

Research Institute for Global Change Annual Report FY2011



JAMSTEC

独立行政法人
海洋研究開発機構

JAPAN AGENCY FOR MARINE-EARTH SCIENCE AND TECHNOLOGY

Cover: Glacier Milk

The water flowing from a glacier is muddy. Because it contains tiny bits of rock by the glacier's grinding action to bedrock. These colors of muddy water are different by local geological feature where a glacier exists. In this area, whitish-gray colored water runs from a glacier.

It is called "glacier milk" (glacial milk). Whitish flow shown on the left in the picture is streaming from a glacier behind. And snowmelt water is running from the right side. There is a distinct difference in the water colors.

Photography taken at Potanin glacier, Mongolia

Provided by: Dr. Keiko Konya (Northern Hemisphere Cryosphere Program)

Preface

The earth we inhabit consists of the natural habitats such as ocean, air, and land, and all the ecosystems that the habitats 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, drastic environmental changes stemming from human activities including global warming have been world-widely reported in recent years accompanied by with the increase in of occurrence of extreme weather events. It has become a significant and urgent issue for the world to examine the statuses of the environments under these changing conditions, to describe the changes in the earth's environments under the specific conditions, investigate their causes, and forecast their future evolution.

Under the vision of Research Institute for Global Change (RIGC), namely, "To prepare and to compile the knowledge through our science for society to help create more sustainable and productive society under harmonious relationships between human and the environment", we actively work on comprehensive global environmental research including observation and prediction to provide scientific information to society. We proudly believe that we can help JAMSTEC fulfill evolving social needs not only in Japan but also in the world.

In 2011, Japan was attacked by the massive earthquake, which caused ruinous tsunami along the eastern coast of Japan. The tsunami deprived more than 15,000 people's lives and destroyed the Fukushima First Nuclear Power Plant. RIGC immediately launched a special team for monitoring and forecasting the dispersion of radio nuclides off the coast of Fukushima. The results were disseminated through the website of the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) to prevent people from being affected by possible dangers of radio nuclides. Most of these activities were outside the scope of the RIGC's interim research plan. Nevertheless, it should be noted here that these activities well represents the heart of RIGC scientists under our vision.

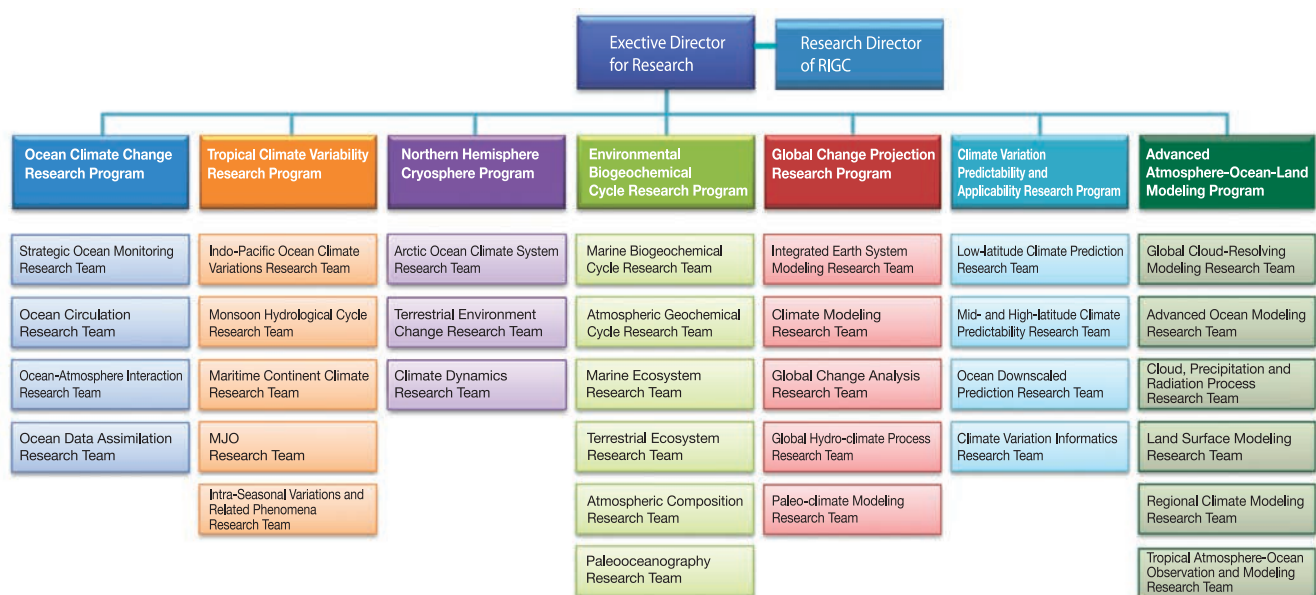
Another big topic should be introduced here. A leading project (LP), "Global Warming Research Project for IPCC-AR5", which had close linkage with RIGC, was finished on in March 2012. Although the report from Working Group 1 of IPCC AR5 is still under second revision process, more than 100 articles written by RIGC scientists as the first author are cited in the draft not only in its model projection sections but also in its observational sections. It is a great pleasure of RIGC that we could contribute to IPCC activities so deeply through our interim research plan. Also it should be noted here that a new research project which follows and develops former LP is starting in 2013 within RIGC to assess risks of climate changes including global warming.

The science of RIGC is a field that aims to monitor the oceans, air, land, and ecosystems by using various techniques to define the prevailing conditions of the global environment, to understand the mechanisms of the changes, and at the same time to develop forecasting models that combine the findings from monitoring with the expertise in various subjects to better predict future global changes. Furthermore, we, Research Institute for Global Change, have cooperated with institutions both at home and abroad. Through promoting 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 the leading institutions in the research for global climate change.

In October 2012

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

Organization



Research Institute for Global Change (RIGC)

Annual Report FY2011

(April 2011 – March 2012)

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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 large amounts of heat and dissolved chemical substances, and ocean circulation has a substantial impact on global climate. The purpose of the Ocean Climate 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 periodically surface, to automatically measure and transmit 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 moored buoys to measure heat flux between the atmosphere and ocean in the Kuroshio Extension region (Fig.1). 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 fiscal year 2011:

- Ninety-two ARGO floats were deployed;
- The World Ocean Circulation Experiment (WOCE) line P10 (145°E) was revisited for repeat hydrographic observations;
- A surface buoy was moored in the Kuroshio Extension region to observe air–sea interactions.

Our analysis of data from these observations along with oceanographic data previously collected yielded results regarding changes in heat and chemical materials in the oceans. These results are described in detail in the sections that follow.

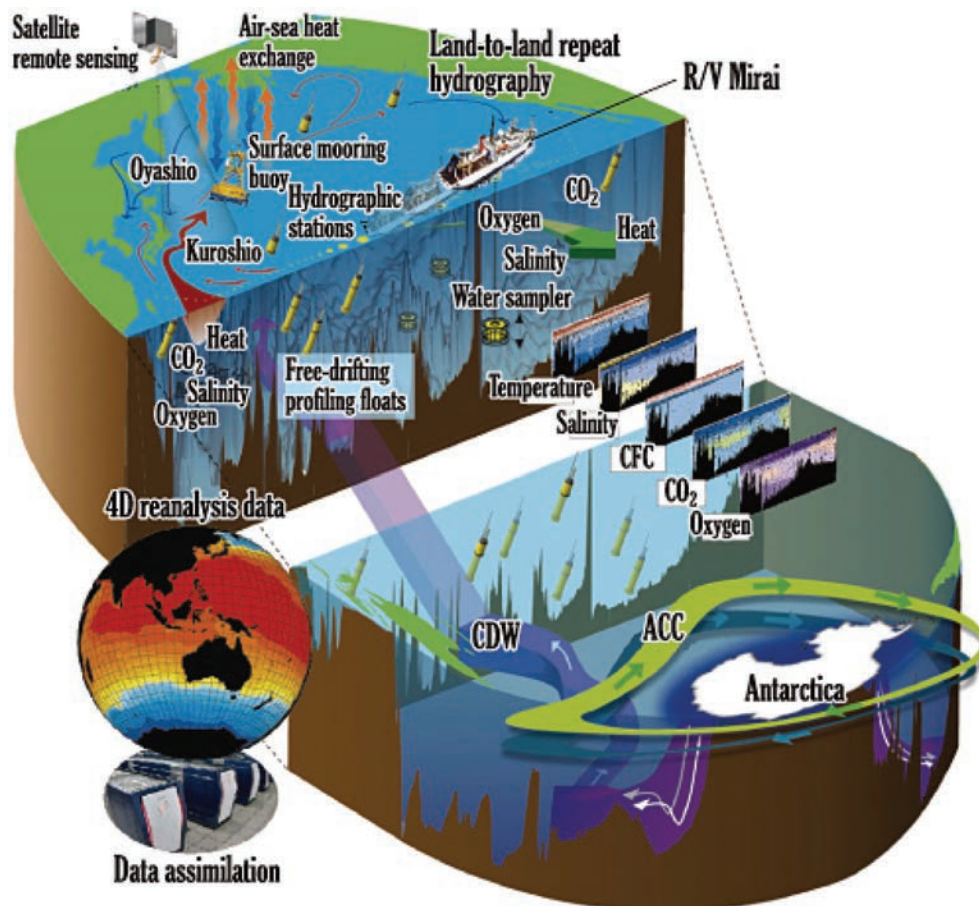


Fig. 1 Schematic Sketch of the activity of Ocean Climate Change Research Program.

