

Research Institute for Global Change Annual Report FY2010



JAMSTEC 独立行政法人
海洋研究開発機構
JAPAN AGENCY FOR MARINE-EARTH SCIENCE AND TECHNOLOGY

Preface

The earth we inhabit consists of the natural habitats such as ocean, air, and land, and all the ecosystems they nurture interact to shape the global environment. For thousands of years the earth's environment has conferred tremendous benefit to all lives and also protected and fostered human existence and civilization. However, in recent years the drastic environmental changes stemming from human activity, including global warming, have appeared. It has become a significant and urgent problem of the world to examine the specific conditions, investigate their causes, and forecast future developments.

Under a vision of Research Institute for Global Change (RIGC), namely, "A society that expects and makes use of the knowledge we compile through our science to create more sustainable and productive society keeping harmonious relationships between human and the environment", we are conducting comprehensive global environmental research including observation and prediction to provide scientific information to society. We proudly believe that we can help JAMSTEC meet evolving social needs not only from Japan but also from the world.

The science of RIGC is a field that aims to monitor the oceans, air, land, and ecosystems, using various techniques to define prevailing conditions, understand the mechanisms of change, and at the same time to develop forecasting models that combine the findings with the expertise to better predict future changes. The special urgent ocean monitoring and ocean forecast carried out by RIGC at the time of the Great East-Japan Earthquake may showed above nature of RIGC typically.

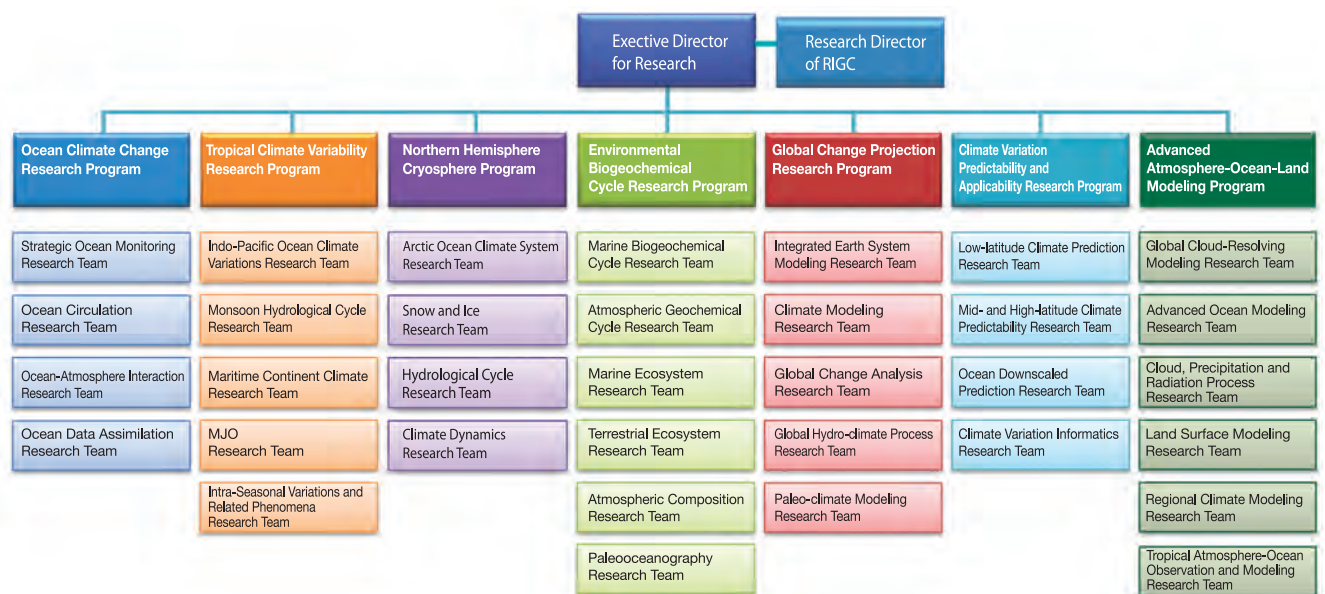
Also, we, Research Institute for Global Change, have cooperated with institutions both at home and abroad. Through promotion of international earth observation and research programs, such as the Global Earth Observation System of Systems (GEOSS) and World Climate Research Program (WCRP), as well as our active participation in the Intergovernmental Panel on Climate Change (IPCC) activities, RIGC/JAMSTEC have been recognized as one of leading institutions in the research for global climate change.

15 December 2011

Masao Fukasawa, Dr.

Research Director, Research Institute for Global Change

Organization



Research Institute for Global Change (RIGC)

Annual Report FY2010

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I. Research Activities and Results

Observe the Ocean to Understand its Role in Climate -Ocean Climate Change Research Program-

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

For these purposes, the following activities were carried out in FY2010.

- A total of 58 ARGO floats was deployed;
- Chemical analyses and data quality control were made for the samples obtained in the cruise of the WOCE P21 which is the hydrographic observation line along 17°S in the Pacific.
- A surface buoy to observe air-sea interaction was moored in the Kuroshio Extension region.

By analyzing data from these observations along with previously collected oceanographic data, we obtained scientific results regarding oceanic changes in heat and chemical materials. These results are described in detail below.

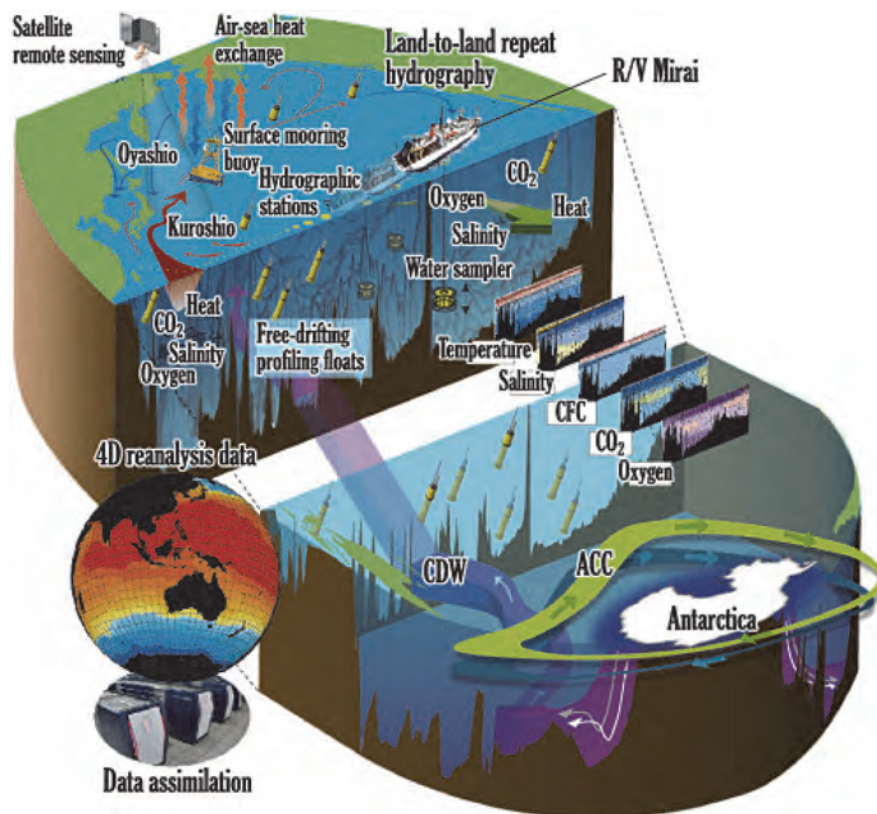


Fig. 1. Time series of composite anomalies in sea surface temperature.

“Eddy Resolving” Observation of the North Pacific Subtropical Mode Water -Strategic Ocean Monitoring Research Team-

The subtropical mode water (STMW) is a dominant water mass in the upper layer of the subtropical gyre with vertically uniform properties, which is formed in the wintertime deep mixed layer mainly south of the Kuroshio Extension. The STMW acquires thermal anomalies, dynamical properties (e.g. potential vorticity),

nutrients, dissolved gasses, etc. during its formation process and distribute them widely with its circulation. While the STMW had been described extensively regarding its large-scale features, recent eddy-resolving ocean general circulation model simulations suggest that the formation and circulation of STMW are substantially governed by mesoscale eddies. However, it has been very difficult to examine mesoscale features related to STMW due to lack of enough data with sufficient spatial and temporal coverage. The purpose of this research is to elucidate roles of mesoscale eddies on the spreading and modification of North Pacific STMW by using Argo data and ship-based hydrographic measurements [Oka *et al.*, 2011a]

Hydrographic data obtained by high-resolution shipboard observations and Argo profiling floats have been analyzed to study the mesoscale structure and circulation of the North Pacific STMW. The float data show that in the late winter of 2008, STMW having a temperature of approximately 18.8°C (18.2°–19.1°C), 17.7°C

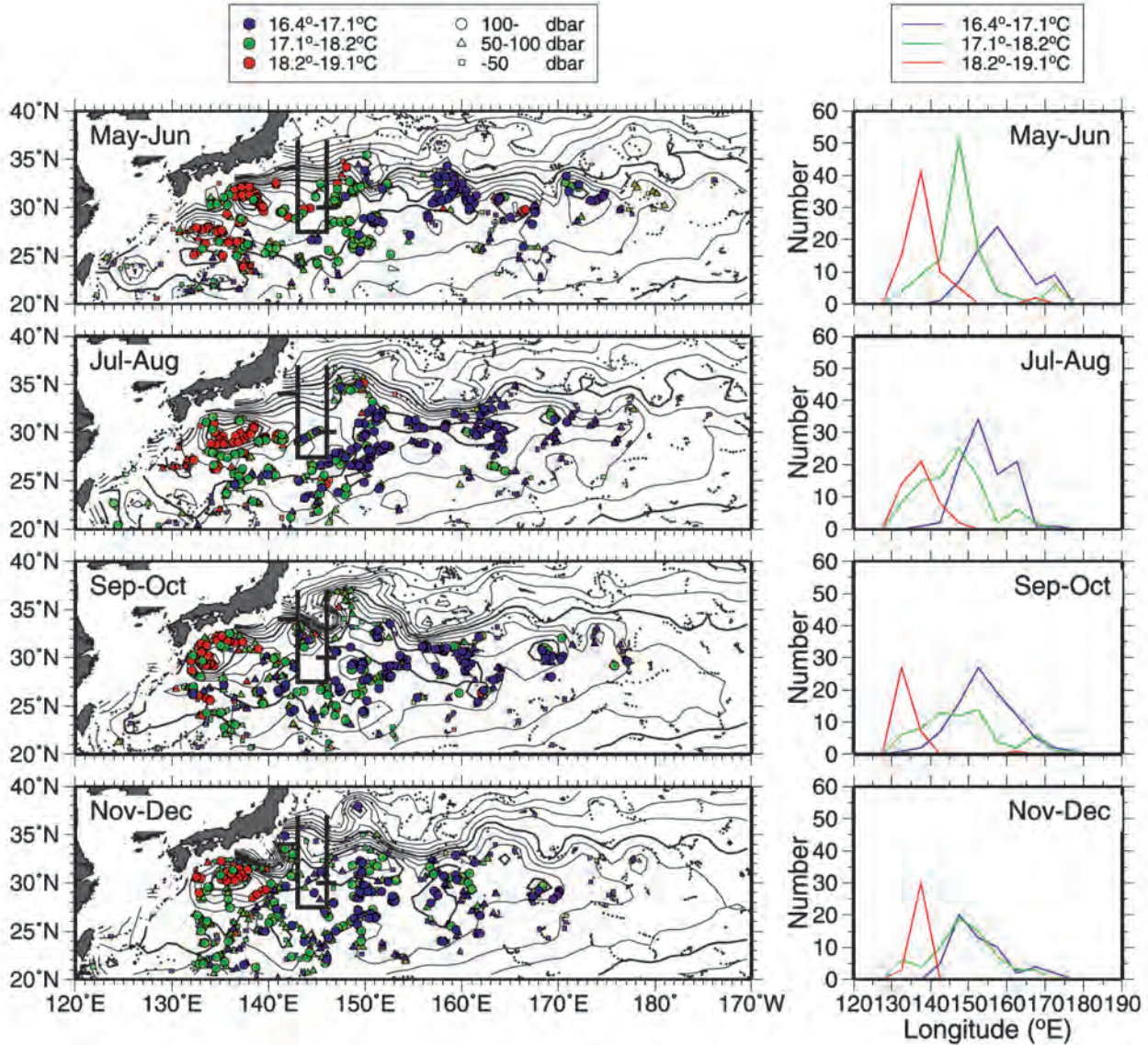


Fig. 2. (left) Distribution of nonoutcropping STMW with a core potential temperature, q , of 16.4°–17.1°C (blue symbols), 17.1°–18.2°C (green symbols), and 18.2°–19.1°C (red symbols) and geopotential anomaly at 250 dbar relative to 950 dbar ($\text{m}^2 \text{s}^{-2}$; contours) from May–June through November–December in 2008, based on Argo float data. The symbol type denotes STMW thickness: greater than 100 dbar (circles), 50–100 dbar (triangles), and less than 50 dbar (squares). The black dots denote float observation points with STMW having the other core q , those with outcropping STMW, and those without STMW. The geopotential anomaly at 250 dbar (average depth of the STMW core from spring through fall) was calculated from the float data using an optimal interpolation technique, and its contour is drawn at an interval of 0.5 $\text{m}^2 \text{s}^{-2}$, with thick ones at 10, 12, and 14 $\text{m}^2 \text{s}^{-2}$. The thick black lines denote the observation lines of the KH-08-3 cruise leg 2. (right) Number of profiles with nonoutcropping STMW thicker than 100 dbar located north of 25°N with a core u of 16.4°–17.1°C (blue curve), 17.1°–18.2°C (green curve), and 18.2°–19.1°C (red curve) from May–June through November–December in 2008, counted for each 58 bin of longitude.

(17.1°–18.2°C), and 16.6°C (16.4°–17.1°C) formed west of 140°E, at 140°–150°E, and east of 150°E, respectively, in the recirculation gyre south of the Kuroshio Extension (see May–June panels of Fig. 2). After spring, the newly formed STMW gradually shift southward, decreasing in thickness. Simultaneously, the STMWs of 16.6° and 17.7°C are gradually stirred (see the left panels of Fig. 2) and then mixed in terms of properties (Fig. 3a). In late fall, they seem to be integrated to form a single group of STMWs having a temperature centered at 17.2°C (see the bottom panel of Fig. 3a). Such STMW circulation in 2008 is much more turbulent than that in 2006 (Fig. 3b), which was investigated in a previous study. The difference between the two years is attributed to the more variable state of the Kuroshio Extension in 2008, associated with stronger eddy activities in the STMW formation region, which enhance the eddy transport of STMW.

High-resolution shipboard observations were carried out southeast of Japan at 141°–147°E in the early fall of 2008. To the south of the Kuroshio Extension, STMW exists as a sequence of patches with a horizontal scale of 100–200 km, whose thick portions correspond well to the mesoscale deepening of the permanent pycnocline. The western (eastern) hydrographic sections are occupied mostly by the 17.7°C (16.6°C) STMW,

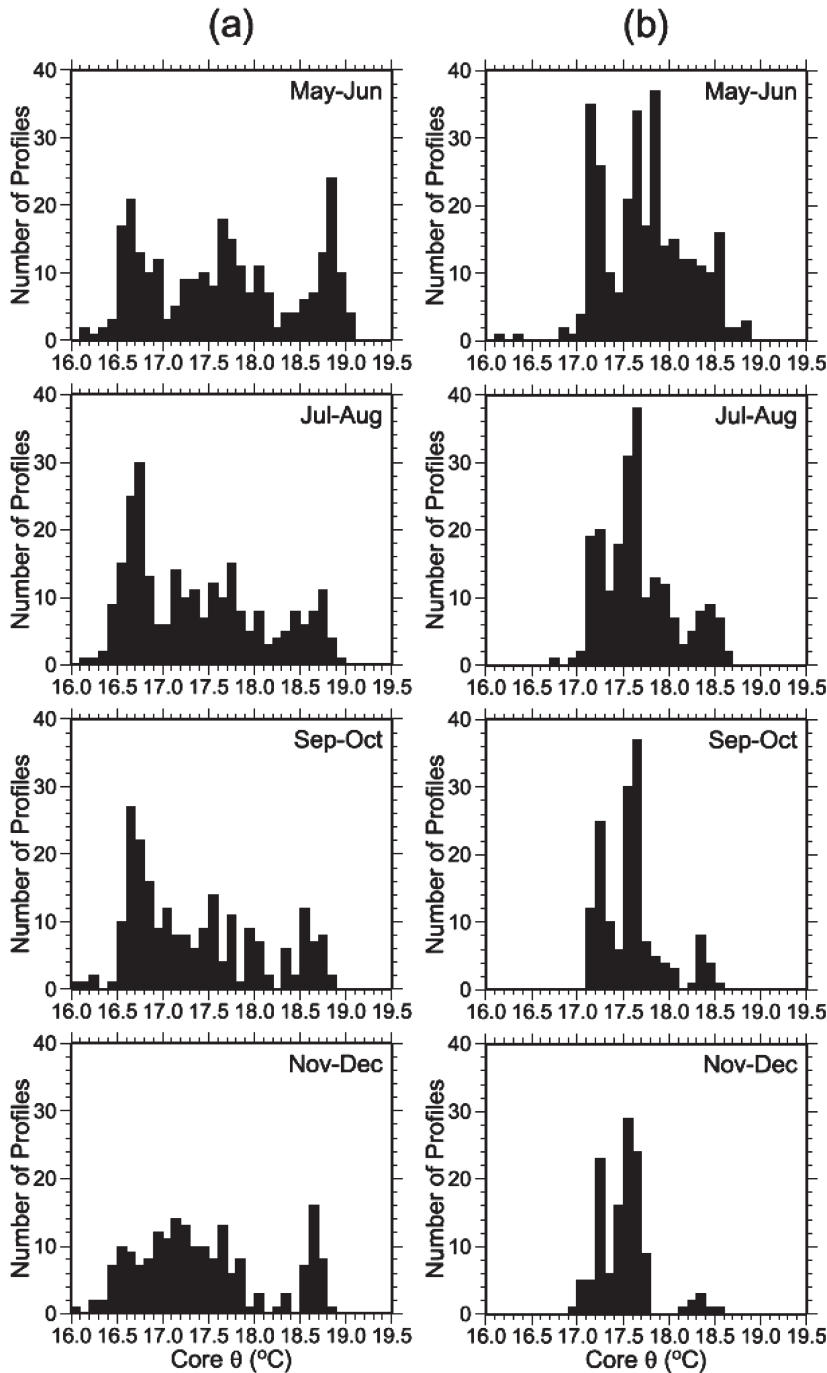


Fig. 3. Number of profiles with nonoutcropping STMW thicker than 100 dbar in each 0.1° bin of core θ from May–June through November–December in (a) 2008 and (b) 2006, based on Argo float data.

within which the 16.6°C (17.7°C) STMW exists locally, mostly at locations where both the permanent pycnocline depth and the STMW thickness are maximum. This structure implies that the STMW patches are transported away from their respective formation sites, corresponding to a shift in the mesoscale anticyclonic circulations south of the Kuroshio Extension. Furthermore, 20%–30% of the observed STMW pycnostads have two or three potential vorticity minima, mostly near temperatures of 16.6° and 17.7°C. We presume that such a structure formed as a result of the interleaving of the 16.6° and 17.7°C STMWs after they are stirred by mesoscale circulations, following which they are vertically mixed to form the 17.2°C STMW observed in late fall. These results indicate the importance of horizontal processes in destroying the vertically uniform structure of STMW after spring, particularly when the Kuroshio Extension is in a variable state.

Reference

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Ocean Transport Changes Estimated by a Box Inverse Model: Southern Ocean -Ocean Circulation Research Team-

The Southern Ocean is believed to play a key role in controlling the world ocean circulation [e.g. *Webb and Suginohara*, 2001]. With the effort of the hydrographic research groups world wide under the auspices of the Global Ocean Ship-based Hydrographic Investigations Program, some of the long sections have now been reoccupied. It is, then, of interest to see what difference exists between these two occupations. Figure 4 shows one such comparison made possible with the use of a box inverse model.

There are nine (or ten if we count I3 and I4 separately) hydrographic sections occupied at least twice. The first occupation was between 1987 to 1996 as part of the World Ocean Circulation Experiment (labelled WOCE Hydrographic Programme, or WHP in the figure). These lines were reoccupied between 2003 to 2009 (labelled as Revisit). In a box inverse model, the temperature and salinity measurements were converted to the geostrophic shear using the regular method. The barotropic correction to the geostrophic shear along with the diapycnal transports were then estimated using the Gauss-Markov theorem. The present box inverse model is different from past ones in (1) the velocity at 1000 dbar is constrained by the velocity estimated by the neutrally buoyant floats including the Argo floats [*Katsumata and Yoshinari*, 2010], and in (2) there is a separate surface layer box with the fixed thickness of 300 dbar sitting on top of the other boxes. The use of the float velocity greatly reduced the underdeterminedness. The surface box enabled estimation of the diapycnal transports near the surface and interior, separately.

The estimated transports overlap, within the uncertainties, with those by *Ganachaud and Wunsch* [2000]. The zonal transport of the Antarctic Circumpolar Current (ACC) was estimated somewhat (about 30 Sv) larger. We note here that the uncertainty shown in the Figure is likely a lower bound because it does not reflect the uncertainty due to the sensitivity to the choice of the initial surface of zero velocity, errors in the wind product used to estimate the Ekman transports (NCEP-DOEII, here), errors in the a priori covariances, although it includes those errors listed in *Ganachaud* [2003] such as the non-synopticity, internal tides, treatment of the bottom data. Given the minimum uncertainty, it is probably too hasty to conclude whatever the difference between the two panels is real. We therefore compared the results from three numerical general circulation simulations, namely Ocean model for Earth Simulator [OFES, *Sasaki et al.*, 2008], Simple Ocean Data Analysis [SODA, *Carlton and Giese*, 2008], and K7 model [*Masuda et al.*, 2010].

One of the robust changes in the Southern Hemisphere circulation between the WOCE and Revisit periods is in the decrease of the ACC transport through the Drake Passage; 178 ± 6 Sv during the WOCE period while it is 150 ± 3 Sv during the Revisit period.

The model transports fluctuate around different mean values, reflecting complicated physics determining the ACC transport. Interestingly, the K7 and SODA model show a decreasing trend while the OFES model shows a slight increase in the transport. We note that the K7 and SODA models were constrained by the observed data

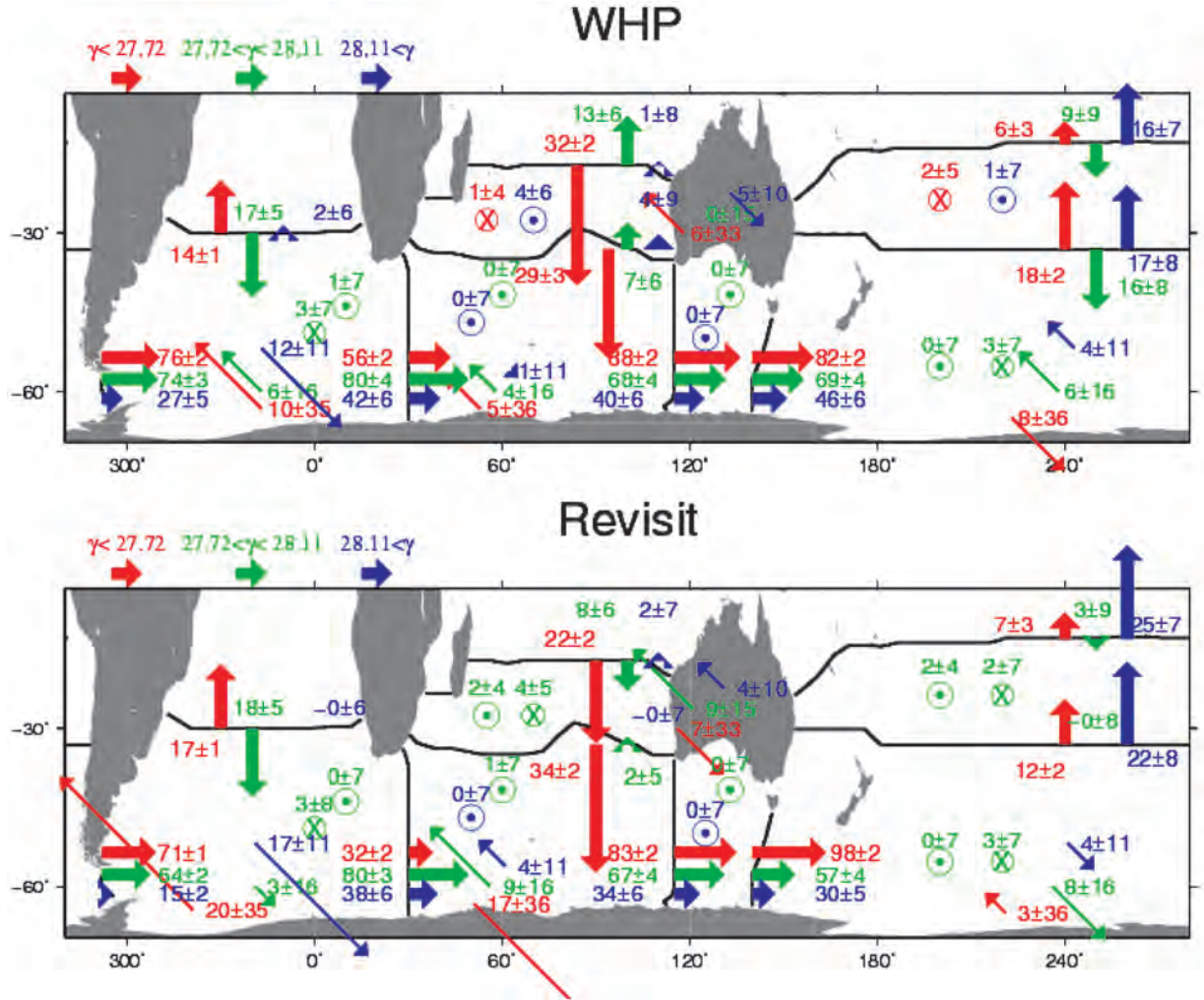


Fig. 4. Transport across hydrographic lines estimated by a box inverse model. The arrows show transport in Sv ($1 \text{ Sv} = 10^6 \text{ m}^3 \text{ s}^{-1}$). The colour shows the density class measured in the neutral density $1000 + \gamma$ (kg m^{-3}); red is the upper waters roughly corresponding to the intermediate and mode waters, green is the deep waters, and blue is the bottom water. The diapycnal transports are indicated by filled circle (upwelling) or crosses (downwelling), with the colour indicating the origin (for example, the blue solid circle in the South Pacific in the upper panel with the transport 1 ± 7 Sv is from the bottom to the deep layer). The oblique arrows in the Southern Ocean are the upwelling into or subduction from the surface layer. Northwestward arrows are upwelling and vice versa. For example, the red arrow in the Indian Ocean section in the lower panel with the transport 17 ± 36 Sv (with the arrow head out of the figure boundary) means this much of water subducts in this basin at the density $< 1027.72 \text{ kg m}^{-3}$.

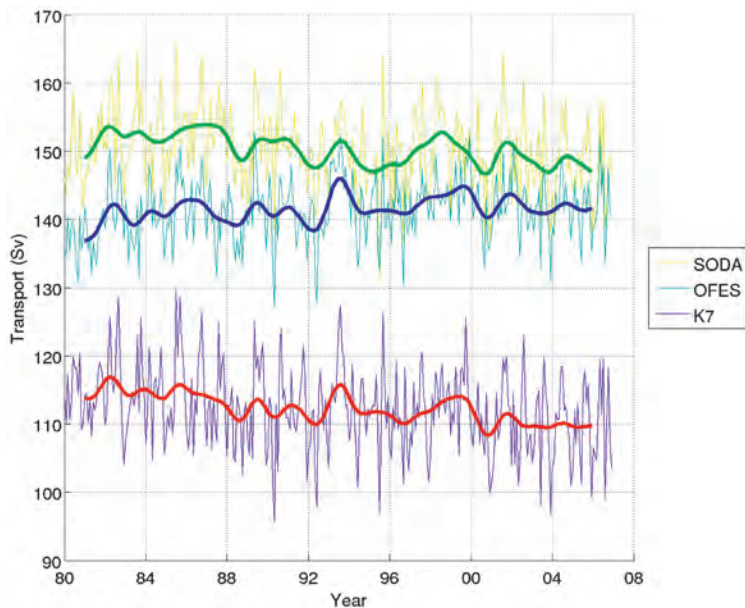


Fig. 5. Transport across the Drake Passage estimated by three numerical simulations; SODA (yellow), OFES (cyan), and K7 (magenta). Monthly data are plotted along with the smoothed lines with a 25-month Hamming filter. In SODA and K7 strong seasonality can be seen in the monthly plots (thin lines) where the transports are enhanced during the winter, but the seasonality is not clear in the OFES. The SODA and K7 were constrained by the observed data, but OFES was not.

while OFES was not. All model lack sea ice, although the effect of sea ice could influence the data-constrained models through little winter data. It is encouraging that the data-constrained model support the result of the box inverse model that the ACC transport is decreasing. The mechanism behind this decrease is now under investigation and will hopefully be published elsewhere.

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Air-sea Heat Flux Variations Around the Kuroshio Extension -Ocean-Atmosphere Interaction Research Team-

The role of the air-sea interaction is quite important for the mid-latitude climate variation, especially in the region where the turbulent heat flux (THF) is very large. The surface heat flux variability in the western boundary current region such as the Kuroshio Extension (KE) region is one of the keys for revealing the role of the thermal coupling between the ocean and the atmosphere.

Recently, Nakamura *et al.* [2008] suggested from atmospheric general circulation model experiments that the strong restoring of the near-surface air temperature to the SST front affected the activity of the mid-latitude storm tracks through the adjustment of the turbulent surface heat flux. Although many surface heat flux data sets show that the area of the large sensible (SHF) and latent heat fluxes (LHF) expands to both sides of the KE in cooling seasons [*e.g.* Qiu *et al.*, 2004], the boundary layer processes and the oceanic and meteorological parameters are likely to be quite different on either side of the KE. Such a discrepancy suggests a spatial difference of the ocean-atmosphere feedback system in the KE region.

From these perspectives, our team started monitoring surface meteorology and underwater physical properties in February 2007 to the north of the KE jet by the JAMSTEC Kuroshio Extension Observatory (JKEO) buoy at 146.5°E, 38.0°N, whereas Pacific Marine Environment Laboratory (PMEL)/ National Oceanic and Atmospheric Administration (NOAA) operates the KEO

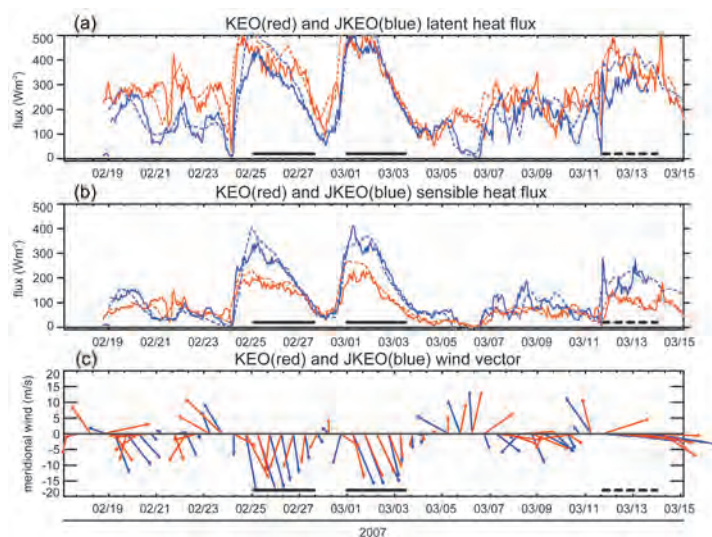


Fig. 6. (a) The latent and (b) the sensible heat flux at (red) KEO and (blue) JKEO during Period I, and (c) the coincident surface wind vectors. Thick black and broken lines indicate the period of the northerly wind condition and the monsoon wind condition, respectively.

buoy to the south of the KE jet at 144.6°E, 32.4°N. We analyzed the winter surface heat flux variability and its difference between the north (JKEO) and the south (KEO) sides of the KE front on daily to synoptic time scales, focusing on two periods of coincident observations at KEO and JKEO; Period I: 18 February to 12 March 2007 and Period II: 1 to 25 January 2008.

In wintertime, the SHF and the LHF sometimes became quite large both at KEO and JKEO concurrently. We found that the LHF exceeded 400 W m^{-2} , while the SHF was also as large as 300 W m^{-2} in certain conditions. When such extreme events occurred, the wind speed and direction at KEO accorded with those at JKEO (Fig. 6).

The northerly wind condition was characterized by cross-frontal northerly wind and extraordinarily large THF both at KEO and JKEO. As a result of the air mass transformation along the prevailing wind, the large air-sea gradient in humidity over the warm ocean south of the KE front can enhance the evaporative cooling, whereas the wind is stronger to the north. As a consequence, LHF has little contrast across the KE front, although SHF in the north is larger due to the stronger wind than to the south. On the other hand, the monsoon wind condition is also characterized by strong northwesterly wind and large heat flux in the KE region. However, the spatial difference of the LHF and SHF did not seem to be systematic. The LHF to the north of the KE front was significantly smaller than that to the south because of the nonlinearly increasing air-sea gradient of humidity. As the prevailing wind is almost parallel with the KE front, changes in the heat fluxes on the north and south sides of the KE front are not necessarily simultaneous.

A reanalysis product (the Japan Meteorological Agency Climate Data Assimilation System from the Japanese 25-year Reanalysis Project, [Onogi *et al.* 2007]) appears to reproduce these heat flux spatial patterns at synoptic scales (Figs. 7 and 8). It is suggested that the relative frequency of these different types of weather conditions results in anomalous spatial patterns in the heat fluxes on monthly timescales. The spatial structures of the THF due to different weather conditions proposed in this study highlights the basic fact that THF and atmospheric modification strongly depend on lateral advection that occurs during weather events. Consequently, the THF and its spatial distribution on near-monthly time scales are generated by the relative frequency of synoptic events. This result accentuates the importance of the high-frequency monitoring of the thermal air-sea interaction in the KE region [Konda *et al.* 2010].

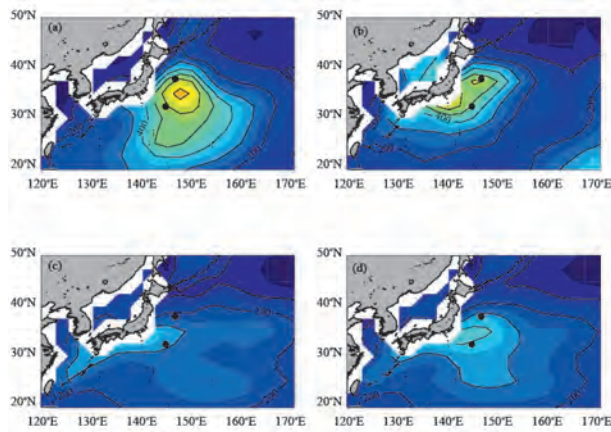


Fig. 7. Composites of the turbulent heat flux during (a) the northerly wind condition, (b) the northwesterly monsoon wind condition, (c) the normal condition, and (d) the mean during Period I, obtained from the JCDAS product. Unit is in W m^{-2} . The position of KEO and JKEO are plotted by black circles.

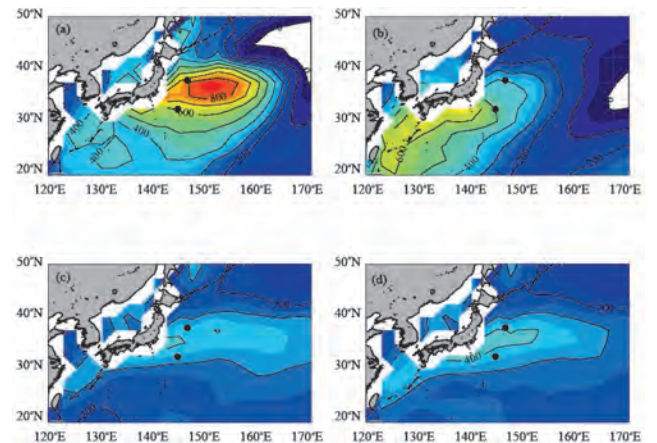


Fig. 8. As in Fig. 7, but for Period II.

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Improved Estimates of the Dynamical Ocean State -Ocean Data Assimilation Research Team-

The spatio-temporal coverage of hydrographic data is still sparse. To obtain a 4-dimensionally continuous state estimation of the global ocean, 4-dimensional variational (4D-VAR) data assimilation system has been developed which is capable of providing an optimal synthesis of the observational data and a climate model by solving a nonlinear least square problem. The obtained dynamically self-consistent 4-dimensional dataset can offer greater information content on ocean climate changes than can be derived from models or data alone [*e.g.*, Stammer *et al.*, 2002].

The used OGCM is based on version 3 of the GFDL Modular Ocean Model (MOM) [Pacanowski and Griffies, 1999] with major physical parameter values determined through a variational optimization procedure [Menemenlis *et al.*, 2005]. The horizontal resolution is 1° in both latitude and longitude, and there are 46 vertical levels for the global ocean basin. The adjoint code of the OGCM was obtained using the Transformation of Algorithms in Fortran (TAF).

Our system has been executed on the Earth Simulator 2 to obtain a comprehensive 4-dimensional integrated dataset [*e.g.*, Masuda *et al.*, 2010]. The assimilated elements are historical hydrographic data of temperature and salinity from the ENSEMBLES (EN3) dataset which was quality controlled using a comprehensive set of objective checks developed at the Hadley Centre of the UK Meteorological Office [Ingleby and Huddleston, 2007]. In addition of EN3 dataset, recent data obtained/compiled in JAMSTEC (independent MIRAI RV profiles and a climatology of subsurface 2-dimensional velocity estimated from Argo floats [Katsumata and Yoshinari, 2010]) are simultaneously incorporated. NOAA Optimum Interpolation SST (NOAA_OI_SST_V2) values, and sea-surface dynamic-height anomaly data derived from the high-precision multi-satellite altimetry products produced by Ssalto/Duacs are also assimilated.

