (in open lounge)



Fig.12 Kindergarten children viewing 3D images (in lecture room)



Fig.11 JICA trainees using terminals (in open lounge)

Research Support Activities

Training and Education Service

1. Outline of activities

JAMSTEC runs training courses on diving skills for engineers and researchers involved in diving services or marine research, and also conducts safety and health education for supervisors of on-site diving operations. In addition, JAMSTEC runs training courses on marine science technology for young people and schoolteachers as part of our outreach program.

As in the last fiscal year, our diving-related training courses consisted of the "training course on diving techniques" and the "training course on diving service management". Furthermore, as part of our outreach program, we conducted the Science Camp for high school students, the Marine Science School (with the support of the Nippon Foundation), and a course entitled "Improvement of Marine Data Utilization in Countries near the Pacific Equator".

2. Training course on diving techniques

This course, which runs for ten days (sometimes five), is for those engaged in diving services. Its goal is the acquisition of knowledge and basic skills in air (scuba) diving. This fiscal year, the number of participants reached 319 from a total of 60 organizations, including police, fire departments, and fisheries high schools (Fig. 1, Fig. 2).

3. Training course on diving service management

This course is intended for those involved in the management of diving services in diving-related companies. It provides a wide range of information covering all-around diving services, such as an overview of saturation diving and the current status of diving operations overseas, in addition to safety and health education concerning diving services. This fiscal year, 11 people from a total of seven organizations participated in this course.

4. Science Camp

This fiscal year, 28 experiment-and-research institutions participated in the Science Camp, including national experiment-and-research institutions, independent administrative institutions, and government-affiliated corporations. The Science Camp has been conducted since 1995, hosted by the Japan Science Foundation.

JAMSTEC brought together 28 high school students from all over Japan for the two nights and three days of the Science Camp, held between August 4 and 6, 2002.

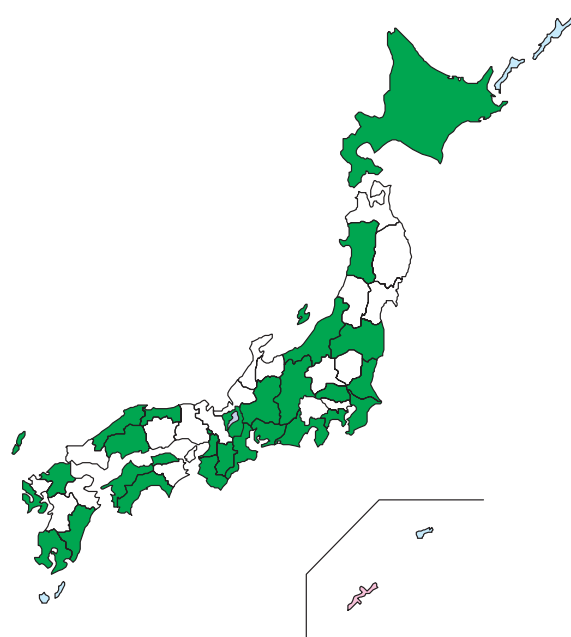


Fig. 1 Prefectures that have taken part in training courses on diving skills



Fig. 2 Training course on diving skills in action

Training and Education Service

5. Marine Science School programs

(1) Marine Science School

The Marine Science School has been conducted since 1996 with the financial assistance of the Nippon Foundation. Its aim is to foster the future human resources of this country's marine science and technology by increasing interest in the ocean among high school students and their teachers. 18 high school teachers participated in the course held between August 6 and 8, 2003, and a total of 44 high school students participated in the courses held between July 23 and 25, 2003, and between March 29 and 31, 2004 (Fig. 3, Fig. 4).



Fig. 3 Learning about pressure in the deep sea using experimental equipment for pressure measurement



Fig. 4 Observing collected plankton samples on the Marine Science School

(2) Marine Science and Technology School

This seminar is intended for university and postgraduate students who will play a role in the research and development of future marine science and technology. It provides instruction on cutting-edge marine research through lectures and practical training using JAMSTEC's facilities and equipment. As in the last fiscal year, this year's seminar was conducted at the Yokosuka Headquarters. The seminar was divided into two sessions: the first session between September 2 and 4, 2003, and the second one between February 24 and 26, 2004, both of which lasted two nights and three days. The number of participants totaled 83 (Fig. 5).

6. Improvement of Marine Data Utilization in Countries near the Pacific Equator

JAMSTEC has been conducting this training course since 2000. Its aim is to enhance the understanding of marine observation among people in the island nations around the western Pacific Equatorial and tropical regions, to cultivate the forecasting ability of oceanographic conditions and meteorological phenomena, and to establish a network of human contacts through these activities. This fiscal year, we gathered young researchers and specialists on the ocean from countries such as Micronesia, Papua New Guinea, Kiribati, Nauru, the Solomon Islands, Vanuatu, Tuvalu, Fiji, Samoa, Tonga and the Cook Islands. Training on pro-



Fig. 5 Participants listening to an explanation of an ocean bottom seismometer on the Marine Science and Technology School

Training and Education Service

cessing methods of meteorological and marine observation data was conducted in the office of SOPAC (South

Pacific Applied Geoscience Commission) in Suva City, Fiji, between October 6 and 28, 2003 (Fig. 6, Fig. 7).



Fig. 6 Training at SOPAC



Fig. 7 Training at SOPAC

Research Support Activities

Research Support Department

JAMSTEC conducts deep ocean research and investigation and marine observation research with submersibles, ROVs and ocean investigation vessels. It also provides large experiment and research facilities for shared use in marine research and development, such as a hyperbaric water tank and supersonic water tank to outside researchers.

The Research Support Department provides support for investigations and observations and R&D carried out by JAMSTEC through the operation and maintenance of observation techniques, JAMSTEC's fleet of vessels, submersibles and ROVs, and the shared use of research facilities.

1. Deep-sea research public participation system

JAMSTEC invites applications for deep-sea research themes in line with JAMSTEC's mid-term research plans and makes a cruising plan for the themes.

The application period for deep-sea research in fiscal 2004 was from September 10 to October 8, 2003, and applications had to be submitted over the internet. The period was initially planned to be from July to August, but postponed to the regular season because of the unknown availability of vessels following the accident involving KAIKO vehicle wreckage at the end of May. The research submersible SHINKAI 2000 ceased deep-sea research operations that started in 1983 due to severe budget reductions. The ROV HYPER-DOLPHIN was chosen instead as the vessel used for the public participation. Operations open to public participation were 60 diving missions using the manned research submersible SHINKAI 6500, independent missions using the deep-sea research vessel KAIREI (excluding an MCS mission), and the support vessel NATSUSHIMA (total of 150 days of cruise with HYPER-DOLPHIN or DEEP TOW). The research submersible SHINKAI 2000 and ROV KAIKO were not used. Applications were submitted by 63 researchers proposing research themes and 608 researchers proposing joint research covering a total of 69 research themes. The deep-sea research promotion committee reviewed and rated these applications and made a draft cruising plan before approving the draft cruising plan for 36 themes.

2. Public participation system for shared use of MIRAI

JAMSTEC invites applications for research using MIRAI based on the long-term observation and

research plan for utilizing the oceanographic research vessel MIRAI, and makes a cruising plan for these themes.

The application period for MIRAI in fiscal 2004 was from June 5 to July 4, 2003, and applications had to be submitted by conventional mail or over the internet. A total of 83 applications were submitted and the total number of applicants for boarding was 168. From these, the Committee selected 80 themes and 149 applicants for boarding. The selected themes consisted of 34 from JAMSTEC, 33 from national, public and private universities, and 13 from national institutes and others.

3. Blue Earth Symposium

As in fiscal 2002, the Blue Earth Symposium (combining the 20th SHINKAI Symposium and the 7th MIRAI Symposium) was held at the Pacifico Yokohama on January 15 and 16, 2004. Numbers were up slightly over the previous year (1,031) with a total of 1,100 participants over the two days. This fiscal year, the symposium featured a panel discussion with researchers actively involved in observation research in both fields instead of a common keynote speech for both symposiums. The theme was "Manned or Unmanned". A lot of comments were made from the floor and the symposium was a great success. The details of the discussion are presented on the JAMSTEC web site. The astronaut Mamoru Mori, director of the National Museum of Emerging Science and Innovation, who experienced a training dive in SHINKAI 6500 in March 2003, gave a presentation at the SHINKAI Symposium as a person with experience. There were 29 oral and 76 poster presentations

Research Support Department

at the SHINKAI Symposium, and 27 oral and 26 poster presentations at the MIRAI Symposium. These numbers have increased and the content has also increased year by year. This fiscal year, in particular, a core time was provided for the poster session to cope with the increased number of presenters, and this was popular with participants.