Long-term variations in surface and intermediate waters along 32°S in the southern Indian Ocean

–Strategic Ocean Monitoring Research Team–

Properties of surface and intermediate water masses are generally determined during the formation process in the surface mixed layer, largely affected by heat and freshwater fluxes at the sea surface. After the water masses are subducted from the mixed layer, their properties are preserved well into the ocean interior over long periods of time. Thus, changes in the water-mass properties likely reflect long-term changes in atmospheric conditions and preserve signals of climate change. Information on changes in water mass properties is useful because surface flux fields are hard to quantify, especially in areas where data are sparse, such as the southern Indian Ocean.

Oceanic responses to anthropogenic climate change (global warming) are attracting increasing attention not only from scientific viewpoints but also from the social perspective. Climate modeling studies have suggested that surface and intermediate waters in the southern Indian Ocean may be some of the most sensitive in the world ocean to global warming. Whereas observations in the southern Indian Ocean are much sparser than in other oceans, there has been a series of observational surveys along a trans-Indian Ocean section at 32°S. Thus, there have been great efforts to detect and characterize changes of the water masses there. It is difficult, however, to resolve the oceanic variations suggested by numerical studies on the basis of the trans-Indian Ocean surveys because of the relatively long intervals of 5–10 years between surveys. The Argo float data, which have enabled detailed examination of property changes with resolution at the seasonal and shorter time scales, presently cover fewer than 10 years, which is insufficient to examine long-term trends and oscillations. As an alternative approach, a time series of water properties along 32°S over 50 years (1960–2010) was reproduced by using an optimal interpolation (OI) technique from all observations—that is, historical hydrographic data and Argo data—and based on the time-series features of the variations in the surface and intermediate waters ($26.0\text{--}27.6\sigma_\theta$) [Kobayashi *et al.*, 2012].

The reproduced water properties show variations with large amplitudes in layers less dense than $26.8\sigma_\theta$ (Fig. 2). Salinity at $26.7\text{--}27.3\sigma_\theta$ has statistically significantly (at 5% level) decreased; the averaged freshening rate during the 50-year period was 0.02 decade^{-1} at maximum, and the maximum rate was observed at $26.8\text{--}26.9\sigma_\theta$, just below the Subantarctic Mode Water (SAMW) pycnostad (Fig. 3). This freshening was found almost uniformly

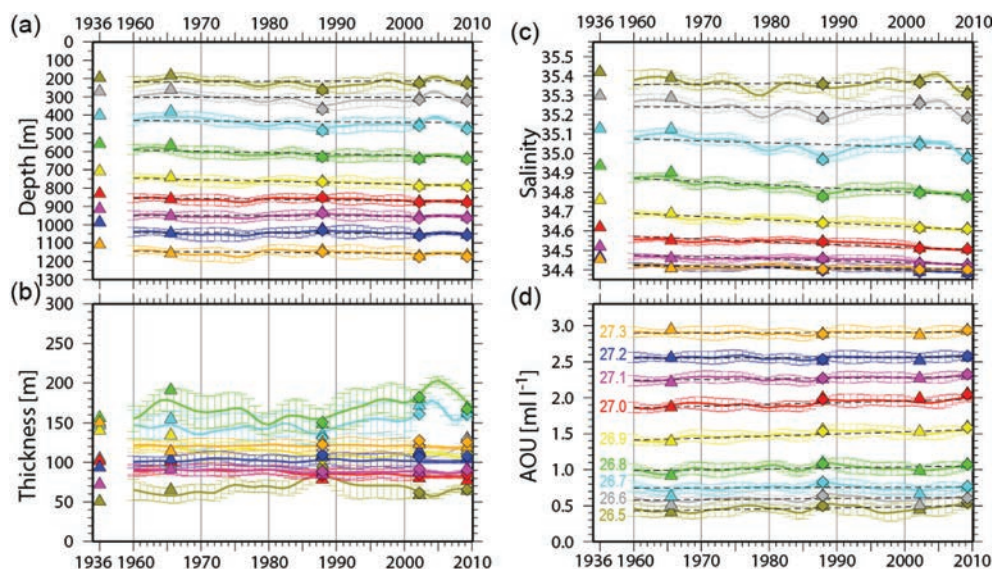


Fig. 2 Variations of (a) isopycnal depth, (b) $0.1\sigma_\theta$ layer thickness, (c) salinity, and (d) AOU averaged over the entire 32°S section (40–110°E) for the $26.5\text{--}27.3\sigma_\theta$ isopycnals. Vertical bars show the estimation errors calculated from root-mean-square of the OI errors over the areas. The dashed lines represent the linear trends for 1960–2010 considering the estimation errors. Triangles and diamonds show the averages of the properties from bottle samples and CTD data, respectively, from the trans-Indian Ocean surveys in 1936, 1965, 1987, 2002, and 2009.

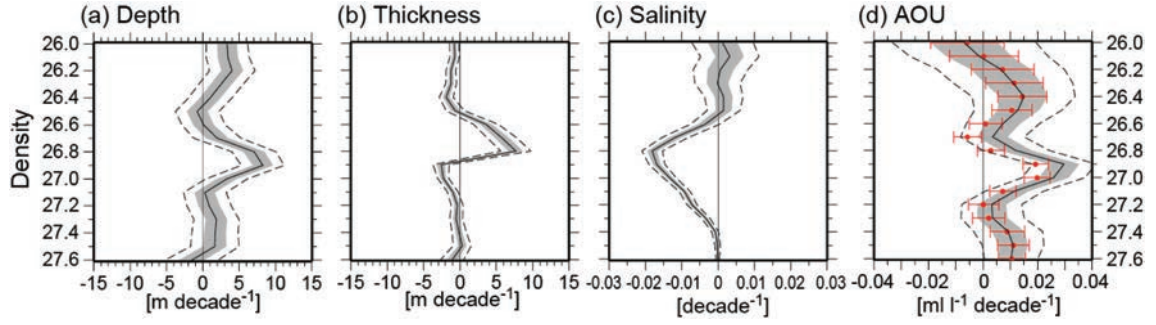


Fig. 3 Vertical profiles of linear trends from 1960 to 2010 averaged over the entire 32°S section (40–110°E) for (a) isopycnal depth, (b) layer thickness, (c) salinity, and (d) AOU. Solid lines and shaded areas represent the trends and the standard errors (SEs), respectively. Dashed lines represent the upper and lower limits of the 95% confidence intervals. The red circles with horizontal bars in (d) represent the trend (sign is converted) and one SE for dissolved oxygen.

over the entire section since 1960 (Fig. 4). A comparison with the trans-Indian Ocean survey of 1936 suggests that the freshening began before 1960. The freshening trend decreased toward the denser layers; thus, the Antarctic Intermediate Water (AAIW) salinity minimum shifted slightly toward the lighter layers, from $27.3\sigma_\theta$ in 1936, to $27.25\sigma_\theta$ in the 1960s, to $27.2\sigma_\theta$ in the 2000s. The thickness of the SAMW core at $26.8\sigma_\theta$ east of 85°E increased significantly at 5% level after 1960. The thicknesses of the layers just above (below) the SAMW pycnostad increased (decreased); thus the density of the SAMW pycnostad appeared to decrease over the 50-year period.

Three deoxygenating regions were found east of 75°E. The increase in apparent oxygen utilization (AOU) in the most prominent region (at $26.9\text{--}27.0\sigma_\theta$) exceeded $0.05 \text{ ml l}^{-1} \text{ decade}^{-1}$. About 75–80% of the AOU increase can be explained by a simple decrease in dissolved oxygen, and the remainder reflects an increase in oxygen solubility due to cooling (freshening). Interestingly, the cores of many of the prominent trends were located offshore of Australia at $26.7\text{--}27.0\sigma_\theta$, in the density range of SAMW. In general, component oscillations in the water properties showed larger amplitudes in layers less dense than $26.8\sigma_\theta$, which then became smaller with depth. A spectrum analysis identified two dominant oscillation components with periods of about 40 years and 10 years.