The analysis fields successfully capture the realistic time trajectory of ocean properties and observed patterns of ocean circulation and surface air-sea heat fluxes. For example, figure 9 shows estimated steric height distribution in an El Niño year. Significant sea level rises appear in the eastern equatorial Pacific and central Indian Ocean in conjunction with interannual changes in oceanic heat storage. Recent-day sea level change is of considerable interest because of its potential impact on human populations living.

By using this ocean state estimation, we performed a global mapping experiment of lower trophic

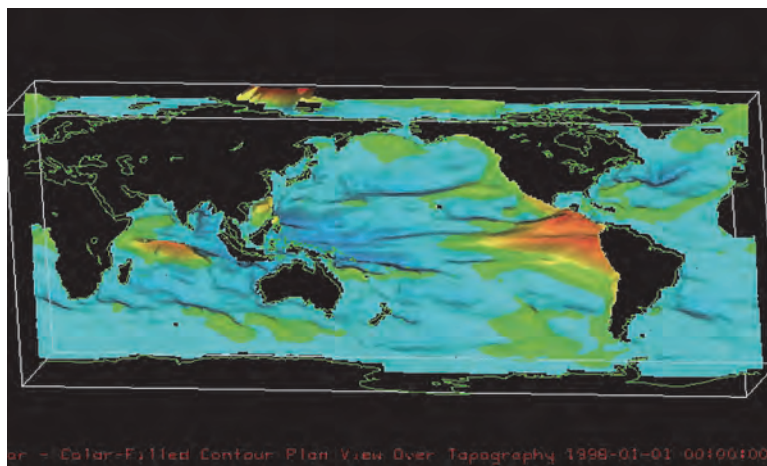


Fig. 9. Distribution of steric sea level change for Jan 1998 (El Niño year) estimated from 4-dimensional synthesis dataset.

level ecosystem with the North Pacific Ecosystem Model for Understanding Regional Oceanography [NEMURO; Kishi *et al.*, 2007]. The 4D-VAR oceanic reanalysis can provide the dynamically self-consistent fields reflecting observations, which are suitable for the basic field to perform an ecosystem model. Considering the locality of the features of lower trophic levels, we optimized model parameters by the Green's function approach, a simple variational data assimilation method. We used the monthly climatological fields of nitrate and silicate from World Ocean Atlas 2005, and the surface chlorophyll-a

data by SeaWIFs as assimilated elements. Figure 10 shows temporal change in estimated surface chlorophyll-a with optimized parameter set (red curve) comparing with observation (black) and a simulation result (blue). The estimated values of lower-trophic-level variables with the optimized parameters are by and large consistent with observations and the previous knowledge. This result would lead to an improved 4-dimensional variational biogeochemical data assimilation system which should play a vital role in the research for global change.

Our variational data assimilation approaches, in turn, can possibly help construct an optimal observing system.

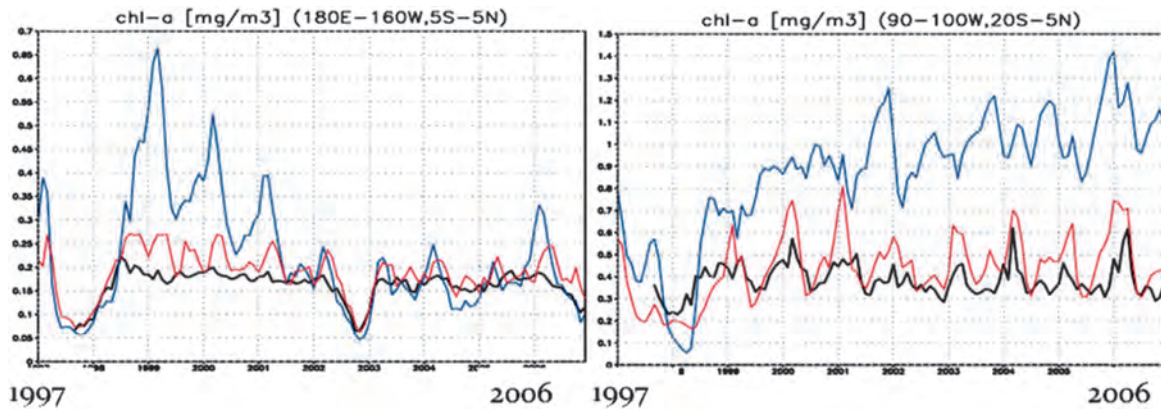


Fig. 10. Temporal change in surface chlorophyll-a in central (left) and eastern (right) equatorial regions from 1997 to 2006. (Red) Estimation with optimized parameter set, (Black) observation, and (Blue) a simulation result.

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Obtained Processes in the Tropical Climate Variation by Intensive Observation and Long-term Sustained Observation -Tropical Climate Variability Research Program-

Tropics is a key area of global climate variation. In fact, unique atmosphere-ocean coupled phenomena with various timescale are observed in the tropical Pacific and Indian Oceans, like El Niño, Indian Ocean dipole mode phenomenon, the Monsoon, and the Madden-Julian Oscillation (MJO) etc. (Fig.1). These phenomena sometimes bring anomalous weather not only to the tropical area but often worldwide with great impacts on human socio-economic activities. This Program aims to reveal the mechanism of these phenomena and their interactions and contributes to improve their predictability.

In order to achieve the aims, we have conducted a variety of observations to detect the ocean/atmosphere variation processes embedded in the phenomena. In the Pacific and Indian Ocean, long-term ocean observation using moored buoy array has been conducted and land based long-term atmospheric observation including Radar array also conducted in the Maritime Continent, Indochina area and Palau islands (Fig. 2).

With these sustained observing systems, process oriented intensive observation campaigns have been conducted occasionally. In FY 2010, we were able to obtain various kinds of data successfully, and most of them are disseminated on web sites and some are available real time. Based on the data set, many research papers were published. Research achievements in this fiscal year are fruitful and significant to attain the aim of our program, and several achievements picked up from each research team are introduced here and shown in the following section.

Significant part of the achievements this year is based on process oriented field experiments. In terms of ocean variation research, convergence/divergence in the central equatorial Indian Ocean is first calculated based on current data set obtained by ADCP array during field experiment (MISMO campaign in 2006). It clearly shows signature of oceanic mixed Rossby-gravity waves, and the vertical motion of thermocline is consistent with calculated upwelling/downwelling speed. Although the thermocline in this area is deep and its motion is not able to change the equatorial SST significantly, it is an important finding to evaluate the role of oceanic wave in SST change.

Another research achievement is on the genesis of MJO derived from the same field campaign "Mirai Indian Ocean Cruise for the Study of the MJO-convection Onset" (MISMO). It reveals a process of humidity accumulation by atmospheric mixed Rossby-gravity wave which plays an important role in initiation of MJO. Following MISMO campaign, we launched a plan of new international in-situ observation campaign "Cooperative Indian Ocean experiment on intraseasonal variability in the Year 2011" (CINDY2011; Oct. 2011- Jan. 2012), aiming to obtain the initiation process of MJO more quantitatively, and it was endorsed by CLIVAR. Many researchers from 11 countries are to participate in this campaign. And our findings contributed to the designing of observing sites in the central Indian Ocean. In this year, a field experiment to understand the heavy rainfall mechanism over Vietnam and Philippine under the La Niña condition was conducted also and the preliminary

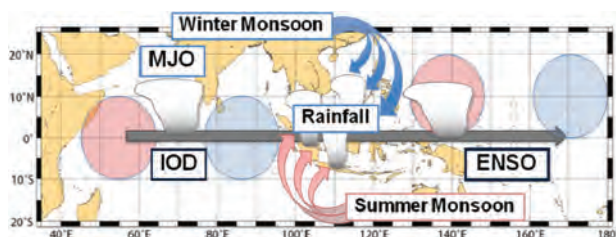


Fig. 1. Sketch of the major ocean/atmosphere variation phenomena, which compose tropical climate.

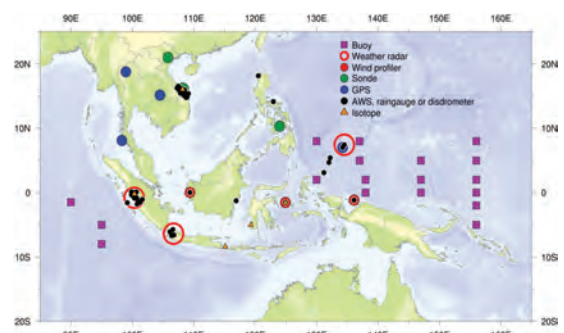


Fig. 2. Sustained Ocean and land observation sites by our program. Square; moored buoy (TRITON), Open red circle; Weather Radar, Solid circles: red; wind profiler, black; AWS, blue; GPS, green; Sonde station.

results are shown.

On the other hand, achievements in terms of rainfall variability around the Maritime Continent based on long-term data are also obtained. The one investigates interannual rainfall variation over the eastern Maritime Continent and around associated with ENSO. It reveals intense dry summer/autumn condition in El Niño year over the area, and proposes mechanisms due to modification of Monsoon circulation over the area by El Niño condition. The other investigates events of cross equatorial northerly wind in the vicinity of Kalimantan and Sumatra during winter monsoon period. Three patterns of atmospheric condition are found to make cross equatorial northerly wind (i.e. cold surge from the mid-latitudes, MJO, and both), and the rainfall pattern over the Maritime Continent is largely controlled by these patterns.

First Observed Current Divergence/Convergence and Estimated Vertical Motion Induced by Equatorial Wave

-Indo-Pacific Ocean Climate Variations Research Team-

In the tropical ocean, equatorial circulation alters horizontal and vertical heat exchange and thereby modulates SST through ocean-atmosphere interactions. However, currently, our understanding of three-dimensional circulation in the tropical Indian Ocean is limited because of the lack of in situ observations. Thus, a better quantitative presentation of ocean current structures in the equatorial Indian Ocean would be beneficial.

We investigated intraseasonal vertical velocity variation in the central equatorial Indian Ocean using observations from the field experiment (MISMO) and from the Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA), in October–November 2006. The triangular region surrounded by four ADCPs (Fig. 3) was used to estimate horizontal velocity divergence/convergence and vertical velocity by applying the continuity equation.

The vertical velocity estimated from integrating the horizontal divergence exhibit alternating downwelling and upwelling episodes, with maximum amplitudes larger than $8.0 \times 10^{-5} \text{ m s}^{-1}$, or about 7 m per day (Fig. 4a). The vertical velocity variation was mainly produced by the divergence/convergence of meridional currents, with a quasi-biweekly period of 11–16 days. To assess our estimate of the vertical velocity, we prepared a time series of the temperature profile of the MISMO region (Fig. 4b). The profile was calculated using CTD observations from the *R/V Mirai* and three moored buoys at the corners of the MISMO triangle (Fig. 3). The deepening or shoaling of the isotherms around thermocline depth, which result in warming or cooling, respectively, is related to the vertical velocity variation.

To expand the quantitative evaluation, we compared temperature changes at the 20°C isotherm with

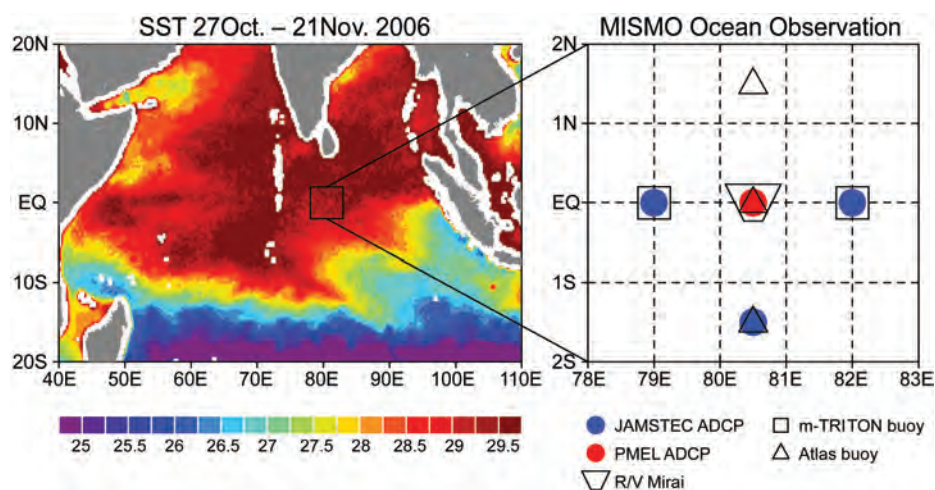


Fig. 3. Location map of the *R/V Mirai* observations and mooring buoys during the field experiment MISMO from 27 October to 21 November 2006. The left panel shows SST during the MISMO period, taken from the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI). The triangular region surrounded by four ADCPs (0° , 79°E ; 0° , 80.5°E ; 0° , 82°E ; and 1.5°S , 80.5°E) was used to estimate horizontal velocity divergence/convergence and vertical velocity.

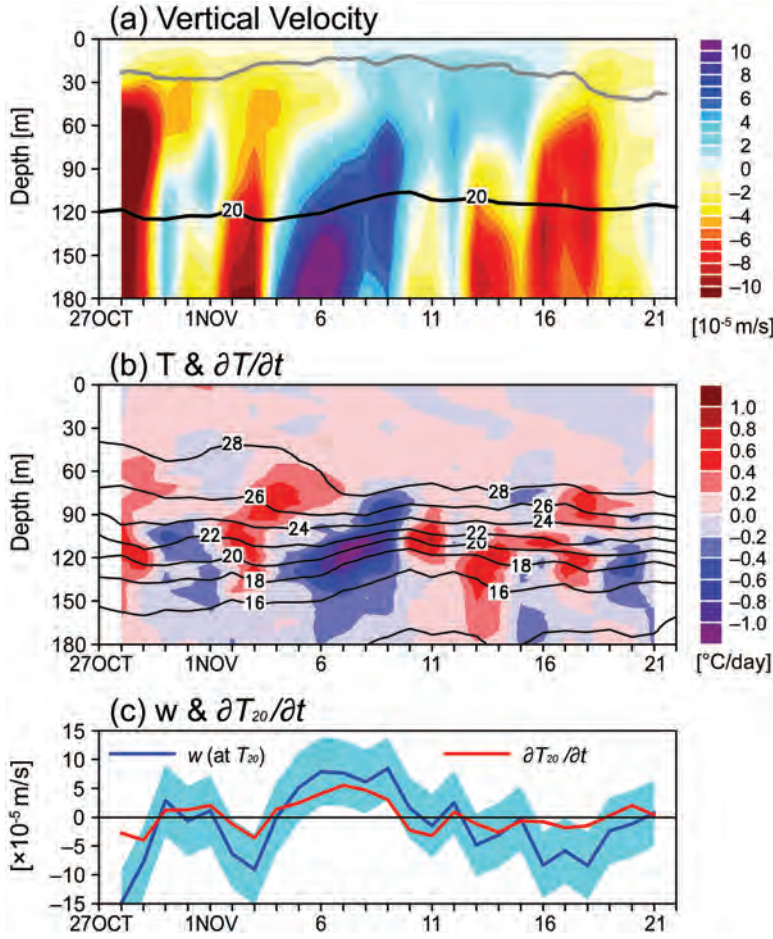


Fig. 4. (a) Time-depth section of vertical velocity estimated by the integration of horizontal divergence/convergence. Black line denotes the 20°C isotherm of the MISO region. Gray line denotes mixed-layer depth (MLD). (b) Time-depth sections of temperature profile (contour) and time tendency (color) [$^{\circ}\text{C day}^{-1}$]. (c) Time series of vertical velocity at 20°C isotherm (blue) and vertical movement of the 20°C isotherm (red) ($\times 10^{-5} \text{ m s}^{-1}$). Light-blue shading indicates vertical velocity error ranges.

vertical velocity (Fig. 4a, 4c). The temporal changes in the depth of 20°C isotherm roughly agree with the vertical velocity at the depth (Fig. 4c). The close correspondence between the vertical movement of the isotherm and the vertical velocity suggests that vertical and horizontal diffusion are small compared with vertical advection around the thermocline depth.

Considering the period and property of the observed signals, we suggest that the vertical velocity variation was driven by the mixed Rossby-gravity waves prevailing in the equatorial Indian Ocean. The theoretical value of a vertical velocity of mixed Rossby-gravity wave in a shallow water model is roughly consistent with the observed values calculated from the ADCP array.

To conclude, the mixed Rossby-gravity wave produces vertical motion in the thermocline, as well as controls subsurface temperature. Whereas this analysis focused on a short-term field experiment, our next goal in this observational study will be to diagnose the long-term mean of equatorial three-dimensional circulation in the Indian Ocean. This will further contribute to

validating and advancing coupled ocean-atmosphere models for climate prediction. To this end, we need to keep constructing, maintaining, and properly extending ongoing Indian Ocean observation systems.

Field Experiment for Heavy Rainfall Mechanism in the Asian Monsoon Area -Monsoon Hydrological Cycle Research Team-

The main rainy season in Central Vietnam, located in the east coast of the Indochina Peninsula, is from September to November when alternation from summer southwest monsoon to winter northeast monsoon occurs. It has been pointed out that the rainfall amount tends to be greater and that the heavy rainfall occurrence is more frequent in La Niña years [Yen *et al.*, 2011]. However, the generation and maintenance mechanism of heavy rainfall is not fully understood and therefore the physical relation to ENSO is still not well known. Understanding of the rainfall variations related to ENSO is strongly expected from the viewpoint of not only scientific interest but also socio-economical importance.

In order to understand the generation and maintenance mechanism of the heavy rainfall in Central Vietnam and in the Philippines, we have conducted the intensive observation, Vietnam Philippines Rainfall Experiment 2010 (VPREX2010) in autumn and early winter of 2011, when La Niña condition developed in the Pacific Ocean. In this experiment, detailed horizontal structures of rainfall events were observed by the dense rain-gauge network distributed at 31 stations and the automatic weather stations at 3 stations around Da Nang



Fig. 5. Location map of major observation stations in VPRES2010.

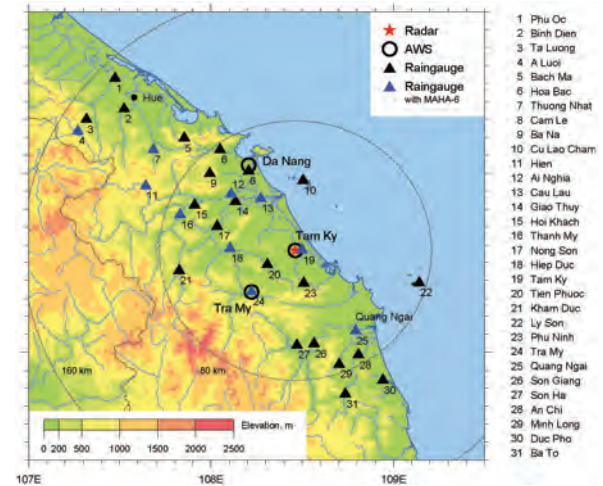


Fig. 6. Location map of dense rain gauge network, AWS, radar around Da Nang in Central Vietnam.

City in Central Vietnam, and by the routine radars (Figs. 5 and 6), hydrological and meteorological instruments of Vietnam National Hydro-Meteorological Service (NHMS). In order to capture the westward-propagating tropical disturbances and the winter monsoon surges and to clarify the vertical structure of the convections, the intensive radiosonde observations were conducted at Da Nang, Vietnam (four times-daily launch) and at Cebu, the Philippines (twice-daily launch) (Fig. 5). The semi-real-time forecast experiment using the Non-Hydrostatic Model (NHM) of Japan Meteorological Agency was executed in parallel with the observations. The VPRES2010 data is also utilized in the ALERA2 experiment to obtain the fine assimilation data. The preliminary results are shown below.

Figure 7 presents the Hovmöller diagram of relative vorticity at 850 hPa averaged between 12°N and 18°N along with daily precipitation at Da Nang for October-November 2010. During VPRES period, seven rain events were captured. In most of these events, heavy rainfalls occurred simultaneously with the arrivals of westward propagating disturbances with negative vorticity to the east coast of the Indochina Peninsula. It must be noted that the intensity of the vortices increased when they approached the coastline. This suggests that the heavy rainfall events were due to not only the passages of the disturbances but also the intensification of the vortex associated with the interaction between the vortex and topography. It is interesting that in some events (e.g., the one occurred around October 15) the cyclonic vortex continued to propagate westward after the intensification of vortex and convection near the coastline, while in

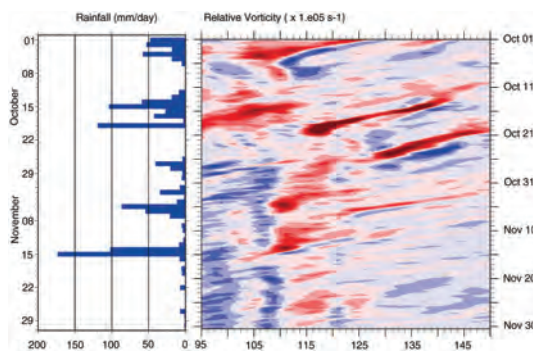


Fig. 7. Daily precipitation at Da Nang (left) and Hovmöller diagram of relative vorticity at 850 hPa averaged between 12°N and 18°N (right) for October-November 2010. Positive and negative vorticity is indicated in reddish and bluish shading, respectively.

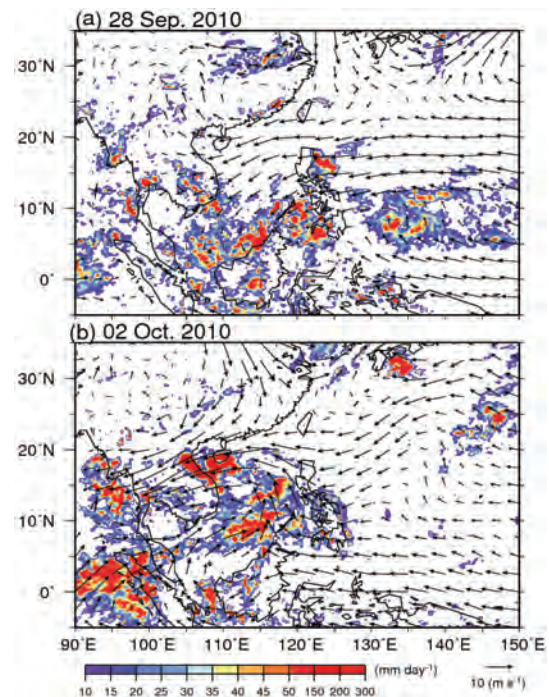


Fig. 8. Daily rainfall obtained from the TRMM satellite 3B42RT dataset and horizontal winds at 850-hPa level from the JCDAS data for a) 28 September and b) 2 October 2010.

some events (e.g., the one occurred around November 5) the vortex seemed to be destroyed at the coastline. Detailed structures of the events and the generation mechanism will be investigated in future.

The atmospheric circulations leading to the extremely heavy rain that occurred in central Vietnam in early October 2010 were investigated by analysis of the Japan Meteorological Agency Climate Data Assimilation System (JCDAS) data [Wu *et al.*, 2011]. The results showed that four factors seemed to be related with the extreme precipitation event: 1) In late September 2010, a westward-propagating synoptic-scale tropical disturbance that originated in the western Pacific hit central Vietnam (Fig. 8a). 2) An increase in strength and westward extension of the North Pacific subtropical anticyclone occurred in late September, which resulted in persistent strong easterly winds at the lower troposphere across the Philippine Sea and the northern South China Sea. 3) MJO strengthened in late September, provided a large-scale environment that is favorable for enhanced convection in central Vietnam. As the MJO enhanced convection migrated eastward over the South China Sea in early October, strong southwesterly winds occurred at the lower troposphere from northern Sumatra Island to the Indochinese Peninsula (Fig.8b). 4) A persistent northeasterly winter monsoonal flow occurred over the northern South China Sea along the southern coast of China.

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The Cross-Equatorial Northerly Surge and Precipitation over the Maritime Continent

-Maritime Continent Climate Research Team-

During the boreal winter, a low-level north-northeasterly flow, namely Asian winter monsoon is widely observed in East and Southeast Asia [Chang, 2004]. It corresponds to the cold air outbreak in the lower layer associated with the development of the surface Siberia–Mongolia High (SMH), and is consistently observed from November to March over Eurasia. In the steady cold northerly flow, intermittent variations in temperature, pressure, and wind speed are often observed and called the cold (pressure) surge, an intra-seasonal variation in Asian winter monsoon. The cold surge is associated with intensified northerly winds, decreased temperatures, and increased pressure over the South China Sea. This northerly flow area sometimes extends to the south over the South China Sea and up to the equatorial region. Recently, it is noticed that the cross-equatorial flow originating from mid-latitudes in the northern hemisphere is an important environmental factor related to heavy rainfall in Jakarta [Wu *et al.*, 2007].

In order to identify the characteristics of the northerly flow over the southern part of the South China Sea and the equatorial Maritime Continent, this study defined the cross-equatorial northerly surge (CENS) and investigated its relationship to the precipitation over the Maritime Continent during the 10 years from December 1999 to March 2009. The CENS was defined here as an area-averaged meridional wind that exceeds 5 m s^{-1} over 105°E – 115°E , 5°S – EQ based on the QuikSCAT sea surface wind data. This area-averaged meridional wind speed was defined as CENS index. During 10 years, 62 CENS events were extracted and classified into the following patterns: 11 events were associated with the cold surge and termed the CS pattern; 20 events were associated with the tropical intra-seasonal variation and termed the MJO pattern; 16 events were associated with the both the cold surge and the MJO and termed the CS–MJO pattern; and other 15 events were not associated with these patterns.

Figure 9 shows the composite sea surface wind on day 0 for the (a) CS, (b) MJO and (c) CS–MJO patterns. Day 0 was defined as the day when the CENS index reached the maximum. In the CS pattern, the northerly winds were enhanced over the equator as a result of the southward propagation of the northerly wind field with the cold surge that originated from the cold SMH. Before the peak of the CENS, a tongue-shaped cold

and high pressure area was distributed over the eastern part of Vietnam and the South China Sea, and the northerly winds were widely enhanced over the East China Sea, the South China Sea, and the Philippine Sea. At the peak of the CENS, an area of strong northerly winds extended to the south and up to Java. After the peak of the CENS, the cold and high pressure area extended further east over the East China Sea and the Philippine Sea, and the northerly winds weakened.

In the MJO pattern, the northerly winds over the equator were enhanced as a result of the formation of a depression around 10°S, which was associated with the tropical intra-seasonal variation. The CENS lasted for a longer period in the MJO pattern than in the CS pattern. Before the peak of the CENS, the northerly winds over the South China Sea, the East China Sea, and the northern part of the Philippine Sea were weak, and a warm and low-pressure area was distributed over mainland China. In contrast, significant northerly wind anomalies were seen in the vicinity of the depression around 10°S. At the peak of the CENS, the depression around 10°S was enhanced, and the northerly winds in the southern hemisphere intensified significantly. After the peak of the CENS, the northerly winds were continuously associated with the depression.

The CS–MJO pattern has the features of the northerly wind field of the CS pattern in the northern hemisphere and those of the MJO pattern in the southern hemisphere. The northerly wind component over the equator in the CS–MJO pattern was the greatest of the three patterns, and the northerly wind area extended beyond 10°S. The lower temperature/higher pressure was distributed in the region north of 10°N, while the higher temperature/lower pressure was distributed in the regions south of 10°S: the meridional contrast between the pressure and temperature was very significant. Before the peak of the CENS, a tongue-shaped cold and high-pressure area extended over the Indochina Peninsula and the South China Sea, similar to the CS pattern. After the peak of the CENS, the northerly winds and the depression continued over a wide area of the Maritime Continent, although the cold and high-pressure area decayed slightly.

The CENS is an important environmental factor for the formation of precipitation over the Maritime Continent. Figure 10 shows composite precipitations

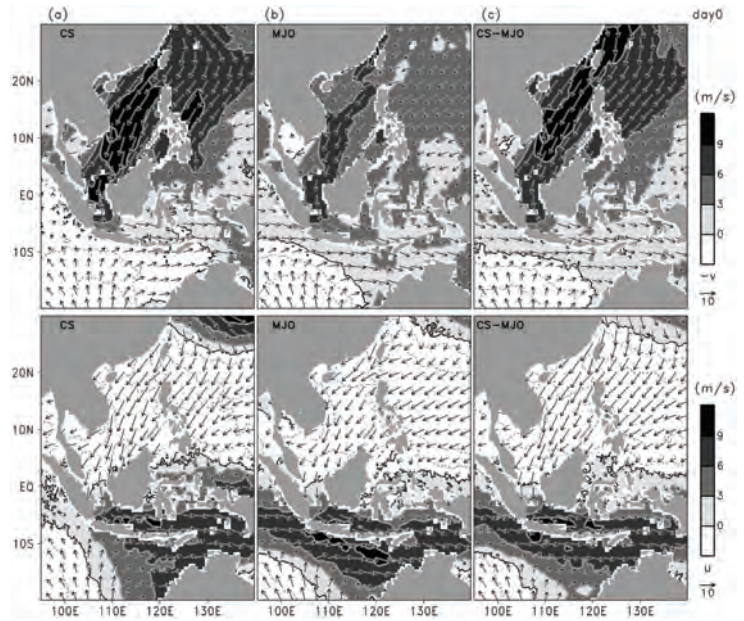


Fig. 9 Composite sea surface wind on day 0 for the (a) CS, (b) MJO and (c) CS–MJO patterns. Gray shading and contour lines in the upper (lower) figure show the northerly (westerly) components of the sea surface wind. The solid (dashed) line indicates the positive (negative) wind component with 3 m s⁻¹ interval. Thick solid line indicates 0 m s⁻¹ in meridional wind speed.

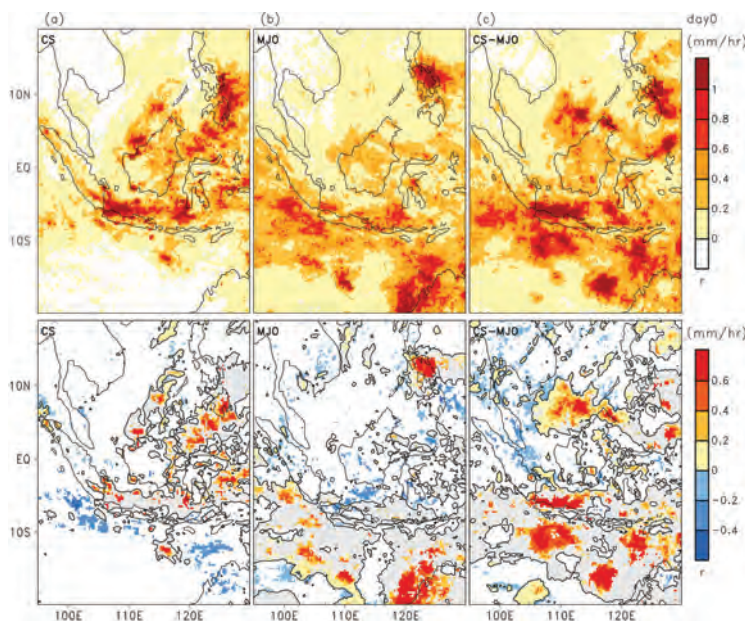


Fig. 10 Composite precipitations on day 0 (upper) and the anomalies from the 11-winter mean for DJFM (lower) in the (a) CS, (b) MJO and (c) CS–MJO patterns. The solid contour in the lower figure represents an anomaly of 0 mm hr⁻¹. Positive anomalies are indicated by light gray shading and only anomalies above the 90% significance level are represented by color shading.

on day 0 (upper) and the differences from the 10-winter mean for DJFM (lower) in the (a) CS, (b) MJO and (c) CS–MJO patterns. The positive anomalies of precipitation were significant, especially over the oceans south of 5°S (the Java Sea and the eastern part of the Indian Ocean) and east of Kalimantan. In the CS pattern, the precipitation was heavy over the northern part of Java, east of the Philippines and west of Kalimantan but light over the oceans west of Sumatra and south of Java. In the MJO pattern, the precipitation was heavy over the eastern part of the Indian Ocean, the Java Sea and the central Philippines but light over the Java Island. In the CS–MJO pattern, the precipitation was heavy over Java Island, the eastern part of the Indian Ocean, the Java Sea, east of the Philippines and west of Kalimantan. In other word, it is revealed that the major environment causing the increase of precipitation in each area was different over the Maritime Continent; the precipitation in the Java Sea was controlled by the CS pattern, whereas that in southwest of Sumatra, south of Java and northwest of Australia was controlled by the MJO pattern. The cold surge coincided with the tropical intra-seasonal variation (CS–MJO pattern) contributed significantly to the increase of the precipitation in those area. The convective activities associated with these patterns are thought to contribute to precipitation during the boreal winter season; future studies should investigate its specific contributions to and dynamic mechanisms for increased precipitation.

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A Key Component on the MJO Initiation Process has been Proposed -MJO Research Team-

MJO is known as the dominant intraseasonal (30-60 days) variability in the Tropics. The MJO is an eastward propagating ($\sim 5\text{m/s}$) disturbance with strong atmospheric convection, which usually occurs over the central and eastern Indian Ocean. Influences of the MJO spread over the world through the interactions with monsoons, El Niño, and others. Explaining the initiation process of MJO convection has been a major concern of MJO studies since its discovery in the early 1970s.

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

Based on the satellite-derived cloud data analyses, it was confirmed that MISMO observation network

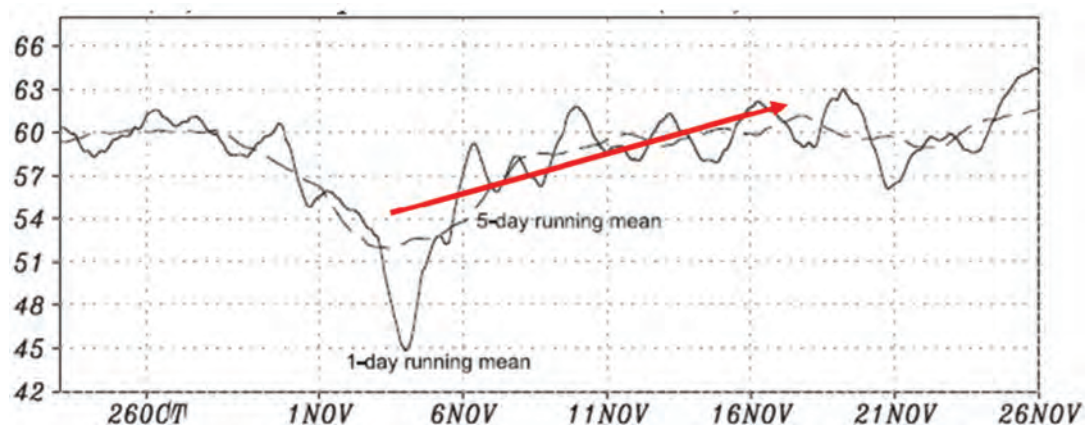


Fig. 11. Time-series of GPS-derived water vapor obtained onboard the R/V Mirai at 0, 80E from October 24 to November 26, 2006. Solid (dashed) line indicates 1-day (5-day) running mean values.

could capture the onset of large-scale cloud systems associated with the MJO in the mid-November. GPS-derived column-integrated water vapor (CWV), radiosonde-derived vapor mixing ratio, and precipitation system number have prominent 3-4-day-period variations as well as meridional wind component (Fig. 11). In the 500-400 hPa level, where the largest amplitude of the 3-4-day-period variations in the radiosonde-derived meridional wind is found, meridional wind anomalies in the reanalysis data propagate westward, and vorticity center is located over the equator (Fig. 12). These features suggest that the 3-4-day-period variations are associated with mixed Rossby-gravity (MRG) wave. The dominance of the MRG wave is also found in other outbreaks of MJO convection over the Indian Ocean from September to December in 2006. Composites of 3 samples in the inactive and active periods of MJO convection reveal that convective type radar echoes prevail in the inactive period, while stratiform type radar echoes are dominant in the active period. It is likely that the 3-4-day variations in water vapor and precipitation system contribute to the increase of 8-10 mm from early November to mid-November. In fact, CWV increases after the precipitation peak in the MJO inactive period, suggesting a tight relationship between the development of MJO convection and moistening associated with equatorially trapped large-scale waves. Recent numerical studies also support the idea that these waves (especially “more-rotational” wave) play a key role for moistening processes.

To further advance our knowledge on the initiation process of MJO convection as well as to improve the skill of numerical simulation and prediction, a new international field experiment called CINDY2011 is going to take place in the central Indian Ocean during October 2011 through January 2012. More than 300 researchers from 13 countries/territories are expected to join this campaign. During the campaign, we will form a quadrilateral atmospheric sounding array with islands and ships, since the results above mentioned suggest the importance of measurement of meridional moisture advection for precise budget analyses.