4. Research support

Observation engineers from Nippon Marine Enterprises, Ltd., Marine Works Japan Ltd., and Global Ocean Development Inc. provide a range of onboard and onshore research support (e.g. operation of observation equipment and systems, deep-sea survey support, data processing, etc.). The observation equipment includes TRITON buoys, a multi-channel reflection survey system and ocean-bottom seismometers for structural research of deep sub-seafloor, a deep tow system (deep tow camera and sonar), 20 m piston corers for deposit extraction, dredges, a CTD water sampling system, various analyzers, gravitation meters and magnetometers.

A major topic in fiscal 2003 was the navigation cruise around the southern hemisphere BEAGLE (Blue Earth Global Expedition) 2003 by the oceanographic research vessel MIRAI. The cruise started at Brisbane, Australia, and took an easterly course. About six months later, MIRAI arrived at Fremantle, Australia. During the cruise, MIRAI collected a mass of valuable observation data using CTD and water sampling from surface water to the sea bottom at about 500 observation points and using mud sampling with the piston corer and multiple corer along the observation line specified in WHP (Woce Hydrographic Program). The analysis results of the cruise obtained by the observation engineers were the most detailed in the world, and were highly acclaimed.

Deep sub-seafloor structural research (MCS; Multi Channel Seismic Profiler, OBS; Ocean Bottom Seismometer) was planned in cooperation with

Canadian researchers at the offshore Victoria Island, Canada. However, operations were not possible due to problems on the Canadian side, and the operation site was changed on very short notice to the offshore Sanriku. In seafloor seismic surveys, 130 seismographs are operated using the science and technology promotion budget "southeast and east sea areas", and in fiscal 2003, the seismograph recovery rate was 98.0% (251 deployed, 246 recovered).

In the public participation of cruise with not only JAMSTEC staff but also domestic and foreign researchers on board, we operated the above-mentioned observation equipment, made cruise reports, helped their research in managing data and samples, and, even on land, made a contribution in quality management and provision of collected data. Furthermore, with our program to refine the observation techniques for three research-affiliated company engineers, we improved the performance of various observation equipment and data quality.

5. Operation of the TRITON ocean observation buoy system

Since 1998, we have used the TAO/TRITON buoy array covering the entire equatorial area in the Pacific Ocean in collaboration with the TAO project of the Pacific Marine Environmental Laboratory (PMEL) of the National Oceanic and Atmospheric Administration, U.S. Department of Commerce for oceanic change research conducted by the Ocean Observation and Research Department in relation with climate changes such as El Niño and the Asian monsoon. Some of the collected data are provided to the general public on the internet.

In fiscal 2003, we collected and placed 17 TRITON buoys. In normal operation, the buoys are replaced during the MIRAI cruises twice a year. In fiscal 2003, however, MIRAI was used for BEAGLE 2003, and the later-stage cruise to replace the buoys was conducted by KAIYO and YOKOSUKA, which placed and collected three and six buoys, respective-

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ly. This was the first full-scale buoy operation for YOKOSUKA and required careful preparation, such as the manufacture and installation of necessary equipment, loading of equipment and materials, securing of work space and confirmation of work procedures. With this thorough preparation as well as the skill and efforts of crew members and observation engineers on site, the mission was completed without incident.

Buoy number 17 located at latitude 5° south and longitude 95° east in the Indian Ocean could not be collected because of bad weather. In view of the risk of losing positional information of buoys due to depleted batteries, the buoy was collected by the R/V Baruna Jaya I under the agreement with the Indonesia Agency for the Assessment and Application of Technology (BPPT). Due to its light weight of less than 1000GT, the Baruna Jaya I rocked in the rough swells, making the recovery operation difficult. The large TRITON buoy was however successfully recovered, a remarkable tribute to the BPPT staff.

During the recovery work, we found a lot of fishing equipment entangled with buoys, as is typical in coastal areas relatively close to shores where fishing boats operate. A typical case of such damage was buoy number 16 placed at latitude 2° north and longitude 103° east, whose flotation section had broken off and drifted away. It was suspected that a fishing

boat had moored to the buoy and towed it forcefully, breaking the thin fiber ropes. (YOKOSUKA changed its planned mission to collect the drifting buoy immediately.)

Some improvements were necessary in the buoy operation. We intended to locate the cause of problems with the wind direction and speed meter occurring at low temperatures (no problems with observations in tropical areas) and ask the manufacturer to change the circuit. We also planned to take advantage of this opportunity and enhance the performance of the signal processing circuit.

Executive Director Mr. Chijiya, Research Support Department Director Mr. Monma and Ship Operations Division Manager Mr. Nakai attended the International Research Ship Operators Meeting (ISOM) in Valparaiso, Chile, and exchanged information on research vessels. The participants at the meeting had a chance to view MIRAI while it was at the port as part of the BEAGLE 2003 cruise. The participants from various countries were surprised at the scale of MIRAI and its enhanced research equipment.

6. Ship operations

JAMSTEC carries out deep-sea research and ocean observation using the five research vessels, NAT-SUSHIMA, KAIYO, YOKOSUKA, KAIREI and MIRAI, and the deep-sea research systems of SHINKAI 6500, HYPER-DOLPHIN, KAIKO and DEEP TOW. These vessels also take part in open days at various ports of call and other dissemination and public relations activities.

The operation and maintenance of the vessels and the deep-sea research systems are commissioned to a ship operation company.

As for statutory annual overhaul, in fiscal 2003, NATSUSHIMA, KAIREI and MIRAI underwent an annual overhaul, KAIYO underwent a midterm overhaul, and YOKOSUKA underwent a routine overhaul.



Fig. 1 R/V Baruna Jaya collecting TRITON buoy number 17.

Research Support Department

1) NATSUSHIMA

NATSUSHIMA undertook 13 missions and was at sea for a total of 290 days on deep-sea research themes by public participation and JAMSTEC research themes. (The operation performance and navigational charts are shown in Table 2 and Fig. 2, respectively.) A breakdown of NATSUSHIMA operations are: HYPER-DOLPHIN operations – nine diving missions for a total of 221 days (offshore Tokachi, offshore Sanriku, Sagami Bay, Suruga Bay, Izu-Ogasawara, Kagoshima Bay, west offshore Kagoshima and Nansei Islands); DEEP TOW operations – one deep-sea towing mission for 16 days (Suruga Bay and Nansei Islands); single operation – three missions for a total of 42 days. As a part of the open day for the general public at the Yokosuka Headquarters, NATSUSHIMA was open to the public on May 10, 2003. An open day was also held during a port visit to Nago in Okinawa on August 23.

From December 15, 2003 to January 22, 2004, NATSUSHIMA underwent an annual overhaul. Improvement work was carried out on the vessel body and propulsion unit to maintain the fundamental performance of the vessel, as well as on the special equipment to maintain its functioning. The following performance-improvement work was also performed: new installation of a 3,000 m class multi-narrow-beam echo sounder, addition of OBS positioning function to acoustic navigation unit, maintenance of laboratory, improvement of function and safety of five-ton crane,

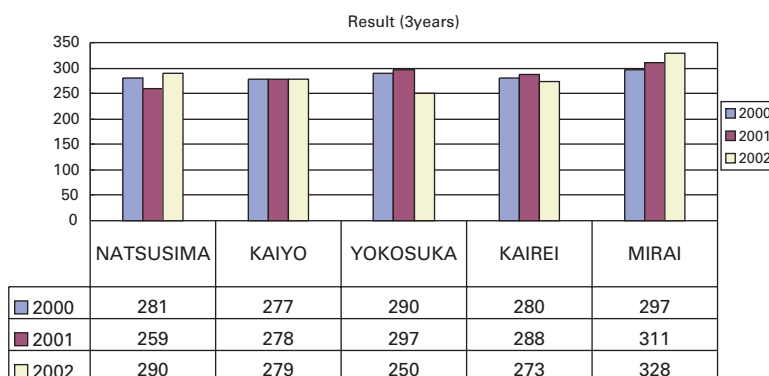
and new installation of rotary jib crane for transporting heavy loads.

2) KAIYO

KAIYO undertook 14 missions for a total of 279 days on JAMSTEC research themes. (The operation performance and navigational charts are shown in Table 3 and Fig. 5, respectively.) A breakdown of KAIYO operations are: DEEP TOW operations – two missions for a total of 21 days (Izu-Ogasawara, Suruga Bay and offshore Kagoshima); MCS (Multi Channel Seismic Profiler) and OBS (Ocean Bottom Seismometer) research – five missions for a total of 110 days (Kumanonada, Mariana sea area, Nankai Trough and offshore Kochi); DEEP TOW and MCS research – one mission for 17 days (Izu-Ogasawara); others – five missions for a total of 94 days. As a part of the open day for the general public at the Yokosuka Headquarters, a navigation experience tour was conducted in the Port of Yokohama.