The features found in this study were fairly consistent with findings of previous observational studies and also with numerical model predictions. Thus, the model predictions that subsurface waters in the southern

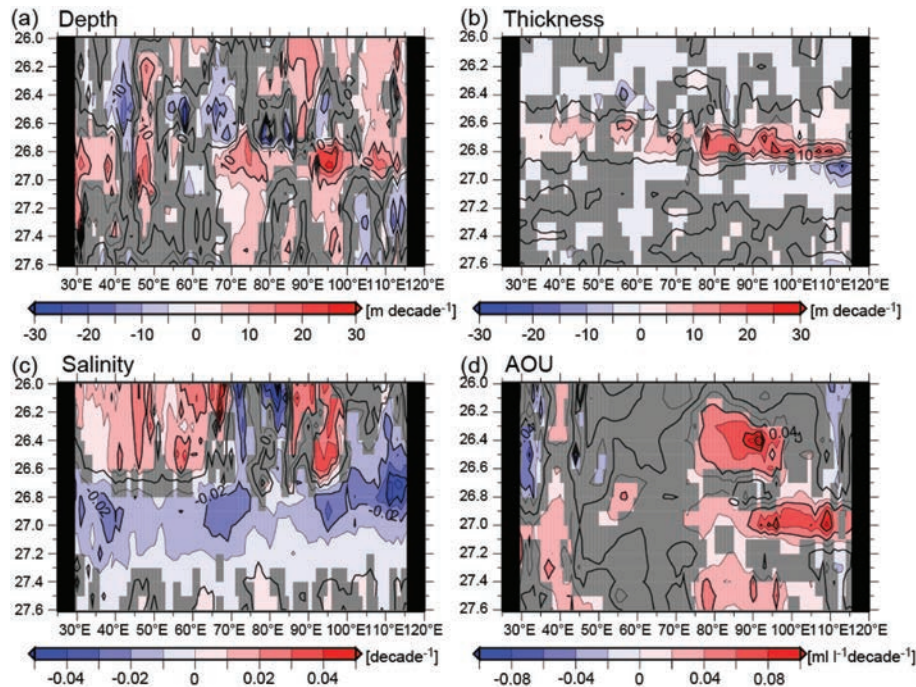


Fig. 4 Distributions of linear trends in (a) isopycnal depth, (b) layer thickness, (c) salinity, and (d) AOU, for 1960–2010 along 32°S in the Indian Ocean. Colored shading shows areas where the trends are statistically significant at the 5% level (Student's *t*-test).

Indian Ocean become fresher under anthropogenic climate change, accompanied by large, abrupt variations, are supported to some degree by the hydrographic data. The features of the variations found in this study are valuable for future studies investigating their causes and the mechanisms of ventilation in the southern Indian Ocean.

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The Pacific Ocean has accumulated anthropogenic CO₂ steadily over the last decade –Ocean Circulation Research Team–

The ocean acts as a major sink for anthropogenic CO₂. The Intergovernmental Panel on Climate Change. [IPCC, 2007] estimated that the ocean absorbs up to 30% of the planet's anthropogenic CO₂. It is now of interest to determine whether the ocean can continue to absorb anthropogenic CO₂ at the same rate as in the past. During the 2000s, we conducted repeat observation cruises along some of the original WOCE hydrographic lines (hereafter referred to as “WOCE revisit cruises”) under the international framework of the Climate Variability and Predictability (CLIVAR)/CO₂ Repeat Hydrography program. This enabled us to detect recent decadal changes of anthropogenic CO₂ storage in the ocean interior. In this study, we examined the decadal changes of dissolved inorganic carbon in the Pacific Ocean and attempted to quantify the increases of anthropogenic CO₂ using the method of *Murata et al.* [2007].

Recently, the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) conducted three new WOCE revisit cruises along lines P01 (47°N), P14 (179°E), and P21 (17°S) in the Pacific Ocean. In comparing the data from these cruises with those from the WOCE cruises carried out in the 1990s, we found both positive and negative decadal changes in anthropogenic CO₂ in thermocline waters (Fig. 5). As a result, decadal-scale storage of anthropogenic CO₂ north of 40°N in the North Pacific was close to 0 mol m⁻² y⁻¹, except in the western subarctic Pacific. In contrast, in the subtropical regions of both hemispheres, we found an increasing trend of >10 μmol kg⁻¹ for oceanic uptake of anthropogenic CO₂, reflecting CO₂ accumulation in mode waters. Along 17°S, increases of anthropogenic CO₂ were >20 μmol kg⁻¹, larger than expected from increases of anthropogenic CO₂ in the atmosphere.

To assess the changes in total stored anthropogenic CO₂, we calculated the changes in annual water column inventories of anthropogenic CO₂ for 20°-longitudinal or 10°-latitudinal bands along the observation sections throughout the Pacific Ocean (Fig. 6). There were relatively high values (>0.7 mol m⁻² y⁻¹) in the

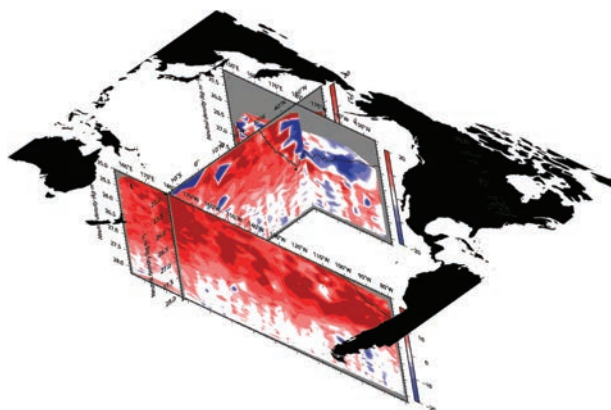


Fig. 5 Changes in anthropogenic CO₂ (μmol kg⁻¹) in the observation sections at 47°N, 179°E, and 17°S. Red and blue indicate areas of increase and decrease of anthropogenic CO₂, respectively. The darkest red indicates increases in excess of 15 μmol kg⁻¹.

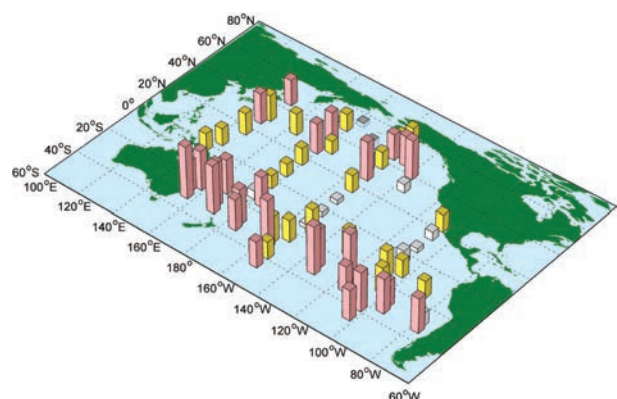


Fig. 6 Decadal anthropogenic CO₂ storage along all sections revisited in the Pacific Ocean. Pink and yellow denote storage increases of 0.5-0.7 mol m⁻² y⁻¹ and >0.7 mol m⁻² y⁻¹, respectively. White indicates <0.5 mol m⁻² y⁻¹.

subtropical regions of both hemispheres and low values in the tropical Pacific. The fact that this pattern is similar to previous estimates for the Anthropocene implies that the processes affecting redistribution of anthropogenic CO₂ have not changed on a basin scale over the last decade. Furthermore, we estimated the total change in stored CO₂ in the Pacific (50°S–65°N) by summing up area-averaged water-column inventories in four latitudinal bands: northern subarctic, northern subtropical, tropical, and southern subtropical (Fig. 6). The increases in total anthropogenic and natural CO₂ storage in the Pacific Ocean were estimated at 8.4 ± 0.5 and 0.6 ± 0.4 petagrams of carbon (Pg-C) decade⁻¹, respectively.

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Locally enhanced air-sea interaction processes and deep mixed-layer formation associated with the subarctic front

–Ocean-Atmosphere Interaction Research Team–

The Kuroshio and Oyashio Extensions are associated with two major oceanic fronts in the upper ocean, namely the Kuroshio Extension front (KEF) and the subarctic front (SAF), respectively. Such mid-latitude upper-oceanic fronts significantly influence the atmosphere through local air–sea interaction processes and the associated surface heat flux (HF) [e.g., Xie, 2004; Minobe *et al.*, 2008]. In order to better understand the influence of the SAF on the formation of the deep winter mixed layer to its southeast, we analyzed satellite-derived high-resolution air–sea flux data (J-OFURO2 [Japanese Ocean Flux data sets with Use of Remote sensing Observations]) [Tomita *et al.*, 2010] and Argo float data to reveal the fine-scale spatial structures of air–sea turbulent heat and momentum fluxes and their relationship with the deep oceanic mixed layer around the subarctic front (SAF) in the North Pacific.