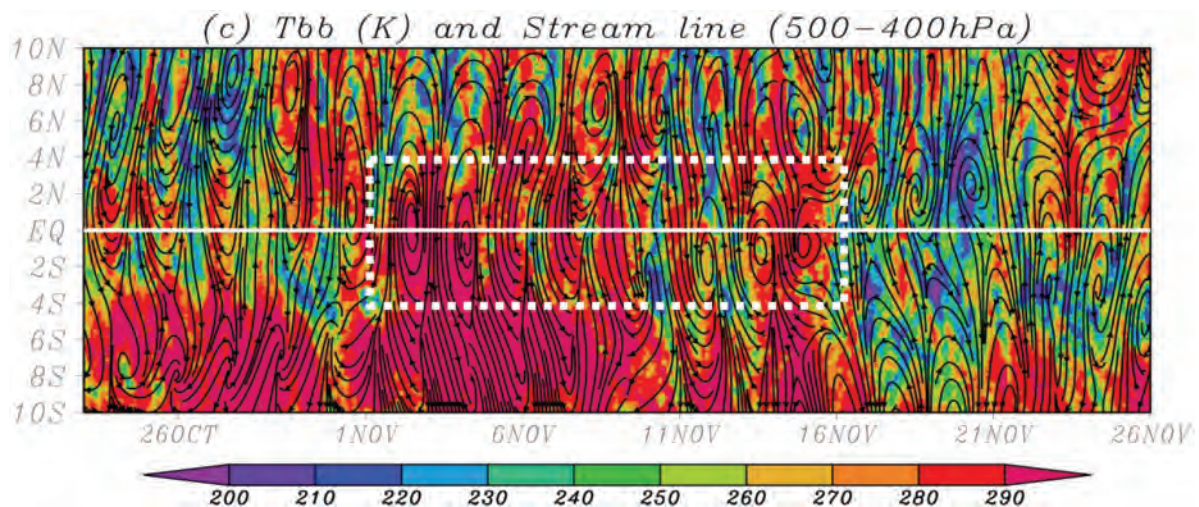


Fig. 12. Time-latitude cross section of the 3-4-day period component of equivalent blackbody temperature (shading) and stream lines (contour) in the 500-400 hPa level at 80E. Reanalysis data set known as Japan Meteorological Agency Climate Data Assimilation System (JCDAS) were used to calculate stream lines. White solid line indicates the equator. White dashed line indicates the period when the vortex centers are located over the equatorial region.

Mechanism of Interannual Rainfall Variability over the Eastern Maritime Continent in Relation to ENSO and Monsoon

-Intra-Seasonal Variations and Related Phenomena Research Team-

We investigated the interannual rainfall variability over the eastern maritime continent using station rainfall data in the Republic of Palau during 1923-2009 and Eastern Indonesia during 1973-2008. Two possible mechanisms are proposed to explain the interannual rainfall variability associated with the El Niño/ Southern Oscillation over the surrounding region of the Banda and Arafura seas.

Rainfall data are combined by our observation data in Palau, National Oceanic and Atmospheric Administration, and South Seas Bureau observation and created 6 stations dataset from 1923 to 2009. Daily station

rainfall data at 11 stations over the Sulawesi and Maluku islands in eastern Indonesia are observed by the Agency for Meteorology and Geophysics from 1973 to 2008.

During the El Niño developing year, rainfall starts to decrease, first in region close to the equator in summer than in northern hemisphere off-equatorial region in autumn in maritime continent. Eastern Indonesia has a dry season during boreal summer in general, and the dry season becomes a significantly drier condition during El Niño years (Fig. 13).

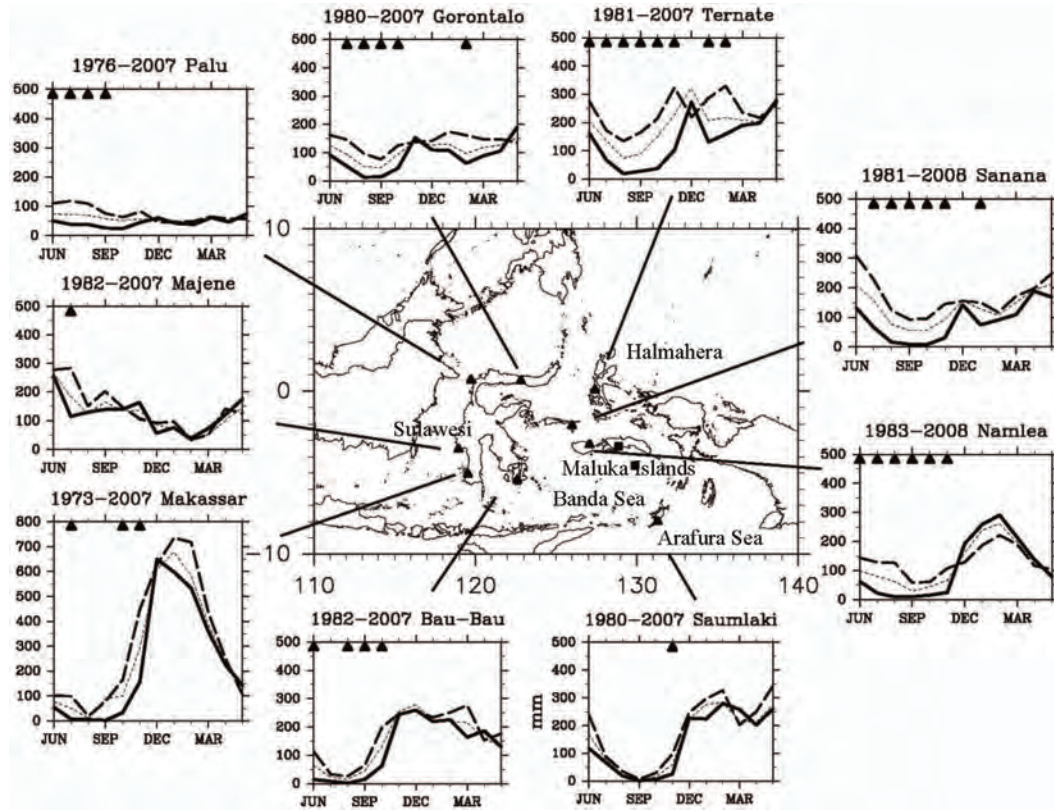


Fig. 13. Monthly rainfall for average over El Niño years (solid line), La Niña years (dashed line), and all available years (dotted line). Triangle represents when the difference of each month rainfall between El Niño year and La Niña year is statistically significant at the 95% confidence level.

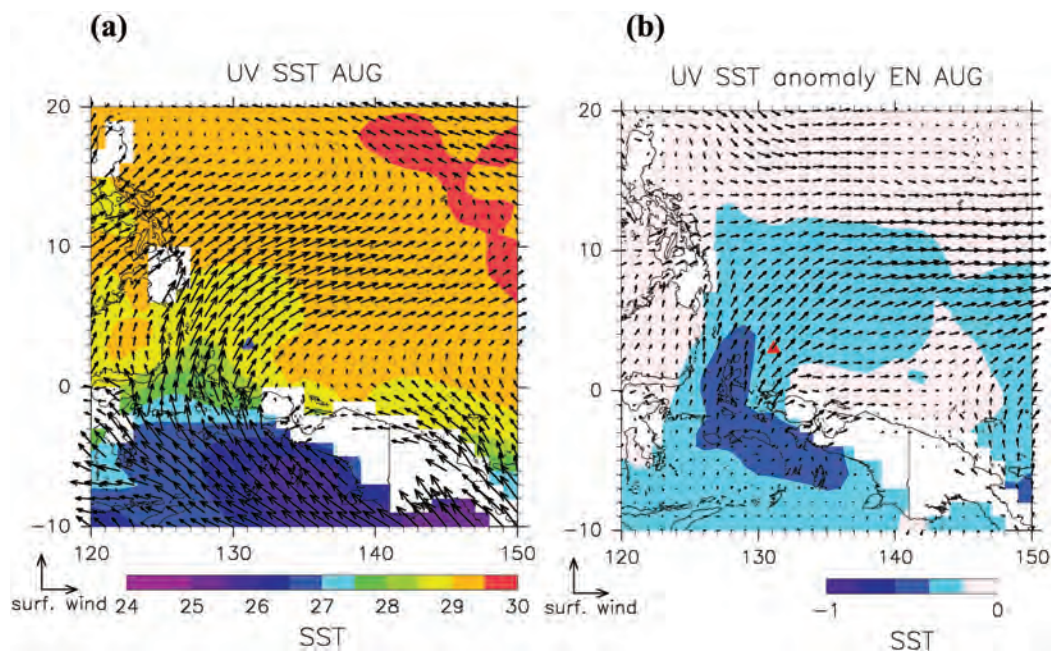


Fig. 14. SST (color contour) and surface wind (vector) in August in climatology (a) and as El Niño year anomaly (b).

One of the mechanisms for these changes is the air-sea interaction over the Banda and Arafura seas. Intensification of seasonal southerly wind associated with the western North Pacific monsoon decreases sea-surface temperature (SST) over the Banda and Arafura seas, and convection is more suppressed during El Niño years than other years (Fig. 14).

Another mechanism is the subsidence over the Banda and Arafura seas during the pre-monsoon of the Australian summer monsoon. Land-ocean thermal contrast between Australia and its surrounding seas is intensified during El Niño years. Shallow thermal convection produces subsidence over the Banda and Arafura seas, and extremely dry condition spreads over the surrounding region in October during El Niño years (Fig. 15).

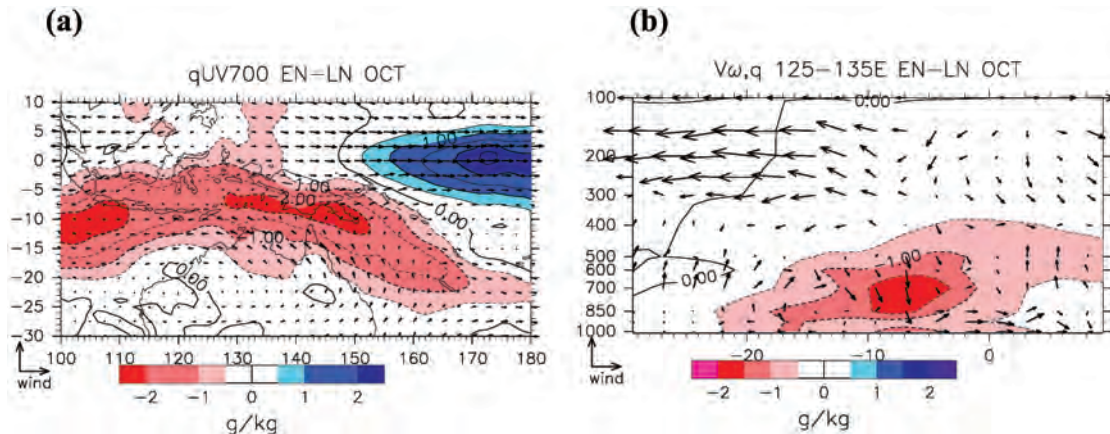


Fig. 15. Difference of 700 hPa moisture (contour) and horizontal wind (vector) (a) and vertical cross-sections of moisture (contour) and vertical-meridional winds (vector) from 125° to 135°E (b) between El Niño years and La Niña years during October.

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Understanding the Drastic Change in the Arctic and Surrounding Regions: Evidence, Processes and Resultant Influences -Northern Hemisphere Cryosphere Research Program-

The aim of the research in the Northern Hemisphere Cryosphere Research Program is to reveal the past/present conditions and its processes of the ocean- snow/ice- atmosphere- land system of Northern Hemisphere Cryosphere, through combination of in-situ observation under international collaboration, and integrated data analysis based on satellite and data archive, and numerical experiments. Through these research, we are expecting to evaluate the influence of Global Warming to the cryosphere, and clarify the role of this region to the global-scale climate, and to contribute to the better future prediction. The main focus is put to the drastic change occurring in the Arctic Ocean, the surrounding continental region, mainly Siberia, and the high latitude atmosphere. In order to implement the research, 4 teams, treating the main components of the, that is Ocean, Cryosphere, Water Cycle, and Atmospheric Processes, are in the Program. The main observation system is described in Figure 1.

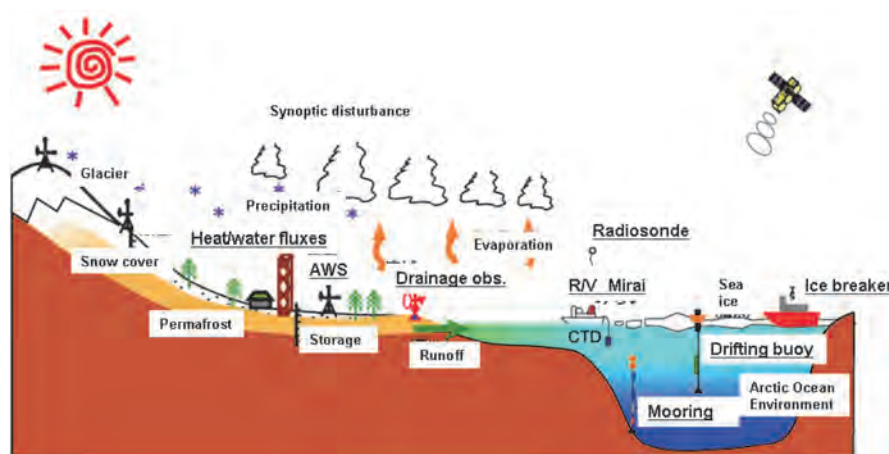


Fig. 1. Main observing components and observation method in the Arctic Ocean and Eurasia.

Rapid Sea Ice Reduction and Arctic Ocean Environmental Changes -Arctic Ocean Climate System Research Team-

In summer/autumn 2010, the minimum sea ice extent in the Arctic Ocean was about $4.81 \times 10^6 \text{ km}^2$, which was the 3rd minimum value in the satellite observation period since 1979. To quantify on-going environmental changes in ocean, atmosphere, and marine bio-geochemistry of the Arctic Ocean and to clarify the important processes of the Arctic Ocean environmental changes, Arctic Ocean Climate System Research Team conducted observational missions during 2010 FY, as shown in Figure 2.

In the Pacific side of the Arctic Ocean, we had R/V Mirai Arctic research cruise (MR10-05) from September 2 to October 16, as shown in blue line of Figure 1. MR10-05 was conducted as part of an international collaboration between JAMSTEC and Department of Fisheries and Ocean, Canada, and also in collaboration with 14 parties of Japanese research institutions and universities. MR10-05 cruise occupied the western part of the Canada Basin and Chukchi Sea and could reach at 79.2 N 164.9W where the most northern point of all of R/V Mirai cruises is. The cruise activities includes 178 CTD casts, 215 radio sonde measurements, 6 mooring deployments, 63 plankton nets samplings, 5 casts of piston core sampling, and continuous monitoring of hydrographic and meteorological data.

Polar Ocean Profiling System (POPS) #13 was put on ice at the North Pole ice camp (89.28N, 89.66E) on April 16, 2010. As shown in white line of Figure 2, POPS #13 drifted toward the Greenland Sea with measuring and transmitting ocean profiling and meteorological data as well as the previous measurements using POPS. Summer ice concentration was lower than usual in the Atlantic side of the Arctic Ocean and POPS #13 was able to collect unique data which showed important interaction among atmosphere, sea ice, and ocean.

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We also collaborated with Institute of Marine Research, Norway and participated in the Barents Sea cruise conducted by R/V Johan Hjort both in September 2010 and January 2011 (pink and orange lines in Figure 2). Purpose of the collaboration was to understand air-sea interaction in the Barents Sea and its influence to Japanese climate suggested by recent publications (refer the section of Climate Dynamics Research Team). During the cruise, simultaneous observations using radiosondes and XCTDs had been conducted. Especially on the observational results from the winter cruise, huge heat transfer from ocean to atmosphere can be observed near ice edge.

Analytical results using observational data especially obtained during International Polar Year (March 2007 to March 2009) were published in this fiscal year and revealed recent environmental conditions and important processes in the Arctic Ocean (see Publication list). For example, *Itoh et al.* [2011] showed the relationship between ice concentration observed by on-board ice watches and water temperature measured by hydrographic observations, focused on a transmission of solar radiation through ponded ice. *In-situ* sea-ice and ocean condition data were obtained in the Canada Basin in summer 2006 and 2007 by the Canadian Coast Guard Ship, *Louis S. St-Laurent* (LSSL) (Figure 3: ice conditions observed during LSSL 2007 cruise), and in the eastern and central Arctic Ocean in summer 2007 by the German research vessel (R/V) *Polarstern*. These data showed negative correlations between sea ice concentration and surface mixed layer temperature. This implies that as ice concentration decreases, the upper ocean becomes warmer due to greater absorption of solar radiation into open water, which promotes ice melting. However, heating of surface water is significant even in regions that were almost completely ice-covered, suggesting that transmitted solar radiation through the ice is also effective at melting sea ice. A simple ice-upper ocean coupled model was applied to examine the effect of heat input from open water, thick ice, and thin ice. The ponded thin ice is estimated to transmit approximately three times more solar radiation than ponded thick ice (Figure 4). Model results suggest that transmission of solar radiation through ponded ice amplified the ice-albedo feedback mechanism, particularly in thin ice region. Recently, the extent of old and thick multi-year ice in the Arctic Ocean has been rapidly reduced. As a result, heat input to the upper ocean through the ice is enhanced and ice melt is further accelerated.

For better understanding the on-going changes in the Arctic Ocean, sustainable and integrated observations should be conducted to carefully analyze the influences for the Arctic environment and global climate. Such research activities will offer new insight into Arctic climate variations and corresponding ecosystem changes.

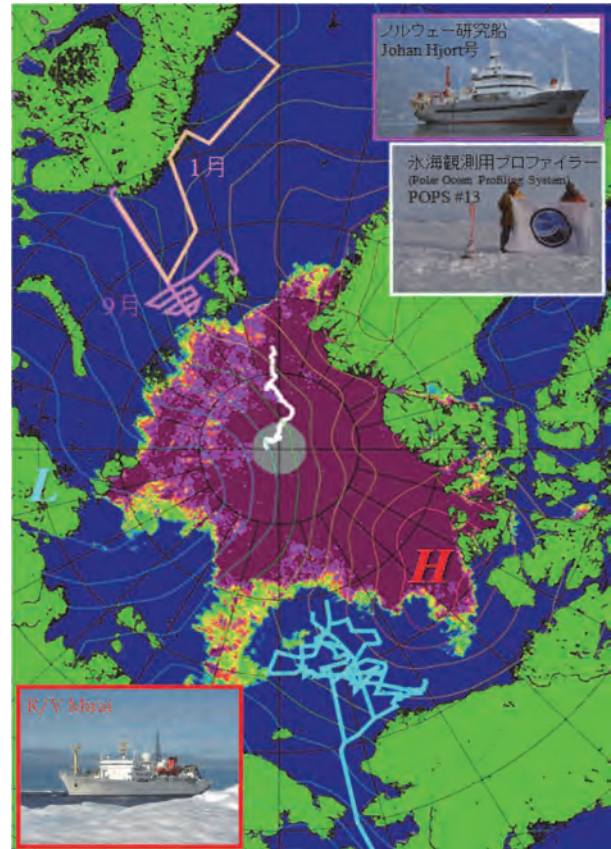
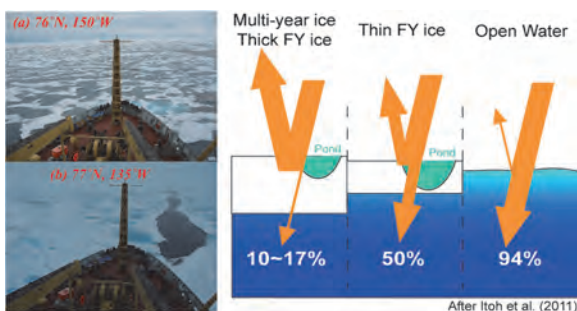


Fig. 2. JAMSTEC observational activities in the Arctic Ocean during 2010 FY. Color tones in the Arctic Ocean show sea ice concentration on September 18, 2010. Contour lines show average sea level pressure in August-September 2010.



Left) Fig. 3. Photos of ice condition during LSSL2007 cruise in the Canada Basin [after Itoh et al., 2011].

Right) Fig. 4. Schematic drawings about contributions of transmitted solar radiation through ice [after Itoh et al., 2011].

Snow and Ice in Northern Eurasia is Deleting

-Snow and Ice Research team-

The warming occurring at stronger intensity in the high latitude region of Northern Hemisphere since the late 1900's is affecting the snow and ice condition in that region. The influence is due not only to the rise in the temperature itself, but also to change in the atmospheric circulation such as the increased precipitation due to intensified low pressure system. Along with the detection of the changes, consideration on the future variability is becoming important.

In our Program, observation network on cryosphere components, such as snow cover, frozen ground and glaciers are established which takes the form of mountain super-site, winter traverse measurement and distributed observation site (Fig. 5). Furthermore, satellite data is used to detect the regional changes. The following results were obtained for FY2010. Most of the results shows the shrinking of the snow/ice mass and warming of the cryosphere components.



Fig. 5. The sites and routes which snow/ice changes are observed.

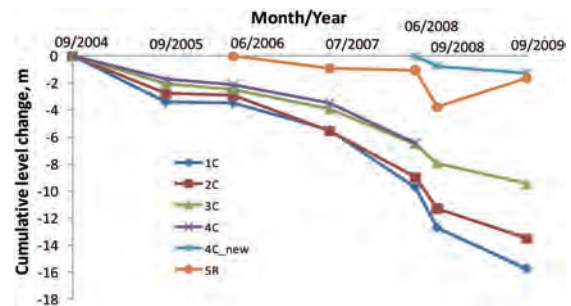


Fig. 6. Large surface lowering, shown as level change, at ablation area of Potanin Glacier, from 2004 to 2009. GPS Theodolite and others are used.

(1) Shrinking glaciers in Mongolia.

Most of the glaciers in the world is said to be shrinking (IPCC, 2007). Our team has been surveying the glaciers in the Mongolian part of the Altai Mountain, which is located at the southern periphery of the permafrost area, since there has been no such studies there in the past. Figure 6 shows the surface level change in the ablation area of Potanin Glacier (10.4km in length), the largest glacier in Altai. Lowering of 2~3m/y is occurring during this five years [Kadota *et al.*, 2011], and also in 2010. The reason for the large lowering is due to the small inflow from the upper area in contrast to the large negative mass balance. If the same condition continues, nearly half of the ablation area will be lost. Climate-glacier relation is discussed by Konya *et al.* [2010], and inventory has been made by Yabuki [in preparation].

(2) Ground warming detected through development of permafrost monitoring network in Mongolia.

Since 2009, network for permafrost monitoring in Mongolia has been developed under cooperation between Institute of Geography of MAS, JAMSTEC and Hokkaido University. 40 monitoring stations are distributed (20 in FY2010) at Altai mountains in the western part to Hentei Mountains in the central part. Comparing the newly taken data and the available past data in 1980s, show that soil temperature increase is seen at all the stations. Figure 7 show the position of the stations and the temperature increase (deg per 10years). Along with measurement, archive of past data is being done.

(3) Snow cover shows large variation and inadequacy of archived data in circum-Arctic region.

Since 2003, snow course data including high altitudes has been taken in mid-winter at Mongolia, Siberia and Alaska, for improving the circum-polar snow cover data-sets. Main purpose of this observation, is to increase information at high elevation and improve the satellite algorithm for snow cover. Following findings has been obtained.

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Northern Hemisphere Cryosphere Research Program

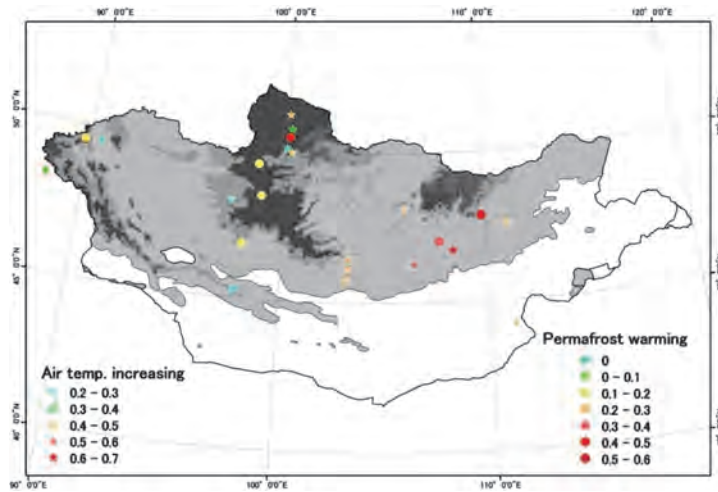


Fig. 7. The position of the monitoring site newly established, which has past data ($\circ$, deg/decade), and the amount of ground warming. The temperature change ($\star$, deg/decade) for meteorological stations nearby are also shown.

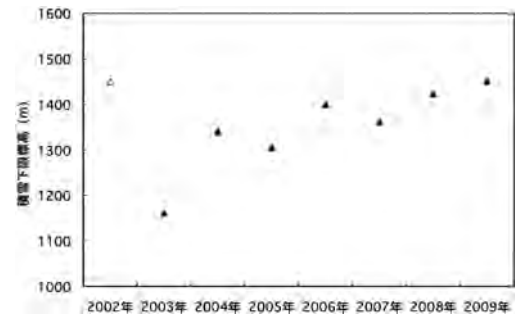


Fig. 8. Estimated elevation of lower limit for snow cover in mid-winter at Tuul River basin, Northern Mongolia. (2002 ~2009).

- Results at a drainage area (100km scale) in Northern Mongolia, show that the elevation of snow cover lower limit has a tendency of getting higher (Fig. 8), but the total snow amount does not show certain change.
- Comparing the result of satellite derived snow water equivalent and surface observation data, satellite overestimates the amount, and still need improvement. Improvement of algorithm is being done under cooperation with Univ. of Tokyo.
- The relation between snow depth and elevation using station observation data and field observation data, latter show increase with elevation, but no such tendency with the former data. There is a need to clarify the cause of this discrepancy.

(4) Change in the surface hydrological conditions in Siberian permafrost area.

It is generally said that the lake area increases at continuous permafrost region, and decreases at discontinuous to sporadic region, as degradation of permafrost occur due to temperature warming. Based on analysis of satellite data, the lake area distribution since 1980 obtained for northern part of north-east Siberia and Lena drainage, following more detail regional results were obtained.

- As a whole, lake area is increasing, and the cause of it does not seem to be only the melting of permafrost, but also the increase of the precipitation due to the change in atmospheric circulation.
- Taking the central part of Lena drainage (200km square), the lake area from 1982 to 2000, increased from 4.9% to 5.1%. During this period, the number of small lakes less than area of 0.01km², increased tremendously, and not the large ones (Fig. 9). This seemed to occur due to the development of thermokarst lake, which has been detected clearly in Yakutsk area.

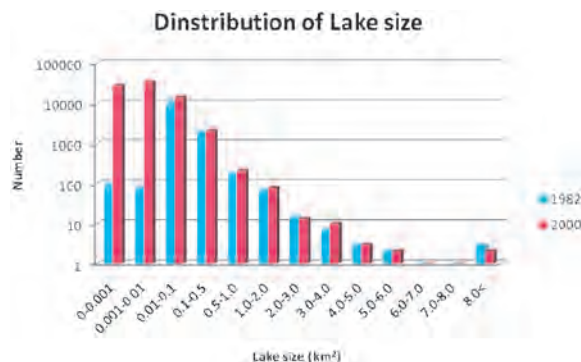


Fig. 9. Size distribution of lakes in 1982 and 2000, at a 200kmx200km area north of Yakutsk in Lena River Basin.

Changes in Terrestrial Hydrological Processes -Hydrological Cycle Research Team-

(1) Forest/ storage/permafrost changes

Iijima et al. [2010] have exhibited unusual increase in ground temperature and active layer thickness (ALT) in response to subsequent increase in both rainfall in pre-winter and snow accumulation since 2004 in the central Lena river basin in eastern Siberia. The consecutive positive anomalies of snow depth and rainfall, which occurred widely in the central and southern Lena River basin during this three-year period, increased soil moisture and appear to have altered the active layer thermal properties. Surface water provides an important positive feedback that enhances degradation of permafrost, topography, and consequently vegetation when water is impounded in subsiding depressions. In fact, *Iwasaki et al.* [2010] reported that yellowing and browning of larch trees occurred in an undisturbed forest due to abnormally high soil water content in the same forest observed by *Iijima et al.* [2010]. This moistening land surface potentially has a great impact on boreal ecosystem and should be considered as another aspect of environmental perturbation induced by Arctic climatic change. We, thus, need to clarify the response and vulnerability of boreal forest under the wet climate in terms of changes in energy, hydrology, and carbon cycles. Given this back ground, the present study examines recent changes in permafrost

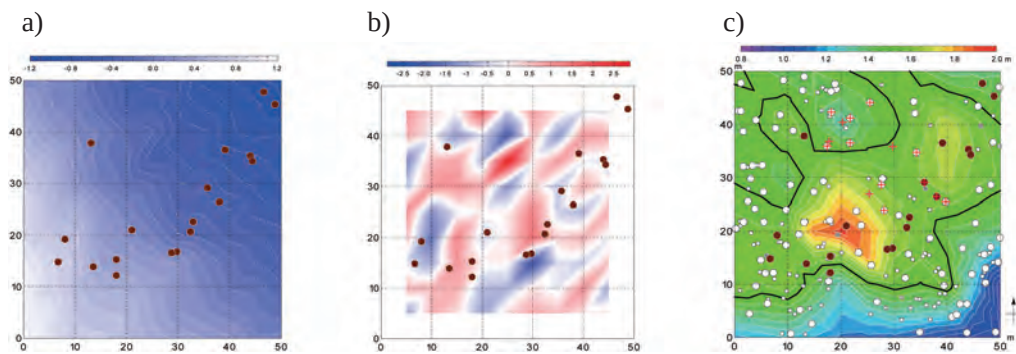


Fig. 10. (a) Micro-topography and (b) The laplacian of relative altitude at a quadrat plot in larch forest (50 x 50m), (c) Distribution of active layer depth and larch trees (50 x 50 m quadrat plot) near the tower in Spasskayapad, Yakutsk. Black line denotes the depth of 150 cm. Brown circle denotes damaged (dead) larch tree. Large (small) circle indicates larch trees with more (less) than height of 15 m, respectively. Cross symbol denotes a tree measured sap flow.

environment and evaluates their impact on boreal larch forest based on intensive sap flow observation at the eastern Siberia after abrupt deepening and wetting active layer occurred under wet climate years in the eastern Siberia.

The area where the active layer depth is increased and the soil moisture is saturated is at the depression or the valley-like micro-topography (Figure 10a and b). In these area some of the larch trees higher than 15 m were suppressed their foliation and some are dead in 2009. For 15 larch trees, of which the sap flow was measured, the mean stomatal conductance under 1 kPa of the water vapor deficit were calculated based on the transpiration for an unit leaf area obtained from the leaf area before the disturbance using an allometry equation. As the result, some of the larch trees showed no change in the conductance of 2006 and 2009, whereas some

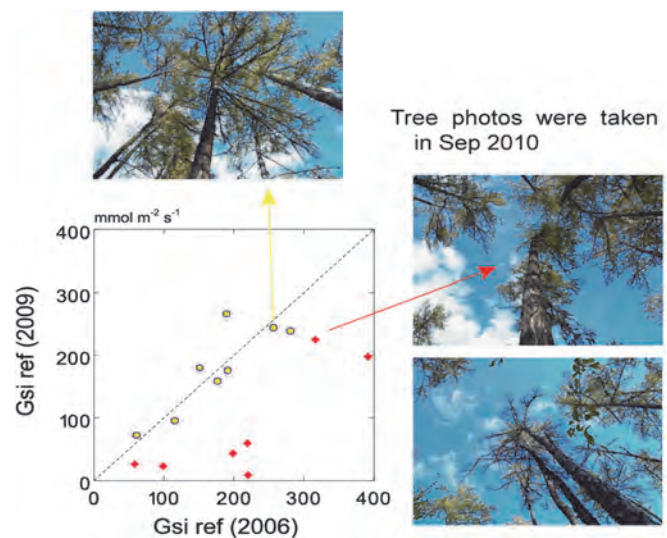


Fig. 11. Relationship of mean stomatal conductance for individual tree (Gsi ref) in 2006 and that in 2009. The values are in average of daytime GSi ref from June to August. Open and closed circle denote tree with less variation between two years and large reduction (more than 15% of GSi in 2006) from 2006 to 2009, respectively.

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larch trees showed the large reduction in the conductance from 2006 to 2009 (Fig. 11). The field survey in 2009 showed that larch trees with a large conductance decrease from 2006 to 2009 reduced the leaf area. The larch trees at the larger active layer thickness and higher soil water contents have smaller stomatal conductance (Fig. 10c). On the other hand, the evapotranspiration rate (evapotranspiration divided by potential evaporation) at the top of the tower calculated by the eddy covariance method showed a reduction in 2007 and 2008 when compared with the one in 2005 and 2006, whereas the evapotranspiration rate at the ground showed no change from 2005 to 2008. These results suggest that the moist environment in eastern Siberian in the recent years affects not only the reduction of evapotranspiration of forest and the changes in the permafrost but also water and heat fluxes in the broader area.

(2) Modeling of thaw depth change

The change of thaw depth in the high latitude region from 1048 to 2006 was simulated using the hydrological model “CHANGE.” Figure 12 shows yearly changes of the thaw depth for four large northern river basins. These four basins shows the same thaw depth change pattern before 1985, but, after 1985 the thaw depth in the Eurasia basins shows almost opposite course from the North American basins, like a seesaw pattern. The thaw depth of northern Eurasia is becoming deeper, whereas the ones in North America is getting shallower, which is inconsistent with the observed results. The difference in thaw depth between Eurasia and North America is due to the snow depth (Figure 13). The decrease of snow depth in North America is seen after 1990 and becomes obvious after 2000. The snowpack has an effect of thermal insulation. The thick snowpack reduces the penetration coldness into soil in winter, therefore, summer soil temperature increases. But the thin snowpack allows the penetration of coldness into soil in winter and the thaw depth is smaller even under warmer air temperature. The snow depth in North America is in reducing trend in 1990th, and it becomes obvious after 2000. Further, the lowering of summer air temperature in North America is seen since 2000. In Eurasia basins, snow depth and summertime air temperature is increasing since 2000. The seesaw pattern in thaw depth between northern Eurasia and North America river basins is due to the different snow depth and summer air temperature trends.

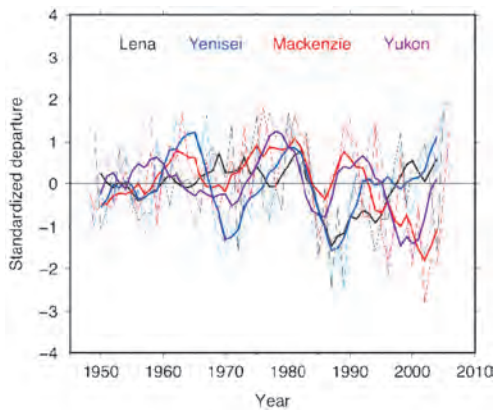


Fig. 12. Thaw depth change of four large northern river basins in Eurasia and North America.

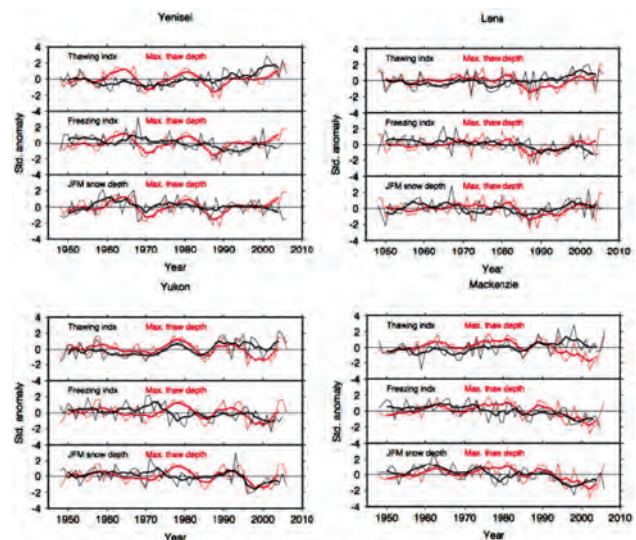


Fig. 13. Change of thaw depth with the warm degree days, frost degree days and snow depth for four large northern river basins.

Atmospheric Variability over the Barents and Kara Sea and Eurasian Continent which Brings Severe Cold Air Outbreak in Japan and East Asia -Climate Dynamics Research Team -

One of the most important purposes of this research team is to understand the remote influence of recent anomalous Arctic sea-ice conditions upon the weather and climate of Japan through atmospheric large-scale circulations. Climate Dynamics Research Team investigated the cold air outbreak that frequently arrived during the 2009-2010 winter [Hori *et al.*, 2011], and discovered that the process is governed by a 2-step mechanism where (1) a strong cold air build up occurs over the Eurasian continent when there is a positive anomaly in the pressure over the Barents/Kara Sea, and (2) following this pressure anomaly, meandering of the jet stream develops and brings the cold air buildup towards Japan and the East Asia region. The following is an outline of Hori *et al.* [2011] published in SOLA.

In the winter of 2009 and 2010, Japan and the East Asian region experienced a frequent occurrence of cold air outbreaks. Although the winter average temperature in the Japan main islands was slightly positive ($+0.81^{\circ}\text{C}$ for December to February (DJF) average and $+0.71^{\circ}\text{C}$ for November to March (NDJFM) average), repeated decline in temperature was notable throughout the season. From October 2009 to March, 2010, there were 10 cases of cold air outbreaks reaching Japan. Except for the case in mid-January, the negative peak is preceded by a positive temperature anomaly that drops rapidly within 6-10 days. Among these cases, December 18th is marked to be the most intense, where the negative anomaly reached -3.47°C , the lowest in DJF average, and the difference of temperature from 6 days ago (Dec.12) was 8.41°C . Focusing on the 500hPa geopotential height field which represents the location of the high/low pressure system, it was found that 10 days prior to the arrival of cold air strong high pressure ridge was present over the Barents and Kara Sea which created a cold air build up in the Western Siberian region (Fig. 14a). High pressure ridge over the Barents Sea gradually moves westward to form a persisting blocking high. On the other hand, the cold air build up in western Siberia is elongated along the low-pressure trough (Fig. 14b). Finally, a wave pattern on the eastern side of the blocking high corresponding to the meandering of the jet stream brings the cold air eastward towards Japan (Fig. 14c).