From April 4, 2003 to May 5, 2003, KAIYO underwent a midterm overhaul. Improvement work was carried out on the vessel body and propulsion unit to maintain the fundamental performance of the vessel, as well as on the special equipment to maintain its functioning. The following performance-improvement work was also performed: development of inboard LAN system utilization environment, development of laboratory and improvements to the A-frame crane.

Table 1



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253

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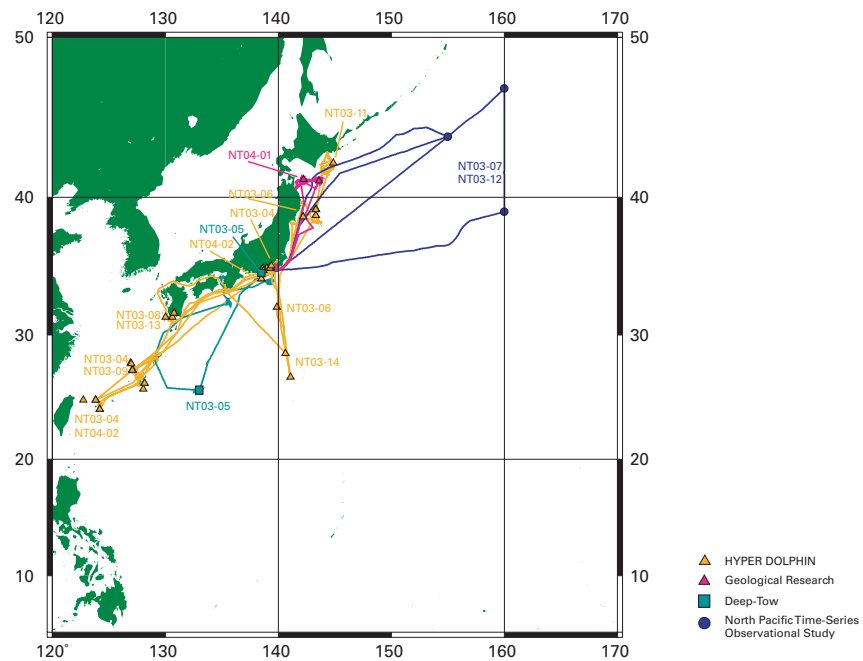


Fig. 2 M/V NATSUSHIMA Cruise Tracks, FY03



Fig. 3 Transducer of multi-narrow-beam echo sounder



Fig. 4 Transducer dome of multi-narrow-beam echo sounder

Research Support Department

Table 3 Operations Schedule of RV "KAIYO" in 2003 Fiscal year

2003.4.																															
4 Apr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu
「KAIYO」Annual Maintenance																															
5 May	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat
	「KAIYO」Annual Maintenance				JAMSTEC				JAMSTEC				Sea trial				Wakayama				KY03-05 OBS Kumano NADA				Tamano				Open ship		
6 Jun.	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue
	Open ship		Cruising		JAMSTEC Landing Loading		Yokosukashinko		Cruising		KY03-06 MCS/OBS (Mariana area)				Saipan																
7 Jul.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu
KY03-06 MCS/OBS (Mariana area)																															
Cruising																															
JAMSTEC																															
Yokosukashinko																															
8 Aug.	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
	Cruising		JAMSTEC		Landing Loading		Yokosuka shinko		Cruising		KY03-08 PIES (Okinawa area)		Naha		KY03-09 Heat Flow · Piston Core (Okinawa area)		Cruising		JAMSTEC												
9 Sep.	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed
	Landing Loading		Yokosuka shinko		KY03-10 DEEP · TOW / MCS / Gravity Core (Izu · Ogasawara)				JAMSTEC Landing				Yokosukashinko				Loading														
10 Oct.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri
KY03-11 Wadatumi, PC, BOX Core (Off Sanriku)																															
JAMSTEC Landing																															
Loading																															
Yokosuka shinko																															
Cruising																															
Guam																															
11 Nov.	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon
	KY03-12 TOCS																				Palau				Cruising						
12 Dec.	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed
	Naha		KY03-13 PIES (Okinawa area)		Cruising				JAMSTEC				Landing Loading				Yokosukashinko				Cruising				Wadatumi, PC, BOX Core (Enshu-nada)						
1 Jan.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat
KY04-01 DEEP TOW (Off Kagoshima)																															
Cruising																															
C																															
Landing																															
Yokosukashinko																															
Loading																															
2 Feb.	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue
	KY04-02 MCS · OBS (Nankai Trough)				Wakayama												JAMSTEC				Yokosukashinko				Cruising						
3 Mar.	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed
	KY04-03 Primary Production				Cruising				JAMSTEC				Yokosukashinko				Cruising				KY04-04 OBS (Off Kochi)				JAMSTEC				Cruising Loading		

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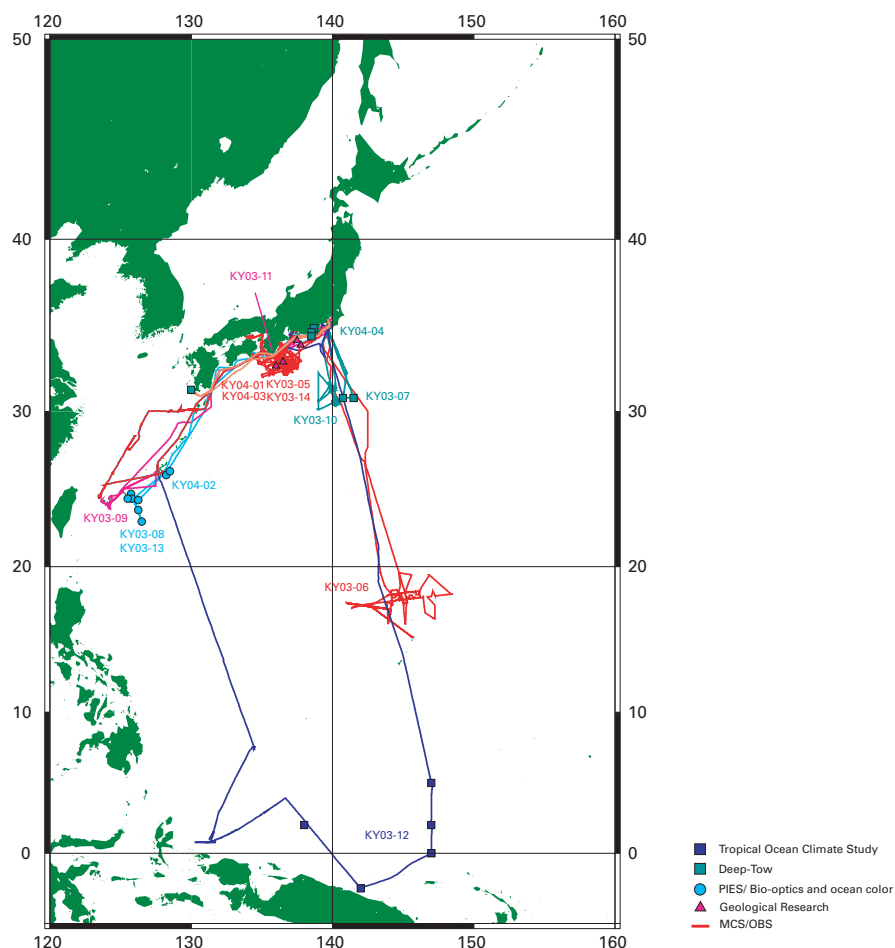


Fig. 5 R/V KAIYO Cruise Tracks, FY03

3) YOKOSUKA

YOKOSUKA undertook 12 missions for a total of 250 days on deep-sea research themes by public participation and JAMSTEC research themes. (The operation performance and navigational charts are shown in Table 4 and Fig. 6, respectively.) A breakdown of YOKOSUKA operations are: SHINKAI 6500 diving – five missions for a total of 149 days; sea test operation of the deep sea cruising AUV URASHIMA in actual sea conditions – three missions for a total of 17 days (Suruga Bay); sea test operation of the marine robot MR-X1 – one mission for six days (Suruga Bay); single operation for research on the monitoring technology for the hydrothermal plume – three missions for a total of 60 days (Nansei Islands). As a part of the Yokosuka Kaikokusai festival, YOKOSUKA was opened to the public at Yokosuka New Port on August 2, 2003.