The location of the two major oceanic fronts—SAF and KEF—can be inferred from the winter SST and its southward gradient distribution (Fig. 7). The large southward SST gradient along the SAF, as compared with that along the KEF, reflects the quasi-stationary nature of the SAF. Turbulent winter air–sea fluxes, namely the sensible heat flux (SHF), latent heat flux (LHF), and momentum flux (MF), averaged over the period from January to April from 2002 to 2007, demonstrate the fine-scale spatial structure of the air–sea fluxes in the open North Pacific Ocean. Before temporal averaging, a spatial high-pass filter was applied to highlight variation at scales smaller than 1000 km (Fig. 8). The obtained spatial pattern has not been clearly captured in previous datasets, including the National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) reanalysis. We investigated

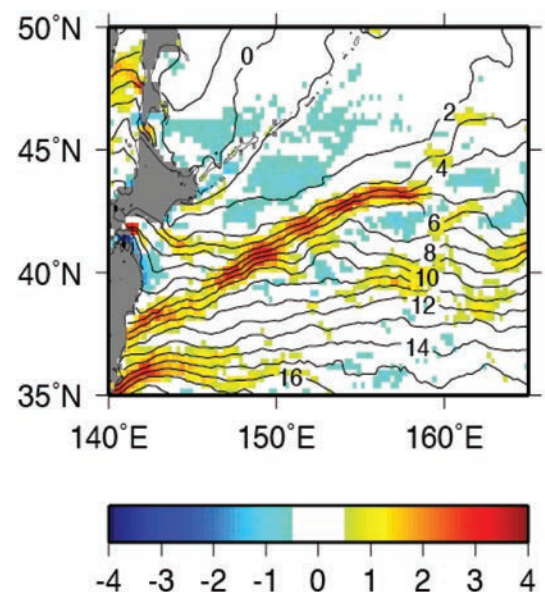


Fig. 7 Spatial distribution of sea surface temperature (SST) (contours, °C) and its high-pass-filtered southward gradient (colors, °C/100 km) averaged over the period from January to April from 2002 to 2007, obtained using J-OFURO2 data.

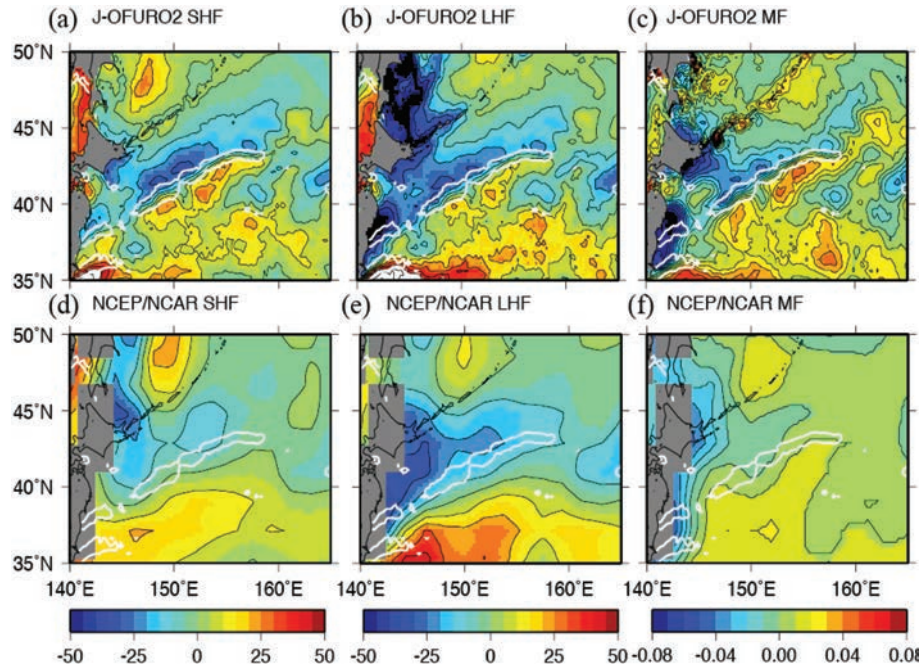


Fig. 8 High-pass-filtered spatial distributions (color and black contours) of the sensible heat flux (SHF), latent heat flux (LHF) (W/m^2 ; positive upward), and momentum flux (MF) (N/m^2) anomalies averaged over the period from January to April from 2002 to 2007 obtained using (a–c) J-OFURO2 and (d–f) NCEP/NCAR reanalysis datasets. The southward gradient of sea surface temperature (SST) obtained from J-OFURO2 was superimposed for the value of $1.5\text{ }^\circ\text{C}/100\text{ km}$ (white contour).

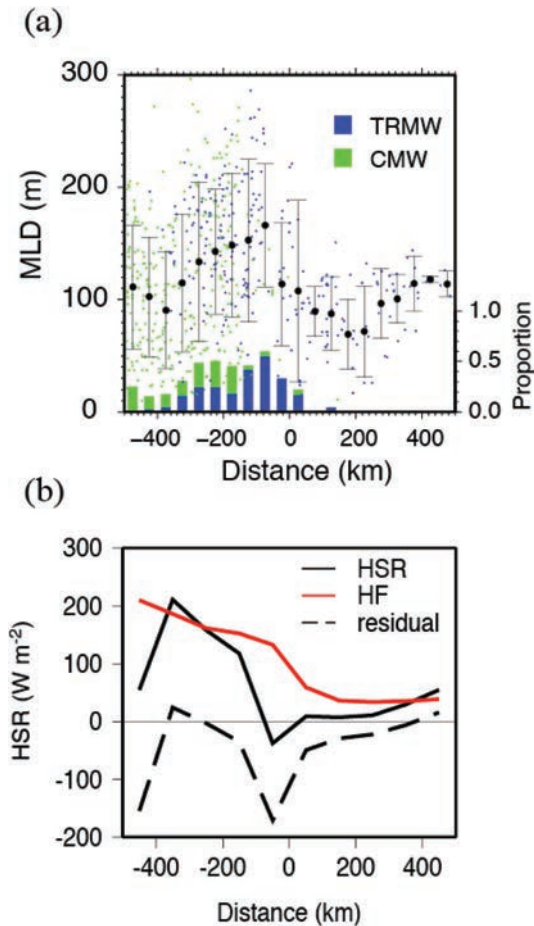


Fig. 9 (a) Composite cross-frontal sections of oceanic mixed-layer depth (small colored dots) in the period from January to April from 2002 to 2007. Large black dots and lines show the average and standard deviation for each bin of 50-km width. Colored bars indicate the proportion of all mixed layers deeper than 150 m. (b) Composite cross-frontal sections of heat storage rate (HSR) and its budget, averaged over January to April from 2002 to 2007.

the cross-frontal variations in the turbulent heat flux anomaly and contributions from the ocean and atmosphere and concluded that the SAF plays a significant role in determining the fine-scale structure of air–sea fluxes.

To investigate the influence of fine-scale air–sea fluxes on the upper ocean, we examined the distribution of the winter oceanic mixed layer around the SAF; this distribution is based on the hydrographic data obtained by Argo profiling floats (Fig. 9). The winter mixed layer is much deeper on the southern side of the SAF than on the northern side, with the maximum depth reached approximately 50–100 km away from the SAF, where air–sea fluxes also reach their local maxima. This co-variation suggests that the mesoscale distribution of air–sea fluxes in association with the SAF has a significant influence on the layers in the surrounding upper ocean. To the south of the SAF the heat loss through air–sea HF is approximately 150–200 W/m², which explains the temporal changes in heat storage from early winter to late winter. Near the SAF heat loss through the air–sea HF greatly exceeds the temporal change of heat storage. The difference is probably caused by transport of warm water from the upstream region by the quasi-stationary jet [Isoguchi *et al.*, 2006]. Most of the locally deep mixed layers approximately 100 km south of the SAF have salinities lower than 33.9, which are characteristic of Transition Region Mode Water (TRMW) rather than Central Mode Water (CMW). In contrast, mixed layers approximately 200–300 km south of the SAF are characteristic of CMW, which is more saline (>33.9) and warmer. This provides strong evidence that a deep mixed layer constituting the source of the TRMW is locally formed south of the SAF. We conclude that the active air–sea interaction attributed to the existence of the SAF enhances local air–sea heat and momentum fluxes to the south of the SAF and selectively produces the deep oceanic mixed layer.

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Effective ocean observing system design using adjoint sensitivity analysis –Ocean Data Assimilation Research Team–

Resources for conducting oceanographic research are sometimes limited (research vessels, floats, XBTs, etc.), and thus there is a need for an optimal design for ocean observing systems so as to provide sophisticated estimates of the ocean state or to better use hydrographic data to further promote climate research.