It can be seen that the December 18 case proceeded in 2 steps; 1) a strong cold air buildup corresponding to the high pressure system over the Barents Sea becomes apparent in Western Siberia, and 2) meandering of the jet stream in the downstream of the blocking high advects the cold air buildup towards Japan. This process can be seen in at least 5 out of the 10 cases of cold air outbreak that occurred during 2009 and 2010. To show that this process was dominant

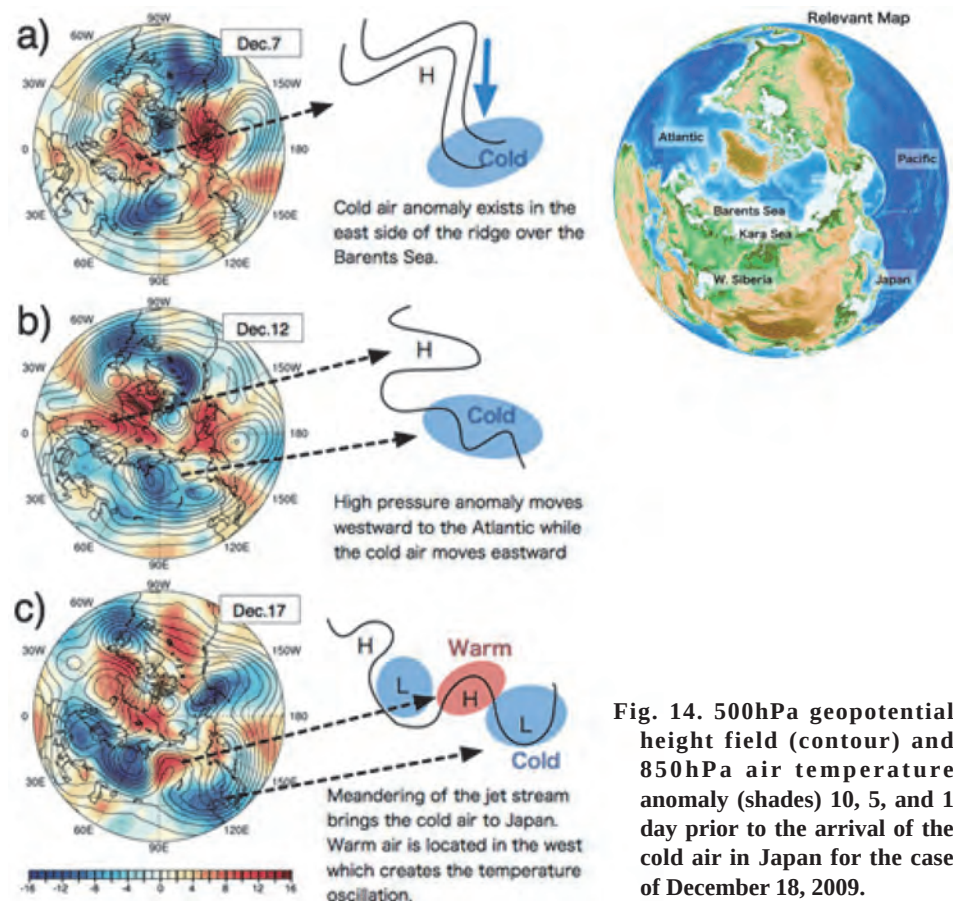


Fig. 14. 500hPa geopotential height field (contour) and 850hPa air temperature anomaly (shades) 10, 5, and 1 day prior to the arrival of the cold air in Japan for the case of December 18, 2009.

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during the 2009-2010 season, a lag regression analysis of temperature and geopotential height field against the temperature anomaly time series over Japan from October 1 through March 30 is shown in Figure 15. This corresponds to the relative change in pressure and temperature when Japan experiences a 1°C change in surface temperature in the following days. Here again, 10 days prior to the arrival of cold air, a positive pressure can be seen over the Barents Sea which creates a cold air anomaly over the Western Siberian region (Fig. 15a). In the following days, a wave pattern induced by the blocking high over the Atlantic Sea brings the cold air anomaly eastward (Fig. 15b and c).

Previously, the negative phase of the Arctic Oscillation (AO) was blamed for the dominance of cold air in the mid-latitudes. However, the Arctic Oscillation alone is insufficient in explaining why and when such cold air outbreak occurs locally in Japan. This study shows the strong ties of the Arctic and the mid-latitudes temperature variability which governs the local temperature over Japan. Also, the oscillatory manner in which the temperature rises and falls due to this process can be related to a traditionally known weather phenomenon, the San-Kan-Shi-On (3 days of cold followed by 4 days of warm weather), which prevails from winter through spring. It is expected that by utilizing the results of this study, it is possible to make a forecast of cold air outbreak 7-10 days prior to reaching Japan. This process was also evident in the 2010-2011 winter. The most notable example was the case during late December 2010 where a strong cold air build up in Europe was followed by a strong cold air outbreak in western Japan around the early January of 2011. It is also expected that the study will be an important step in determining how global warming will affect the winter climate in the region.

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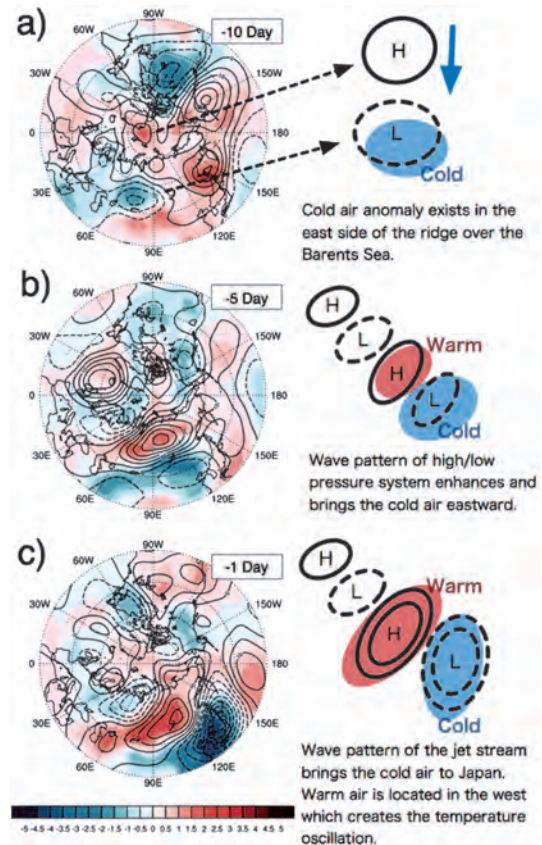


Fig. 15.. Lag regression of 500hPa geopotential height field (contour) and 850hPa air temperature anomaly (shades) against the surface temperature anomaly over Japan corresponding to (a) 10 days, (b) 5 days, and (c) 1 day prior to the arrival of the cold air.

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To Understand the Function of Ecosystems in Biogeochemical Cycles -Environmental Biogeochemical Cycle Research Program-

After the major reconstruction of the program in FY2009 the Environmental Biogeochemical Cycle Research Team (EBCRP) put an emphasis to increment inter-team collaborative studies. To facilitate inter-team collaboration, a program-wide aim and an inter-program collaboration scheme (Fig. 1) were set up at the beginning of the FY2010. Each Team Leader was asked to organize his/her team to fit the program-wide aim and inter-program collaboration scheme, and pursue the team's goal with enhanced collaboration between research teams and/or research programs. Additionally, a series of review seminars were given by Invited Principal Scientist to the EBCRP in order to provide opportunities for program members to attain basic knowledge from the Invited Principal Scientists, covering isotope ecology, marine biogeochemistry, atmospheric geochemistry, paleoceanography, etc. The series of seminars followed by program-wide gatherings promoted interaction among the program members. As a whole the research activities of EBCRP in FY2010 were improved and satisfactory.

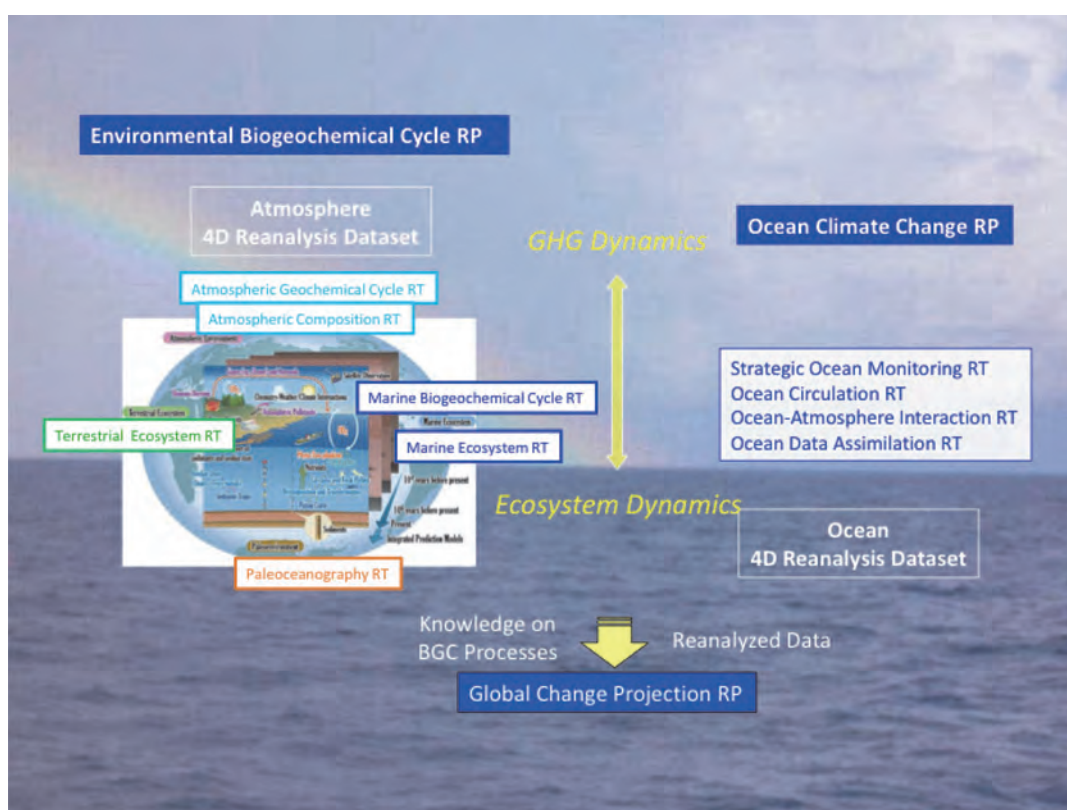


Fig.1 Aim of the Environmental Biogeochemical Cycle Research Program and schematic diagram of inter-program collaboration with Ocean Climate Change Research Program and Global Change Projection Research Program. The EBCRP aims at providing objective reanalysis data by 4 dimensional data assimilation of greenhouse gasses in the atmosphere and the biogeochemical constituents in the ocean, and mechanistic understandings of the interactions between dynamics of greenhouse gases and ocean and land ecosystems which enables process models, in order to contribute to validate and refine the Integrated Earth System Model for Global Change Projection.

How Do Regional Ecosystem and Biogeochemical Cycle Respond to Climatic Forcing?

-Marine Biogeochemical Cycle Research Team-

-Marine Ecosystem Research Team-

Marine Biogeochemical Cycle Research Team (MBCRT) and Marine Ecosystem Research Team (MERT) are conducting studies based on the time-series observation and numerical modeling, respectively, aiming to understand mechanisms linking physical, chemical and biological processes of various time and

spatial scales. Recent retrospective studies have suggested that ecosystem response to a large climatic forcing and its consequence in biogeochemical cycle differ region to region. To predict impact of on-going and future environmental changes in global scale, there is increasing demand for better understanding of regionally specific mechanisms of variations in ecosystem and biogeochemical cycle. We here highlight accomplishments from the 2010-fall time-series observation research and warming scenario experiment by the 3D-ecosystem model.

(1) Comparison study of ecosystem and biogeochemical cycle between the western Pacific subarctic and subtropical gyres (MBCRT)

In MR10-06 cruise (October-November 2010), MBCRT started time-series observation at stations located in the subarctic gyre (K2: 47°N, 160°E) and the subtropical gyre (S1: 30°N, 145°E).

At station K2, chlorophyll-a concentration (Chl-a) in the upper 40 m was about 0.6 mg m^{-3} (Fig. 2). Below 40m, Chl-a decreased largely. Based on measurement of accessory pigments by HPLC, Haptophyte was pre-dominant and abundance of diatom that is representative of phytoplankton in the subarctic gyre was quite low. At station S1, Chl-a was smaller than that at K2. Subsurface maximum of Chl-a was observed at around 90 m water depth. *Prochlorococcus* was pre-dominant and diatom was low.

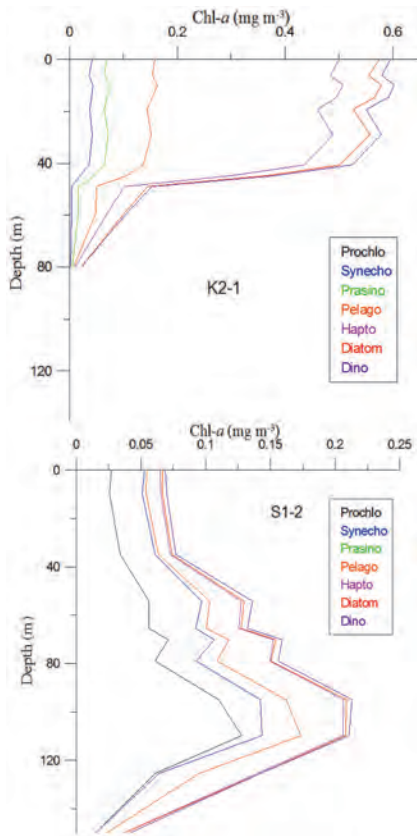


Fig. 2. Vertical profiles of Chl-a and composition of phytoplankton at K2 (upper panel) and S1 (lower panel).

At both stations, primary productivity (PP) was measured by simulated in situ incubation method (Fig. 3). At K2, PP decreased with depth and became zero at the bottom of the euphotic layer (about 50 m). Integrated PP ranged from 284 to $401 \text{ mg-C m}^{-2} \text{ day}^{-1}$. Compared to winter PP observed during MR10-01 cruise (about $100 \text{ mg-C m}^{-2} \text{ day}^{-1}$), integrated PP increased. PP at S1 also decreased with depth, however, PP was detected by about 100 m. Integrated PP at S1 ranged from 131 to $186 \text{ mg m}^{-2} \text{ day}^{-1}$ and one third or one fourth of magnitude

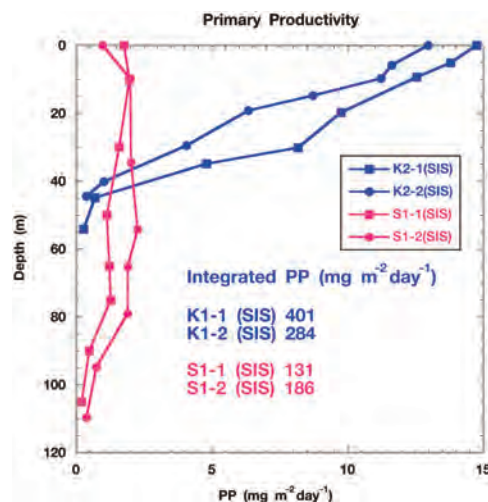


Fig. 3. Vertical profiles of PP at K2 (blue) and S1 (red).

lower than winter integrated PP (about $500 \text{ mg-C m}^{-2} \text{ day}^{-1}$). Note that weather was cloudy or rainy when the above incubation for PP measurement was conducted and PAR was quite low (about $7 \text{ mol quanta m}^{-2} \text{ day}^{-1}$). During MR10-06 cruise, sediment trap mooring systems and FRRF mooring system that were deployed in January / February 2010 were recovered and re-deployed successfully.

(2) Projection of global warming impact on marine ecosystem by eddy-permitting, high-resolution 3-D ecosystem model (MERT)

In recent years impacts of global warming on physical environment have been predicted by climate models through some scenario experiments. However, projections of potential impacts on marine ecosystems are still in the early stage. As a challenge to clarify the impacts, we developed an eddy-permitting version (i.e., horizontal grid-spacing of 0.28° (zonally) $\times 0.19^\circ$ (meridionally)) of the 3-D ecosystem model, COCO-NEMURO (the CCSR Ocean Component Model coupled with the North Pacific Ecosystem Model Used for Regional Oceanography), and applied it to the surface 1500 m in the western North Pacific (about 110°E - 180° , 10° - 60°N) with an offline calculation method. Using this model with a projected physical environment from a high-resolution

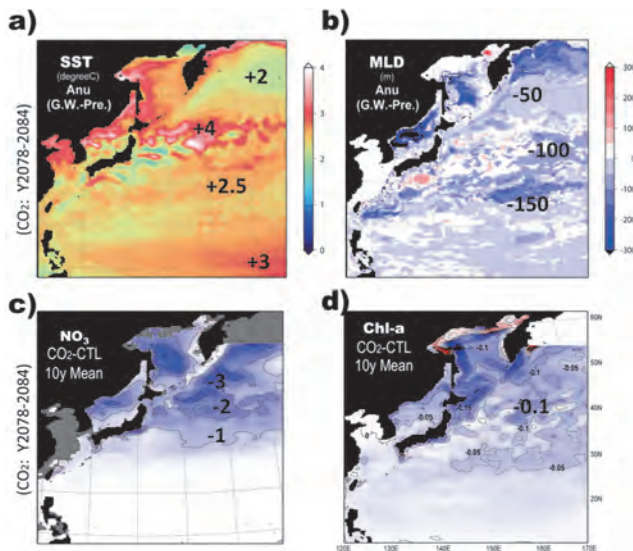


Fig. 4. Projected change (global warming minus pre-industrial) of a) annual mean SST (°C), b) depth of wintertime mixed layer (m), c) surface NO₃ concentration (mM), d) surface Chl a concentration (mg m⁻³)

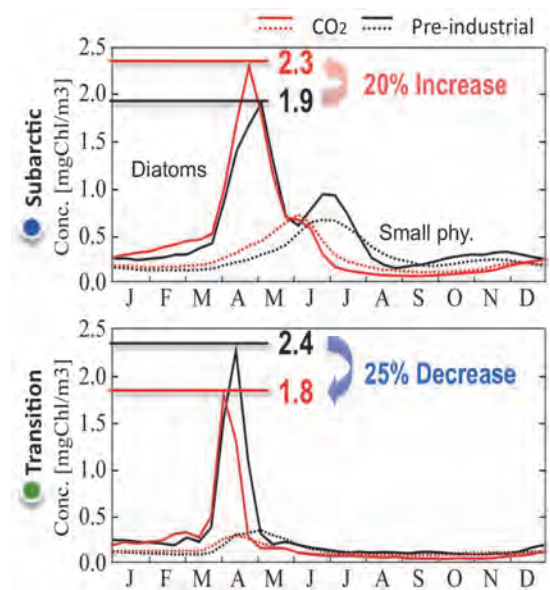


Fig. 5. Projected change (global warming minus pre-industrial) in monthly phytoplankton biomass in subarctic (upper) and transition (lower) regions. Solid and dotted lines indicate diatom and small phytoplankton, respectively

climate model (the Model for Interdisciplinary Research on Climate, MIROC, version 3.2), we explored the potential impact of global warming on spring blooms in the western North Pacific. Considering 2xCO₂ conditions at the end of the 21st century, we found 2-4°C increase in SST (Fig. 4a), 50-150 m decrease in winter mixed layer depth (MLD)(Fig. 4b) and 10-20% decrease in surface nutrients concentration (Fig. 4c). Those resulted in decrease in phytoplankton biomass by 10-30% over the study area (Fig. 4d).

Change in phytoplankton seasonality under the warming scenario was compared in the subarctic and southern transition regions. The timing of peak phytoplankton biomass was found to occur 10 to 20 days earlier relative to pre-industrial simulation due to strengthened stratification in both regions (Fig. 5). The magnitude of diatom bloom increased by 20% in the subarctic region (Fig. 5 upper), where photosynthesis is not strongly limited by nutrients, even though the annually averaged biomass slightly decreases. On the other hand, the maximum biomass decreased by 25% due to nutrients decline in transition region (Fig. 5 lower). Our results clearly demonstrated regionally specific ecosystem response to global warming, and reveal that even if global warming only weakly affects annually averaged quantities, it could significantly affect certain secondary to higher trophic level species and biogeochemical processes, which depend on seasonal events such as phytoplankton blooms.

How Does the Vegetation in Boreal and Tropic Regions Vary? -Terrestrial Ecosystem Research Team-

Terrestrial ecosystem RT investigates the geographical distribution of vegetation and its temporal change, and the behavior of ecosystem-related green house gasses by remote sensing data and ecosystem numerical models. This report picks up the studies on the modeling of the soil organic carbon in boreal region and the detection of the land cover change in the tropical forest by satellite images.

(1) Vertical stratification of a soil carbon model and integration to a soil physics model

Because the amount of soil organic carbon (SOC) is about twice as much as the carbon in the atmosphere, accumulation and decomposition of SOC have a significant potential to affect the atmospheric CO₂ concentrations. In northern high-latitude regions, large amount of SOC has been accumulated due to low decomposition rates caused by low soil temperature and highly water-saturated soils. However, due to the climate change, soil

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warming and soil drying will activate soil microorganisms and decomposition of SOC will be significantly accelerated. In spite of the importance of the SOC in northern high-latitudinal regions, the knowledge for accurate prediction of SOC dynamics in future was insufficient.

Thus, we simulated effects of temperature and precipitation changes using a physics-based soil model, in order to reproduce SOC dynamics under climate change. We introduced a vertical stratification structure to the SOC model to reproduce vertical patterns of soil temperature and moisture explicitly. Then the estimated soil physical conditions were used to calculate SOC decomposition rates by soil microorganisms. Moreover, we explicitly simulated a feedback between soil physics and SOC dynamics. In organic soils, an accumulation of SOC increases soil depth and thus increases in soil water-holding capacity and insulation. These physical changes then in turn modify the SOC decomposition rates. This feedback was successfully included in the SOC model and the simulation showed the SOC dynamics in decadal to century scales.

The results have been compared to observation data from Fairbanks, Alaska, and we evaluated the dependability of the model. The model successfully reproduced sub-daily, daily, seasonal, and inter-annual variations of soil observational data such as soil temperature, soil moisture, and snow depth. We also simulated a profile of SOC qualitatively (Fig. 6), where SOC densities in shallow layers were low, and those in deeper layers are high.

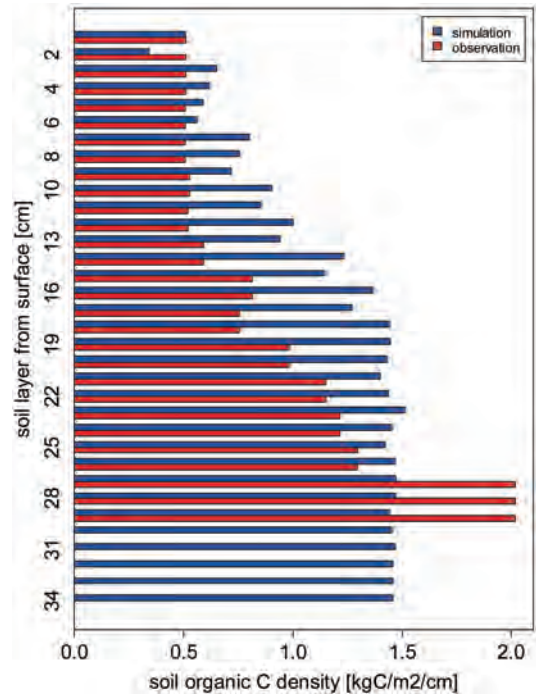


Fig. 6. Comparison of model simulated profile of the soil organic carbon (blue) with the observation at Fairbanks (red).

(2) Land cover change detection using satellite remote sensing data in Borneo

Tropical terrestrial ecosystem is strongly influenced by the global weather interannual variability such as El-Niño Southern Oscillation (ENSO) and by human activities such as the deforestation and the swidden

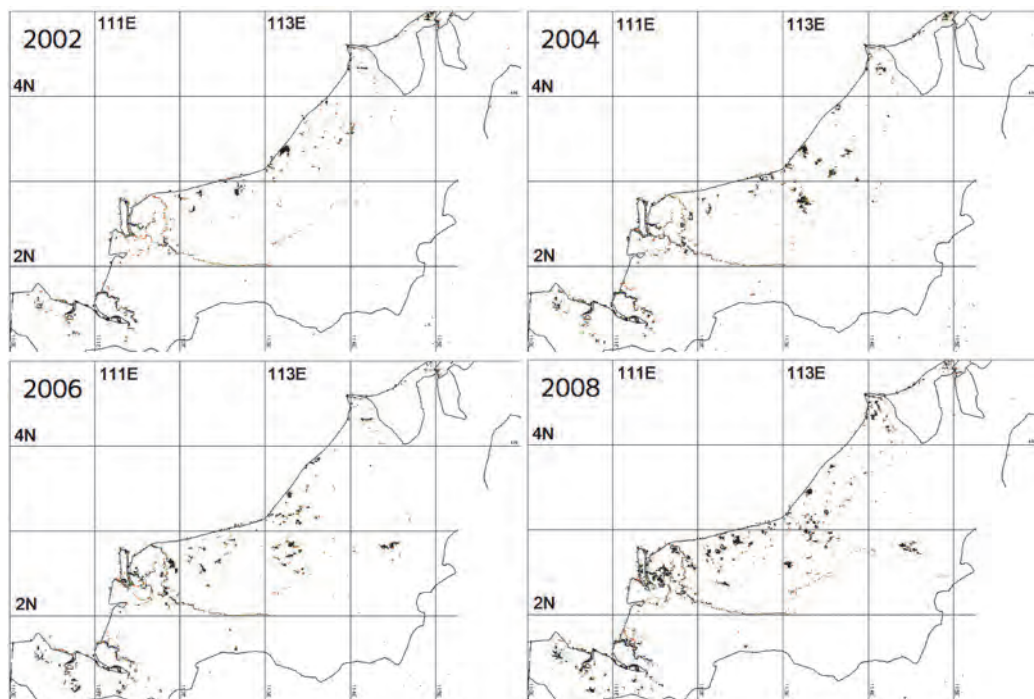


Fig. 7. Land cover change in 2002, 2004, 2006, and 2008 in Sarawak, Borneo based on the daily GRVI derived from the Terra/MODIS observation. The black-coloured areas showed the region with extensive land cover changes.

cultivation. Accurate mapping of spatial and temporal variations in vegetation is required to evaluate precisely the water budget and carbon cycle processes of ecosystems in tropics.

In this study, we examined the land cover change in Borneo by using the daily green-red vegetation index (GRVI) derived from Terra/MODIS observations. GRVI is defined as $GRVI = (R_g - R_r) / (R_g + R_r)$, where R_g and R_r are the reflectance in green and red bands of the spectrum, respectively, with 500 m spatial resolution at a yearly time step from 2001 to 2009. We also evaluated the characteristics of land cover change by using field observations and governmental inventory data. During no green vegetation period (e.g., pre-leaf expansion and post leaf fall periods), the values of GRVI are always under 0. This characteristic indicates the possibility that we can detect the land cover change by examining the continuous period of GRVI values of under 0. In this study, we extracted the noise-free (i.e., no effect of cloud contamination and atmospheric aerosol) daily GRVI (GRVI_{best}) and then examined the ratio of numbers GRVI_{best} values of under 0 and all GRVI_{best} values (GRVI_{best} ratio; i.e., land cover change) at a yearly time step.

Fig. 7 showed the land cover change based on GRVI time series in Sarawak in 2002, 2004, 2006, and 2008, respectively. In the coastal and central regions (3°N, 113.5°E and 3°N, 114.5°E), the spatial and temporal variability of the GRVI_{best} ratio was large. In these regions, the land cover was changed from tropical rain forests to the grassland or oil palm plantation, as shown in Fig. 8(a). In contrast, in the area which showed no temporal variability of GRVI_{best} ratio, the vegetation was not changed, as shown in Fig. 8(b).

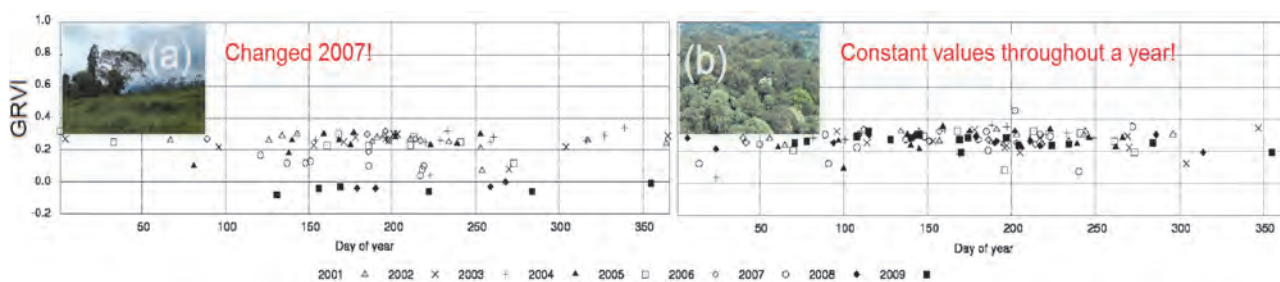


Fig. 8 Time-series in daily GRVI derived from Terra/MODIS observation in a 'deforested' area (a) and tropical rain forest (Lambir Hills site; b).

To reveal key processes of atmospheric chemistry and transport

-Atmospheric Geochemical Cycle Research Team-

-Atmospheric Composition Research Team-

Atmospheric Geochemical Cycle Research Team (AGCRT) and Atmospheric Composition Research Team (ACRT) focus on investigating 1) global distribution and transport of long-lived greenhouse gases and 2) production, transformation, and transport processes of short-lived aerosol particles and trace gases with relevance to global change. We here highlight key observations of $PM_{2.5}$ and NO_2 in East Asia and development of a new data assimilation system as major accomplishments in FY2010.

(1) $PM_{2.5}$ observations at Fukue Island, on the frontline of trans-boundary air pollution

It is known that $PM_{2.5}$, fine particles suspended in the atmosphere whose diameters are smaller than 2.5 micrometers, could significantly impact the Earth's climate through their direct and indirect effects and also could exert health effects such as asthma. We observed $PM_{2.5}$ mass concentrations at Fukue Atmospheric Environment Monitoring Station (32.75N, 128.68E), where local industrial emissions are regarded to be minimal, for a year from 9 September 2009, when a new environmental standard regarding $PM_{2.5}$ mass concentrations was announced. The influence of relative humidity on the measurement of $PM_{2.5}$ mass concentrations was minimized by using a sophisticated pre-heating system. The observed annual average, $17.3 \mu g m^{-3}$, was not readily concluded to exceed the long-term standard value ($15 \mu g m^{-3}$) when the uncertainty of the zero level was taken into account. On the other hand, the 98 percentile of the daily average values during the year was $56.5 \mu g m^{-3}$, clearly exceeding the short-term standard value ($35 \mu g m^{-3}$) as shown in Fig. 9. The backward trajectory analysis suggested that

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the influence from the Asian continent was strong for the high $\text{PM}_{2.5}$ days. The high $\text{PM}_{2.5}$ days were found irrespective of the detection of soil dust at the Nagasaki meteorological station. The influence of air pollution was implied from the association of high black carbon concentrations with the elevated $\text{PM}_{2.5}$ events. In general, such long-range transportation of the $\text{PM}_{2.5}$ particles from the continent is also important in the aspect of nutrient supply to the ocean. We plan to analyze chemical composition of $\text{PM}_{2.5}$ to elucidate their sources and to study impacts on the Asian and oceanic environment.

(2) Continuous monitoring of atmospheric NO_2 at Cape Hedo, Okinawa: Contribution to GEOSS

Since 2006 we have taken the initiative to establish an observational network for atmospheric gases and aerosols, employing MAX-DOAS (Multi-Axis Differential optical absorption spectroscopy) instruments, over Japan, China, Korea, and Russia. At Cape Hedo (26.87N, 128.25E), one of the observational sites located in a remote area of Okinawa Island, it was ensured that the instrument was capable of quantifying trace levels of NO_2 (0.2–1 ppbv) present in the lower troposphere. We newly found that the NO_2 mixing ratios had a clear decreasing trend against the transportation time for the air mass required to travel from the Asian continent to Okinawa (Fig. 10). Because the atmospheric lifetime of NO_2 is generally short (ca. less than 1 day), such feature relevant to long-range transportation was not expected to be observed before. Our further analysis showed that the tendency was consistent with the theoretical behavior of NO_2 , which in turn suggested the reliability of our observations. Based on the high performance of our MAX-DOAS instruments verified in this way, our observational network covering polluted and non-polluted areas would provide useful data to reveal regional-scale air pollutions and to validate satellite observations.

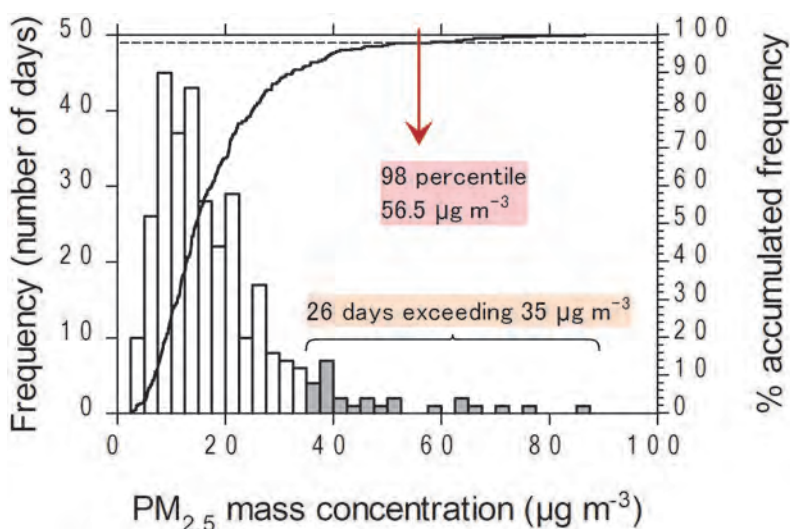


Fig. 9. Distributions of frequency (bars) and percent accumulated frequency (solid line) of the daily $\text{PM}_{2.5}$ mass concentrations for 1-year period (from 9 September 2009 to 8 September 2010). A horizontal broken line indicates the 98 percentile threshold.

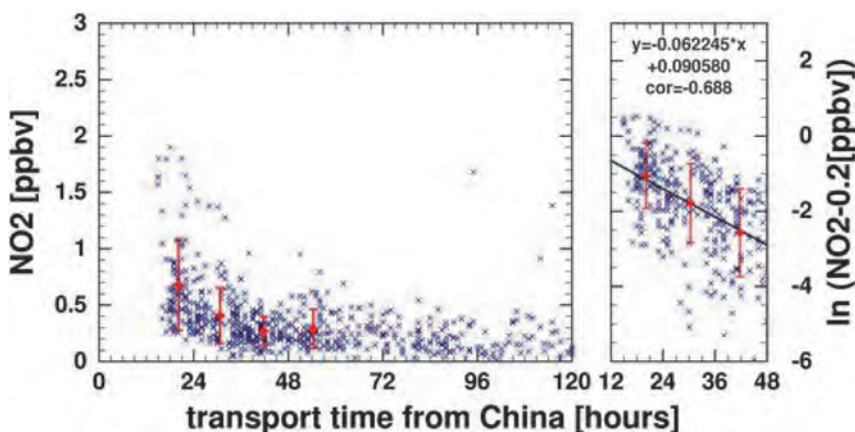


Fig.10. Scatterplot of advection time from the east coast of central China to Cape Hedo (hours) versus NO_2 mixing ratio at Cape Hedo at 0-1 km (ppbv). Also plotted are mean values (diamonds) and one-sigma standard deviations (error bars). A natural log plot of NO_2 is shown in the right-hand panel.

(3) Development of four-dimensional data assimilation system for greenhouse gases

A data assimilation system for the analysis of atmospheric circulation and long-lived tracer distributions in the troposphere and stratosphere has been developed by using a local ensemble transform Kalman filter (LETKF), which has been applied to assimilate both meteorological fields and tracer concentrations into a general

circulation model and an atmospheric transport model. The ensemble Kalman Filter (EnKF) system is one of the recently developed advanced data assimilation techniques that are based on the representation of the probability density of the state estimate by a finite number of system states. In the EnKF system, the state update is computed in the low-dimensional space, and the forecast error covariance is advanced by using the model itself, rather than by estimating the error as a constant covariance matrix. In this study, we adopt a LETKF system, which has conceptual and computational advantages over the original EnKF. In our data assimilation system, we employed the Center for Climate System Research/National Institute for Environmental Studies/Frontier Research Center for Global Change (CCSR/NIES/FRCGC) atmospheric general circulation model (AGCM) version 5.7b and an online atmospheric transport model (embedded in the AGCM) developed at FRCGC for the forecast models. The global distribution of carbon dioxide (CO₂) was calculated from the transport model with a time interval of 10 min, by using the meteorological fields obtained from the GCM. The grid-scale advection of CO₂ was calculated explicitly by using the simulated wind fields and the transport scheme at each model grid point on the basis of a fourth-order flux-form advection scheme. We considered sub-grid transport processes by moist convection and vertical diffusion in which a parameterized convective transport represented the updraft and downdraft of CO₂ by cumulus convection, and turbulent mixing was dependent on the vertical diffusion coefficient estimated using a turbulent closer. The surface flux data obtained for CO₂ were based on the results of the TransCom3 experiment, which consisted of anthropogenic emissions, atmosphere-biosphere exchange flux, and atmosphere-ocean exchange flux. To estimate the performance of our data assimilation system, we executed a ‘perfect model’ experiment and assimilation model with artificial observational data (aircraft, ground-based, and satellite). The results showed that the satellite data improved the analysis especially in the Africa and South America region, where the ground-based and aircraft observation could not available (Fig. 11).