From May 5, 2003 to June 13, 2003, YOKOSUKA underwent a routine overhaul. Improvement work was carried out on the vessel body and propulsion unit to maintain the fundamental performance of the vessel, as well as on the launch and recovery system for SHINKAI 6500 and special equipment such as diving support system to maintain their functioning. The following performance-improvement work was also performed: addition of placing and collecting function for six TRITON buoys, maintenance of laboratory and addition of maintenance function for URASHIMA now equipped with fuel batteries.

4) KAIREI

KAIREI undertook 14 missions for a total of 273 days on deep-sea research themes by public participation and JAMSTEC research themes. (The operation performance

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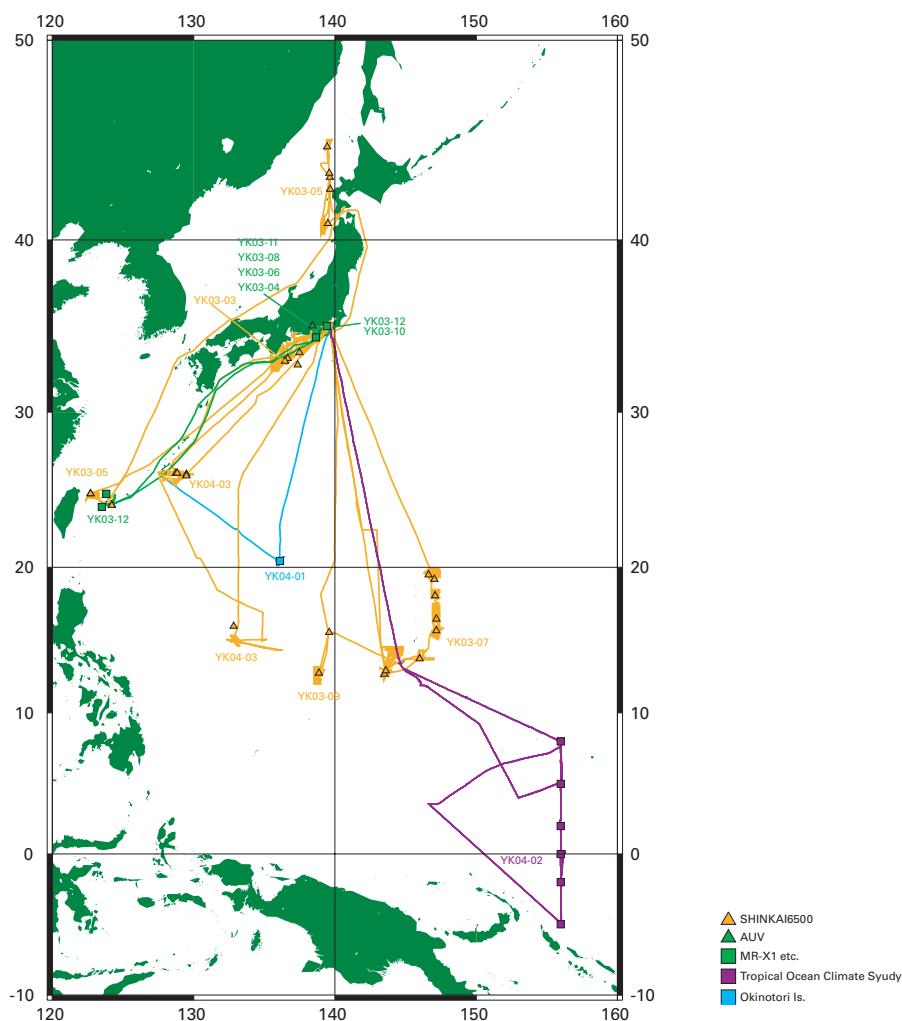


Fig. 6 M/V YOKOSUKA Cruise Tracks, FY03



Fig. 7 YOKOSUKA TRITON buoy loaded

and navigational charts are shown in Table 5 and Fig. 8, respectively.) A breakdown of KAIREI operations are: KAIKO diving operation: three missions for a total of 45

days (Izu-Ogasawara, West Philippine Sea and Nankai Trough); test and training activity of KAIKO 7000 – one mission for five days (Izu-Ogasawara); single operation – ten missions for a total of 190 days, and others.

From January 28 to March 9, 2004, KAIREI underwent an annual overhaul. Improvement work was carried out on the vessel body and propulsion unit to maintain the fundamental performance of the vessel, as well as on the launch and recovery system for KAIKO, diving support system and primary cable-handling equipment to maintain their functioning. The following improvement work was also performed: improvement of function and safety of the launch and recovery of operating vessels, maintenance of MCS compressor room and replacement of workstation for multi-narrow-beam echo sounder.

Research Support Department

Table 5 Operation schedule of RV "KAIREI" in 2003 fiscal Year

2003.4.																																			
4 Apr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31				
	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat		
	KR03-03 ROV 「KAIKO」 Support Operation (Izu・Ogasawara)										KR03-04 ROV 「KAIKO」 Support Operation (West Philippine Basin)																								
5 May																																			
	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun			
	KR03-04 ROV 「KAIKO」 Support Operation (West Philippine Basin)										KR03-05 「KAIREI」 Operation (Nankai Trough)										KR03-05 「KAIKO」 Support Operation (Nankai Trough)														
6 Jun.																																			
	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu		
	KR03-05 「KAIKO」 Support Operation (Nankai Trough)										KR03-06 「KAIREI」 Operation (Honshu-E.Coast・Japan Sea)										KR03-07 ROV 「KAIKO」 Support Operation (Tokachi, Japan Trench)														
7 Jul.																																			
	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat		
	KR03-07ROV 「KAIKO」 Support Operation (Tokachi, Japan Trench)										KR03-08 ROV 「KAIKO」 Support Operation (NW-Pacific)																								
8 Aug.																																			
	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue		
	KR03-09 MCS Support Operation (Vancouver I)																																		
9 Sep.																																			
	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	
	KR03-10 「KAIREI」 Operation (Midriornh Pacific)										KR03-11 Time Series Operation (NW ronih Pacific)																								
10 Oct.																																			
	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun		
	KR03-11 Time Series Operation (NW ronih Pacific)										KR03-12 「KAIREI」 Operation (Mariana Trough)										KR03-12 「KAIREI」 Operation (Mariana Trough)														
11 Nov.																																			
	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	
	KR03-12 「KAIREI」 Operation (Mariana Trough)										KR03-13 「KAIREI」 Operation (Mariana Trough)										KR03-13 「KAIREI」 Operation (Mariana Trough)														
12 Dec.																																			
	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	
	KR03-13 「KAIREI」 Operation (Mariana Trough)										KR03-14 ROV 「KAIKO」 Support Operation (Suiyo Seamount)										KR03-14 ROV 「KAIKO」 Support Operation (Suiyo Seamount)														
1 Jan.																																			
	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	
	KR04-01 「KAIREI」 Operation (Izu Bonin)										KR04-02 ROV 「KAIKO」 Support Operation (Nansei Islands)										KR04-02 ROV 「KAIKO」 Support Operation (Nansei Islands)														
2 Feb.																																			
	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat
	KR04-03 「KAIREI」 Operation (Izu Bonin)										KR04-04 「KAIREI」 Operation (Izu Bonin)										KR04-04 「KAIREI」 Operation (Izu Bonin)														
3 Mar.																																			
	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	
	KR04-05 「KAIREI」 Operation (Izu Bonin)										KR04-06 「KAIREI」 Operation (Izu Bonin)										KR04-06 「KAIREI」 Operation (Izu Bonin)														

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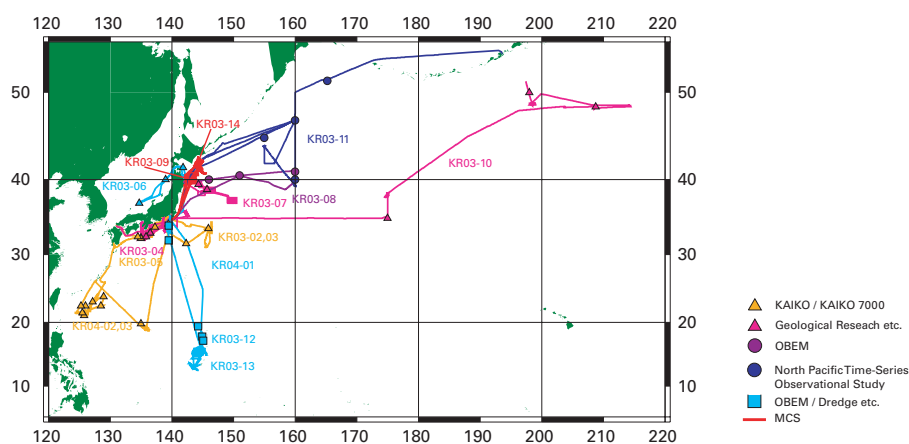


Fig. 8 R/V KAIREI Cruise Tracks, FY03

5) MIRAI

MIRAI undertook five missions for a total of 328 days including the navigation cruise around the southern hemisphere BEAGLE 2003 for 204 days (mid-latitude area in the southern hemisphere, west sea area of Chile, southern sea area of the Indian Ocean) on research themes for shared use. (The operation performance and navigational charts are shown in Table 6 and Fig. 9, respectively.)