A central aim of observing strategies targeting climate time-scales and diagnostics is to improve understanding of the origin, propagation, and growth of climate signals. Ocean data assimilation systems provide a tool to assess the strengths and weaknesses in both observations and models [e.g., Stammer *et al.*, 2002]. For example, an estimate of the adjoint solution of a general circulation model enables us to detect sensitivity to fluctuations of model variables, which can facilitate the identification and characterization of the origins and pathways of specific water masses [e.g., Fukumori *et al.*, 2004]. The information obtained should help to develop a strategic plan for the spatial and temporal deployment of measurement instruments (e.g., moored buoys, drifting buoys), and for hydrographic surveys.

We applied adjoint sensitivity analysis to subtle changes in the subsurface water temperature in the Pacific Ocean by using the K7 4D-VAR ocean data assimilation system [e.g., Masuda *et al.*, 2010] on the Earth Simulator, in which we investigated the sensitivity to an artificial “cost” given at the locations of subsurface water

temperature at grid points every 20° of longitude from 155°E to 105°W and every 10° of latitude from 45°S to 35°N (Fig. 10). The obtained sensitivity to these water temperature changes helped us to identify key regions to be monitored for analysis and prediction of their temporal evolution. In this study we focused on a representative layer (at 1000 m) and on annual and decadal timescales.

Figure 11 shows the values of the temporal rate of change of subsurface water temperature taking place at the grid points shown in Figure 1 in an allocated model time (defined as year zero) when water temperature changes by +1 K in an arbitrary grid point at each level over a specific time period (in this case from 0 to –10 years in reverse chronological order). Around the 1-year period, large positive values (the same sign as given in the year zero) tend to remain near each grid point (Fig. 11a). These sensitivities imply that changes in the water temperature at a depth of 1000 m have a memory of more than 1 year in the large scale resolvable by the general circulation model with 1° resolution.

The positive sensitivity values gradually cover the Pacific Ocean over a 10-year period (Fig. 11b) and show an uneven distribution. This pattern reflects subtle ocean circulations or subsurface oceanic structure governed by large-scale ocean dynamics. The larger sensitivity values are found near eastern subtropical regions. This means that decadal evolution in spatially averaged subsurface water temperature at this depth in this Pacific region can be more influenced by these “key” regions. Note that these values are the sensitivities assuming that water temperature changes with constant amplitude (1 degree Kelvin) at each grid point.

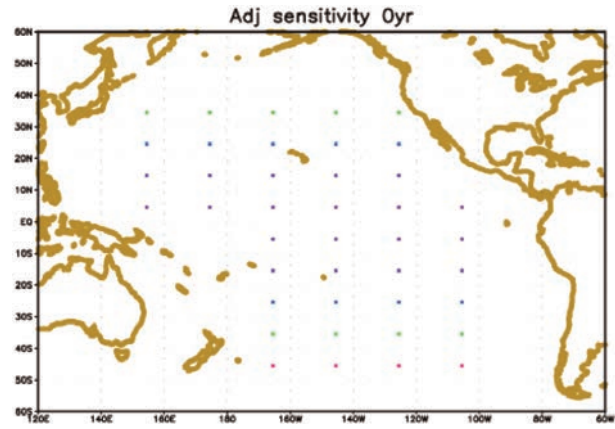


Fig. 10 Initial arrangement of the artificial cost for the adjoint sensitivity analyses.

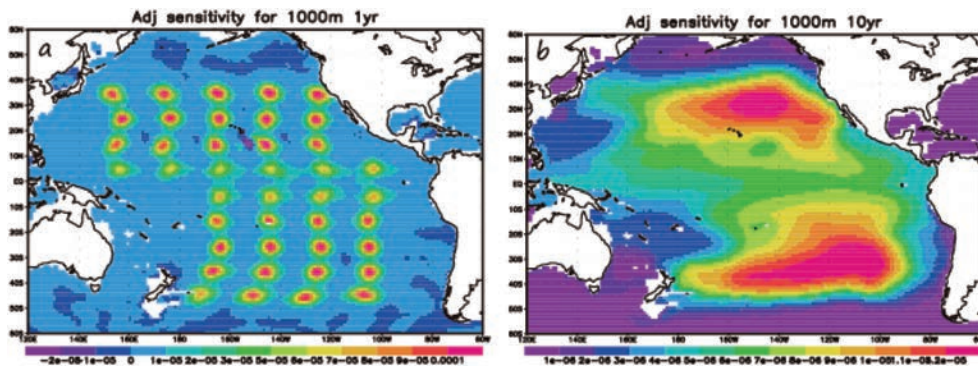


Fig. 11 Temporal rate of change of subsurface water temperature taking place at each point shown in Fig. 10 at a depth of 1000 m in an allocated model time (defined as year zero) when water temperature changes by +1 degree Kelvin in an arbitrary grid point at 1000-m depth, showing the impacts of the change in subsurface water temperature which will cause the warming trend at this depth after (a) 1 year, and (b) 10 years. Units are dimensionless.

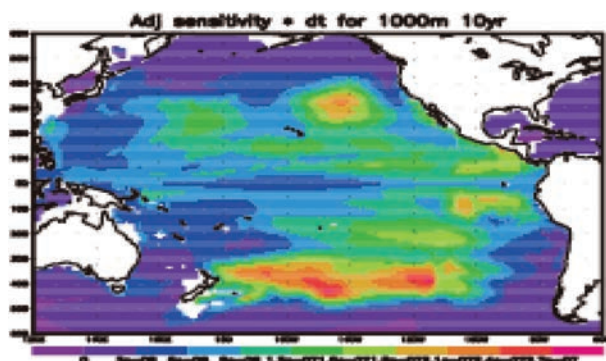


Fig. 12 Sensitivities modified as the product of the sensitivity values in Figure 2b and the standard deviation of oceanic variability. See the text for details. Units are degrees Kelvin.

It is possible that the regions with higher sensitivity values in Figure 11 can have less influence if the ocean state in that region has a small variability at the targeted time scale. To estimate the practical impact of each region for monitoring the temporal evolution of the spatially-averaged subsurface water temperature in the Pacific region, we calculated the product of the sensitivity values in Figure 11 and the standard deviation of oceanic variability. The climatological standard deviations at this depth for each time scale were determined from a long-term ocean state estimate deduced from the K7 4D-VAR ocean data assimilation system [Masuda *et al.*, 2010; Kouketsu *et al.*, 2011].

Figure 12 shows the distribution of the products at a depth of 1000 m in the same allocated model time as in Figure 11b. By considering the oceanic variability, the sensitivity distribution shows a different pattern than that in Figure 11b. The larger positive values are in the northeastern part of the North Pacific subtropical gyre and in the southern part of the South Pacific subtropical gyre. It is worth pointing out that the former is near one of the central regions for activity of the Pacific Decadal Oscillation [e.g., Tanimoto *et al.*, 1993], and the latter is consistent with some signatures for decadal variability in the South Pacific [e.g., Qiu and Chen, 2006].

These results imply that, if our attention is focused on the climate change at the subsurface layers in decadal time-scales, the pattern shown in Figure 12 provides a new strategy for effective monitoring. The strategy can of course be changed according to the targeted subject. Further work along these lines will lead to an optimal observing system that can be practically applied, and will also enable us to identify the optimal requirements for future observing instruments.

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Studies on Mechanisms of Tropical Climate Variation and Efforts to Construct In-situ Observing System –Tropical Climate Variability Research Program–

In the tropics, unique atmosphere-ocean coupled phenomena with various timescale are observed like El Niño, IOD, the monsoons, and the Madden-Julian Oscillation (Fig. 1). Since they have great impacts on global weather and short term climate variation, we aim to reveal the mechanism of these phenomena and their interactions and contribute to improvement 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 has also been 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 2011, we conducted an international field campaign named CINDY 2011 in the central equatorial Indian Ocean targeting the initialization process of MJO. CINDY 2011 received a special attention in this fiscal year and was completed successfully as will be mentioned below in detail.

We have obtained various kinds of observed data set from our observing systems, and most of them are disseminated on web sites and some are available in real time. Based on the obtained 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 topics picked up from each research team are introduced here and shown in the following section.

Among our achievement in this year, four topics are shown below. The first one is a study on the wind-evaporation-sea surface temperature (WES) feedback, which effectively works in mature phase of El Niño in the western Pacific and is suggested to contribute to the termination of El Niño. The second one explains a mechanism of torrential rainfall in the central Indochina peninsula by the interaction between westward-propagating disturbances and MJO based on intensive observation in FY 2010. The third one is an introduction and early achievements of above mentioned field campaign CINDY 2011. Cooperating with U.S. programme “DYNAMO”, they are endorsed by CLIVAR. CINDY 2011 became to a large scale intensive observation that covered tropical Indian Ocean from east coast of Africa to Indonesian Maritime Continent. Finally, our progresses for constructing international atmospheric and ocean observation network in Indonesian maritime continent area is introduced.