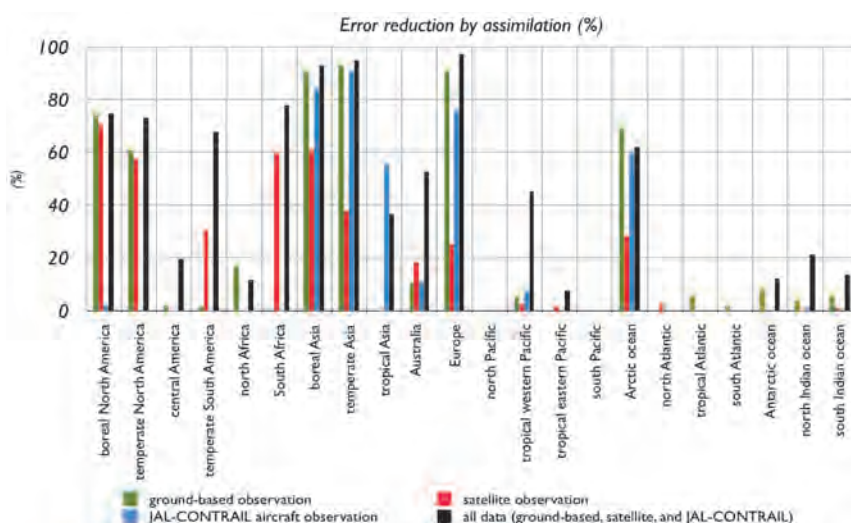


Fig. 11. Error reduction rates for regional mean surface CO₂ fluxes (in %) calculated using the surface network data (green bar), GOSAT data (red bar), CONTRAIL data (blue bar), and all the data (black bar) in the 4-D data assimilation system with a 3 day assimilation window, averaged on 1–7 December 2007.

Reconstruction of Paleoenvironment –toward the elucidation of modern biogeochemical cycles– -Paleoceanography Research Team-

The purpose of this research team is to understand: 1) the past marine biogeochemical processes and carbon cycles; 2) its responses to climate changes during the past thousand to several decades thousand years that was not influenced by human activity. The strategy is to extend observational data toward the past by reconstructing climate variations by using high time resolution paleo proxies recorded in marine sediments. Here, we report a new regime of the deep-water circulation during the last glacial termination obtained from the North Pacific.

Deep water formation in the North Pacific during the last glacial termination

Deep water circulation plays an important role of poleward heat flow that influences to the global climate

I. Research Activities and Results

Environmental Biogeochemical Cycle Research Program

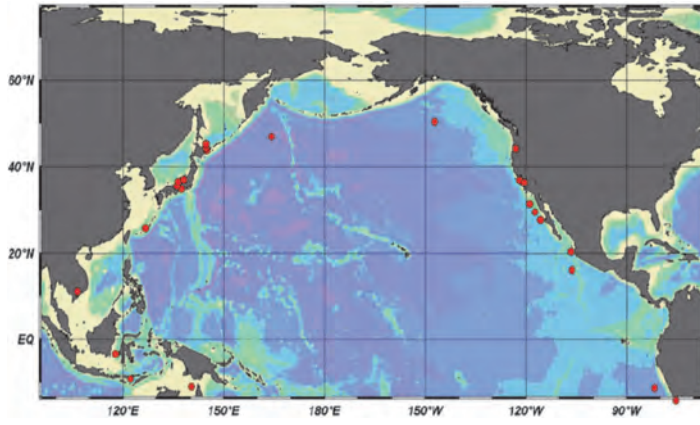


Fig. 12. Location map of sediment collection (red circle)

atmospheric and oceanic teleconnections, climatic condition in the Northern hemisphere including North Pacific changed, as documented by numerical climate modeling studies and paleo-proxy data. However, a comprehensive view of what happened in the North Pacific during the early deglaciation and spatial patterns and pathways of intermediate-deep water circulation have not been clarified. Therefore, we compiled a comprehensive data set of published radiocarbon from 23 to 10 ka, which is based on ^{14}C age differences between coexisting benthic and planktic foraminifers from sediment cores in the North Pacific (Fig.12), with temporal coverage large enough to resolve the H1 and the Bølling-Allerød (BA: ~14.5 to 13 ka) warm period transition. Together with the Earth system climate model of intermediate complexity LOVECLIM (version 1.1) that mimics H1, we determined the effects of AMOC changes on the large-scale conveyor-belt circulation, with an emphasis on the North Pacific. The western North Pacific radiocarbon ages (Fig.13 for depth range 900 to 2800 m) reveals notable changes in deep water ventilation during the last deglaciation, indicating ventilation age estimates for the H1 period ~950 years, which was 800-900 years younger than that at present (1800 years). It suggested that the ventilation at intermediate-deep layer was quite active during the H1 in the western North Pacific. On the other hand, no coherent averaged age ventilation changes were observed between the LGM (~1540 years), H1 (~1450 years), and BA (~1600 years) in the eastern North Pacific (not shown). Our reconstructed ventilation changes during H1 show a much more pronounced reorganization of deep western North Pacific flow.

The freshwater perturbation experiments simulate the climate response to an idealized glacial meltwater pulse. By linearly increasing the freshwater forcing to 2 Sv in the northern North Atlantic for 100 years, the water becomes less dense, leading to a reduction of deep convection in the North Atlantic and a subsequent collapse of the AMOC. An associated reduction of poleward heat transport leads to large-scale cooling in the Northern Hemisphere. Air-sea interactions in the North Atlantic and emanating atmospheric teleconnections are vital for cooling the western North Pacific [Okumura *et al.*, 2009]. Furthermore, in response to the AMOC

changes. The high latitude in the North Atlantic and the Antarctic regions are only location for deep water formation at present, whereas no deep water is formed in the North Pacific due to surface low salinity. According to the sediment records, massive meltwater discharges (collapse of continental ice sheet on the North America) during the last glacial termination (-19 to 10 kilo years ago (ka)), such as Heinrich event 1 (H1: 17.5 to 14.5 ka) reduced North Atlantic surface density conditions and interrupted the steady flow of the Atlantic meridional overturning circulation (AMOC). Through

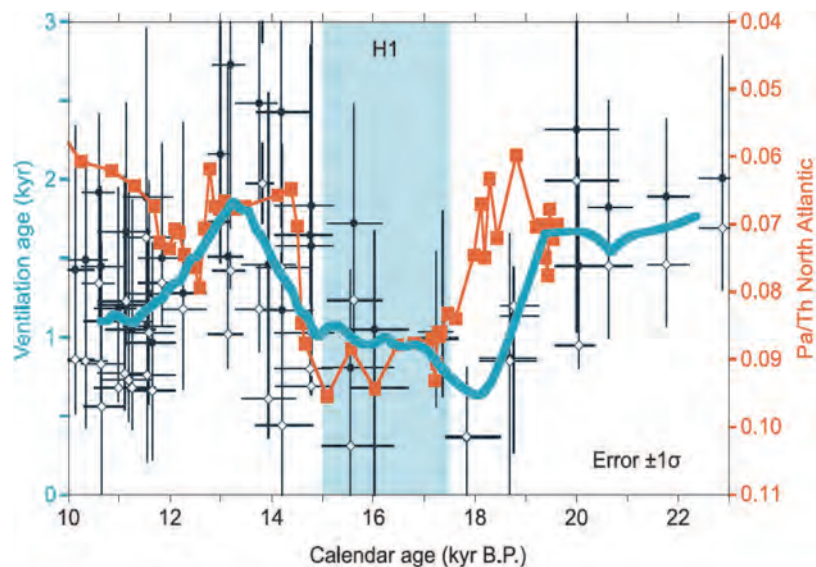


Fig. 13. Compilation of ventilation age changes based on published radiocarbon data in the western North Pacific [Okazaki *et al.*, 2010]. Benthic foram (BF) – Planktic foram (PF) ages (open diamonds), projection ages (gray circles), and smoothed spline interpolation of averaged BF–PF and projection ages (blue line). Uncertainty of calendar age and ventilation age is 1sigma; Pa/Th ratio (orange squares) as a proxy for the AMOC strength in the North Atlantic [McManus *et al.*, 2004].

weakening and the associated North Atlantic cooling, the Atlantic-Pacific moisture transport weakens [Krebs and Timmermann, 2007] and the Pacific Intertropical Convergence Zone shifts south, leading to a persistent reduction of precipitation and hence an overall increase of surface salinity in the North Pacific. Once the Pacific meridional overturning cell (PMOC) establishes, the anomalous poleward surface currents transport more saline subtropical waters into the North Pacific, thereby providing a positive salinity feedback. A closed Bering Strait facilitates the build-up of such North Pacific salinity anomalies [Hu *et al.*, 2007]. The resulting changes in surface density trigger deep oceanic convection in the subarctic Pacific. The three-dimensional adjustment to the resulting North Pacific density anomalies in the preindustrial and the freshwater perturbation experiment leads to the establishment of a deep PMOC (Fig. 14), which distributes young and oxygen-rich deep water throughout the entire western North Pacific down to ~2500 m (Fig. 14).

The shutdown of the AMOC in our model reduces the Atlantic heat transport at 40°N by ~0.6 PW (1 PW = 1015 W). At the same time, and in response to the establishment of a PMOC, poleward heat transport in the Pacific at 40°N increases by 0.4 PW. The PMOC hence played an important role in buffering the decrease in the poleward global oceanic heat transport caused by the shutdown of the AMOC. The evidence presented here demonstrates that the North Pacific was a very active region of thermohaline flow during the deglaciation and operated out of phase with the North Atlantic [Okazaki *et al.*, 2010].

We are now investigating carbon cycles during H1 in the higher latitude of the North Pacific. At the next step, we would like to clarify the response of carbon cycles associated with changes in the deep water ventilation during the last glacial termination.

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Publication List

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- Aoki, S., Y. Sasai, H. Sasaki, H. Mitudera, and G. D. Williams (2010), The cyclonic circulation in the Australian-Antarctic basin simulated by an eddy-resolving general circulation model, *Ocean Dynamics*, **60**(3), 743–757, doi:10.1007/s10236-009-0261-y.
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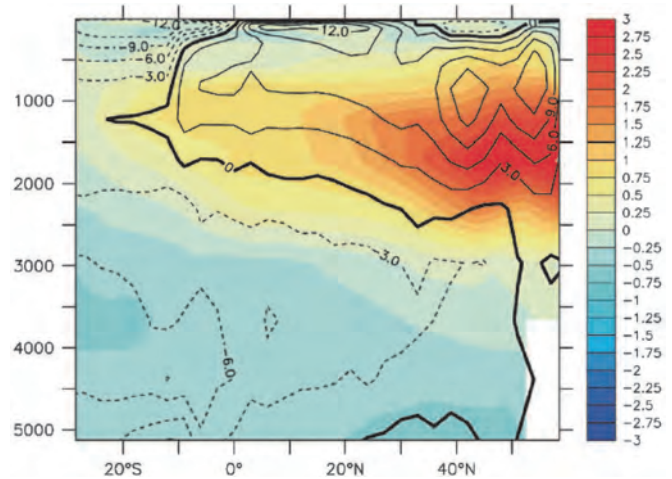


Fig. 14. Shading indicates simulated zonally averaged Pacific oxygen anomalies (in ml oxygen per l of water) between a collapsed AMOC state (years 400 to 500 of the freshwater experiment) and the preindustrial control simulation. The contours indicate the simulated Pacific mean meridional stream function ($Sv: 10^6 \text{ m}^3 \text{ s}^{-1}$) (years 400 to 500 of the freshwater experiment).

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I. Research Activities and Results

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Toward the Prediction of Global Change

-Global Change Projection Research Program-

This program investigates the projection of global change by developing an integrated earth system model that includes explicit representations of biogeochemistry, such as carbon-cycle feedback among ocean, air, and land, and interactions between aerosols and atmospheric chemistry. The model is further improved by evaluating its performance against observational data. This program also studies mechanisms of climate change and variation, using paleoclimate simulations and analyses of observed and simulated data to clarify how global change, especially global warming, proceeds in a climate system that fluctuates naturally in various space and time scales, even without changes in external forcing.

The program consists of the following five teams as shown in Fig. 1:

- * Integrated Earth System Modeling Research Team led by Dr. Michio Kawamiya
- * Climate Modeling Research Team led by Dr. Tatsushi Tokioka
- * Global Change Analysis Research Team led by Dr. Akira Noda
- * Global Hydro-climate Process Research Team led by Dr. Tetsuzo Yasunari
- * Paleo-climate Modeling Research Team led by Dr. Ayako Abe

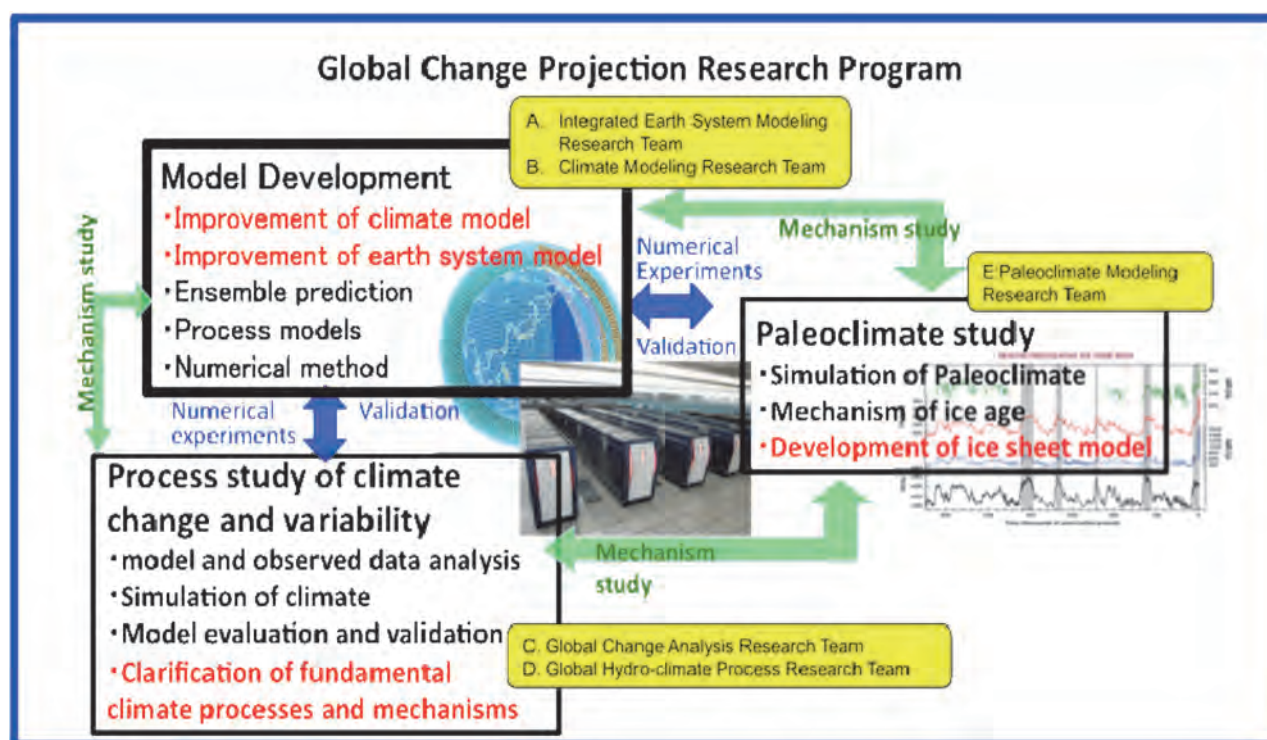


Fig. 1. Research teams and targets of Global Change Research Program

As experts in climate change science and global warming projection, members of the program have been contributing not only to IPCC assessment reports but also to society as lecturers, authors of books and writers of other publications in publicizing important scientific results obtained.

Research highlights from each team in the fiscal year 2010 are shown in the following sections.

Shaping Future Scenarios for Projection of Global Environment

-Integrated Earth System Modeling Research Team-

(1) Evaluation of consistency in the emission from land-use change in Representative Concentration Pathways (RCPs)

For a Fifth Assessment Report (AR5) of Intergovernmental Panel on Climate Change (IPCC), Representative Concentration Pathways (RCPs) scenarios, which will be the forcing of climate and earth system

models used for the future climate change simulations, have been constructed and now open to the public. Our team constructed the net land-use change (LUC) carbon emission and aerosol emissions from open biomass burning in RCP6.0 scenario whose radiative forcing is stabilizing 6W/m^2 at 2100. In this study, to evaluate consistency of LUC emission and spatially explicit gridded land-use data of RCPs, net land-use change carbon emissions for all four RCPs scenarios are estimated with an ecosystem model, and the emission of RCP6.0 is also evaluated with an earth system model to see the effect of climate and carbon interactions.

In RCPs, scenario of gridded LUC transitions and CO_2 concentrations has been produced by each Integrated Assessment Modeling groups (IAMs) with the corresponding radiative forcing. Using these data as a forcing of terrestrial ecosystem model VISIT, we estimated the net LUC carbon emissions. While LUC emission data are also distributed in the RCPs dataset as a standard scenario emission and these emissions were used to make the CO_2 concentration scenarios combined with the fossil fuel emissions. We evaluated the consistency of scenario by comparing these two LUC emission estimates.

As a result, it turns out that the consistency of RCP6 is high as expected because the VISIT model was used to produce the standard data of the RCP6 scenario. Contrarily, other scenarios show some period with large differences of emissions between two estimates. Main difference of these inconsistencies can be attributed to the model difference on the estimation of regrowing absorptions and deforested emissions of CO_2 .

In the above, LUC emission scenarios were evaluated with consideration of CO_2 fertilization effect, but effect of climate change on the terrestrial ecosystem was not considered. To include the effect of climate change into the evaluation, we analyzed model output of an earth system model (ESM) developed for climate change prediction, whose coupled ecosystem component responds to the climate. Figure 2 shows the result of LUC emission by ESM for RCP6 scenario. After 2020, with an increasing trend of the signal of climate change, effect of climate change on LUC emission predominates and it shows maximum difference about 3 Pg C/yr in the evaluations.

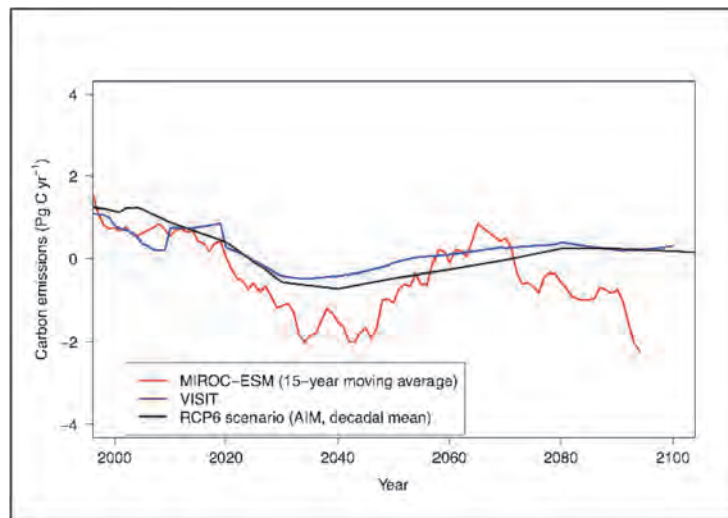


Fig. 2. Future net land-use change carbon emission estimates for RCP6.0. Red line indicates the estimate with an earth system model. Black line shows standard data from RCP dataset. Blue line indicates the estimate by a terrestrial ecosystem model.

(2) Building convenient user environment for data publishing server of climate change projection

This activity is conducted by a support by Global Environmental Research Fund of Ministry of Environment, in collaboration with a leading project (Global Warming Projection Research Project for Contribution to AR5 of IPCC) and Data Integration and Analysis System (DIAS) of Ministry of Education, Culture, Sports, Science, and Technology. The aim is to provide the framework of system development and information sharing for making data products of these projects used in wide ranged area.

User environment such as sophisticated command line tools has been built on the data publishing server of the climate change projection data. Also, model output with the experimental protocol of IPCC AR5 have been

converted to the format conforming international standard. In the process of data conversion, we contributed development and implementation of the international standards by reporting some inadequacy in specification. Workshop was held for the discussion and exchange of information about the procedures of preparing papers for AR5, and researchers of both impact assessment and model development areas joined in the workshops.

Development of New Cumulus Parameterization and LES-Based Modeling -Climate Modeling Research Team-

(1) High-resolution cloud resolving model simulations of deep convective clouds in tropical Pacific

A result of high-resolution cloud resolving model simulation of deep convective clouds in the tropical Pacific (Fig. 3) was analyzed in detail, in order to understand the processes in deep convective clouds and to improve cumulus convection parameterization scheme for GCMs. The simulation was conducted using a 200m resolution non-hydrostatic model JMA/MRI-NHM. The model was integrated for 15 hours starting at 09UTC of 28 August 2004. The computation domain covers 60km by 60km area in the central tropical Pacific. Focused on a meso-scale linear convection system moving from north-east to south-west of the computation domain, spatial distribution and temporal variation of updraft, downdraft, cloud water and ice, snow, rain, graupel, and potential temperature and equivalent potential temperature fields were analyzed. The analysis results indicate the following points regarding the convective clouds parameterization scheme. 1) Individual cloud consists of many updraft and downdraft bubbles of 1km scale. As the situation depends on the life stage of cloud, it is not appropriate represent a cloud by a single quasi stationary plume model. 2) In a low resolution model (50km or larger grid size), it may be possible to represent the ensemble of clouds in various life stage by plume model. 3) In a high resolution model, a more direct representation of life cycle of cloud is needed if only a few clouds are included in the model grid area. 4) Even in a very high resolution model (less than 5km grid size), a sort of parameterization may be needed if both updraft and downdraft are included in the model grid area.

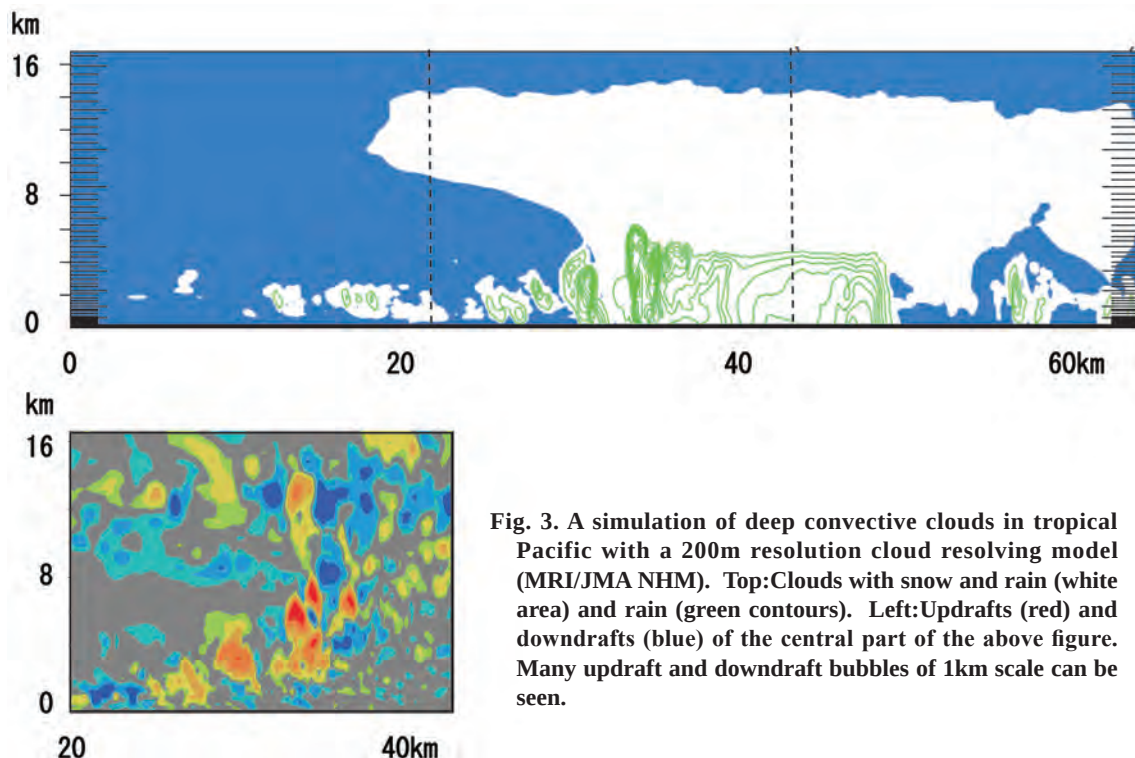


Fig. 3. A simulation of deep convective clouds in tropical Pacific with a 200m resolution cloud resolving model (MRI/JMA NHM). Top: Clouds with snow and rain (white area) and rain (green contours). Left: Updrafts (red) and downdrafts (blue) of the central part of the above figure. Many updraft and downdraft bubbles of 1km scale can be seen.

(2) Study on the hurricane boundary layer using large-eddy simulation (LES)

For the last decade, horizontal roll vortices have been often observed in hurricane boundary layers (HBLs). Large-eddy simulation is performed to explore the mechanism of instabilities that generate the horizontal roll vortices in a HBL at 100 km (R100) and 40 km (R40) away from the center of the hurricane. Results are examined

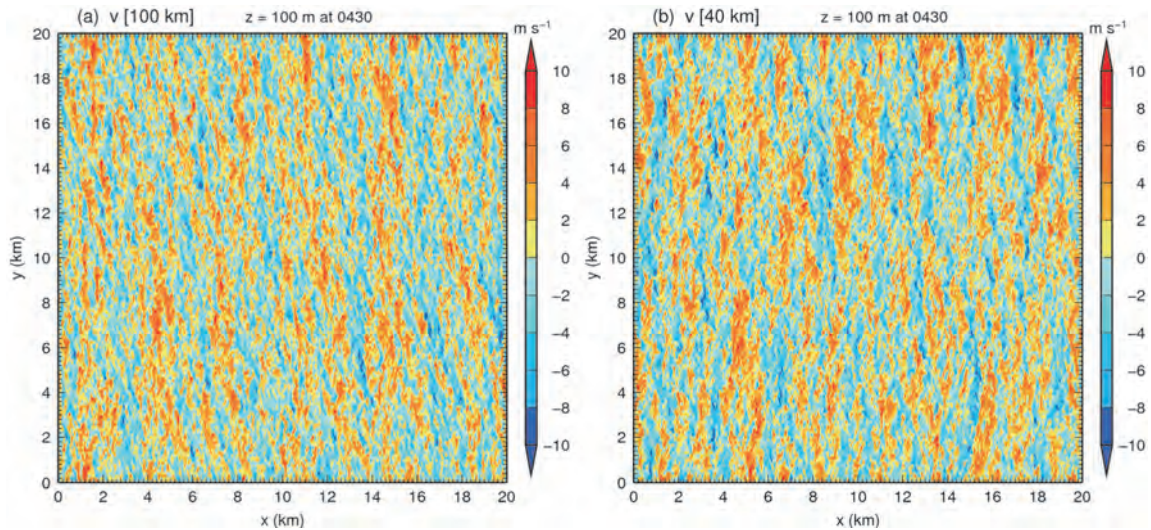


Fig. 4. Horizontal distributions of azimuthal wind velocity fluctuations at a height of 100 m at 0430 for (a) R100 and (b) R40. 0430 denotes four and a half hours after the initial time.

through turbulence statistics and proper orthogonal decomposition (POD) analysis, which is called empirical orthogonal function analysis in the atmospheric sciences literature. The POD analysis and budgets of turbulent kinetic energy demonstrate that an inflection-point instability in the radial velocity profile is responsible for the horizontal roll vortices with wavelengths of 1.5–2.4 km in the HBL both for R40 and R100. The roll vortices for R100 are oriented slightly to the left of the gradient wind (Fig. 4a), while those for R40 are nearly aligned with that wind (Fig. 4b). Also the horizontal distributions of velocity fluctuations suggest the presence of streak-like structures at horizontal intervals of several hundred meters near the ground surface, which are more likely related to small-scale wind damage often observed after hurricane landfalls.

Internal gravity waves, Kelvin-Helmholtz waves, and entrainments occur above the HBL and are partly coupled with the roll vortices in the HBL, implying an enhancement of vertical transports of momentum and other quantities between the HBL and free atmosphere. Detailed analyses of these results are important to the improvement of turbulent parameterizations in meteorological and climate models.

Dynamical Climate Processes in Changing Climate -Global Change Analysis Research Team-

(1) The quasi-biennial oscillation (QBO) in a doubled CO₂ climate

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

Figure 5 shows a time–height cross-section of the monthly-mean zonal-mean zonal wind over the equator in the present and future climates. Westerly (red color) and easterly (blue color) alternate with a period of about 2-year with descending their phases. Thus the QBO oscillation is well simulated by the model. In the

future climate, the QBO period becomes longer and QBO amplitude weaker than in the present climate. The downward penetration of the QBO into the lowermost stratosphere is also curtailed in the future climate.

Figure 6 shows latitude–height cross-sections of climatological annual mean zonal mean temperature and zonal wind in the present and future climates. The black and red contours correspond to present and future climates, respectively. The tropopause shifts slightly higher in the future climate. A warming in the troposphere and cooling in the stratosphere are evident. The upper parts of the subtropical jets strengthen. The upward displacement of a zero wind line is obvious in the extra tropics. These temperature and zonal wind changes result in a significant increase of the mean upwelling in the equatorial stratosphere. The effect of this enhanced mean circulation overwhelms counteracting influences from strengthened wave fluxes in the warmer climate, which makes the future QBO changes seen in Fig.5b.

(2) A generalized 3-dimensional transformed Eulerian mean (TEM)

The transformed Eulerian mean (TEM) formulation for equations of motion, which was originally defined for waves on a zonally averaged flow, is extended three-dimensionally to a nonhydrostatic Boussinesq fluid in the general coordinate system. The three-dimensional antisymmetric diffusion tensor that plays a central role in defining the residual circulation and the Eliassen-Palm flux tensor is derived systematically by assuming that eddies consist of neutral waves. It is shown that the Charney-Drazin non-acceleration theorem is directly related to the wave energy equation and does not hold generally in three-dimensional case. A modification of the formulation for application to practical data analyses is made by introducing a symmetric eddy diffusion tensor. Since the three-dimensional TEM thus derived contains no specific wave form, it can be applied for finite amplitude eddies, although the Eliassen-Palm flux tensor has a clear physical meaning only for neutral waves of small amplitude.

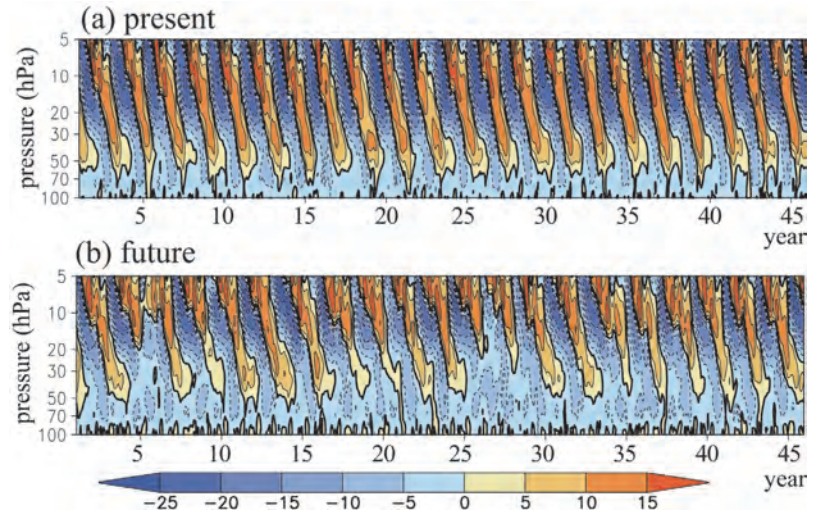


Fig. 5. Time-height cross sections of zonal mean zonal wind at equator in (a) present and (b) double CO₂ climates. The contour intervals are 5 ms⁻¹. Red and Blue colors correspond to westerly and easterly, respectively.

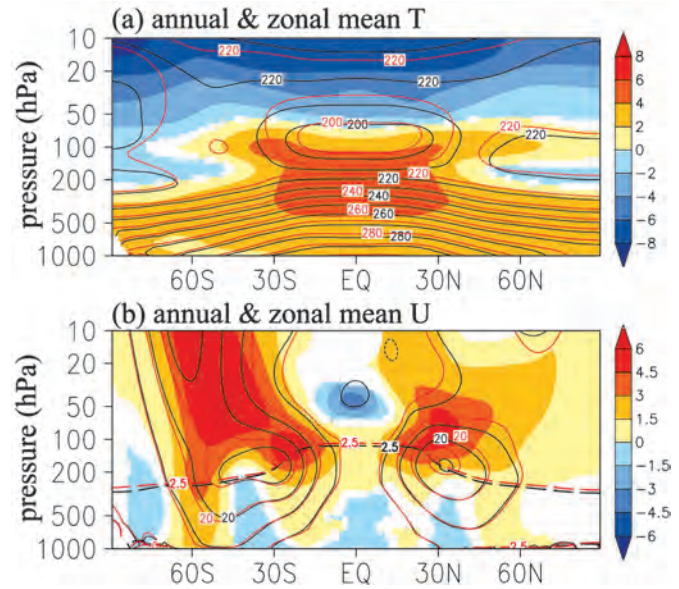


Fig. 6. Climatological annual and zonal mean (a) temperature and (b) zonal wind. Black and red lines correspond to the present and future climates, respectively. The tropopause is illustrated by the dashed line in (b). Differences with statistic significance $\geq 95\%$ are colored. Contour intervals are (a) 10 K and (b) 10 ms⁻¹. Color intervals are (a) 2 K and (b) 1.5 ms⁻¹.

Global Hydro-Climate Processes in Changing Climate

-Global Hydro-climate Process Research Team-

(1) The role of cold surges of the East Asian winter monsoon in the generation of tropical disturbances

The impact of northerly surges of the East Asian winter monsoon on tropical cyclogenesis over the eastern Indian Ocean and maritime continent was examined for the 6-month period of October to March from 1979/1980 to 2006/2007 based on case studies and lag-composite analysis (Fig. 7). We focused on long-lasting northerly surge events at 6- to 30-day (sub-monthly or intraseasonal) time scales over the South China Sea. In addition, we examined seasonal differences in the impact of northerly surges over the South China Sea on tropical atmospheric circulation.

The results show that northerly surges occur frequently in the period from October to March. Long-lasting northerly surges over the South China Sea intrude into tropical regions. Over the eastern Indian Ocean and maritime continent, the surges are associated with the appearance of tropical cyclones. A cyclone pair symmetric with respect to the equator also appears over the eastern Indian Ocean in November and is responsible for the enhancement of the horizontal gradient of zonal wind by the northerly surge. In contrast, in December, January, and February, an asymmetric cyclone pair (the so-called Borneo vortex) develops around Borneo. The asymmetric cyclone pair around the maritime continent is associated with intensification of low-level wind along a channel between the islands of Borneo, Sumatra, and Java.

(2) Estimation and verification of daily surface shortwave flux over China

Global solar radiation is the energy resource of living things and it is important for clarifying the features of the climate change. Although meteorological data have become much more plentiful and accessible in recent years, daily data of downward shortwave flux at the surface over wide areas are still lacking. In this study, daily solar radiation has been estimated from solar duration data at more than 190 stations in China. Climatic maps of surface solar radiation were produced from 1971 (Fig. 8). The sunshine duration-based shortwave flux was used to check satellite observation-based datasets and it will be useful for accuracy enhancement for satellite-based datasets. This study was supported by JSPS and China NSFC under the Japan-China Scientific Cooperation Program, and the Strategic Japanese-Chinese Cooperative Program on "Climate Change" between JST and MOST.

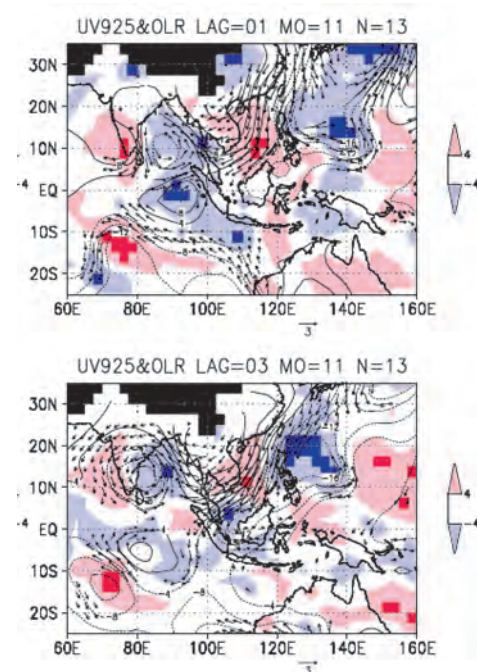


Fig. 7. An example of the genesis of disturbances over the eastern Indian Ocean associated with the cold surge over the South China Sea. Circulation and convection anomalies at one day after the cold surge peak phase (upper panel) and three days after the cold surge peak phase (lower panel). (Takahashi, Fukutomi and Matsumoto, JMSJ, 2011)

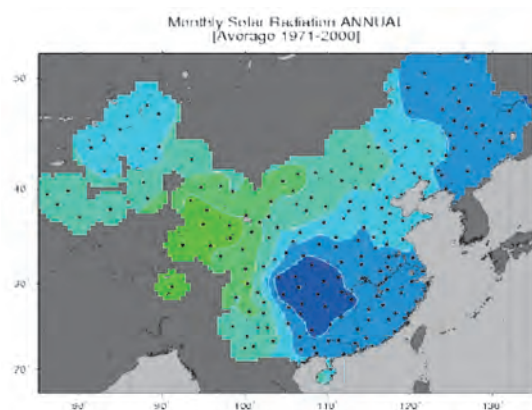


Fig. 8. Distribution of annual climatological shortwave flux at the surface (1971-2000). (Xu et al., JMSJ, 2011)

Simulations of Paleoclimate by GCMs and Ice Sheet Model

-Paleo-climate Modeling Research Team-

(1) Improvement of global sea level projection by melting of ice sheets

It is reported in IPCC AR4 that main sources of changes in the global sea level due to climate changes (in a relatively short time scale around 100 years) are thought to be thermal expansion of ocean, and next the melting of small mountain glaciers and ice caps IPCC AR4, and that contribution from melting of Antarctic and Greenland ice sheets can be larger than current projections if those models include the processes such as ice streams neglecting in many ice sheet models. Recent observations have reported the accelerations of outlet glaciers drained from the ice sheets, and it is very important to include such processes for more accurate projections. SeaRISE and ice2sea projects are both international projects to improve the simulation of ice sheet models under future climate changes. Under the framework of these projects, we perform the simulation of Greenland ice sheets at the present-day as well as under the future climate changes. There are two important aspects to improve the simulation of ice sheets: realistic representation of the bedrock topography under ice sheets, and realistic simulation of the present-day observed surface topography by the ice sheet model, which is used for the initial condition of the future projection. For the former aspects, IcIES is improved so that higher horizontal resolution (10 km) experiments become practicable. For the latter aspects, the present-day condition is obtained through the simulation from the last interglacial period (125,000 years ago) and the present (Fig. 9). From this condition, future global warming experiments are performed under SRES A1B scenarios. From 500 years simulation from the present-day, contribution of Greenland ice sheets is evaluated as 12 to 38 cm of global sea level changes. The horizontal resolution, however, is not enough to simulate the ice streams and outlet glaciers, and therefore IcIES is still being developed toward much higher resolution to include such process better.