Outline of the cruise around the southern hemisphere BEAGLE (Blue Earth Global Expedition) 2003

On May 21, 2003, a departure ceremony was held at the International Passenger Terminal of Osanbashi at the Port of Yokohama to pray for a safe cruise and successful research, attended by Mr. Kisaburo Tokai, the Vice Minister of Education, Culture, Sports, Science and Technology. (See figure 10.) Following the observation operation in the central sea area of the North Pacific Ocean, equatorial zone in the West Pacific Ocean and equatorial zone in the East Indian Ocean, MIRAI entered Brisbane, Australia on July 30. The cruise around the southern hemisphere BEAGLE 2003 started on August 3. MIRAI stopped at the port in Papeete, Tahiti on September 5 and entered Valparaiso, Chile on October 16. From there, MIRAI took a southern course. After passing through the Magellan Channel, MIRAI navigated northward in the Pacific Ocean and entered Santos, Brazil on November 2. MIRAI then crossed the Atlantic Ocean,

entered Cape Town, South Africa on December 5, navigated the Indian Ocean, and stopped at Tamatave, Madagascar on December 20 and Port Louis, Mauritius on December 27. MIRAI crossed the Indian Ocean and entered Fremantle, Australia on January 24, 2004. MIRAI then navigated down in the Indian Ocean toward Kerguelen Islands and came back to Fremantle on February 19, finally finishing the cruise around the southern hemisphere.

During the cruise, MIRAI held open days for the general public, lecture meetings and exchange events such as plaque exchanges at the ports of call, playing a significant role in international friendship. (See figure 11.) The number of participants to the public opening of the vessel was 691 in Brisbane (August 2), 371 in Santos (November 5), 43 in Cape Town (December 8), 103 in Tamatave (December 20) and 857 in Fremantle (January 25).

On the way from Fremantle to Japan, MIRAI conducted observations in the West Pacific Ocean and returned to the Port of Yokohama on March 22. On March 27, a ceremony celebrating the success of the observational cruise was held again at the International Passenger Terminal of Osanbashi at the Port of Yokohama, attended by Mr. Yamato Inaba, the Vice Minister of Education, Culture, Sports, Science and Technology. It completed its ten-month long cruise including a seven-month cruise around the southern hemisphere and the world's first marine

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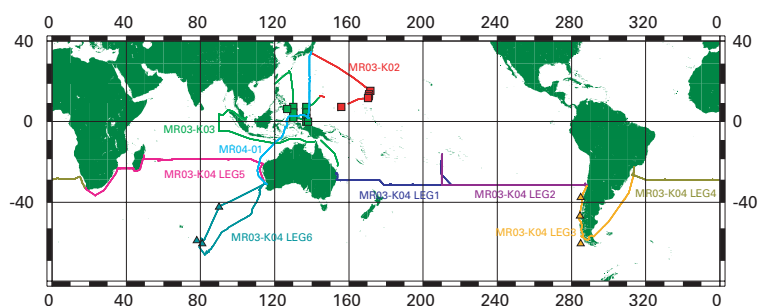


Fig. 9 R/V MIRAI Cruise Tracks, FY03



Fig.10



Fig.11

observation across three oceans to make its name in marine observation history.

From April 1 to May 2, 2003, MIRAI underwent an annual overhaul. Improvement work was carried out on the vessel body and propulsion unit to maintain the fundamental performance of the vessel. The following work for BEAGLE 2003 was also performed: relocation of compact CTD winch crane, reconstruction of CTD room, installation of compact CTD spare winch, maintenance of analysis room, observation room and



Fig.12 Compact CTD winch crane on MIRAI

storage, as well as speed enhancement of inboard LAN system, replacement of INMARSAT-A satellite communication unit with INMARSAT-B satellite communication unit for high-speed communication, reformation of the crane to improve function and safety, maintenance of residential facilities and replacement of waste oil incinerator.

7. Operation of deep-sea survey systems

1) SHINKAI 2000

The registration was deleted on March 4, 2004, and SHINKAI 2000 was retired.

2) SHINKAI 6500

SHINKAI 6500 was scheduled to undertake five missions and 75 dives (including test and training dives) during the year, and completed 57 research dives and 11 test/training dives for a total of 68 dives around the Sea of Japan, Nankai Trough, Nansei Islands, Mariana sea area and east offshore

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Philippines. SHINKAI 6500 completed its 800th dive in Parece Vela Basin on November 8, which was accomplished more than 14 years after its first dive on June 5, 1990.

From November 25, 2003 to February 27, 2004, SHINKAI 6500 underwent a midterm overhaul at the submersible serving yard. Following this inspection, it conducted four test dives around the Nansei Islands sea area. All tests and overhaul were completed on March 11.

In the midterm overhaul, routine inspection and maintenance was carried out on equipment, and parts were replaced to maintain performance. The main battery unit was changed from silver oxide-zinc secondary battery to lithium-ion secondary battery. Old facilities were also maintained and repaired.

3) HYPER-DOLPHIN

HYPER-DOLPHIN undertook nine missions, 87 research dives and 39 training dives for a total of 126 dives during the year around the offshore Kushiro-Tokachi, offshore Sanriku, Izu-Ogasawara, Sagami Bay, Suruga Bay, west offshore Kagoshima, Kagoshima Bay and Nansei Islands.

HYPER-DOLPHIN underwent maintenance to maintain the performance of the entire system. Also a digital still camera with laser beam scale was installed on HYPER-DOLPHIN and the functions of the high vision camera were improved.

4) KAIKO

KAIKO undertook three missions, ten research dives and eight training dives (including three dives to search for the KAIKO vehicle and three test/training dives of "KAIKO 7000") during the year for a total of 18 dives around the Izu-Ogasawara, Nankai Trough and West Philippine Sea.

The 10,000 m class Deep Sea ROV KAIKO succeeded in collecting long-term observation data on the Nankai Earthquake in the investigation of the Nankai Trough (4675 m deep) about 130 km southeast off-

shore Muroto Cape, Kochi Prefecture on May 29, 2003. Immediately after the investigation, the secondary cable broke and the KAIKO vehicle rose to the surface and drifted away. A search for the vehicle was conducted for more than three weeks, but it is still missing.

Because of the significance of the accident, an investigative committee on KAIKO vehicle drifting accident was set up. The committee investigated the cause and submitted a final report to the President on January 19, 2004.

It was clarified that repeated bending of the secondary cable in normal operation had degraded the aramid fiber at the opening of external sheath and led to the breaking of the cable, causing the accident.

To cover for the missing vehicle, we remodeled the 7000 m class compact ROV UROV7K with fine optical fiber and connected it to the KAIKO's secondary cable temporarily, becoming KAIKO 7000.

From November 27, 2003 to March 31, 2004, the KAIKO system without its vehicle underwent an annual maintenance at the ROV serving yard. In addition to the routine maintenance, the power system was modified to supply electric power to the launcher even in accidental power failure. The primary cable was also cut at about 400 m away from the launcher and was used for tensile tests to check the remaining strength.

For the temporary operation of UROV7K as an alternate vehicle, we also carried out the following work: removal of lithium-ion secondary battery, installation of high voltage transformer, installation of six additional thrusters, replacement of manipulator and addition of metal halide lights. After the remodeling, we named the operation system of the temporary vehicle "KAIKO 7000". We also made two secondary cables with the same structure as the secondary cable number 4 for the temporary operation.

5) DEEP TOW

DEEP TOW undertook four missions during the

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year around the Izu-Ogasawara, Suruga Bay, offshore Kagoshima and Nansei Islands.

6) UROV-7K

UROV-7K was remodeled as the KAIKO 7000 vehicle.

7) URASHIMA

URASHIMA conducted three sea trials in Suruga Bay, and the operational status of the fuel battery and

various equipment systems replaced at the end of last year were checked.

From December 12, 2003 to March 26, 2004, URASHIMA underwent annual maintenance at the AUV serving yard. In addition to the routine maintenance, the emergency safety equipment was improved.