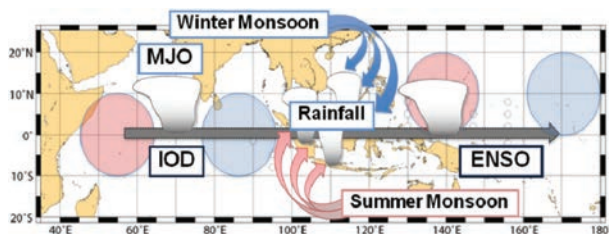


Fig. 1 Sketch of the major ocean/atmosphere variation phenomena, which compose tropical climate.

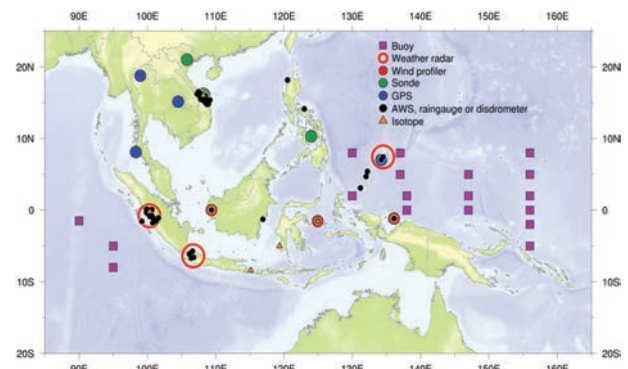


Fig. 2 Sustained Ocean and land observation sites by our program. Square; moored buoy (TRITON), Open red circle; Weather Radar, Solid circles: red; wind profiler, black; AWS, blue; GPS, green; Sonde station

Possible effect of Wind-Evaporation-Sea Surface Temperature (WES) feedback on 1997-98 El Niño termination

–Indo-Pacific Climate Variations Research Team–

The evolution of the 1997-98 El Niño (EL97) has been examined from various perspectives over the past decade. *Vecchi and Harrison* [2006] and *Vecchi* [2006] presented consistent demonstrations including the equatorial oceanic wave processes and ocean responses to unusual wind patterns determined by sea surface temperature (SST) fields in the tropical Pacific. Although these papers concentrated on wind and SST fields especially from central to eastern equatorial Pacific, the same fields in the western Pacific warm pool also showed anomalous distributions.

A major portion of the ocean-atmosphere interaction in the tropical Pacific is recognized as Bjerknes feedback [*Bjerknes*, 1969], which is associated with the zonal SST gradient and thermocline tilting. In addition to the basin-wide Bjerknes feedback, the Wind-Evaporation-SST (WES) feedback [*Xie and Philander*, 1994] also appears over the eastern tropical Pacific in association with the meridional SST gradient caused by the presence of a cold tongue and the migration of the inter-tropical convergence zone. However, the anomalous SST distribution, which has a large meridional SST gradient across the equator caused by the strong EL97, may produce conditions favorable for the WES feedback in the western Pacific warm pool.

The focus of this study is to describe anomalous SST, wind and heat flux distributions in the western tropical Pacific warm pool during the mature phase of EL97, corresponding to December-February (DJF) in 1997-98, and to identify aspects of unusual ocean-atmosphere interactions especially in terms of the WES feedback.

During the mature phase of EL97, a high-SST region exceeding 29 °C extended eastward to 120°W, and two SST maxima were located at 9°S 145°W and 10°S 170°E. In association with the anomalous SST distribution, the atmospheric convection center shifted southeastward following the highest SST region. In addition, the wind pattern in the tropical Pacific also changed drastically; the northerly winds were particularly dominant within the equatorial band. For the western tropical Pacific, there is a relatively low-SST region north of the equator, whereas a high-SST region is seen south of the equator (Fig. 3a). Winds tend to turn toward the high-SST region and form unusual cross-equatorial northerly. These distributions are far different from those of the climatology for the DJF season (Fig. 3b). In association with the unusual SST pattern, wind speed increases north of the equator, whereas it decreases south of the equator (Fig. 3c). According to this meridional contrast, the LHF from the ocean to atmosphere decreases south of the equator.

The WES feedback requires an equatorially asymmetric distribution of the SST anomaly, a cross-equatorial meridional wind, and a background zonal wind such as the easterly trade wind. During the mature phase of EL97, there are nearly equatorially anti-symmetrical SST distributions, the strong northerly cross-equatorial wind, and the relatively weak easterly wind. These features are favorable for the WES feedback and the temporal evolutions of these fields support the dominance of positive WES feedback from December 1997 to February 1998.

Although the dominance of the WES feedback in the western Pacific warm pool during the mature phase of EL97 is recognized, there is only one case derived from detailed satellite-based SST and wind data from 1991

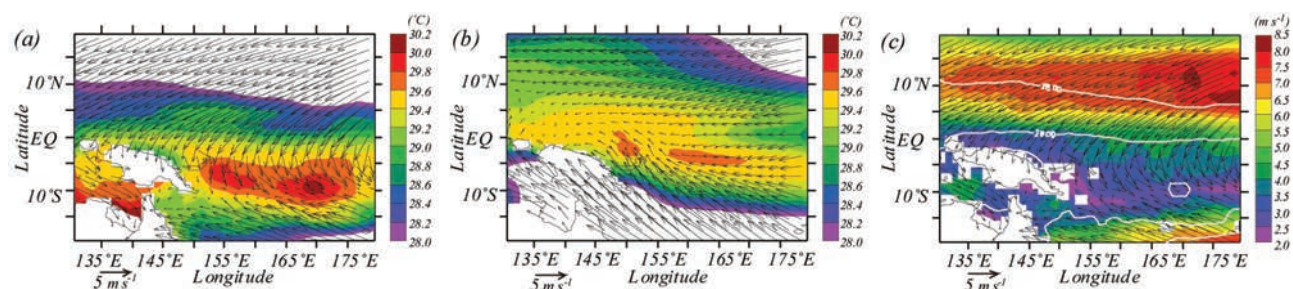


Fig. 3 Distributions of DJF-means of the (a) SST and wind vector in 1997-98, (b) SST and wind vector of the climatology, (c) wind speed and wind vector in 1997-98. The white contour in (c) indicates the SST.

to 2008. Reanalysis data from National Centers for Environmental Prediction show the dominance of the WES feedback with identical anomalous SST and wind distributions during the mature phase of the strong 1982-83 El Niño. The dominance of WES feedback may associate with strong El Niño.

Vecchi and Harrison [2006] proposed that the initial stage of EL97's termination was a southward shift of equatorial westerly anomalies near the date line in DJF season. Based on some atmospheric model experiments, Vecchi [2006] suggested that the atmospheric response to the unusual El Niño SST anomalies were important for the southward shift of equatorial westerly anomalies. Although reduction of equatorial westerly with southward shift of high SST region is recognized in other El Niño events, larger reduction and much southward shift are found in 1997-98 El Niño. Vecchi [2006] also suggested the difference is caused by the nonlinear relationship between SST and convection. The WES feedback in the western Pacific warm pool can be another candidate to enhance the southward shift of westerly anomalies in terms of intensification of the equatorial asymmetric structures.

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The Impact of the MJO on Extreme Central Vietnam Precipitation -Vietnam Philippines Rainfall Experiment (VPREX) 2010- –Monsoon Hydrological Cycle Research Team–

Differing from other areas in the Asian monsoon region, the eastern coastal areas of the Indochina Peninsula and the Philippines receive the bulk of their annual rainfall in the regional wet autumn to early winter season. In most years heavy rainfall occurs in the period and often causes severe flooding and great damage. However, there was limited knowledge of rainfall and its variation in the regions for lack of observation data. In order to have a better understanding of the formation mechanism of heavy rainfall in the regions and to improve the prediction of precipitation in various spatiotemporal scales, we conducted an intensive observation, Vietnam Philippines Rainfall Experiment 2010 (VPREX2010), during October 2010 to January 2011 using automatic-weather stations, rain-gauge network, meteorological radars and radiosondes, as a part of the international project of the Asian Monsoon Year (AMY) 2007-2012.

During the VPREX2010 observation in early October 2010, heavy rain events over a large area at a rate of more than 100 mm per day were observed in central Vietnam for four consecutive days 2-5 October. Daily rainfalls of 208.3, 410.7 and 104.4 mm were observed at Hue Meteorological Observatory on 2, 3 and 4 October (Fig. 4). The heavy rain resulted in the most disastrous flood that has ever been experienced in central Vietnam. At least 59 people lost their lives and tens of thousands of houses and large areas of crop field were inundated.