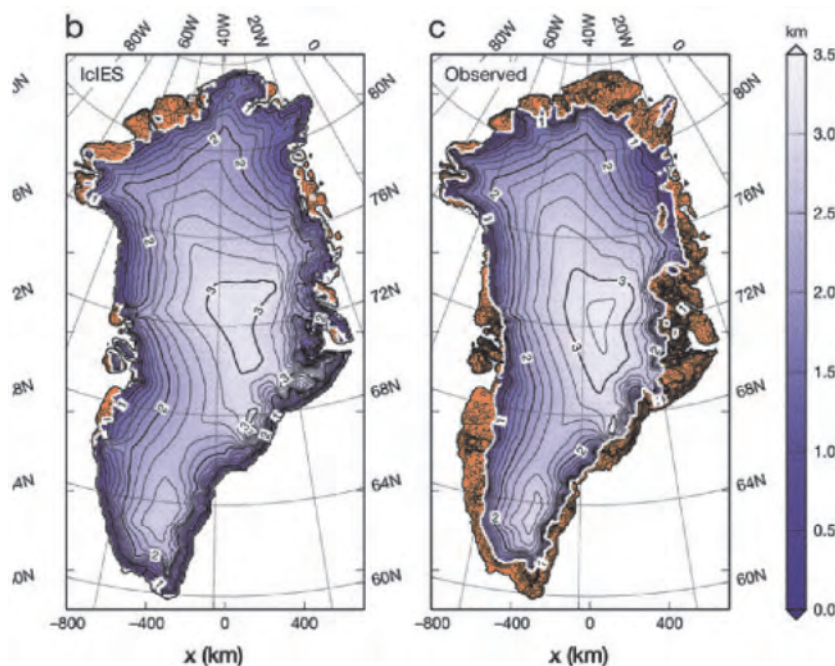


Fig. 9. Simulated present-day ice sheet topography of Greenland obtained by a higher-resolution version of IcIES.

(2) North Pacific climate change during Heinrich event 1

During the deglaciation, freshwater discharge caused by melting icebergs reduces the surface water density in the North Atlantic Ocean and the associated weakening of Atlantic Meridional Overturning (AMOC). This event, known as Heinrich event 1, causes significant cooling in the northern hemisphere and also affects North Pacific climatology. In this study we evaluate the North Pacific climate responses to a 1-Sv freshwater discharge using an atmosphere-ocean coupled GCM MIROC and an earth system model LOVECLIM simulation. In the freshwater experiment, the added freshwater from the North Atlantic/Arctic Ocean cannot escape in the

North Pacific with a closed Bering Strait.

The responses of North Pacific temperature are different between two models (Fig. 10a and b). In MIROC, the negative SST anomaly extends eastward in the North Pacific Ocean. In the tropical Pacific, the surface water warms and the northeasterly trade winds are slightly enhanced. In LOVECLIM, the warming starts to occur in the eastern North Pacific. This is contributed by the poleward heat transport intensifies due to the establishment of a stronger Pacific meridional overturning (PMOC) compared to that in MIROC.

The sea surface salinity in the Pacific Ocean except for the Okhotsk Sea is slightly reduced north of 40°N in MIROC (Fig. 10c). In contrast, LOVECLIM simulates a larger salinity increase in the entire North Pacific Ocean (Fig. 10d). This can be explained by the positive Stommel feedback: an intensified PMOC leads to an enhanced poleward salinity transport from the subtropics to the extratropics. Furthermore, the transport through the Indonesian Throughflow is strongly reduced, which leads to a greater transport of warm and saline equatorial waters to the North Pacific. The salinity change in the North Pacific Ocean represents the combined effects of anomalous precipitation minus evaporation, meridional salinity gradient in the Pacific Ocean and salinity transport from the equatorial regions.

The different North Pacific response between MIROC and LOVECLIM may be affected by the differences in background density stratification and winter mixed layer in the glacial control run. The representation of ocean stratification based on glacial salinity and temperature fields may have been instrumental for abrupt climate transitions in a coupled atmosphere-ocean model.

This study is collaborated with Naomi Harada and Yusuke Okazaki (RIGC, JAMSTEC) and Axel Timmermann (IPRC, University of Hawaii) under the JAMSTEC-IPRC Initiative.

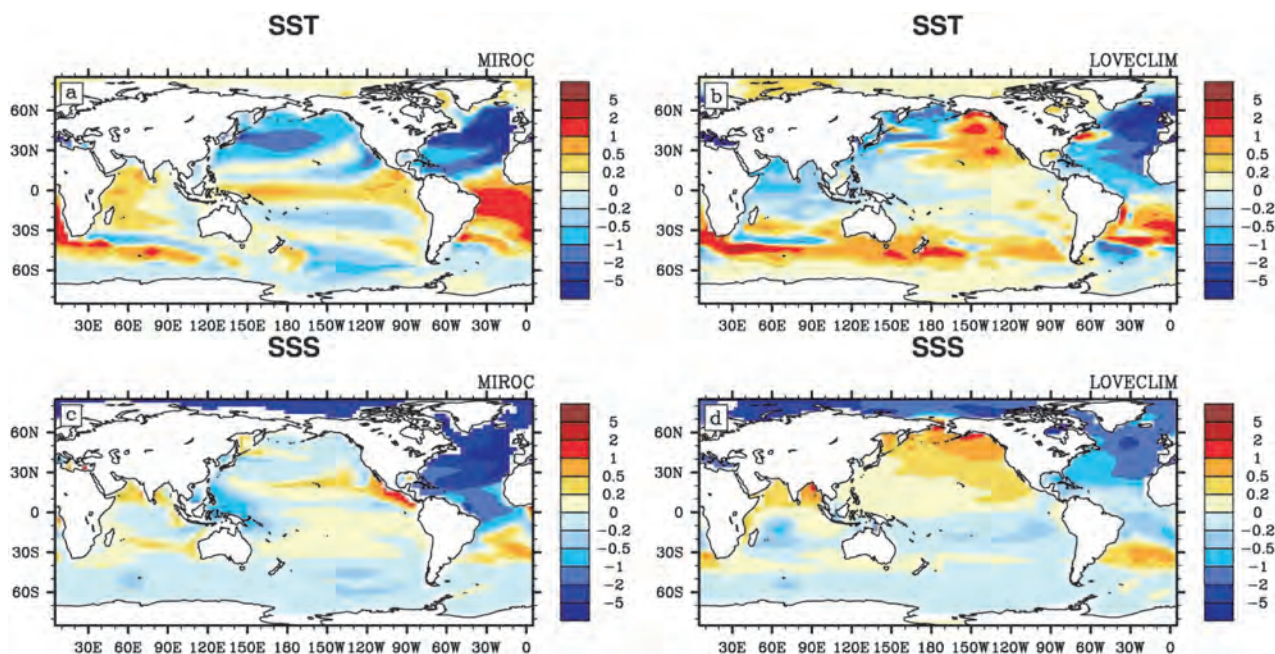


Fig. 10. Anomalies of SST (a and b) and SSS (c and d) in the 1 Sv hosing experiment from the glacial control experiment in MIROC (a and c) and LOVECLIM (b and d).

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Understand Processes for Better Prediction of Ocean and Climate Variations

-Climate Variation Predictability and Applicability Research Program-

Short-term climate variability and ocean variations, at a typical time-scale of months to decades, have significant impacts on our everyday life. Tropical air-sea coupled climate modes, such as El Niño and Indian Ocean Dipole (IOD) events, for example, are dominant signals in the Indo-Pacific basins, whose influences are observed not only in the tropical regions but also in the global climate conditions via atmospheric teleconnections. Location of Kuroshio path is affected by instability of the current and meso-scale eddy activities as well as large-scale ocean responses to atmospheric forcing. Accurate prediction of such the variability and dissemination of predicted information in an appropriate way are highly required from our society. We are, therefore, conducting researches on oceanic and atmospheric processes responsible for the climate and ocean variations, mainly using high-resolution ocean, atmosphere, and coupled models, together with analyses of available observed and reanalysis datasets.

One of the major achievements in this year is the advancement of our knowledge on the processes in the climate and coastal ocean systems. Using SINTEX-F1 coupled general circulation model, impacts of sea surface temperature (SST) warming trends in the ocean on predictability of the short-term climate variations are investigated and results demonstrate significant importance of the trends for long lead predictions. We found two characteristic patterns in the upper troposphere associated with interannual variability of the East Asian winter monsoon. Analyses of air-sea interactions in the Kuroshio extension region demonstrate that the SST anomalies east of Japan and within Japan Sea are highly correlated with meridional migration of the westerlies over Japan. Predictability of the Kuroshio extension current and its relation to oceanic internal variability is also investigated using a high-resolution ocean model. Multi-scale operational ocean forecasting model is developed and utilized for concurrent simulations of ocean currents, tides, and river discharges. Results from the high-resolution downscaled ocean model indicate significant impacts of tides and river discharges on sea level, salinity, and coastal currents near Japan.

Application of climate prediction data is one of our research topics. Combining such the climate model outputs with a large-scale crop model can provide useful information for agriculture in some specific regions. A new attempt to realizing this coupling of the information has been done and preliminary experiments show promising results.

All the studies conducted in our program contribute to better understanding of processes which are key for the climate and ocean predictions. Selected highlights of our achievements in this year are shown below.

The Anatomy of Benguela Niño Generation Process

-Low-Latitude Climate Prediction Research Team-

Benguela Niños occur when warm seawater replaces the seasonal nutrient-rich water off the southwest coast of Africa. The phenomenon that is less intense and less frequent than its Pacific counterpart owes its name to the Benguela Current, which forms the eastern branch of the South Atlantic Ocean gyre. The current system, extending from Cape Point of South Africa to the Angola-Benguela Front at around 16°S, is well known for a sustained productive ecosystem associated with the coastal upwelling off Namibia and Angola. The seasonal southeasterly winds entrain the cold nutrient-rich waters to fuel high rates of phytoplankton growth (Fig. 1). A seasonal feature of the region is the intrusion of warm Angolan water to the northern part of Benguela.

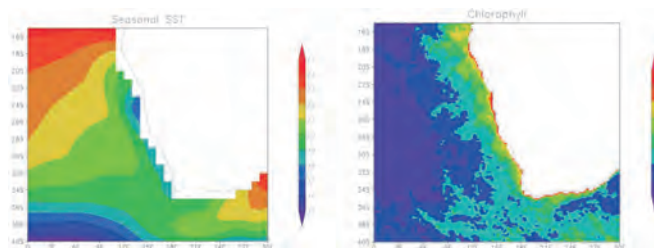


Fig. 1. (left) SST and (right) chlorophyll distributions in the Benguela region during austral fall.

During a Benguela Niño, the Angola-Benguela Front is displaced far south causing the advection of warm and saline water that devastates the local ecosystem. Some of the events are marked by up to 5 °C warmer than normal waters along the Angolan and Namibian coasts. For example, during the 1995 event the entire coast was covered by abnormally warm water to a distance of more than 300 km offshore. Sardine, horse mackerel and silver kob died en masse.

Most of previous studies suggest that Benguela Niños are caused by downwelling Kelvin waves that originate from the western and central equatorial Atlantic and, upon reaching the African coast, travel southward as coastal Kelvin waves. The role of local along-shore winds, on the other hand, has received little attention so far. It is important to understand the origin of the triggering mechanism for monitoring and seasonal prediction purposes. Here, the relative roles of remote and local forcing in the generation of Benguela Niños were investigated by using satellite derived data and general circulation model (GCM) results. The satellite observations include QuikSCAT surface wind, AVHRR SST, and AVISO sea surface height (SSH). The GCM used in this study is the coupled GCM for the Earth Simulator (CFES), integrated for 120 years at a resolution of T119 (~1°) and 48 σ -levels in the atmosphere, and 0.5° and 54 vertical levels in the ocean. Unlike most current general circulation models, that have large biases in the Atlantic, CFES achieves a very realistic simulation of the tropical and southeast Atlantic. Both Atlantic and Benguela Niños are simulated with realistic amplitude and phase locking, making the model suitable for investigating the relation between these two warm events.

The analyses of satellite data indicate that along-shore wind anomaly play an important role in the generation of Benguela Niño but does not discount the influence of Kelvin waves. Regression of daily SST anomalies in a region of 8°E-coast, 25-15°S (hereafter AB1 region) on surface winds and SST tendency reveals that SSTs in the region are highly sensitive to local along-shore winds on synoptic scales, which have large spatial structure extending far offshore (Fig.2). A similar sensitivity is found in the CFES simulation. On monthly timescales, the pattern of surface wind anomalies indicates a basin-scale weakening of the subtropical anticyclone. This also explains the high correspondence between equatorial westerlies and along-shore southerly wind anomalies seen in the composites (Fig.3).

Detailed examination of the CFES simulation suggests that pronounced warm events occur during periods when frequent northerly wind anomalies coincide with the arrival of downwelling Kelvin waves from the equatorial region. To track the evolution of Benguela Niños in CFES results, we plot composited monthly anomalies as longitude-time sections along the equator, averaged between 2°S – 2°N (Fig.3a), and latitude-time sections along the southwest African coast (Fig.3b), where only ocean points between the coast and 4° offshore are selected. Composite is made of 13 events for which SST anomalies in the AB1 region exceeded 2 standard deviations. Latitude-time sections of anomalous upper-ocean heat content (integrated from 0 to 150m

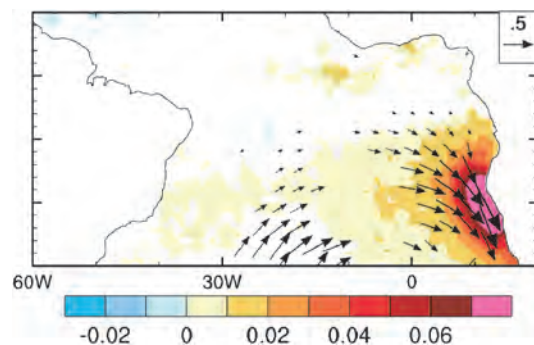


Fig. 2. Regression coefficients obtained by regressing the normalized AB1 index of daily mean AVHRR SST on SST tendency (shading; K/day), and QuikSCAT surface winds (vectors; m/s).

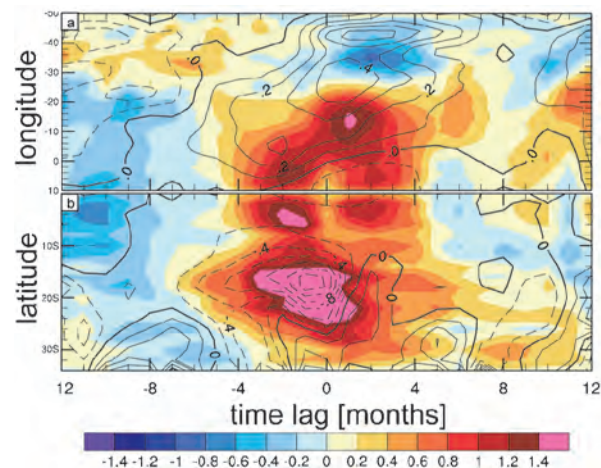


Fig. 3 Composite evolution of a Benguela Niño in the CFES simulation. Shading indicates SST anomalies (°C) while the contour lines indicate zonal wind anomalies (m/s) in the longitude-time section along the equator (a), and meridional wind anomalies (m/s) in the latitude-time section along the southwest African coast (b). Dashed contour lines indicate negative values. The longitude-time section is averaged between 2°S-2°N, the latitude time section is averaged between the coast and 4° offshore.

depth) and meridional wind stress (Fig.3b) indicate that there is a high degree of correspondence between these two fields along the southwestern African coast. Positive heat content anomalies appear 7 months before the peak of the composite event and are accompanied by northerly (downwelling favorable) surface wind anomalies. In the central and eastern equatorial Atlantic, on the other hand, positive heat content anomalies develop 1-2 months later and thus appear to be dynamically unrelated to the onset of the Benguela Niño. Subsequently, the equatorial warm anomalies propagate eastward and southward toward the AB1 region and likely strengthen the event.

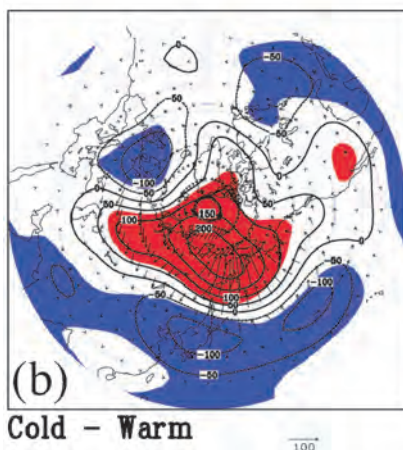
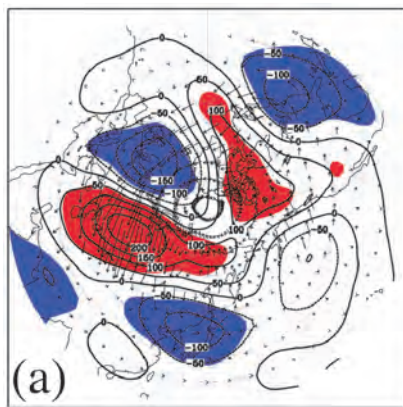
Besides its impact on the coastal ecosystem, Benguela Niños cause floods along the coast of Angola and Namibia, similar to the cases for El Niños that influence the neighboring regions of Pacific. Therefore, it is important to understand the formation and termination processes to develop an effective early warning system for Benguela Niños. Further analysis will be conducted to quantify the relative role of local and remote influences and to understand the origin of prolonged along-shore wind anomalies off the coast of southwest Africa.

Two Patterns of Cold Januaries in Japan

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

The East Asian winter monsoon has been known to play a crucial role in regional winter climate over the Far East, including Japan, and the North Pacific. Strengthening (weakening) of the East Asian winter monsoon at intraseasonal time scales causes abnormally cold (warm) winter conditions. At the same time, the East Asian winter monsoon also varies in strength at interannual time-scale. It has been shown that the interannual variability tends to be associated with circulation anomalies in the upper troposphere, although the winter monsoon activity itself is confined within the lower troposphere.

A composite analysis based on observational data over the recent 50-year period shows two typical patterns of height anomalies in the upper troposphere associated with the winter monsoon variability. In Fig. 4a,



as EU-like pattern). Interestingly, source regions of the wavy signature in the EU-like pattern may be found over the North American continent, implying concomitant occurrence of cold (warm) temperature anomalies over the Far East and the North America. In contrast to the EU-like pattern, a meridional dipole pattern similar to the West Pacific (WP) pattern can be found over the Far East region (hereafter cited as WP-like pattern) in Fig. 4b.

The variability of the atmospheric circulations may relate to modulations of planetary wave formations associated with a seasonal march to midwinter. Fig. 5 shows seasonal marches from December to January associated with the WP-like pattern and climatology. In the climatological seasonal march (Fig. 5c), geopotential height in the upper troposphere generally lowers since temperature in the lower troposphere also decreases toward midwinter. Decreasing tendencies are especially

Fig. 4. Composited height anomalies at the 250-hPa level in January based on the NCEP/NCAR reanalysis data. Height anomalies are obtained by subtracting composited height anomalies for warm Januaries over the Far East from those for cold Januaries. (a) Composite based on cold (warm) Januaries selected by strong negative (positive) anomalies of averaged surface temperature over the Far East (25-40N, 100-140E) and strong positive (negative) anomalies of averaged height at the 250-hPa level in (50-70N, 50-90E). (b) Same as (a) but for the temperature anomaly and averaged height anomalies in (60-80N, 90-180E). Height anomalies are contoured every 50m (dashed for negative). Red and blue shadings mean statistically significant region with 90% confidence level of the t-test. Arrows signify wave-activity flux which shows stationary Rossby wave propagation (Takaya and Nakamura 1997; 2001).

strong in the mid latitudes. They are, however, very weak in high latitudes, especially over the eastern Siberia and Alaska, and even a positive tendency can be found over the Bering Strait. Such an asymmetry in the height tendencies corresponds to evolutions or formations of the planetary waves; weak (strong) decreasing signals are associated with anticyclonic (cyclonic) tendencies, which tend to form ridges (troughs) of the planetary waves. In the seasonal marches in the WP-like patterns (Figs. 5a and 5b), anticyclonic tendencies over the eastern Siberia and Alaska region are strengthened (weakened) in cold (warm) Januaries. The seasonal marches in the WP-like patterns shown in Fig. 5 are consistent with the distributions of height anomalies in Fig. 4b. For the EU-like patterns, we can verify similar patterns of the seasonal march (not shown).

As shown above, we have found two typical patterns of the height anomalies associated with interannual variability of the East Asian winter monsoon, and they can be interpreted as modulations of the planetary wave formations. Further dynamical processes of the winter monsoon are now being investigated to prolong the predictability of the wintertime Far East climate.

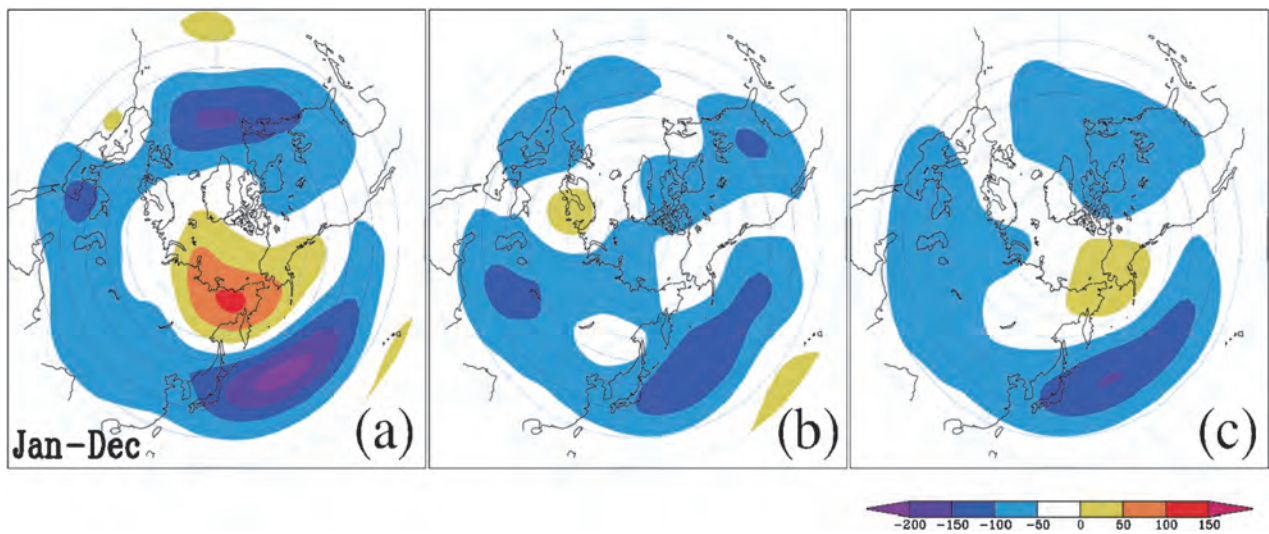


Fig. 5. Seasonal marches from December to January defined by subtracting total height fields at the 250-hPa level in December from those in January, (a) for cold and (b) warm Januaries over the Far East selected for Fig. 4b, and (c) for climatology. Shading convention for height tendencies (unit: m/month) are given below the panel (c).

Concurrent Simulation of Ocean Currents, Eddies, Tide, and River Discharge for Ocean Weather Predictions

-Ocean Downscaled Prediction Research Team-

Ocean downscaled prediction is one of the useful tools to investigate predictability of ‘ocean weather’, which includes oceanic phenomena in and around coastal regions with broad spatio-temporal scales. We have established a prediction system, using an ocean general circulation model (OGCM) with data assimilation schemes, that can simulate meso-scale eddies and current variations down to the time scale of O (10day) and the spatial scale of O (100km). However, possible effects of finer temporal and spatial scale phenomena such as tides and river discharges on the meso- and large-scale variations are still unclear, and concurrent simulations of ocean currents, eddies, tides, and river effects have been one of the challenging topics. In FY2010, we have developed a regional high-resolution ocean forecast system based on a tide-resolving OGCM with horizontal resolution of 1/36° (3 km) covering the Japan coastal ocean, from 28°N to 44°N and from 125°E to 148°E.

The astronomical tidal forcing is added in the model, together with the lateral boundary condition of tides from the recently developed barotropic tide model. Special numerical techniques for minimizing errors associated with the lateral boundary conditions from open ocean and barotropic tide models together with a reasonable representation of bottom dissipation due to the tidal currents allow us to simulate both the meso-scale phenomena and tides, as well as the large-scale circulations, stably and concurrently.

Five-day lead forecasts are updated daily using realistic wind and surface forcing obtained from the latest

available operational weather forecast data. Information of the observed meso-scale phenomena is introduced in the model by nudging the model variables toward the data assimilation products. In addition, this model includes lateral fresh water fluxes from more than 30 main rivers around the Japan coasts.

Fig. 6 compares modeled (red line) and observed (blue line) sea level variations at Miyake-jima Island south of Japan for the period from 20 May to 6 June 2010. The model well reproduced the observed sea level variations by adding the barotropic tidal effects on the Kuroshio path variations. For example, relatively low sea levels with small tidal variations during 20-22 May are in good agreement with the observation, while a simple barotropic tide model (green line) shows a significant bias. The effects of the fresh water fluxes from the river mouths are clearly visible in simulated sea surface salinity fields (Fig. 7). In particular, the fresh water distribution is significant in the Set Inland Sea in the western part of Japan and several low salinity patches can be seen around the coastal regions. The model can be used to investigate possible interactions between the fresh water and the salty water originated from the Kuroshio around this region.

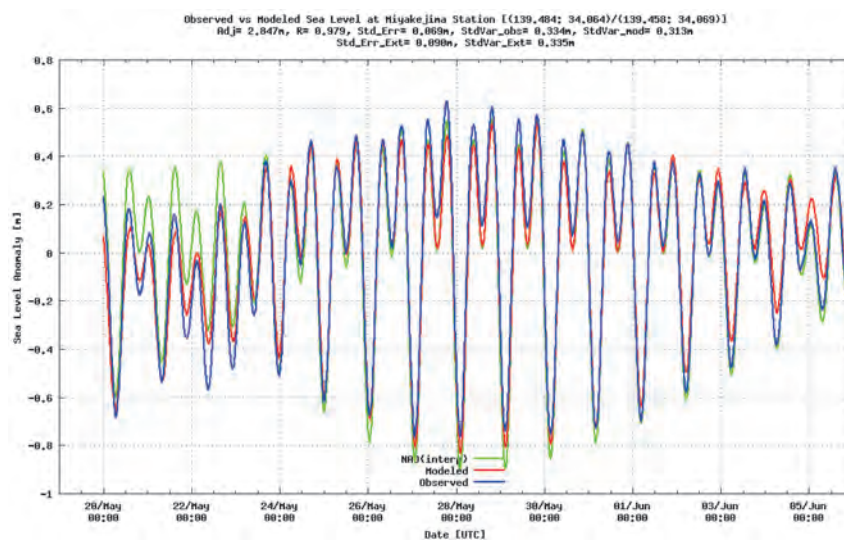


Fig. 6. Time series of modeled (red line) and observed (blue line) sea levels at the Miyakejima Island. A green line indicates the sea levels estimated using the barotropic tide model.

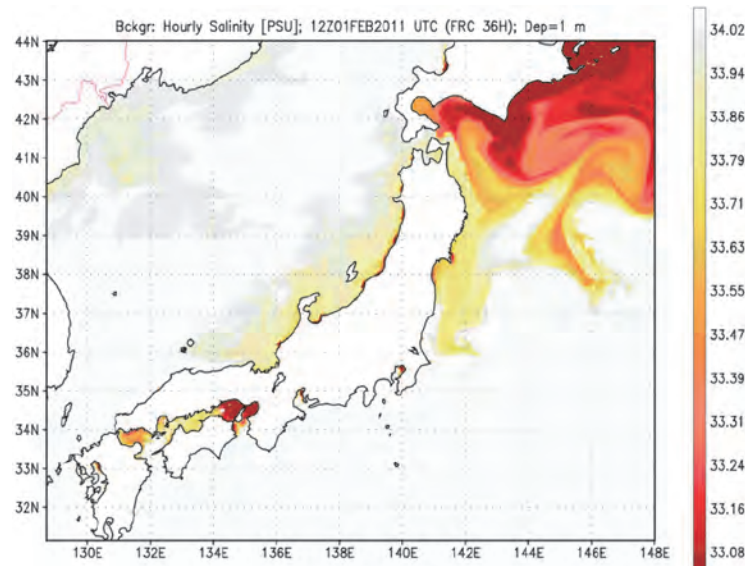


Fig. 7. Hourly snapshot of modeled sea surface salinity on 12Z, 1 February 2011.

Strong Impacts of SST Anomalies in the Vicinity of the Kuroshio and Oyashio on the Large-scale Atmospheric State

-Climate Variation Informatics Research Team-

Finding evidence of strong impacts exerted by SST anomalies along the Kuroshio and Oyashio on the large-scale atmospheric circulation has been a very challenging task in the past. We examined the ERA-40 reanalysis data and Hadley Centre SST data with a focus on the near-surface baroclinicity, Bx, and successfully found that SST anomalies along the Kuroshio and Oyashio do have strong impacts on the atmospheric circulations of the synoptic to planetary scales in some cases and that oceanic factors are likely to be important in these cases.

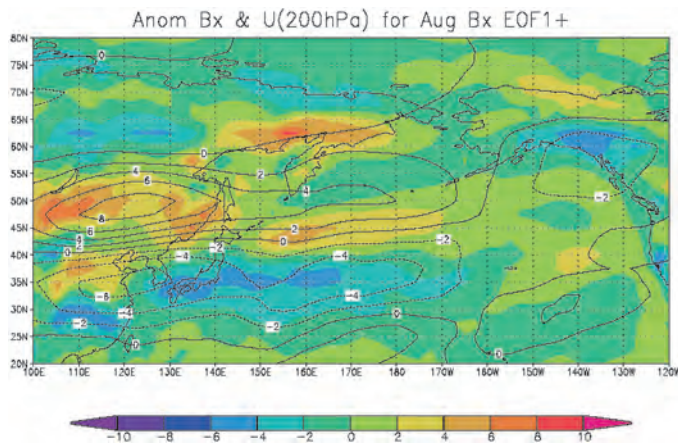


Fig. 8. Composited anomalies in the zonal wind at 200hPa (contours, in m/s) and Bx (color, /s) for the positive phase of the most dominant mode of Bx in August. Note that the band of large Bx shifts northward and is accompanied by a northward shift in the tropospheric jet. Anomalies in the synoptic-scale transient disturbances exhibit the same shift (not shown). The contour interval is 2.

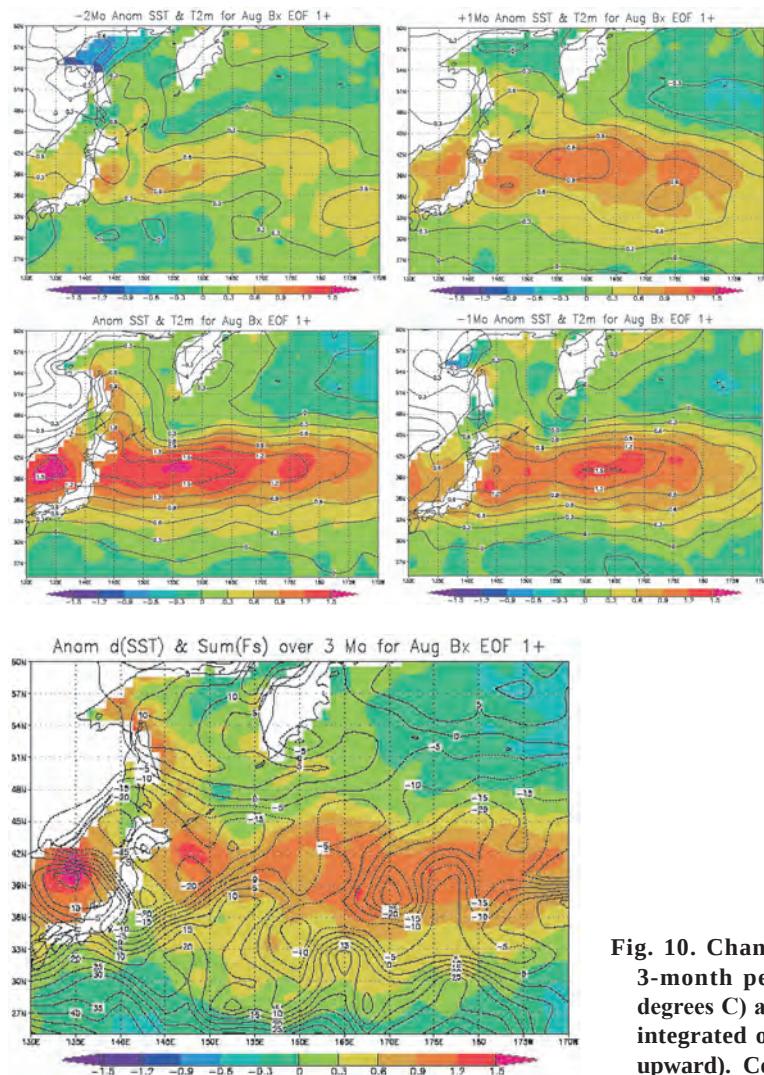


Fig. 9. Time series of composited anomalies in the SST (color, °C) and near-surface air temperature (contours, °C) for the positive phase of the most dominant mode of Bx in August. Top left: 2 Mo before (Jun). Top right: 1 Mo before (Jul). Bottom left: Mo 0 (Aug). Bottom right: 1 Mo after (Sep). The contour interval is 0.3.

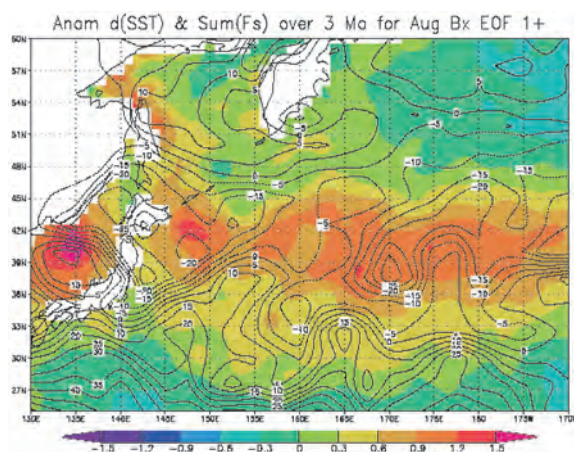


Fig. 10. Change in the composited anomalous SST over the 3-month period preceding the anomalous August (color, degrees C) and the composited anomalous net surface heat flux integrated over the same period (contours, W/m², positive upward). Contour interval is 5.

Unlike in the tropics, the large-scale extratropical atmospheric circulation is primarily driven by the large-scale available potential energy generated by the meridional temperature gradient. In the northern hemisphere, particularly strong westerly jets exist over areas of large Bx along the Kuroshio Extension/ Oyashio and Gulf Stream. We calculated the dominant modes of monthly Bx in these areas and examined the state of and the relationship between the atmosphere and oceans accompanying these modes by compositing various atmospheric fields, SST, and the net surface heat flux at the air-sea boundary. One of the first two dominant modes of Bx suggests a pattern of a meridional shift of the band of large Bx in the storm track, while the other suggests an increase or decrease in Bx in the band.

One of the most interesting findings from this study is the impact of SST anomalies in the vicinity of the Kuroshio Extension/Oyashio and Sea of Japan on the large-scale atmospheric circulations in July and August. Composited anomalies in the SST, near-surface temperature, Bx, tropospheric zonal wind, and synoptic-scale transient disturbances suggest that the SST anomalies modify Bx in such a way that the upper tropospheric jet shifts northward or southward, resulting in anomalous conditions throughout the troposphere (Fig.8).

When the time series of the anomalous SST, near-surface air temperature, and the net surface heat flux are examined, we find that SST anomalies begin developing in May or June and persist into September (Fig.9). Anomalous near-surface atmospheric temperature follows the anomalous SST very closely in July and August, reflecting the fact that the large-scale atmospheric advection plays less important roles in determining the near-surface temperature in the mid summer. The anomalous net surface heat flux does not clearly show one way or the other regarding the cause-effect relationship between the SST anomalies and atmospheric anomalies, except for September in which the oceanic anomalies are clearly forcing the atmosphere. Since the SST anomalies already exist in July, at least, the atmospheric anomalies found in the August composites are much more likely to be the products of the SST anomalies.

At the same time, when the change in the SST anomalies over the 3 months period preceding August is compared with the net surface heat flux anomalies integrated over the same period (Fig.10), a complex relationship between the atmosphere and ocean is suggested. Broadly speaking, the anomalous thermal forcing during the 3-month period suggests that both the atmosphere and ocean are playing important roles in generating the anomalous conditions in July and August. Further investigation is needed to understand the mechanisms that generate the anomalous summer in the region.

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I. Research Activities and Results

Climate Variation Predictability and Applicability Research Program

Miyazawa, Y. (2010), Wave forecast in the Indian Ocean, *Monthly Captain*, 399, 2-6 (in Japanese).