8) BENKEI

BENKEI underwent proper maintenance and operational checks at the ROV serving yard.

Research Evaluation

On Nov. 28, 2001, the Prime Minister decided on the "National Guideline on the method of Evaluation for Government R&D" and on Jun. 20, 2002 the Minister of Education, Culture, Sports, Science and Technology decided on "Guideline on the Method of Evaluation for Ministry's R&D". In response to that, JAMSTEC evaluates research and development projects aiming effective and productive allocation of research resources (human resources and budgets). Actually, JAMSTEC evaluates research every year under the "Outline of Steps Taken to Evaluate Research at the Japan Marine Science and Technology Center". In fiscal 2002 JAMSTEC began examining R&D cost effectiveness and quantitative evaluation methods.

1. R&D Theme Evaluation

R&D theme evaluation applies to all R&D projects implemented by JAMSTEC except those classified as large-scale and important projects (e.g., mega-science projects carried out at a national level and projects of high interest to society). These projects are evaluated by a specially-established committee.

Evaluation is conducted by the R&D Theme Evaluation Committee and Subcommittees, consisting of third-party experts and intellectuals. The R&D projects that are promoted by priority fund (Research Project; Category 1) are subjected to the in-advance evaluation, and interim and result evaluation, the R&D projects promoted by basic fund (Research Project; Category 2, Personal Research, Cooperative Research) are subjected to the result evaluation. These evaluations are conducted strictly based on the evaluation items and methods set by the R&D Theme Evaluation Committee.

In fiscal 2003, the in-advance evaluation was conducted on August 1, 2003, and the interim and result evaluation was conducted from October 2003 to February 2004. The results of evaluations are disclosed

on the JAMSTEC's web (<http://www.jamstec.go.jp>), together with the JAMSTEC's policy in response to the results and the documents of the relevant research.

(1) In-advance Evaluation

1) Themes for the evaluation (Table 1)

The in-advance evaluation was conducted for the Project Research that would newly start or would restructure in fiscal 2004 before budget request.

2) System of the evaluation

The R&D Theme Evaluation Committee (Table 3) conducted evaluations.

3) Method of the evaluation

Each researcher made a presentation on the research theme, and follow-up question-and-answer sessions were held between the researcher and the committee. The committee evaluated the R&D projects based on the key points given in 4) after discussion among the committee.

Table 1 Subject for In-advance Evaluation in Fiscal 2003

Subject		Department
1	Research and development of next-generation simulations	Earth Simulator Center
2	Research on remote control of marine equipment using satellites	Marine Technology Department
3	Research on environmental measurement technology	Marine Technology Department
4	Development of deep earth exploration system	OD21 Program Department
5	Development and operation of a global environmental data archiving system	Computer and Information Department

Research Evaluation

4) Key points/factor of the evaluation

The R&D themes were evaluated from the following key points.

- Adequacy of purposes, targets, and direction of the research and development
- Adequacy of planning and approaches of the research and development
- Adequacy of funds and framework for research and development
- Expected results

(2) Interim and Result Evaluation

1) Themes for the evaluation (Table 2)

The Interim and Result Evaluation was conducted for the Project Research that have passed five years after commencement, or that have completed since last year. Also evaluated were basic researches (Special Research, Ordinary research, Cooperative Research) that were completed since last year or before.

Table 2 Subject for Interim and Result Evaluations in Fiscal 2003

R&D based on Priority Funding (Project Research)			
Subject		Department	Evaluation Category
1	Research and development of advanced technology (stage 1)	Marine Technology Department	Result
2	Research and development of autonomous underwater vehicle	Marine Technology Department	Interim
3	Research on estuary environmental remediation	Marine Technology Department	Interim
R&D based on Basic Funding (Special Research < S >, Ordinary Research < O >, Cooperative Research < C >)			
Subject		R&D	Evaluation Category
1	Integrated solid earth research in Java-Sunda Trenches around Indonesia	S	Deep Sea Research Department
2	Study on development of oceanic arc (Izu · Ogasawara · Mariana)	S	Deep Sea Research Department
3	Research on the autonomous underwater vehicle technology in ice-covered sea area	S	Marine Technology Department
4	Study on sea bottom gamma ray measurement by manned submersibles and ROVs	O	Deep Sea Research Department
5	Feasibility study on the methane flux monitoring in the area of gas hydrate distribution	O	Deep Sea Research Department
6	Study of crustal generation and deformation in the Mid-Atlantic Ridge	O	Deep Sea Research Department
7	Study on early detection of tsunami and crustal deformation based on deep sea floor observation	O	Deep Sea Research Department
8	Basic study on geophysical measurement in seafloor boreholes	O	Deep Sea Research Department
9	Study on the safety assessment of the deep seawater quality	O	Marine Technology Department
10	Research to clarify variations of hydrothermal plumes with long-term monitoring	C	Deep Sea Research Department

Research Evaluation

11	Basic research on network observation for seismogeodetic applications on the seafloor	C	Deep Sea Research Department	Result
12	The research of electric field fluctuation measurement by the submarine cable	C	Deep Sea Research Department	Result
13	Fundamental research on network observations of ocean bottom electromagnetic field	C	Deep Sea Research Department	Result
14	Study on sensitive and precise analysis of radionuclides in oceanic samples	C	Ocean Observation and Research Department	Result
15	Observational study on variability of intermediate and deep ocean circulation in the tropical Pacific	C	Ocean Observation and Research Department	Result
16	Research on the spawning characteristics of the Japanese eel (<i>Anguilla japonica</i>)	C	Marine Technology Department	Result
17	Study on the utilization of deep seawater by using hot spring as the heat source	C	Marine Technology Department	Result
18	Study on the property of deep seawater in Toyama Bay	C	Marine Technology Department	Result
19	Research on long-term rearing of mid-water animals	C	Marine Ecosystems Research Department	Result
20	Study on dynamic behavior of marine flexible pipe	C	Marine Technology Department	Result

2) System of the evaluation

The R&D Theme Evaluation Committee (Table 3) and four Subcommittees conducted evaluation. These four Subcommittees were the Subcommittee for the Ocean and Solid Earth Science, the Subcommittee for Ocean Observation and Research, the Subcommittee for Marine Biology and Ecology, and the Subcommittee for Marine Technology (Table 4).

3) Method of the evaluation

First, each Subcommittee heard a presentation by each researcher on the research theme, followed by a question-and-answer session between the Subcommittee and the researcher. Committee members evaluated the projects in line with the items listed in 4) based on the question and answer session, and such material as R&D reports prepared by researchers, and separately published papers.

Thereafter, the R&D Theme Evaluation Committee finalized the result of interim and result evaluations,

referring to the discussions of each Subcommittee.

4) Key points / factor of the evaluation

The research themes were evaluated based on the following items categorized according to the progress of the each theme.

- (a) Interim Evaluation (ongoing projects but five or more years passed after commencement)
 - Adequacy of purposes, targets, and direction of research and development
 - Adequacy of the outline, plan, and method of research and development
 - Adequacy of expenses and framework for research and development
 - Progress of research and development
 - Future plan
- (b) Result Evaluation (projects that have been completed by the preceding fiscal year)
 - Adequacy of purposes and targets of research and development

Research Evaluation

Table 3 Member List of the R&D Theme Evaluation Committee in Fiscal 2003

Chairman	TAIRA, Keisuke	Inspector General, Japan Society for the Promotion of Science
Member	ASAI, Tsuneo	Executive Director, Japanese Association of Science & Technology Journalists
Member	IMAWAKI, Shiro	Professor, Research Institute for Applied Mechanics, Kyushu University (Chief, Subcommittee for Ocean Observation and Research)
Member	KINOSHITA, Takeshi	Professor, Institute of Industrial Science, University of Tokyo (Chief, Subcommittee for Marine Technology)
Member	NITTA, Yoshitaka	Chief Organizer, Central CS Promotion Office, Central Research Institute of Electric Power Industry
Member	NOTSU, Kenji	Professor, Laboratory for Earthquake Chemistry Graduate School of Science, University of Tokyo (Chief, Subcommittee for Ocean and Solid Earth Science)
Member	TANIGUCHI, Akira	Professor, Graduate School of Agricultural Science, Tohoku University (Chief, Subcommittee for Marine Biology and Ecology)

(Listed alphabetically except chairman)