We analyzed the data obtained from the intensive observation and examined the atmospheric circulations leading to the extraordinary heavy

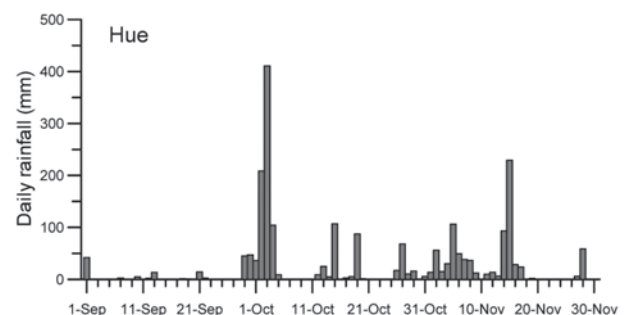


Fig. 4 Time series of daily rainfall (mm) observed at Hue Meteorological Observatory (16.433°N, 107.583°E) in central Vietnam for 1 September to 30 November, 2010.

precipitation event by analysis of data from the Japan Meteorological Agency Climate Data Assimilation System (JCDAS). As illustrated in Fig. 5, a westward-propagating synoptic-scale tropical disturbance that originated near Palau moved west-northwestwards from 27 September, 2010. As the disturbance was approaching the eastern coast of Vietnam, extreme heavy rainfall was observed in central Vietnam for four consecutive days from 2 to 5 October, 2010. Yokoi and Matsumoto [2008] investigated the causes of a heavy precipitation event that occurred in central Vietnam in early November, 1999. Their results showed that westward-propagating tropical disturbances and a winter monsoon cold surge are two important factors of extreme central Vietnam precipitation events. Similar results were obtained from an investigation of the causes of an extreme rain event in northern Vietnam in October, 2008, showing that tropical disturbances and the Asian winter monsoon play major roles in extreme precipitation events [Wu *et al.*, 2011]. Therefore, the westward-propagating tropical disturbance was the main factor of the extreme precipitation event of 2010.

Every year between September and November, westward-propagating synoptic-scale tropical disturbances from the western Pacific make landfall or strike the eastern coast of the Indochina Peninsula, causing heavy precipitation in central Vietnam. So why did this unusually extreme precipitation event occur in early October 2010 when a tropical disturbance struck the region? To answer this question, the intraseasonal variations in the tropical atmosphere and occurrences of heavy precipitation events in central Vietnam were investigated in the present study.

The strongest and most coherent MJO activity in 2010 occurred during late September, as enhanced convection developed over the Indian Ocean with eastward propagation evident through mid-October. Eastward propagation of an active phase of the MJO from the Indian Ocean significantly affects atmospheric circulation in the Maritime Continent and western Pacific regions. As illustrated in Fig. 6, with the eastward propagation of the active phase of the MJO, cyclonic circulation anomalies were evident on either side of the equator over the eastern Indian Ocean. Southwesterly wind anomalies were evident from northern Sumatra Island to the southern part of the Indochina Peninsula. Convergence of the zonal winds was thus evident over the South China Sea.

As discussed, westward-propagating tropical disturbance was a main factor of heavy rainfall events in the region, the MJO-related impacts on extreme central Vietnam precipitation events are thought to be linked to the growth and maintenance of westward-propagating tropical disturbances. It is known that when Rossby-mode waves move into regions where the zonal flow is becoming more easterly towards the

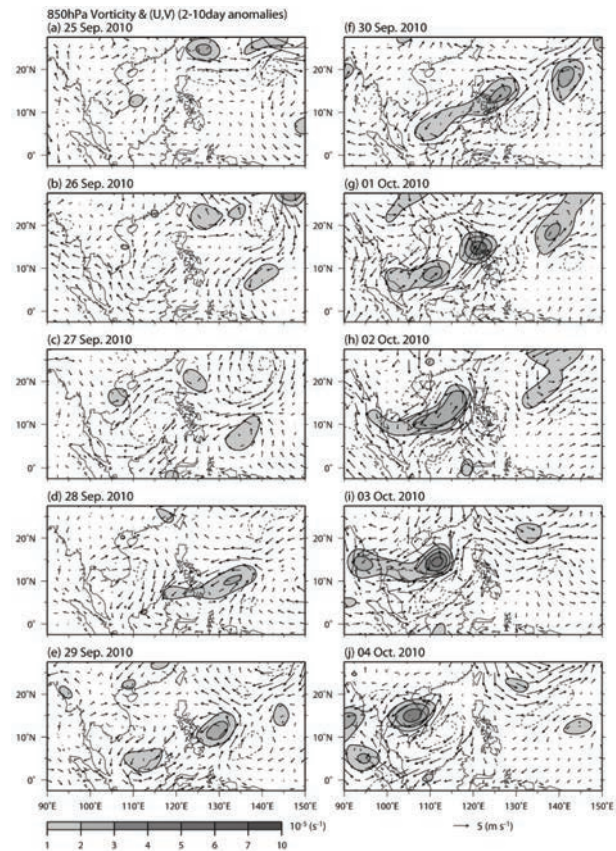


Fig. 5 Evolution of 2-day to 10-day bandpass-filtered 850 hPa winds and vorticity anomalies for 25 September – 4 October, 2010. Solid contours and shaded areas indicate cyclonic anomalies. Dashed contours represent anticyclonic anomalies.



Fig. 6 Five-day mean 850 hPa stream function anomalies and wind anomaly vectors for 3-7 October, 2010. The contours show stream function anomalies at intervals of $2 \times 10^6 \text{ m}^2 \text{ s}^{-1}$.

east (i.e. $dU/dx < 0$), the group speed decreases and the energy density and vorticity increase [Holland, 1995]. As illustrated in Fig. 7, during late September to early October 2010, with the eastward propagation of the active convective phase of the MJO, an area of enhanced convection moved eastward from about 60°E to 120°E , as indicated by the eastward propagation of outgoing longwave radiation (OLR). Easterly wind decreased in the region, that is $dU/dx < 0$ (green contours), as large westerly anomalies were observed across the eastern Indian Ocean and the Indochina Peninsula. Meanwhile, a packet of tropical disturbances propagated westward from the western Pacific (red line and arrow). These two systems met near central Vietnam at about 110°E , with the result that the MJO amplified tropical disturbances, which caused extreme heavy precipitation in central Vietnam in early October. These results suggest that a possible mechanism by which the MJO impacts extreme central Vietnam precipitation is a wave energy accumulation that is enhanced by the active phase of the MJO [Wu *et al.*, 2012 submitted].

We further investigated MJO activity during the September-November regional wet season from 1981 to 2010. Strong MJO activities occurred in the five years 1988, 1998, 1999, 2008 and 2010. In each case, a strong active phase of the MJO was accompanied by a long spell of rain in central Vietnam. However, widespread heavy rain over an extended period tends to occur when an active phase of the MJO coincides with a westward propagating synoptic-scale tropical disturbance from the western Pacific. Unusual extreme precipitation events in November 1999 and October 2010 occurred at the same time as strong MJO activity. The new finding of this study is that along with westward-propagating tropical disturbances, the intraseasonal oscillations in the tropical atmosphere (MJO) are an important factor in the formation of extreme precipitation events in central Vietnam. Further studies by analysis of the VPRESX 2010 observation data and employing numerical experiments with the aid of regional circulation models will be performed to elucidate the detailed physical mechanism by which the MJO induces extreme precipitation in the region.

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CINDY 2011 -International Field Campaign for the MJO Study- -MJO Research Team-

The Madden-Julian Oscillation or MJO, which is named after its discoverers, is characterized as a phenomenon identified as a large-scale ($O(1,000\text{km})$) cloud ensemble propagating eastward at on average 5 m/sec usually from the Indian Ocean to the Pacific with a periodicity of 30-60 days. Influences of the MJO spread over the world through the interactions with monsoons, El Niño, tropical cyclones, and others. In spite of much

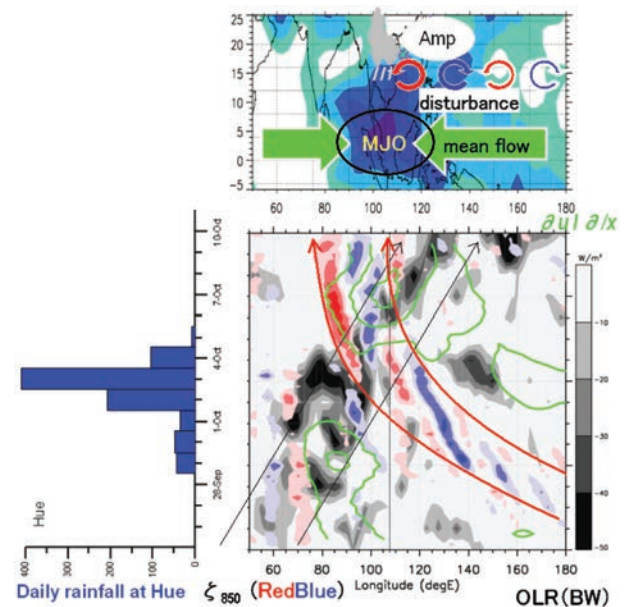


Fig. 7 (upper) A sketch of the mechanism by which the MJO induces extreme precipitation in central Vietnam. Lower left) daily rainfall at Hue during 26 September to 9 October, 2010. Lower right) Longitude-time series of 850 hPa vorticity, averaged over $5^\circ - 20^\circ\text{N}$, OLR and change of zonal wind with longitude (dU/dx) for 26 September to 9 October, 2010.