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Higher Resolution and Lower Uncertainty -Advanced Atmosphere-Ocean-Land Modeling Program-

To make adaptation strategies, we need to know how change in occurrence of heavy rainfall, typhoons and extremely high temperature events in nations, prefectures or even cities levels. However, considerable uncertainty still exists in weather forecasting and the prediction of climate change. For example, the cost of building a new dam for the adaptation to climate change is extremely high and it will take long term. This adaptation would be difficult if the uncertainty of the projection is too large. In addition, climate projections are spatially blurred because of low horizontal resolution of the climate models. This also makes difficult policy makers for prefectures and cities. They need more detail information for their regions.

The aim of this program is to contribute to the projection of global climate change as well as weather prediction using very high-resolution numerical atmospheric-ocean-land models. The higher spatial resolution often reduces the scientific uncertainty. In the atmosphere-ocean-land models so far, small-scale spatial variations and precipitation processes are simplified by the parameterizations. Very high spatial resolution models can reduce assumptions in the parameterizations. To achieve these objectives, six teams to work together. Below is a summary of the research plan for each team this year.

Global Cloud-Resolving Modeling Research Team studies reproducibility of the evolution of MJO using NICAM. They are going to participate Project Athena, which is an international collaboration deriving an utmost efficacy of high-resolution global climate modeling frameworks for seamless weather/climate research.

Advanced Ocean Modeling Research Team studies a new multi-category sea-ice model, which resolves ice thickness distribution. This new model is introduced into a coupled general circulation model, MIROC5, in order to discuss the performance of the multi-category sea-ice model.

Cloud, Precipitation and Radiation Process Research Team studies a new concept of the conditional instability: Instability of a Saturated Air Parcel in an Unsaturated Environment. This new criterion is assessed by observed temperature lapse rate in the tropics. This team also investigates seasonal variation in the ITCZ over Central Africa, which can be expected to have simpler mechanisms than those in other areas.

Land Surface Modeling Research Team investigates long-term hydrological responses using a hydrological model and a regional climate model in order to estimate the changes in river discharge by the effects of global climate change.

Regional Climate Modeling Research Team is developing a new regional climate model based on a global cloud-resolving model NICAM. The developing model allows a seamless nesting between the original NICAM and the regional NICAM with the same dynamical equation system and physics,

Tropical Atmosphere-Ocean Observation and Modeling Research Team intends to understand the genesis process of Typhoons. They study simulation of genesis process of the past observed Typhoon Fengshen (TY0806) using a global 3.5-km mesh NICAM in close collaboration with Global Cloud-resolving Modeling Research Team.

Project Athena: a first grand incentive to seamless weather/climate modeling -Global Cloud-Resolving Modeling Research Team-

Project Athena is an international collaboration deriving an utmost efficacy of high-resolution global climate modeling frameworks for seamless weather/climate research. The expected synergy would overlap with the research goal this team has been dedicated to since the development of the Nonhydrostatic Icosahedral Atmospheric Model (NICAM; *Satoh et al.* [2008], *Tomita and Satoh* [2004]). In this year, we participated in the Project, and compared results from 7-km mesh experiments of NICAM and 10-km mesh experiments of the Integrated Forecast System (IFS) of the European Centre for Medium-Range Weather Forecasts. Specific foci of the project include assessment of 1) the Intra-Seasonal Oscillation (ISO) such as Madden-Julian Oscillation (MJO), and 2) its relationship with tropical cyclones (TC) for boreal summers (21 May - 31 Jul) of 8 years (2001-2, 2004-9).

In the first month of simulation, both models capture the intra-seasonal oscillatory behavior of the

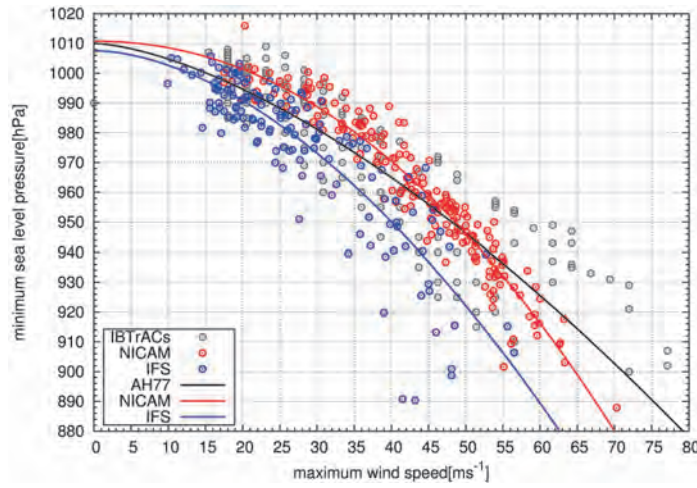


Fig. 1. Relationships between the minimum sea level pressure (MSLP) [hPa] and the maximum 10-m wind speed (MWS) [m s^{-1}] when a tropical cyclone has MSLP in the observations, IFS and NICAM simulations. Black solid line indicates the empirical relationship between MSLP and MWS [Atkinson and Holliday, 1977].

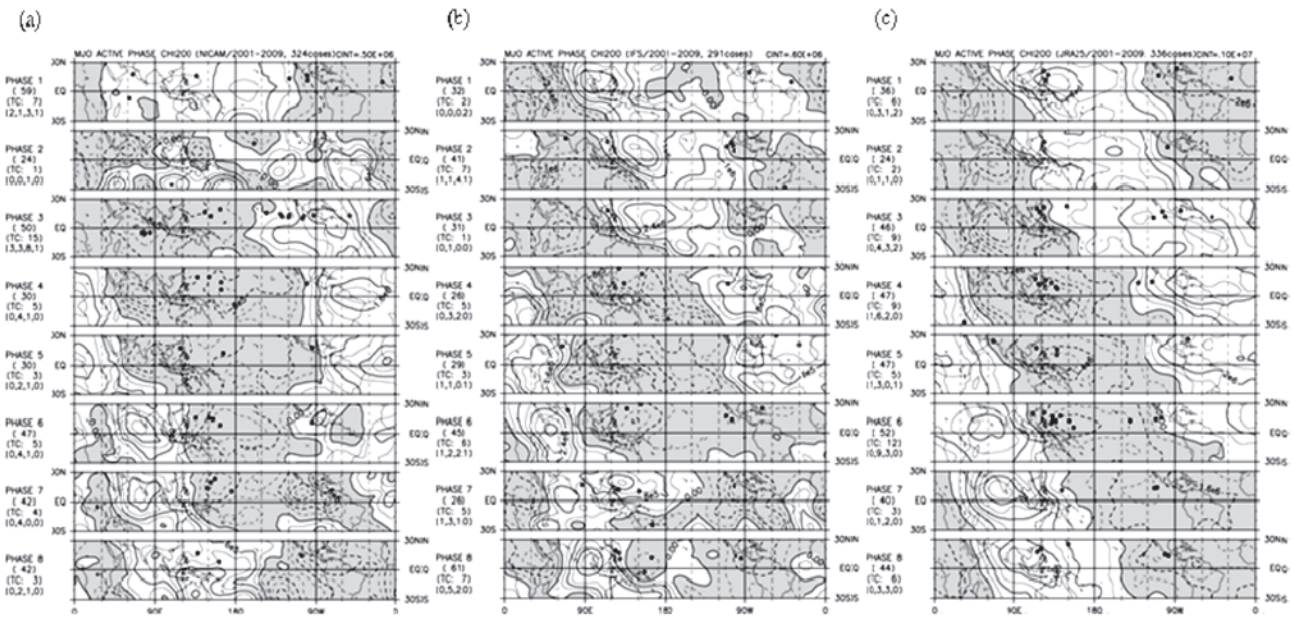


Fig. 2. Composite 200 hPa velocity potential anomalies (shading for negative values and solid contours for positive values) for each phase of the MJO for the MJO-active period defined in the same method as Taniguchi et al. [2010] for 21 May to 31 July 2001 to 2009 except 2003. (a) NICAM, (b) IFS (c) re-analysis by JRA/JCDAS. The total numbers of selected dates for the MJO-active period for figures (a), (b), and (c) are 318, 287, and 336 days, respectively. Contour intervals of (a), (b), and (c) are 0.5×10^6 , 0.8×10^6 , and 1.0×10^6 (m^2/s), respectively. Also plotted are the locations of TC genesis tracked in each phase (solid circles).

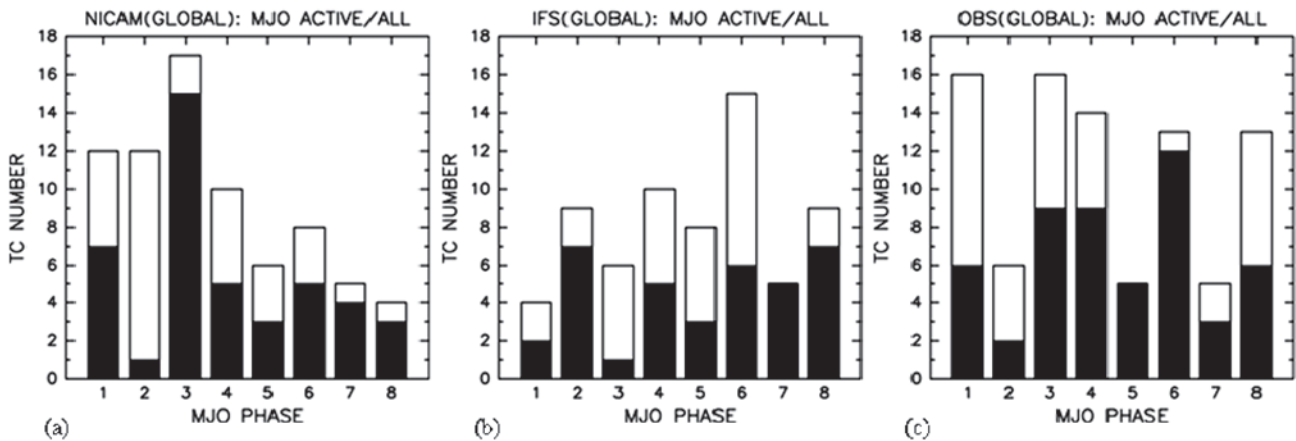


Fig. 3. The occurrence of TC genesis in each phase of the MJO during the period of 2001 to 2009 except 2003. Solid and open square bars indicate the occurrence for the MJO-active period, shown by solid circles in Fig. 15, and the occurrence for the whole period of MJO, respectively. (a) NICAM, (b) IFS, (c) IBTrACS.

Indian monsoon similar to the observed boreal summer ISO in some years. Both NICAM and IFS simulations capture the intensification and northward displacement of maximum westerly in the period corresponding to the Indian monsoon onset. IFS simulated horizontal pattern of precipitation (NW-SE oriented rain-band) and westerly centered at 20°E better than NICAM, whereas northward migration of westerly peak and precipitation at intra-seasonal timescale was better reproduced by NICAM. The IFS simulates the NW-SE-oriented rain-band and the westerly location better, while NICAM reproduces the northward migration of the westerly peak and precipitation well. A case study shows that the meso-scale convective systems embedded in ISO are well represented in NICAM, suggesting that the representation of the convective system can yield a better ISO simulation performance in global cloud-resolving model.

The reproducibility of the evolution of MJO depends on the given year; IFS simulates the MJO signal well for 2002, while NICAM simulates it well for 2006. An empirical orthogonal function analysis shows that both models statistically reproduce MJO signals similar to observations, with slightly better phase speed reproduced by NICAM. Stronger TCs are simulated in NICAM than in IFS, and NICAM shows a wind-pressure relation for TCs closer to observations (Fig. 1). TC cyclogenesis is active during MJO phases 3 and 4 in NICAM as in observations (Figs. 2, 3). The results show the potential of high-resolution global atmospheric models in reproducing some aspects of the relationship between MJO and TCs, and the reliable statistical behavior of TCs.

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An Advanced Ocean Model to Project Future Climate Change

-Advanced Ocean Modeling Research Team-

The mission of this team is to develop an advanced ocean model which has a capability to project future global climate change precisely. In the global climate system sea-ice plays a major role by various ways such as its high albedo, heat insulation effect, brine rejection and freshwater release. It is widely recognized that Arctic sea-ice extent has retreated rapidly in recent years [e.g., *Serreze et al.*, 2007]. We must understand the process of this decline to elucidate its impact on present and future climate systems. In order to tackle this topic, it is essentially important to improve a sea-ice component in a coupled climate model so as to realistically represent sea-ice processes.

A multi-category sea-ice model, which resolves ice thickness distribution in each model grid, has been developed and introduced into our ice-ocean coupled model COCO [Hasumi, 2006] until last year. Compared with a two-category sea-ice model, which assume that sea-ice in each grid has a uniform thickness, the multi-category model can represent subgrid-scale difference in air-sea heat exchange between thin and thick ice area. This new sea-ice model has now been introduced into MIROC5, the newest sion of a coupled model MIROC (Model for Interdisciplinary Research on Climate); using MIROC5, hindcast and forecast simulations for the fifth IPCC (Intergovernmental Panel on Climate Change) assessment report are now being performed.

We will show simulated Arctic sea-ice obtained from the hindcast simulations of twentieth-century climate (20C3M) by using MIROC5, and discuss the performance of the multi-category sea-ice model in the MIROC coupled model. The horizontal resolution of MIROC5 is T85, approximately 1.4 degrees in longitude-

I. Research Activities and Results

Advanced Atmosphere-Ocean-Land Modeling Program

latitude, for the atmospheric component, and 1.4 degrees in longitude and 0.5-1.4 degrees in latitude for the oceanic and sea-ice component. The initial conditions are taken from a control experiment under 1850 condition. External forcings such as the solar irradiance, greenhouse gasses, and aerosols are given as the boundary condition. Three-member ensemble simulations are performed for the 20C3M runs, and all the results shown below are ensemble means of these members.

Figure 4 depicts climatology of sea-ice concentration for the 20C3M experiments in March and September. Ice edges obtained from satellite observations (defined as a concentration of 0.15) are also shown. The climatology of the model is defined as the monthly mean of the period 1979-1999, for which the SMMR and SSM/I satellite data are available. In winter (Figure 4(a)), the ice edge agrees well with the observation except in the Gulf of Saint Lawrence and off Newfoundland where almost no ice was found in MIROC5. The MIROC5 summer ice-edge also resembles that of the observation as a whole, except too much ice in the Kara Sea and Barents Sea (Figure 4(b)). The annual cycle of the ice area (figure not shown) indicates that the difference in ice area between winter and summer is consistent with the observation except the impact of the mid-latitude bias in winter. These results show that MIROC5 successfully reproduces the northern hemisphere sea-ice extent, especially in the Arctic Ocean.

Figure 5 depicts climatology of Arctic sea-ice thickness for the 20C3M experiments in March and September. Because of difficulty in observing the ice thickness, the horizontal distribution of sea-ice thickness is not well known. However, some observations from submarines [e.g., *Laxon et al.*, 2003] showed that the thickest ice is found along the Canadian Archipelago and the northern coast of Greenland. The sea-ice thickness of MIROC5 also shows maxima in these areas. *Rothrock et al.* [2008] estimated the annual mean ice thickness

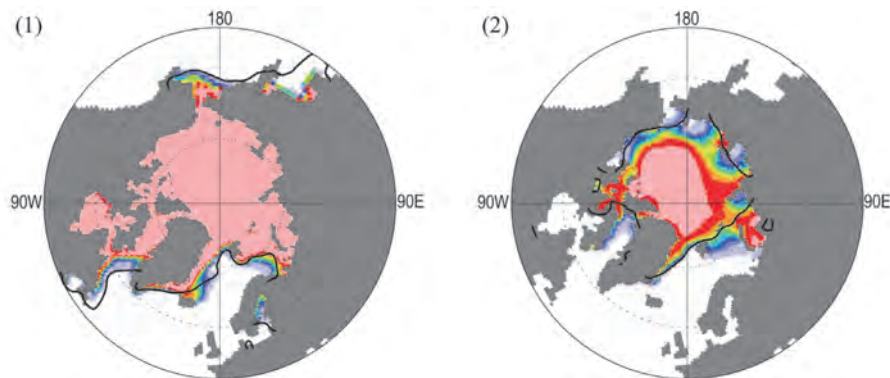


Fig. 4. Monthly sea-ice concentration in the Northern Hemisphere for MIROC5, averaged over 1979-1999. Thick lines indicate concentrations of 0.15 in satellite data. (1) March, (2) September.

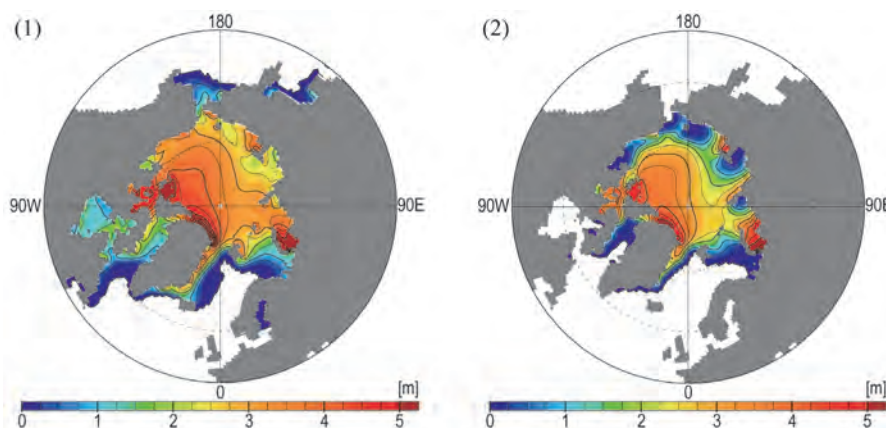


Fig. 5. Grid-averaged sea-ice thickness for MIROC5 averaged over 1979-1999 in the Northern Hemisphere. (1) March, (2) September. Units are m. Contour interval is 0.5 m. Note that open ocean is included in calculating the grid-averaged thickness.

between 1975 and 2000 on an area covering the central part of the Arctic Ocean (known as the “SCICEX box”); their estimated thickness was 3.21 m. In MIROC5, the annual mean thickness calculated on the same region is fairly close to this estimate, with a value of 3.27 m. Thus, the MIROC5 Arctic ice thickness is well reproduced, as far as we can compare with the observational data.

We have also performed the 20C3M hindcast experiments by using another version of MIROC, MIROC4h. MIROC4h has higher horizontal resolution than that for MIROC5, but its sea-ice component is a two-category model. In MIROC4h, the annual mean ice thickness on the SCICEX box is 1.47 m, which is too thin compared with the observation. One of the reasons for the difference in the ice thickness between MIROC5 and MIROC4h is the difference in the sea-ice model. Our study in the last year showed that the multi-category sea-ice model allowed large heat exchange in a subgrid-scale thin ice region and resultant large ice formation there. Therefore, the sophisticated sea-ice treatment in MIROC5 is suggested to contribute the reproduction of the thick and realistic Arctic sea-ice.

Vertical Moist Stability and Its Relation to the ITCZ -Cloud, Precipitation, and Radiation Process Research Team-

The purpose of this team is to improve physical process models related to clouds, precipitation, and radiation. For this purpose, we have developed several models. To validate the results of these numerical models, we also perform observational investigations of meteorological phenomena related to moist convection. Two of the topics related to vertical moist stability are reported here.

Reconsideration of Conditional Instability: Instability of a Saturated Air Parcel in an Unsaturated Environment

The static stability of an atmospheric layer is determined from its temperature lapse rate, if we can ignore the effect of water on density. A layer is said to be conditionally unstable when the temperature lapse rate lies between the moist and dry adiabatic lapse rates. The “conditionally unstable state” is often explained as a state in which a parcel is stable if unsaturated, and unstable if saturated. However, the criteria used in the definition (i.e., the dry and moist adiabatic lapse rates) can be used only for the instability criteria of an air parcel with the same physical properties as its environment. Therefore, neither criterion should be used as the instability criterion for a saturated air parcel in an unsaturated environment. The static stability can be determined from the manner in which the virtual temperature (or density) of a parcel having the same virtual temperature as its environment changes with height, compared with the change in its surroundings. By considering the lapse rate of virtual temperature in a moist adiabatic process, we can find that the lapse rate of temperature for the criterion is larger than the standard moist adiabatic temperature lapse rate by about 20% of the difference between the dry and moist adiabatic lapse rates.

This newly obtained criterion was used to examine the frequency distribution of the sonde-observed temperature lapse rate in the tropics. We found that the maximum frequency of stability occurs at neutral

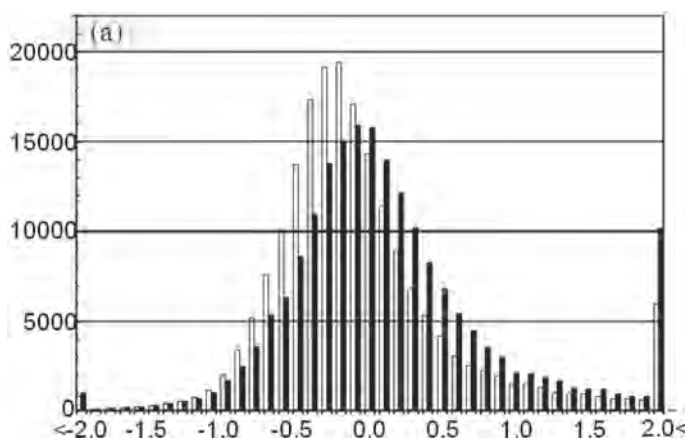


Fig. 6. Frequency distribution of the sonde-observed non-dimensionalized temperature lapse rate in the tropics in 2009. The results for relative humidity of < 95% are shown. The data are non-dimensionalized using the dry and moist adiabatic lapse rates (white bars) and the new criterion (black bars). On the horizontal axis, 0.0 indicates neutral stratification, i.e., moist adiabatic stratification for the black bars, and -1.0 indicates dry adiabatic stratification.

stratification and that about half of all the results are unstable if we consider the stability for a saturated air parcel in an unsaturated environment.

Seasonal Variation in the ITCZ and Its Characteristics o Central Africa

The Intertropical Congence Zone (ITCZ) is the most prominent meteorological phenomenon in the tropics and appears at the ascending branch of atmospheric Hadley cells. We investigated the seasonal march of the ITCZ shown by 22 coupled general circulation models of the 20th Century Climate in Coupled Models experiment in seven regions: Africa, Indian Ocean, western Pacific, central Pacific, eastern Pacific, South America, and Atlantic Ocean. The intermodel differences in the seasonal march of the ITCZ o Africa (10–40°E) were significantly smaller than those o other regions. This indicates that the seasonal march of the ITCZ o Africa is insensitive to differences in model physics and resolution and suggests that robust, simple mechanisms control the seasonal march of the African ITCZ. Motivated by this result, we tried to understand the process of the seasonal march of the ITCZ o central Africa (15–30°E) based on an analysis of European Centre for Medium-Range Weather Forecasts 40-year reanalysis (ERA-40) data. The analysis revealed the following features of the ITCZ in this region: (1) the ITCZ itself produces large convective available potential energy that generates deep convection; (2) the abundant water vapor within the ITCZ is maintained by horizontal moisture flux; (3) shallow convection exists outside, but near, the ITCZ, and may act to pre-moisten deep convection in spring and autumn; and (4) the seasonal change in the ITCZ is preceded by a change in the tical moist instability in the lower free atmosphere caused by the seasonal change in insolation.

In this study, we introduce $-\partial h/\partial p/c_p$ as an indicator of the tical moist stability (VMS), namely, the convective stability [Ninomiya *et al.*, 2002; Suzuki *et al.*, 2008]. Here, h is the moist static energy, and c_p is the specific heat of air at a constant pressure. Figure 7 shows the seasonal march of the VMS in the layer between 600 and 850 hPa (contour), aaged from 15° to 30°E. A negative (positive) value of the VMS means convectively unstable (stable) stratification. O the ITCZ region, the VMS was negative, and the VMS near the ITCZ border was relatively more negative than that around the center of the ITCZ. The minimum VMS appeared at the southern border of the ITCZ from September to March throughout boreal winter. During April and May, the minimum existed at the northern border of the ITCZ. From June to August, the VMS minimum existed at the northern border of the ITCZ, but the minimum value of the VMS in these months was larger (i.e., less negative) than that in other months. From September to December and during April and May, the latitude of the VMS minimum preceded that of the large precipitation area. Therefore, the VMS of the lower free atmosphere might link the seasonal march of the ITCZ to that of insolation.

ERA40 ann cycle ave(1979–1998)

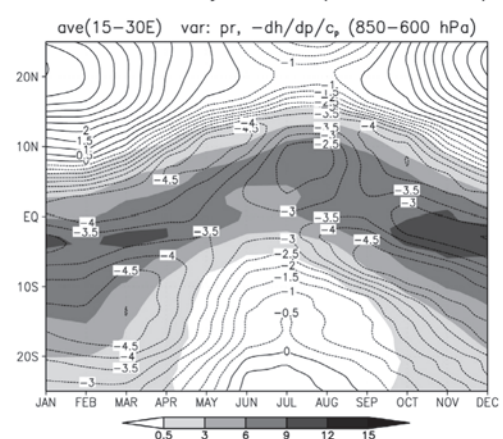


Fig. 7 Time–latitude diagram of the precipitation (shading, mm day^{−1}) and tical moist stability $-\partial h/\partial p/c_p$ calculated for the layer between 600 and 850 hPa [contour, K (100 hPa)^{−1}] aaged o central Africa (15 – 30°E) in the period from 1979 to 1998 using ERA-40 data.

Linkage of Regional Climate Model and Hydrological Model in a Snowfall Area -Land Surface Modeling Research Team-

Climate change is having a conspicuous effect on Japan. In particular, the Japan Meteorological Agency (2002) has reported that snowfall amounts have fallen sharply along Japan’s eastern seaboard since the mid-1980s, resulting in a noticeable decrease in ri discharge in this region in spring. To clarify the possible effects of climate change on water resources, quantitative analysis is required. Such analysis requires information on changes in ri discharge determined from both observation and simulation. Hydrological simulations of ris generally use data obtained from ground-based meteorological stations. The distribution and density of meteorological stations affect

the accuracy of such hydrological modeling, especially for large river basins. In recent years, a downscaling method that links atmospheric and hydrological models has been developed for hydrological simulations. In this study, we examined the projections of a regional climate model used to investigate long-term hydrological responses using a hydrological model. We used the Weather Research and Forecasting (WRF) model with dynamic downscaling to simulate input variables for the Soil-Vegetation-Atmosphere Transfer and Hydrological Cycle (SVAT&HYCY) model. The study site was the Agano River basin, an area in Japan that receives heavy snowfall, located in the Hokuriku region. Model runs over a 20-year period were conducted, and the output hydrographs were compared with observational data. We then examined the effects of global warming on the hydrological processes of the Agano River basin using the pseudo-global-warming (PGW) method.

We used the Advanced Research WRF (ARW) core version 2.2 with a two-way nesting technique and the WRF single-moment 6-class microphysics scheme. The parent domain was set to a wide area on a 20-km grid. The inner domain was located in a smaller area with a 5-km grid (Figure 8a). We conducted two numerical experiments. One was the hindcast run (CTL) used to reproduce past hydrological events of the 1980s and 1990s. The other was a PGW run used to project the hydrological response in the 2070s. The National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) 6-hourly reanalysis data was used as the lateral boundary condition for the CTL. For the PGW, the lateral boundary condition was adopted. A global warming component was added to the NCEP/NCAR reanalysis data for the 1990s. Global warming components were estimated as the monthly temperature difference between the 10-year average of the 21st century projection, based on scenario A2 of the Special Report on Emissions Scenarios (SRES-A2) from 2071 to 2080, and the 20th century simulation from 1991 to 2000, from version 3.2 of the Model for Interdisciplinary Research on Climate (MIROC) (medium, approximately 300 km, T42), an atmosphere-ocean coupled general circulation model. The PGW method allows for the comparison of climate in the present year and that in a PGW year that is similar to the control year in terms of interannual variation while including future climatology. Therefore, by the PGW method, we could evaluate the river discharge under a future climate. The output variables from the WRF model were (1) downward longwave flux at the ground surface, (2) downward shortwave flux at the ground surface, (3) surface air pressure, (4) water vapor mixing ratio at 2 m height, (5) accumulated total grid-scale precipitation, (6) surface air temperature (SAT), and (7) wind speed at 10 m height. The river network was constructed using the GTOPO30 dataset with 0.05° resolution (Figure 8b). The velocity of

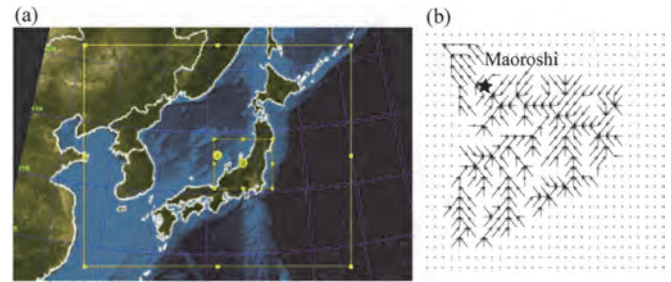


Fig. 8. Domain of the WRF model (a): ① center of the parent domain (20-km grid); ② center of the inner domain (5-km grid). River network of the Agano River basin (b).

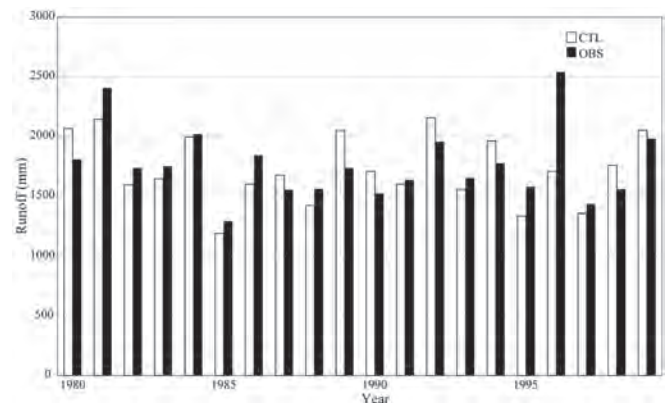


Fig. 9. Comparison of annual runoff between the simulation (CTL) and observations (OBS) at Maoroshi.

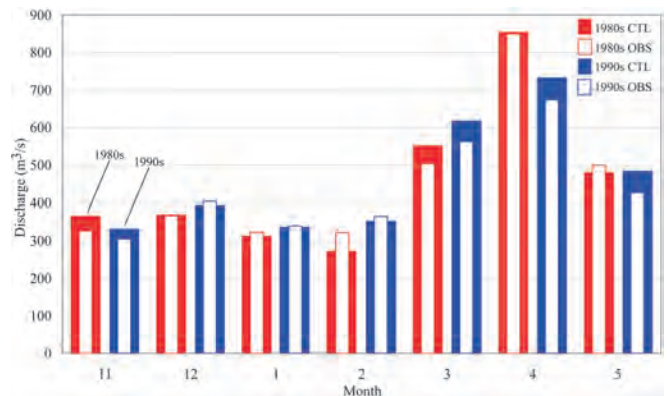


Fig. 10. Comparison of 10-year average monthly mean discharge between the simulation (CTL) and observations (OBS) in the 1980s and 1990s at Maoroshi.

the ri flow was set at 0.7 m/s, in consideration of the mountainous topography. The amount of discharge measured at Maoroshi until 2003 is available from the Japan Ri Association. To confirm the performance of the hydrological model, we ran it for a 20-year experiment period from July 1979 to June 1999. The WRF model was run per year, from June 28 of this year to July 1 of the next year. We did not consider the effect of dams in this study because many dams along the ri are used to operate with high water levels for hydroelectric power generation. We only focused on the relative evaluation of interannual variation, which is greatly influenced by climate factors in the monthly mean discharge.

Figure 9 shows the annual runoff from 1980 to 1999. Simulated annual runoff roughly corresponded to observed values throughout the two decades with the exception of 1996. The simulated interannual variation of annual mean runoff correlated well with the observed data, though the estimated precipitation was oestimated compared to some of the station data. The time series correlation was significant, with a significant level of 95% (0.62 in correlation coefficient). Figure 10 shows the monthly mean discharge in winter from November to May. Although there was no significant difference between the simulation and observation, it is more important to examine the correlation rather than the comparison in absolute values because of human impact. For example, the water controlled by dams was not considered in this study. The correlation coefficient for the monthly mean discharge in aage was 0.79 with a range from 0.66 in December to 0.84 in February. The correlation coefficient was 0.79, 0.75 and 0.83 in March, April and May, respectively. The aage of these time series did not have a significant difference, with a significance level of 5%. It suggests that interannual variation is greatly influenced by the climate factor. The calculated monthly mean discharge in April in the 1990s decreased 16.6% compared with that of the 1980s. As Figure 10 demonstrated, the seasonal variation of ri runoffs during the period is well reproduced in the hydrological model without dam operations, confirming that the effect of the dam operation is minor during the simulated season. Therefore, it is considered that the model is appropriate for studying climate change impact, especially during the winter season. The monthly mean discharge in the 1990s and that under the PGW in the 2070s are shown in Figure 11. The figure presents a clear increase in discharge from 340 to 486 m³/s (43%) in January and from 365 to 565 m³/s (55%) in February. Howe, discharge decreases are shown in both April (from 674 to 417 m³/s, 38%) and May (from 427 to 292 m³/s, 32%). In the 2070s, the flood peak is projected to occur one month earlier, in March rather than April. There was little change between July and November, and in general, the annual mean changes of runoff between the 1990s and 2070s runs were small. This suggests that the total precipitation change between the 1990s and 2070s runs was small. Under global warming, the discharge change is mainly caused by the phase change of precipitation and earlier snowmelt due to increased SAT. The 10-

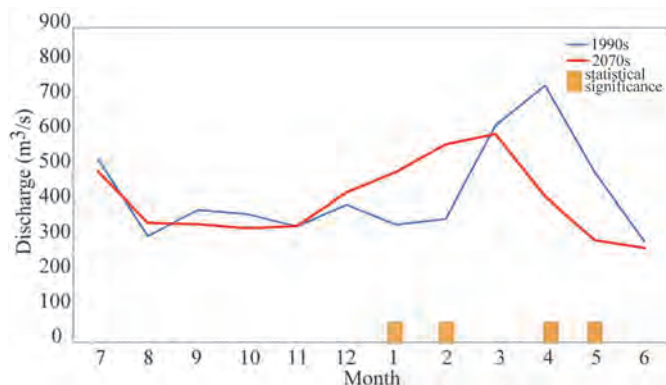


Fig. 11. Monthly hydrographs of the CTL simulation in the 1990s, and the PGW simulation in the 2070s at Maoroshi.

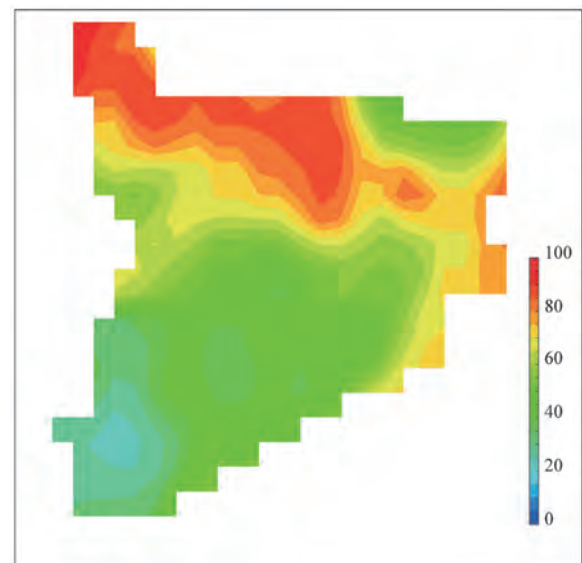


Fig. 12. Distribution of the decrease ratio (percentage) of the 10-year aage snowfall amount in the PGW run compared with the CTL run o the basin.

year age annual precipitation of 2,243 mm in the 1990s run increased by approximately 80 mm (3.6%) to 2,323 mm in the 2070s run. However, the amount of snowfall showed a marked decrease. The 10-year age annual amount of snowfall in the 1990s run was 507 mm, which decreased to 251 mm in the 2070s run, representing a basin-wide reduction of 49.5%. Figure 12 shows the distribution of snowfall decrease across the basin. The snowfall decreased by more than 20% (ranging from 23% to 95%). Particularly large snowfall reductions of more than 80% are shown in the downstream region, mostly because the PGW model projected no snow there. The changes of all grids of the basin were significant by t-test with the significance level of 5%.

Developing a Regional Climate Model Based on Global Cloud Resolving Model, NICAM -Regional Climate Modeling Research Team-

A new regional climate model is developing based on a global cloud-resolving model NICAM that has been developing in cooperation with RIGC, JAMSTEC and AORI, University of Tokyo [Sato *et al.*, 2008]. Applicable domain of the new regional climate model consists of one diamond of NICAM, while the original NICAM global domain is coded by ten diamonds; namely, twenty triangles of an icosahedron (Fig. 13). This approach brings following advantages to developers and users.

- (i) Sharing software framework between the original NICAM and the regional NICAM,
- (ii) Allowing seamless nesting between the original NICAM and the regional NICAM with the same dynamical equation system and physics,

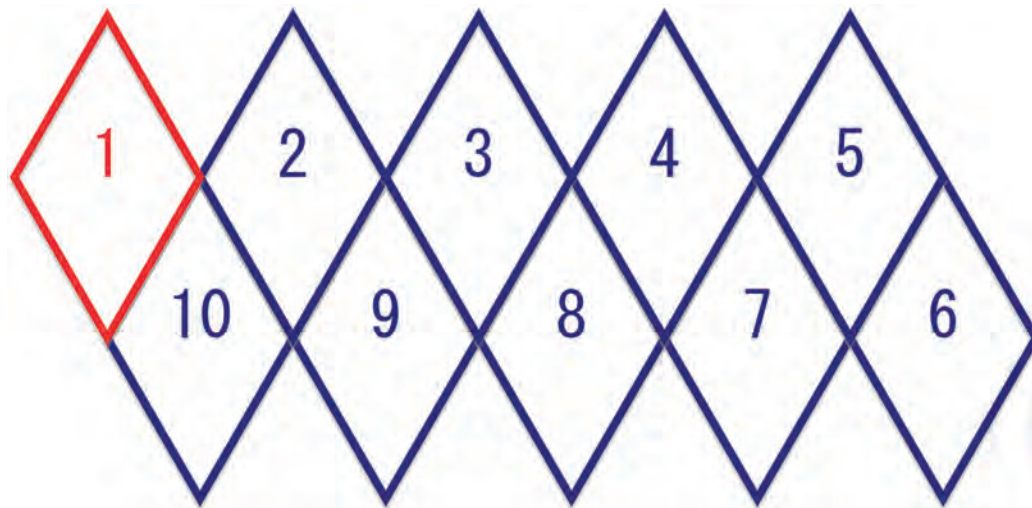


Fig. 13. Conceptual figure of icosahedral grid of NICAM. Global domain is consistent with ten diamonds (red and blue diamonds). Red diamond indicates a domain of regional NICAM.