Table 4 Member list of R&D Theme Evaluation Subcommittees in Fiscal 2003

Subcommittee for Ocean and Solid Earth Science		
Chief	NOTSU, Kenji	Professor, Laboratory for Earthquake Chemistry Graduate School of Science, University of Tokyo
Member	HINO, Ryota	Associate Professor, Graduate School of Science, Tohoku University
Member	SHIMIZU, Hiroshi	Professor, Institute of Seismology and Volcanology, Faculty of Sciences, Kyushu University
Member	YUASA, Makoto	Geologist, Geological Survey Promotion Office, Geological Survey of Japan, The National Institute of Advanced Industrial Science and Technology
Subcommittee for Ocean Observation and Research		
Chief	IMAWAKI, Shiro	Professor, Research Institute for Applied Mechanics, Kyushu University
Member	GAMO, Toshitaka	Professor, Department of Earth and Planetary Sciences, Graduate School of Science, Hokkaido University
Member	KITAMURA, Yoshiteru	Senior Assistant for El Nino Monitoring and Prediction, Climate Prediction Division, Climate and Marine Department, Japan Meteorological Agency
Member	WAKATSUCHI, Masaaki	Professor, Institute of Low Temperature Science, Hokkaido University
Subcommittee for Marine Biology and Ecology		
Chief	TANIGUCHI, Akira	Professor, Graduate School of Agricultural Science, Tohoku University
Member	KUDO, Toshiaki	Director of Bioscience Technology Center, Discovery Research Institute, RIKEN
Member	OMORI, Makoto	Executive Chief Director, Akajima Marine Science Laboratory, Establishment of Tropical Marine Ecological Research Organization
Member	OTA, Suguru	Professor, Ocean Research Institute, University of Tokyo
Subcommittee for Marine Technology		
Chief	KINOSHITA, Takeshi	Professor, Institute of Industrial Science, University of Tokyo
Member	HONDA, Nakaji	Professor, Department of Systems Engineering, University of Electro-Communications

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Member	INOUE, Kiyoshi	Director-General of Marine Project Team, Basic Planning Division, Merchant Ships and Marine Business Headquarters, Universal Shipbuilding Co.
Member	SHIMIZU, Hisaji	Emeritus Professor, Yokohama National University

- Adequacy of outline, plan, and method of research and development
- Adequacy of expenses and framework for research and development
- Degree of achievements of research and development
- Impacts of the outcomes, extensions, and reflection on new projects
- Self-examination on causes for successes and failures

2. Study into R&D Cost Benefit and Quantitative Evaluation Methods

Administrative reform including reform of special corporations, and amendments to the national evaluation guidelines for research and development under the Science and Technology Basic Law now require JAMSTEC to carry out a cost benefit and quantitative evaluation of R&D.

In the light of these requirements and JAMSTEC's own social mission: (1) JAMSTEC will clearly convey the significance and results of its R&D to the government and the people (accountability) to gain the understanding and support of society and the nation as a whole; (2) JAMSTEC will deploy its limited resources effectively to improve organizational efficiency and economic efficiency of R&D projects; and (3) JAMSTEC staff will be conscious of the social relevance of their work, and plan R&D with clearly defined objectives and anticipated results. To achieve this, JAMSTEC began the necessary examinations for introducing R&D cost benefit and quantitative evaluation. We also held an international workshop on research effect analysis, and exchanged views on approaches used overseas.

(1) Examination Committee of Intellectuals

Since there was no domestic precedent of an examination of cost benefit and quantitative evaluation

methods at an R&D institution, and no organization has specifically studied the methodology for this, we again established an examination committee as in the last fiscal year, and continued to evaluate methods. The committee, comprising five members chaired by Emeritus Professor Hirasawa of the University of Tokyo, met four times.

Until the last fiscal year, the committee's examination focused primarily on the research evaluation matrix, a basic data form for research project cycle management. Here cycle management includes project planning, preliminary evaluation, annual progress reviews, interim evaluation, post-project evaluation, follow up evaluation, etc. This fiscal year, the committee reviewed actual usage of the research evaluation matrix in the past year's operations. A report meeting was held by JAMSTEC staff, who visited NOAA (National Ocean and Atmosphere Administration of United States) to discuss and examine the cost benefit analysis introduced into US organizations such as TOGA (Tropical Ocean-Global Atmosphere), GoMOOS (Gulf of Marine Ocean Observing System) and the geostationary meteorological satellite GOES-R, and the economic value of weather forecasts.

(2) Achievement and Proliferation of SHINKAI 2000 Research

The examination committee of external experts also reviewed the proliferation of achievements in select research themes. This fiscal year, the committee chose the development and operation of the SHINKAI 2000 system as an example of research and development, and conducted a survey on its achievements and the proliferation of its research. The committee surveyed the research proliferation in development of the research submersible, support vessel, acoustic naviga-

Research Evaluation

tion and elemental technologies of the SHINKAI 2000 system. It also examined the oceanographic investiga-

tion and observation operations and support and development systems.

Table 5 Members of the committee for examining cost benefit and quantitative evaluation methods for R&D

Chairman	HIRASAWA, Rei	Emeritus Professor, University of Tokyo
Member	HAYASHI, Takayuki	Research Fellow, Faculty of University Evaluation and Research, National Institution for Academic Degrees and University Evaluation
Member	NISHIOKA, Shuzo	Executive Director, National Institute for Environmental Studies
Member	NIWA, Fujio	Professor, National Graduate Institute for Policy Studies
Member	SAITO, Fujio	Guest Professor, Graduate School, Tama University

Appendix A

Research Achievements

(1) Deep Sea Research Department

Publications

Reviewed Articles

- 1) Abe, N., M. Takami and S. Arai, Petrological feature of spinel ilmenite xenoliths from Oki-Dogo Island: An implication for variety of the upper mantle peridotite beneath southwestern Japan, *The Island Arc*, 12, 219-232, 2003.
- 2) Ahagon, N., K. Ohkushi, M. Uchida and T. Mishima, Mid-depth circulation in the northwest Pacific during the last deglaciation: Evidence from foraminiferal radiocarbon ages, *Geophysical Research Letters*, 30, 2097, doi:10.1029/2003GL018287, 2003.
- 3) Arai, S., and N. Abe, Petrological model of sub-oceanic mantle and its bearing on the scientific strategy for IODP. *J. Geography*, 112, 692-704, 2003.
- 4) Deschamps, A., and T. Fujiwara, Asymmetric accretion along the slow-spreading Mariana Ridge, *Geochemistry, Geophysics, Geosystems*, doi:10.1029/2003GC000537, 2003.
- 5) Devey, C. W., J. C. Alt, W. Bach, J. Erzong, A. T. Fisher, K. M. Gillis, M. Kinoshita, P. Nehlig, and H. Staudigel, What is the nature of subseafloor fluid circulation and reaction processes? *Dahlem Workshop Report*, 89, 53-84, 2003.
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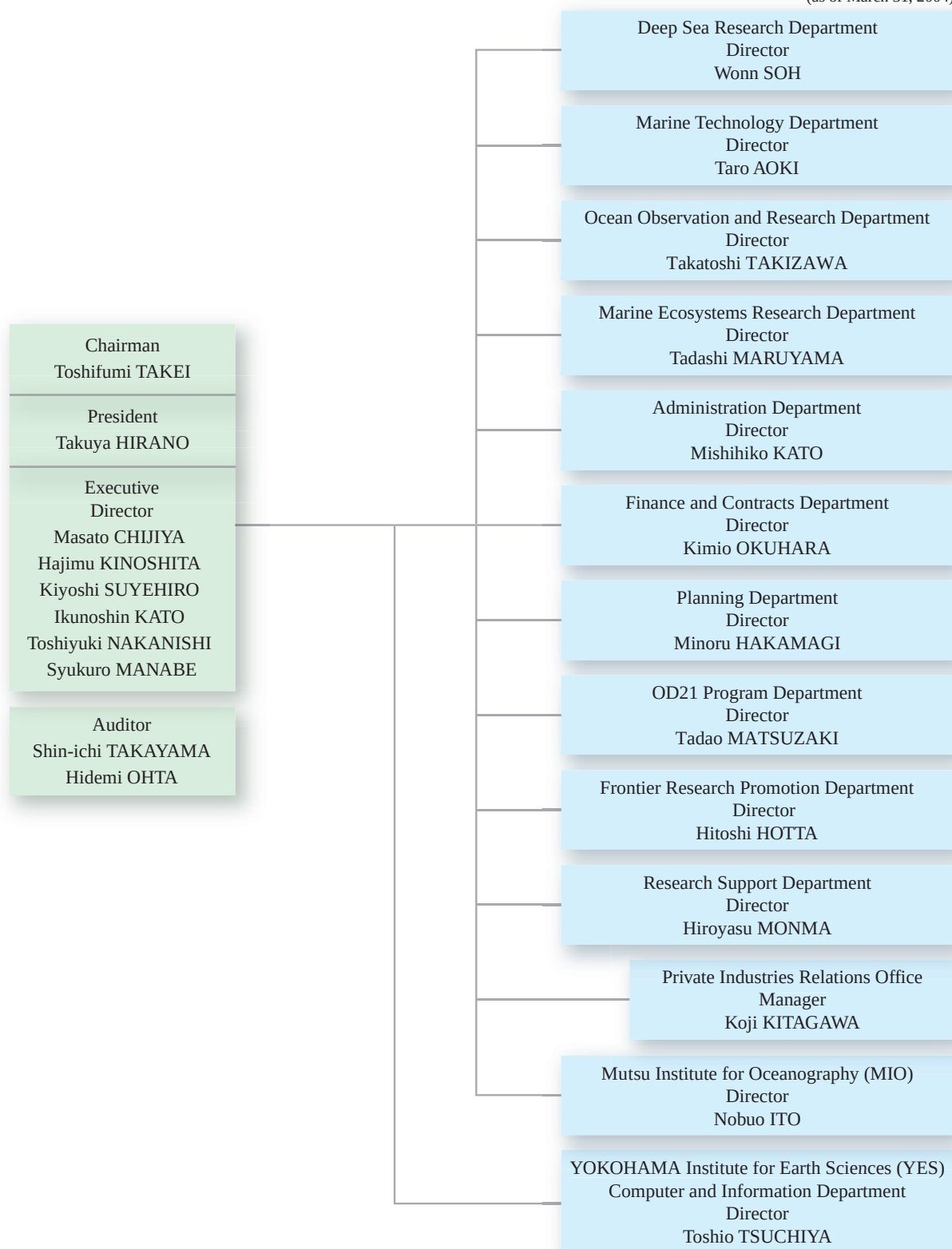
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Appendix B

Organization Chart

(as of March 31, 2004)



Appendix C

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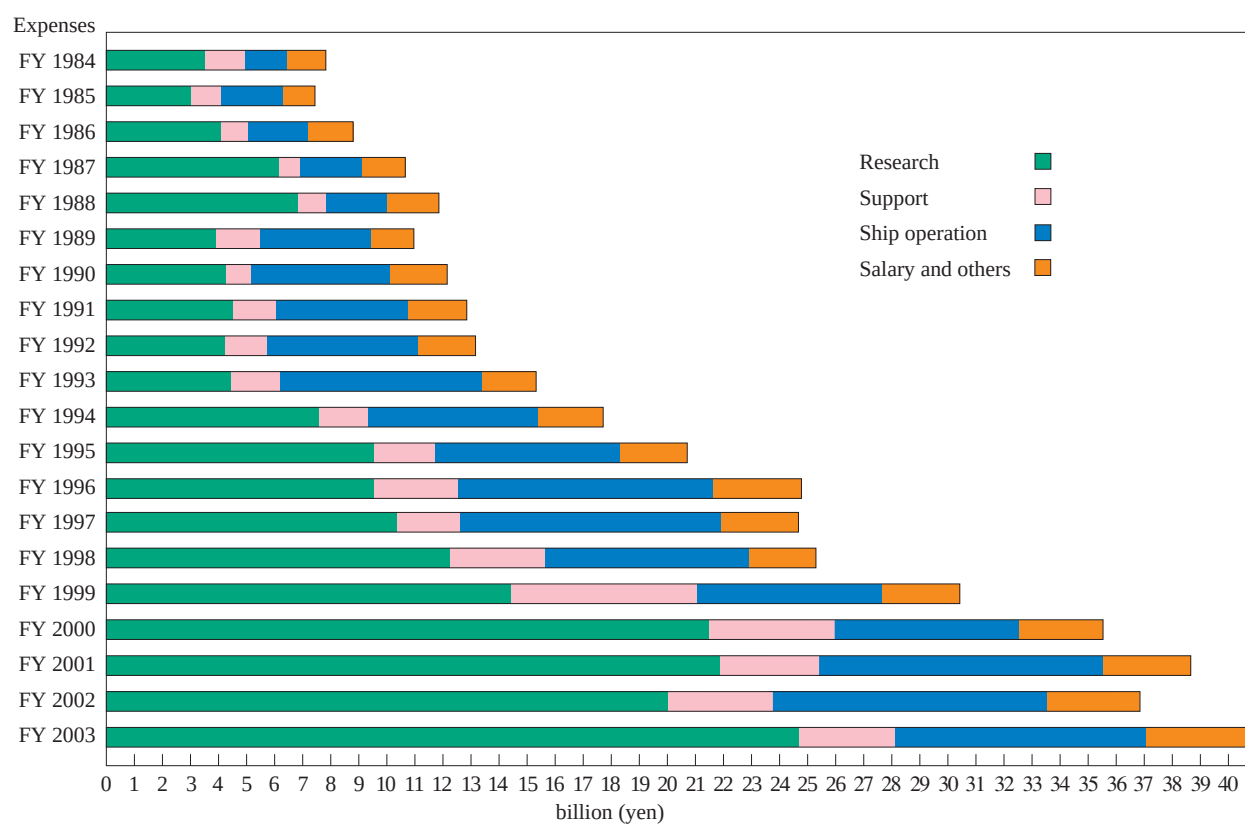
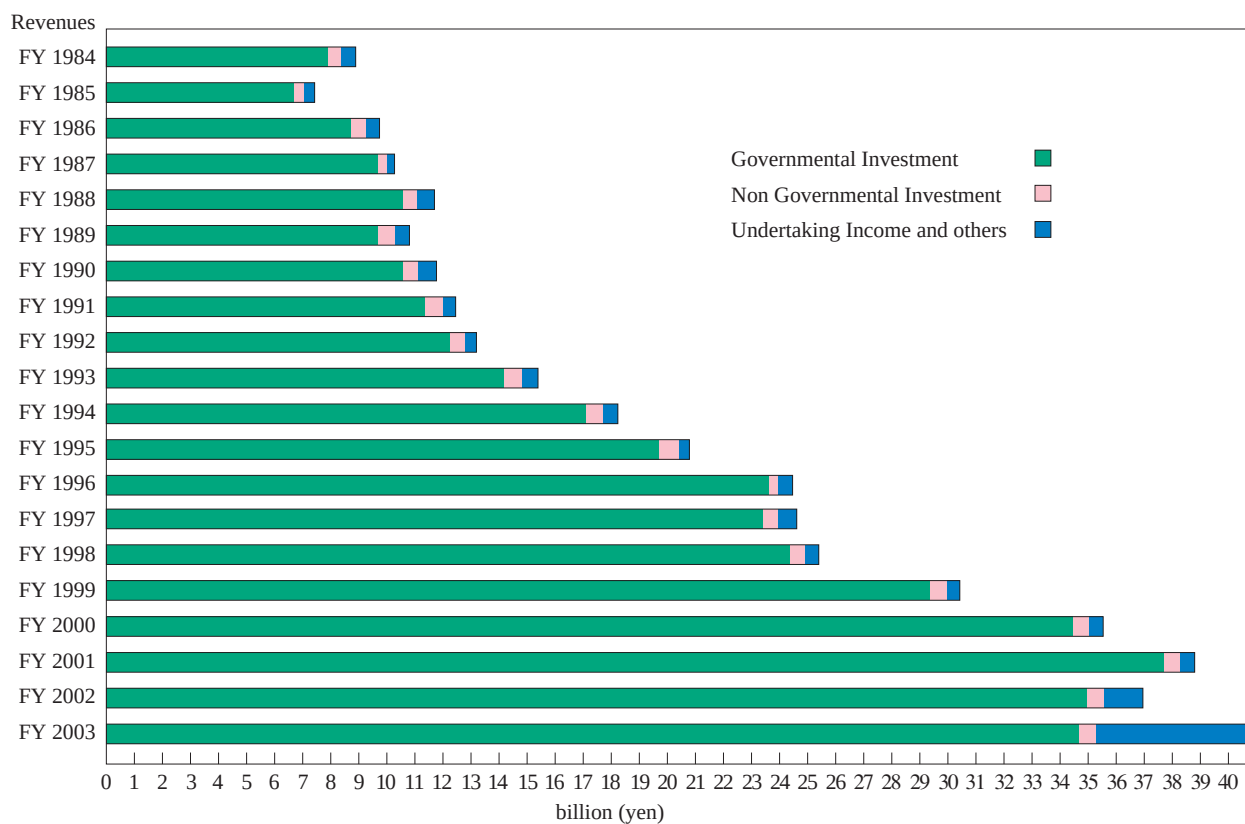
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JAMSTEC 2003 Annual Report

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