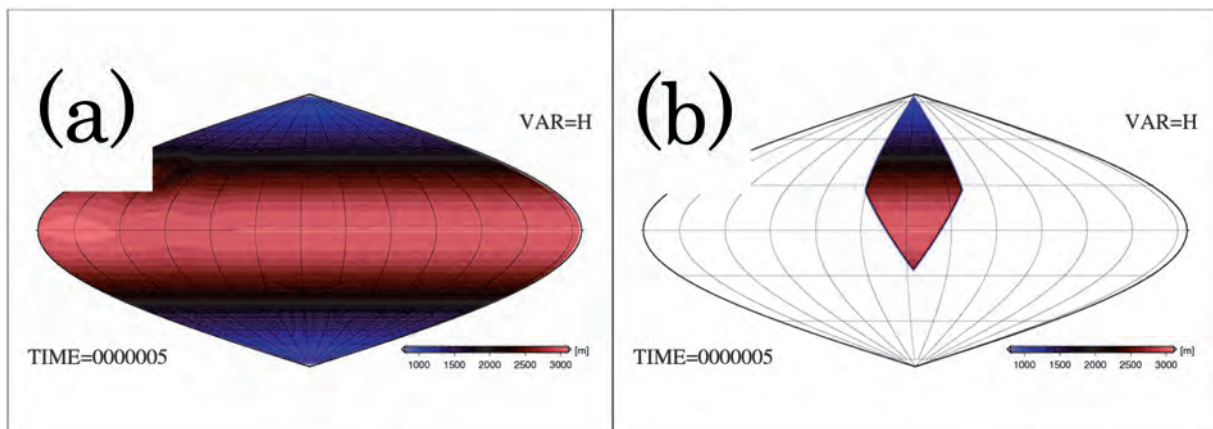


Fig. 14. Shallow water model experiment with (a) global and (b) regional domains.

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- (iii) Making easy to share the basic data such as geographical information between them, which makes easy to perform simulation together.
- (iv) Sharing highly vectorized and/or parallelized source code with the original NICAM.

The original NICAM has an alternative option to simulate regional domain, i.e., the stretching grid system, which allows to concentrate the grid mesh onto an interested area [Tomita, 2008]. The regional NICAM can perform simulations much more efficiently than the original NICAM using the stretched grid system.

In developing the regional NICAM, the framework of the original NICAM (was also) modified, such as dynamically allocated arrays, communication pattern for message passing interface, handling of halo regions, and a new nudging scheme.

For the validation of the modified model, we applied a shallow water equation system model (hereafter SWM) [Tomita *et al.*, 2001] that has the same framework with the original NICAM.

The results of the test bed simulations proposed by Jakob *et al.* [1993] have complete agreement between the newly implemented regional SWM and the original global SWM (Fig. 14). After the validation of the SWM simulation, we are implementing some modification to the original NICAM in order to complete the regional climate model.

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Progress in Joint Research of Tropical Field Observation and Global Cloud-Resolving Simulation

-Tropical Atmosphere-Ocean Observation and Modeling Research Team-

The objective of this research team is to accelerate the understanding of the mechanisms of tropical atmosphere-ocean variabilities by tight collaboration between observation and modeling research activity in RIGC. Global cloud resolving simulations and in-situ field observations have unique advantage in the study of planetary-scale intra-seasonal variabilities (ISV) or Madden-Julian Oscillation (MJO), in which multi-scale and multi-physics interactions are pronounced.

In the FY2009, preparatory study of global cloud resolving simulation of Typhoon Fengshen (TY0806), the genesis process of which had been observed in the field campaign, Pacific Area Long-term Atmospheric observation for Understanding of climate change (PALAU) 2008 by Tropical Climate Variability Research Program Intra-seasonal Variations and Related Phenomena Research Team, have been conducted [The FY2009 Annual Report]. In the FY2010, a 10-day simulation of Fengshen using a global 3.5-km mesh NICAM has been executed in close collaboration with Global Cloud-resolving Modeling Research Team.

The 3.5-km mesh simulation well reproduced large-scale (Fig. 15) and mesoscale (Fig. 16a, b) distributions of clouds in the genesis stage of Fengshen. The simulation also well captured westerlies in the lower troposphere which forms a part of monsoon circulation and intensification of the westerlies in the western Pacific region associated with an ISV event (not shown). The simulated development of upright deep circulation of Fengshen (Fig. 16c, d) was in good agreement with in-situ observations. Detailed analysis of the observation and simulation data revealed that (1) the incipient convective vortex in the lower troposphere had originated from

westward propagating tropical wave disturbances and (2) the rapid intensification of Fengshen occurred when a mesoscale convective system accompanied by middle tropospheric vortex merged with the incipient vortex [Nasuno *et al.*, 2011; Yamada *et al.* 2011]. Fengshen is known as the case subject to significant errors in operational track forecasting. In FY2009, impact of turbulent scheme on the simulated track of Fengshen was investigated by the sensitivity experiments with 14-km mesh [The FY2009 Annual Report]. It is noteworthy that the 3.5-km mesh simulation better reproduced the typhoon track even with the standard setting of the turbulent mixing. These results suggest potential ability of high-resolution models to improve prediction of structure, development, and track of typhoons. This study also contributes to an international research project, Year of Tropical Convection (YOTC, May 2008-April 2010, <http://www.ucar.edu/yotc/index.html>) [Satoh *et al.*, 2011].

In the FY2010, we have created another branch of observation-modeling collaboration in the field campaign PALAU2010 (May-June, 2010). The domain and the intensive observation period was very close to those of PALAU2008, and at this time near-real-time forecasts using the regionally stretched version of NICAM [Tomita 2008] have been operated to assist the field experiment [Oouchi *et al.*, 2012]. Week-long forecasts have been routinely run on a PC cluster system (Fig. 17a) three times a week, and forecast products were released via internet and e-mail. Interestingly, the convective activity of the western Pacific region in 2010 was in clear contrast to those in 2008, and weak long-lived convective vortices have been successfully captured by the aircraft observation. The forecast products (Fig. 17b) had been used to determine the flight schedule. In the FY2011, the forecast system is upgraded for the use in the international field campaign Cooperative Indian Ocean experiment on intraseasonal variability in the Year 2011 (CINDY2011), which is led by Tropical Climate Variability Research Program MJO research team in RIGC.

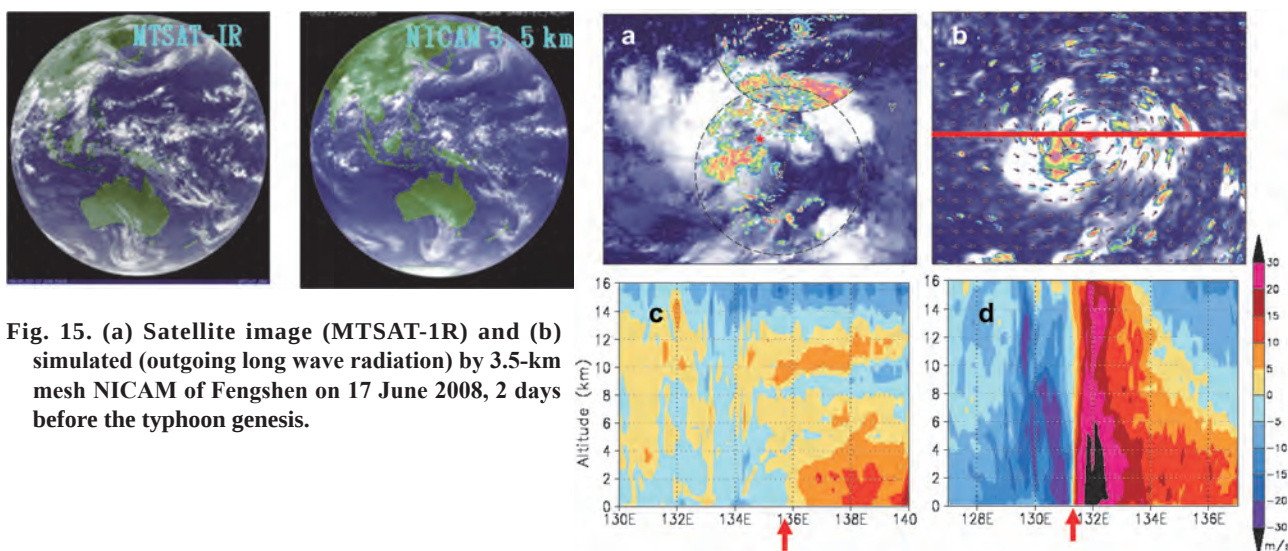


Fig. 15. (a) Satellite image (MTSAT-1R) and (b) simulated (outgoing long wave radiation) by 3.5-km mesh NICAM of Fengshen on 17 June 2008, 2 days before the typhoon genesis.

Fig. 16. Horizontal distribution of (a) MTSAT-1R (white) and radar echo (color) and (b) simulated outgoing long-wave radiation (OLR, white) and surface precipitation (color) in the 3.5-km mesh simulation at 00UTC 17 June 2008. Simulated vertical section of meridional wind along 9.5°N (red line in [b]) at (c) 00UTC 17 June and (d) 00UTC 19 June 2008. Red arrows in (c) and (d) indicate the center of the vortex.

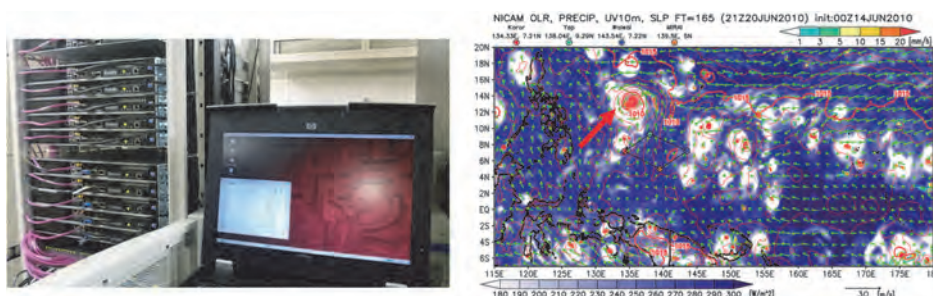


Fig. 17. (a) PC cluster system for the realtime forecast using the regionally stretched NICAM. (b) forecast image of outgoing long wave radiation (white), precipitation (color), and vorticity at 850 hPa (red lines) on 20 June 2010. The red arrow indicates the predicted convective vortex.

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Oouchi, K. (2011), Tropical cyclone (genesis, development, general characteristics, disaster and climate issues), *Earth Environment - Observation and Prediction*, Asakura-Syoten, (Eds. M. Yoshizaki et al.), (in Japanese).

II. Related Activities

Research collaboration

1. Domestic research collaboration

(1) Meteorological Research Institute (MRI), Japan Meteorological Agency (JMA)

Theme:

- Global Cloud Resolving Model Simulations toward Numerical Weather Forecasting in the Tropics:
Validation of Cloud Resolving Model by Satellite Data
- Hygroscopic Seeding Experiments by using Dynamic Cloud Chamber and Detailed Cloud Microphysics Box Model
- Estimation of Future Snow for Adaptation to Climate Change in the Coastal Area of the Sea of Japan
Program: Advanced Atmosphere-Ocean-Land Modeling Program
- Study on High-Accurate Measurement of Dissolved Matters in Intermediate and Deep Layers of the Ocean
Program: Ocean Climate Change Research Program
- Collaborative Study on Estimate Accuracy of Precipitation over Tropical Indian and Western Pacific Oceans with the Cloud-Resolving Model
- Study on the Impacts of Tropical Surface Buoy Array Data to the Ocean Data Assimilation and Coupled Atmosphere-Ocean Model Forecast
Program: Tropical Climate Variability Research Program

(2) Japan Aerospace Exploration Agency (JAXA)

Theme:

- Development and Usage of a semi-real Time Sea-Ice/Atmospheric Data Transmission System in Support of the Arctic Cruises
Program: Northern Hemisphere Cryosphere Program
- Biomass Mapping by ALOS/PALSAR over Boreal Forest in Alaska accompanied with Ground-based Forest Survey
- Study on the Terrestrial Ecosystem Variability by SGLI Accompanied with Field Survey
- Biomass Mapping by ALOS/PALSAR over Forests in Different Climate Zones
Program: Environmental Biogeochemical Cycle Research Program

(3) Snow and Ice Research Center, National Research Institute for Earth Science and Disaster Prevention (NIED)

Theme:

- Snowmelt Floods in the Permafrost Watersheds under Climate Change
Program: Global Change Projection Research Program
- Modeling Deposition, Erosion and Sublimation Processes in Blowing Snow
Program: Northern Hemisphere Cryosphere Program

(4) National Institute of Radiological Sciences (NIRS)

Theme: Study on Advanced Analytical Method to Estimate the Marine Biogenic Fluxes
Program: Environmental Biogeochemical Cycle Research Program

(5) National Institute of Advanced Industrial Science and Technology (AIST)

Theme: Study on Production of Certified Reference Material for Nutrients
Program: Ocean Climate Change Research Program

II. Related Activities

Research collaboration

(6) Fisheries Research Agency

Theme:

- Improvement of the Ocean Forecast Systems coupled with Fishes Transportation Models for Predictions of Oceanic Conditions Associated with Fishing Grounds and Fisheries Resources
- Variability in the Kuroshio and Kuroshio Extension System and its Influence in a High Resolution Ocean General Circulation Model

Program: Climate Variation Predictability and Applicability Research Program

(7) Fisheries Research Agency / Japan Fisheries Information Service Center

Theme: Development of a Management Method of Tuna Resources using the Ocean Forecast Systems

Program: Climate Variation Predictability and Applicability Research Program

(8) School of Engineering, The University of Tokyo

Theme: Long-Term Variability of Snow Cover by Satellite Microwave Radiometric Data with Improved Snow Algorithm

Program: Northern Hemisphere Cryosphere Program

(9) Kyoto University

Theme: Observational Study on Hydrological and Energy Cycles in Atmosphere over the Indonesian Maritime Continent

Program: Tropical Climate Variability Research Program

(10) Solar-Terrestrial Environment Laboratory (STEL), Nagoya University

Theme: Measurement of Uptake Coefficient of Trace Gases with Aerosol Particles using a Laser Spectroscopy

Program: Environmental Biogeochemical Cycle Research Program

(11) Arid Land Research Center, Tottori University

Theme: Hydrological Processes in Grassland Ecosystems in Mongolia and Kazakhstan

Program: Northern Hemisphere Cryosphere Program

(12) School of Marine Science and Technology, Tokai University

Theme: Study of Predictability and Water Mass Variability in the Kuroshio Extension using High-Resolution Ocean General Circulation Models

Program: Climate Variation Predictability and Applicability Research Program

(13) Research Institute for Humanity and Nature

Theme:

- Development of a High Resolution Method for Predicting Vegetation Change: Empirical Studies in Vegetation Transition Zone in Mongolia and Bornean Tropical Forest
Program: Environmental Biogeochemical Cycle Research Program
- Collaboration Research on Validation and Improvement of Hydrological Model in High Latitude Regions
Program: Northern Hemisphere Cryosphere Program

(14) Ocean Policy Research Foundation

Theme: Analysis of Oceanic Variability in the Bay of Bengal and its Relationship to Natural Disasters

Program: Climate Variation Predictability and Applicability Research Program

(15) Wakayama Research Center of Agriculture, Forestry and Fisheries

Theme: Numerical Fisheries Ocean Forecast Experiments off the Kii Peninsula

Program: Climate Variation Predictability and Applicability Research Program

(16) NPO “Valid Utilization of Mt.Fuji Weather Station”

Theme: Establishment of the Trans-Boundary Air Pollution Observation System on Mt.Fuji

Program: Environmental Biogeochemical Cycle Research Program

(17) JFE Advantech Co.,Ltd. / The General Environmental Technos Co.,Ltd.

Theme: Development of a Small and Fast-Responding Optode Sensor and a Reference Material for Dissolved Oxygen for Standardization of Dissolved Oxygen Measurement

Program: Ocean Climate Change Research Program

2. International research collaboration

A. Interagency Agreements for Research Cooperation (*Selected on the basis of RIGC-related cooperation)

(1) The Woods Hole Oceanographic Institution (WHOI), USA

Theme:

- Arctic Research
Program: Northern Hemisphere Cryosphere Program
- Physical Oceanography and WOCE Hydrographic Lines Revisits
Program: Ocean Climate Change Research Program
- Biogeochemistry and the Carbon cycles
Program: Environmental Biogeochemical Cycle Research Program

(2) Scripps Institution of Oceanography (SIO), USA

Theme: Study of Ocean General Circulation and Climate

Program: Ocean Climate Change Research Program

(3) The Trustees of Columbia University in New York, Through Lamont-Doherty Earth Observatory

Theme: Climate Change in Relation to Dynamics of Marine Ecosystem and Biogeochemical Cycles

Program: Environmental Biogeochemical Cycle Research Program

(4) The Office of Oceanic and Atmospheric Research (OAR) of The National Oceanic and Atmospheric Administration (NOAA), USA

Theme:

- Indo-Pacific Tropical Ocean and Climate Research (Scientific and Technology Development Cooperation)
Program: Tropical Climate Variability Research Program
- Cooperation in Maintaining JAMSTEC and PMEL Contributions to Indian Ocean Observing System (IndOOS) (Cooperation with other countries, e.g., Indonesia, France)
Program: Climate Variation Predictability and Applicability Research Program
- Ocean and Climate Research in the North Pacific; Cooperation in Developing and Maintaining JAMSTEC and PMEL Contributions to the North Pacific Surface Mooring Network
Program: Ocean Climate Change Research Program
- Arctic Observation
Program: Northern Hemisphere Cryosphere Program
- Computer Modeling for Global Environment Research

II. Related Activities

Research collaboration

Program: Global Change Projection Research Program

(5) Texas A&M University (TAMU), USA

Theme: Ocean Circulation / Climate Change

Program: Ocean Climate Change Research Program

(6) The University of Hawai'i (UH), USA

Theme: Cooperative Agreement regarding Joint Research Activities at the International Pacific Research Center (IPRC)

(7) The University of Alaska Fairbanks (UAF), USA

Theme: Cooperative Agreement regarding Joint Research Activities at the International Arctic Research Center (IARC)

(8) The National Oceanography Centre, Southampton (NOCS), UK

Theme: Physical Oceanography

Program: Ocean Climate Change Research Program, Tropical Climate Variability Research Program

(9) National Institute of Oceanography (NIO), India

Theme: Ocean Observations Related to Climate Research

Program: Tropical Climate Variability Research Program

(10) Agency for the Assessment and Application of Technology of the Republic of Indonesia (BPPT), Indonesia

Theme:

- Tropical Ocean Climate Observational and Modeling Studies
- Climate Dynamics Research over the Maritime Continent

Program: Tropical Climate Variability Research Program

(11) The Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia

Theme:

- Heat/Material Transports through Ocean Circulation and their Variability
- Fate of Carbon Dioxide in Indian and Southern Ocean

Program: Ocean Climate Change Research Program

(12) Department of Fisheries and Oceans (DFO), Canada

Theme:

- Observing and Modeling Ocean Climate Variability in the upper 200-300m layer of the Arctic Ocean
- Observing and Modeling Physical, Chemical and Biological Processes of Shelf/Basin Interaction
- Determining the Freshwater and Chemical Budgets of the Bering, Chukchi and Beaufort Seas
- Monitoring and Modeling the Evolution of Ice-Thickness Variability in both Shelf and Offshore Domains

Program: Northern Hemisphere Cryosphere Program

(13) Korea Ocean Research and Development Institute (KORDI), Korea

Theme:

- Calibration of Marine Instruments and QA/QC of Data

Program: Ocean Climate Change Research Program

- Moored Buoy System in the western Pacific
Program: Tropical Climate Variability Research Program

(14) The Alfred Wegener Institute for Polar and Marine Research in the Helmholtz Association of German Research Centres (AWI), German

Theme: Polar Research and Technology

- (a) Physical Oceanographic Instrumentation and Observations
- (b) Polar Oceanography and related Moorings

Program: Northern Hemisphere Cryosphere Program

(15) Institut Français de Recherche pour l'exploitation de la mer (IFREMER), France

Theme: Surveillance des océans

Program: Ocean Climate Change Research Program

B. Research Cooperation Agreement between RIGC and foreign institutes

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

Theme: Implementing Arrangement for Indo-Pacific Tropical Ocean and Climate Observational Research
Program: Tropical Climate Variability Research Program

(2) The University of Alaska Fairbanks (UAF), USA

Theme: Implementing Agreement for JFY2010 regarding Joint Research Activities at the International Arctic Research Center (IARC)

Program: Northern Hemisphere Cryosphere Program

(3) Department of Fisheries and Oceans (DFO), Canada

Theme: Implementing Agreement for Pan-Arctic Climate Investigation
Program: Northern Hemisphere Cryosphere Program

(4) Agency for the Assessment and Application of Technology of the Republic of Indonesia (BPPT), Indonesia

Theme:

- Implementing Agreement on Research Collaboration on Observation of Climatology, Meteorology, and Hydrology over Indonesian Maritime Continent
- Implementing Agreement for Tropical Ocean Climate Observational Studies
- Collaborative Research Agreement for Climate Variability Study and Societal Application through Indonesia-Japan "Maritime Continent COE" - Radar-Buoy Network Optimization

Program: Tropical Climate Variability Research Program

(5) Anhui Institute of Optics and Fine Mechanics (AIOFM), Chinese Academy of Sciences, China

Theme: Implementation Arrangement on Research Cooperation of Observations of Atmospheric Composition Change

Program: Environmental Biogeochemical Cycle Research Program

(6) Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences, China

Theme: Implementation Arrangement on Research Cooperation of Atmospheric Composition Change related to Environmental and Climate Change

II. Related Activities

Research collaboration

Program: Environmental Biogeochemical Cycle Research Program

(7) Lhasa Section of the Institute of Tibetan Plateau Research, Chinese Academy of Science, China

Theme: Implementation Arrangement on a Study of Water and Heat Circulation in the Nam Co Basin using Remote Sensing and In Situ Observation Data

Program: Global Change Projection Research Program

(8) Advanced Environmental Monitoring Research Center (ADEMRC), Gwangju Institute of Science and Technology, Korea

Theme: Implementation Arrangement on Research Cooperation of Observations of Atmospheric Composition Change

Program: Environmental Biogeochemical Cycle Research Program

(9) Faculty of Science of the Chulalongkorn University, Thailand

Theme:

- Implementation Arrangement on Research Collaboration of Observation of Atmospheric Radiation at Phimai, Thailand 2008-2011

Program: Environmental Biogeochemical Cycle Research Program

- Implementation Arrangement on Research Collaboration on Observation of Hydrological Cycle over Thailand

Program: Tropical Climate Variability Research Program

(10) Center for Oceanographic Research in the eastern South Pacific (FONDAP-COPAS) of Universidad de Concepción (UDEC), Chile

Theme: Joint Research Agreement regarding Research on Paleooceanography, Biogeochemistry and Physical Oceanography in the Coastal Area off Chile

Program: Environmental Biogeochemical Cycle Research Program

(11) Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) of the Department of Science and Technology (DOST), Philippines

Theme: Implementation Arrangement on Research Collaboration on Observation of Hydrological Cycle over the Republic of the Philippines

Program: Tropical Climate Variability Research Program

(12) National Hydro-Meteorological Service, Ministry of Natural Resources and Environment (NHMS-MONRE), Vietnam

Theme: Implementation Arrangement on Research Collaboration on Water and Energy Cycle Observation over Vietnam

Program: Tropical Climate Variability Research Program

(13) Institute of Geography of Mongolian Academy of Sciences (IG), Mongol

Theme: Implementation Arrangement on Cooperative Study of Hydrological Circulation and Climate Variability over Mongolian Region

Program: Northern Hemisphere Cryosphere Program

(14) Institute of Meteorology and Hydrology of Ministry of Nature and Environment of Mongolia (IMH), Mongol

Theme: Implementation Arrangement on Cooperative Study of Hydrological Circulation and Climate Variability over Mongolian Region

Program: Northern Hemisphere Cryosphere Program

(15) Institute of Atmospheric Physics (IAP), Russian Academy of Sciences, Russia

Theme: Implementation Arrangement on Research Cooperation of Atmospheric Composition Change related to Environmental and Climate Change

Program: Environmental Biogeochemical Cycle Research Program

(16) Institute of Atmospheric Optics (IAO), Russian Academy of Sciences, Russia

Theme: Implementation Arrangement on Research Cooperation of Atmospheric Composition Change related to Environmental and Climate Change

Program: Environmental Biogeochemical Cycle Research Program

(17) Institute of Biological Problems of the Cryolithozone (IBPC), Russian Academy of Sciences, Russia

Theme: Implementation Arrangement on Land Surface Observation of Heat/Water/Vegetation Conditions in the Yakutsk Area

Program: Northern Hemisphere Cryosphere Program

(18) Permafrost Institute (PI), Russian Academy of Sciences, Russia

Theme: Implementation Arrangement on Land Surface Observation of Heat/Water/Vegetation Conditions in Yakutia

Program: Northern Hemisphere Cryosphere Program

(19) P. P. Shirshov Institute of Oceanology (SIO), Russian Academy of Science, Russia

Theme: Implementing Agreement on Arctic Ocean Observational Research

Program: Northern Hemisphere Cryosphere Program

(20) Central Aerological Observatory of Federal Agency for Hydrometeorology and Monitoring Environment of the Russian Federation (CAO), Russia

Theme: Implementation Arrangement on Hydro-Meteorological Monitoring Network for Climate Change over the Siberia

Program: Northern Hemisphere Cryosphere Program

(21) Tomsk State University, Russia

Theme: Cooperative Arrangement on Research Cooperation of Chemical Weather Forecasting

Program: Environmental Biogeochemical Cycle Research Program

Funded research projects

(1) Global Cloud Resolving Model Simulations toward Numerical Weather Forecasting in the Tropics (FY2005-2010)

Fund: CREST (Core Research of Evolutional Science & Technology)

Funding institution: Japan Science and Technology Agency (JST)

Program: Advanced Atmosphere-Ocean-Land Modeling Program

(2) Scale Interaction and Large-Scale Variation of the Ocean Circulation (FY2006-2011)

Fund: CREST (Core Research of Evolutional Science & Technology)

Funding institution: Japan Science and Technology Agency (JST)

Program: Advanced Atmosphere-Ocean-Land Modeling Program

(3) Marine Environmental Simulation for Future Projection of Marine Ecosystems (FY2006-2011)

Fund: CREST (Core Research of Evolutional Science & Technology)

Funding institution: Japan Science and Technology Agency (JST)

Program: Environmental Biogeochemical Cycle Research Program

(4) Construction of a Network of Simultaneous Vertical-Profile Observation of Gases and Aerosol in the Troposphere by Means of Ground-Based Spectroscopic Method (FY2006-2010)

Fund: Japan Earth Observation System [EOS] Promotion Program (JEPP)

Funding institution: Ministry of Education, Culture, Sports, Science and Technology (MEXT)

Program: Environmental Biogeochemical Cycle Research Program

(5) Probabilistic Prediction of Near-Term Climate Change based on Multi-Model Analysis (FY2007-2011)

Fund: Environment Research and Technology Development Fund (ERTDF)

Funding institution: National Institute for Environmental Studies (NIES)

Program: Global Change Projection Research Program

(6) Study on Consistency of Spatially-Explicit Scenarios through Analysis on Climate Change Scenarios (FY2007-2011)

Fund: Environment Research and Technology Development Fund (ERTDF)

Funding institution: National Institute for Environmental Studies (NIES)

Program: Global Change Projection Research Program

(7) Climate Model Reproducibility and Future Changes of Air-Sea Interactions Associated with the Tropical Intraseasonal Variability (FY2007-2011)

Fund: Environment Research and Technology Development Fund (ERTDF)

Funding institution: Atmosphere and Ocean Research Institute (AORI), The University of Tokyo

Program: Tropical Climate Variability Research Program

(8) Climate Model Reproducibility of Radiative Feedback in the Seasonal Cycle, Seasonal Atmospheric Phenomena and their Future Changes (FY2007-2011)

Fund: Environment Research and Technology Development Fund (ERTDF)

Funding institution: Atmosphere and Ocean Research Institute (AORI), The University of Tokyo

Program: Global Change Projection Research Program

(9) Developments and Validations of Physical and Lower Trophic Ecosystem Models in SEA-WP Region (FY2008-2010)

Fund: Environment Research and Technology Development Fund (ERTDF)

Funding institution: Tokyo Institute of Technology

Program: Climate Variation Predictability and Applicability Research Program

(10) Quantification of Ozone and Aerosol Pollution in East Asia and the Hemisphere Synthesizing Numerical Modeling and Observation (FY2009-2011)

Fund: Environment Research and Technology Development Fund (ERTDF)

Funding institution: Ministry of the Environment

Program: Environmental Biogeochemical Cycle Research Program

(11) Construction and Application of Isotopomeric Chemistry Transport Model (FY2009-2011)

Fund: Environment Research and Technology Development Fund (ERTDF)

Funding institution: Tokyo Institute of Technology

Program: Environmental Biogeochemical Cycle Research Program

(12) Evaluation of Combined Effects of Land-Use Changes and Associated Aerosol Changes (FY2009-2011)

Fund: Environment Research and Technology Development Fund (ERTDF)

Funding institution: Nagoya University

Program: Global Change Projection Research Program

(13) Development of an Atmospheric Environmental Reanalysis System (FY2009-2011)

Fund: Environment Research and Technology Development Fund (ERTDF)

Funding institution: Tohoku University

Program: Environmental Biogeochemical Cycle Research Program

(14) Comprehensive Research on Climate Change Impact Assessment and Adaptation Policies; Development of a Climate Change Downscaler and its Practical Implementation; Research on Development of Climate Change Assessment Method and Preparation of Guidelines (FY2010-2014)

Fund: Environment Research and Technology Development Fund (ERTDF)

Funding institution: University of Tsukuba

Program: Advanced Atmosphere-Ocean-Land Modeling Program

(15) Mechanism Elucidation and Future Forecast on the Decreasing Trend of Dissolved Oxygen; Prediction of Anoxia in the Deep Waters of the Japan Sea by Temporal and Spatial High-Precision Mappings of Dissolved Oxygen Concentration (FY2010-2012)

Fund: Environment Research and Technology Development Fund (ERTDF)

Funding institution: National Institute for Environmental Studies (NIES)

Program: Ocean Climate Change Research Program

(16) Observational Arctic Terrestrial Soil Carbon Dynamics Research and Development of their Modeling for Predicting Arctic Climate Change under Global Warming; Modeling of Soil Organic Carbon Dynamics: Development and Refinement (FY2010-2012)

Fund: Environment Research and Technology Development Fund (ERTDF)

Funding institution: National Institute for Environmental Studies (NIES)

II. Related Activities

Funded research projects

Program: Environmental Biogeochemical Cycle Research Program

(17) Instrument Development for on-line Measurements of Classified Organic Aerosol Particles in the Atmosphere based on Laser-induced Fluorescence (FY2008-2011)

Fund: Development Systems and Technology for Advanced Measurement and Analysis

Funding institution: Japan Science and Technology Agency (JST)

Program: Environmental Biogeochemical Cycle Research Program

(18) Climate Variability Study and Societal Application through Indonesia - Japan "Maritime Continent COE" - Radar-Buoy Network Optimization for Rainfall Prediction (FY2009-2014)

Fund: Science and Technology Research Partnership for Sustainable Development (SATREPS)

Funding institution: Japan Science and Technology Agency (JST)

Program: Tropical Climate Variability Research Program

(19) Advanced Downscaling Methods for Adaptations to Future Snow Cover Change in the Sea of Japan Side Areas under the Global Warming (FY2010-2014)

Fund: Initiative for Strategic Adaptation to Climate Change (ISACC)

Funding institution: Ministry of Education, Culture, Sports, Science and Technology (MEXT)

Program: Advanced Atmosphere-Ocean-Land Modeling Program

(20) A Water Resources Management System Enhancing Adaptability to Climate Change (FY2010-2014)

Fund: Initiative for Strategic Adaptation to Climate Change (ISACC)

Funding institution: School of Engineering, The University of Tokyo

Program: Advanced Atmosphere-Ocean-Land Modeling Program

(21) Development of a Sophisticated Downscaling Model using Feedback Parameterizations and its Applications for Adaptations to Urban Heat Islands, Extremely Hot Days, and Downpours (FY2010-2014)

Fund: Initiative for Strategic Adaptation to Climate Change (ISACC)

Funding institution: Graduate School of Environmental Studies, Nagoya University

Program: Advanced Atmosphere-Ocean-Land Modeling Program

(22) Development Research of Conversion of Earth Observation Data to Invaluable Scientific and Societal Information; Investigation of the Variation of Hydrological Cycle and Land-Atmosphere Interaction and Contribution to the Future Projection (FY2006-2010)

Fund: Data Integration and Analysis (DIAS) (MEXT)

Funding institution: School of Engineering, The University of Tokyo

Program: Northern Hemisphere Cryosphere Program

(23) Development Research of Conversion of Earth Observation Data to Invaluable Scientific and Societal Information; Investigation on the Variation of Hydrological Cycle in the Asia Monsoon Region and Contribution to the Improvement of Monsoon Prediction (FY2006-2010)

Fund: Data Integration and Analysis (DIAS) (MEXT)

Funding institution: School of Engineering, The University of Tokyo

Program: Tropical Climate Variability Research Program

(24) Studies on Prediction and Application of Fish Species Alternation (SUPRFISH); Variability in the Kuroshio and Kuroshio Extension System and its Influence in a High Resolution Ocean General Circulation Model (FY2007-2011)

Fund: Research Project of Ministry of Agriculture, Forestry and Fisheries of Japan

Funding institution: Fisheries Research Agency

Program: Climate Variation Predictability and Applicability Research Program

(25) Development of Global Marine Ecosystem Observation System using Continuous Plankton Recorders (FY2009-2010)

Fund: Bilateral Programs

Funding institution: Japan Society for the Promotion of Science

Program: Environmental Biogeochemical Cycle Research Program

(26) A Study of Water and Heat Circulation in the Nam Co Basin using Remote Sensing and in situ Observation Data (FY2010-2011)

Fund: Bilateral Programs

Funding institution: Japan Society for the Promotion of Science

Program: Global Change Projection Research Program

(27) Validation of Microwave Radiometer Data and Development of an Advanced Algorithm for Estimation of Surface Air Specific Humidity using In-situ Observation Data in the Kuroshio Extension Region (FY2008-2010)

Fund: Global Change Observation Mission (GCOM) Research Announcements

Funding institution: Japan Aerospace Exploration Agency (JAXA)

Program: Ocean Climate Change Research Program

(28) Multi-Scale Climatology of Coastal Heavy Rainbands over the Indonesian Maritime Continent using Satellite and Ground Based Radar Observations (FY2010)

Fund: Precipitation Measuring Mission (PMM) Science Research Announcements

Funding institution: Japan Aerospace Exploration Agency (JAXA)

Program: Tropical Climate Variability Research Program

Awards

- **The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology: the Prizes for Science and Technology in Research Category**

Dr. Masao Fukasawa (Research Director, Research Institute for Global Change)

Research of Deep Water Warming in the Pacific Ocean (April, 2010)

- **Best Poster Award of International Symposium on Climate Change Effects on Fish and Fisheries**

Dr. Taketo Hashioka (Environmental Biogeochemical Cycle Research Program)

Potential Impact of Global Warming on North Pacific Spring Blooms projected by an Eddy-permitting 3-D Ecosystem Model (April, 2010)

- **“Horiuchi Award” of the Meteorological Society of Japan**

Dr. Masayoshi Ishii (Global Change Projection Research Program)

Creating Objective Analysis Data Sets from Historical Ocean Subsurface Observations and Contributing to Monitoring and Prediction of Climate Variations with the Data Sets (September, 2010)

- **“Hirata Prize” by the Japanese Society of Snow and Ice**

Dr. Konosuke Sugiura (Northern Hemisphere Cryosphere Program)

Study of Modeling the Splash and Heat Exchange Processes and Estimating the Large-Scale Hydrological Cycle in Blowing Snow (September, 2010)

- **Best Young Scientist Poster Presentation Award of IMBER (Integrated Marine Biogeochemistry and Ecosystem Research) IMBIZO II**

Dr. Taketo Hashioka (Environmental Biogeochemical Cycle Research Program)

Future Changes in Seasonality of Marine Ecosystems projected by an Eddy-permitting 3-D Ecosystem Model (October, 2010)

- **JMSJ Award of the Meteorological Society of Japan**

Dr. Akira Noda (Advanced Atmosphere-Ocean-Land Modeling Program)

A Numerical Investigation of a Supercell Tornado: Genesis and Vorticity Budget (November, 2010)

- **“Miyake Prize” of the Geochemistry Research Association**

Dr. Toshiro Saino (Environmental Biogeochemical Cycle Research Program)

Pioneering Works on the Marine Biogeochemical Cycle using Nitrogen Isotopes and Remote Sensing (December, 2010)

- **Hydrographic Technology Encouragement Award of the Japan Hydrographic Association**

Dr. Hiroshi Uchida (Ocean Climate Change Research Program)

Commercializing the High-Accuracy Optode-based Oxygen Sensor (February, 2011)



RIGC/JAMSTEC

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