effort paid during the past four decades since its discovery, a comprehensive understanding of its initiation process as well as slow eastward propagation mechanism is still elusive. Numerical modelers are also struggling with forecasting and simulating the MJO. The lack of in-situ observations over the Indian Ocean, where the MJO convections often develop, makes difficult to reveal those mechanisms and to produce appropriate numerical parameterizations. To meet the need described above, a field campaign was proposed by JAMSTEC in 2008 as “Cooperative Indian Ocean experiment on intraseasonal variability in the Year 2011 (CINDY 2011)”, and then it was expanded into an international project. The U. S. participation in the field campaign was coordinated under “Dynamics of the Madden-Julian Oscillation (DYNAMO)”. Independent projects “ARM MJO Investigation Experiment (AMIE)” and “Littoral Air-Sea Processes (LASP)” became integrated components of the campaign. The WCRP/CLIVAR scientific steering group endorsed CINDY 2011/DYNAMO in 2009, which made the campaign as a real international project. Observations were conducted in and around the central tropical Indian Ocean from October 2011 to January as an intensive observing period (IOP), and to March 2012 as an extended observing period. Over than 60 institutes/universities from 16 countries joined this field campaign. Based on scientific background, two quadrilateral arrays were formed in both hemispheres by Islands and ships (Fig. 8). From JAMSTEC, we occupied one apex of the southern array at 8S, 80.5E during two months from October to November using the R/V *Mirai* and conducted atmospheric and oceanic observations continuously. In addition, we and BPPT

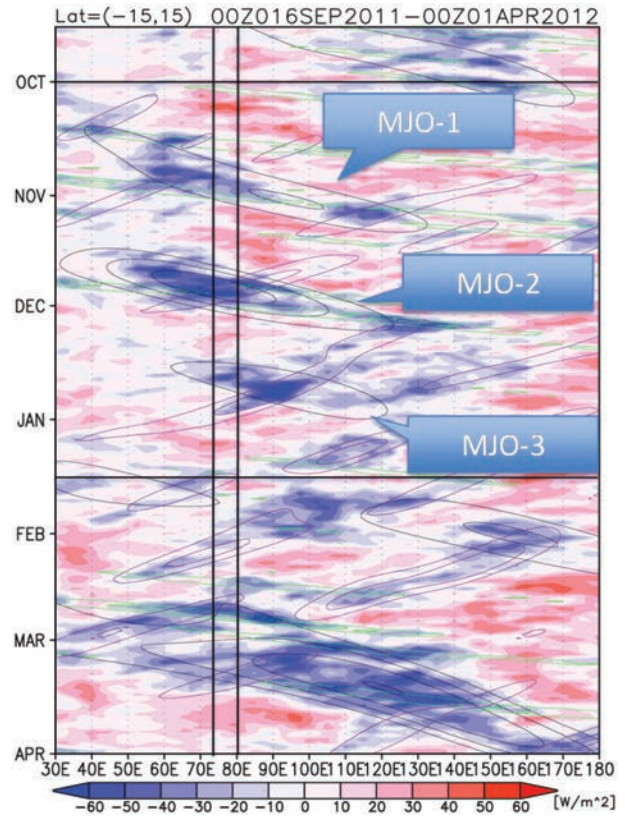


Fig. 9 Time-longitude cross section of outgoing long wave radiation. Contours indicate MJO (black), Kelvin wave (green), and equatorial Rossby wave (purple) based on the work of Wheeler and Weickmann (2001).

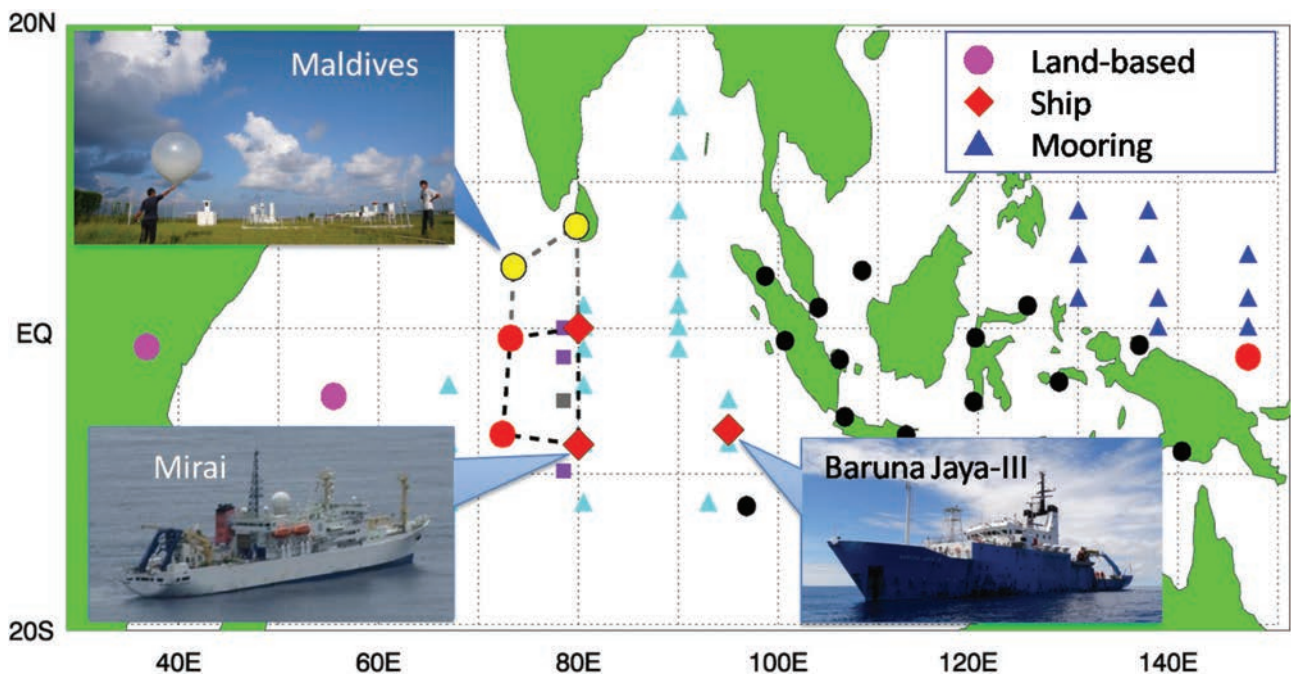


Fig. 8 CINDY2011/DYNAMO observation network.

conducted the cruise using the Indonesian R/V *Baruna Jaya-III* and occupied 7S, 95E about 10-days in December. While land-based super site was deployed at Gan Island near the equator and DYNAMO colleagues were responsible for the site, we also joined radiosonde sounding observations at Male (4N, 73E).

One of the important feature of this campaign is the fact that many numerical model groups from operation centers and research institutes were involved. From JAMSTEC, two modeling groups (NICAM and ALERA) joined and played a key role. It is also expected that they will perform hind-cast (NICAM) and produce reanalysis (ALERA).

During the IOP, three MJO events occurred over the Indian Ocean in late October, late November, and late December (Fig. 9). For the first two events, the center of MJO convection was located near the equator (not shown) and it was convectively inactive over the R/V *Mirai*. Based on satellite-based data analysis, it is suggested that after equatorward propagating clouds reached over the equator, a large cloud ensemble was developed and identified as an MJO convection. This is informative for the role of moisture advection. By combining all datasets at observation array, we will conduct the budget analysis to see the momentum/energy process. As for the oceanic features during the IOP, a unique feature was captured. Figure 10 shows time-depth cross section of salinity and temperature obtained by 3-hourly CTD casting. While thermocline became deep during leg-1 and such condition continued until mid-November, it was abruptly terminated around November 11. This drastic change seems to be caused by cooling water advection from southeast by analyzing Argo float data (not shown). Currently detailed analysis is undertaken to reveal the relationship between oceanic change and atmospheric convective activity, and also examine any relation to the 2nd MJO event which reached over the *Mirai*.

Finally it is worth noting that since the data policy of CINDY 2011/DYNAMO adopts an idea of “timely release and easy access”, quality controlled data will be released by the spring of 2013, so that it promotes the study of the MJO initiation process as well as propagation mechanism by a broader community. All information including data can be found at the CINDY 2011 web site (<http://www.jamstec.go.jp/iorgc/cindy/>).

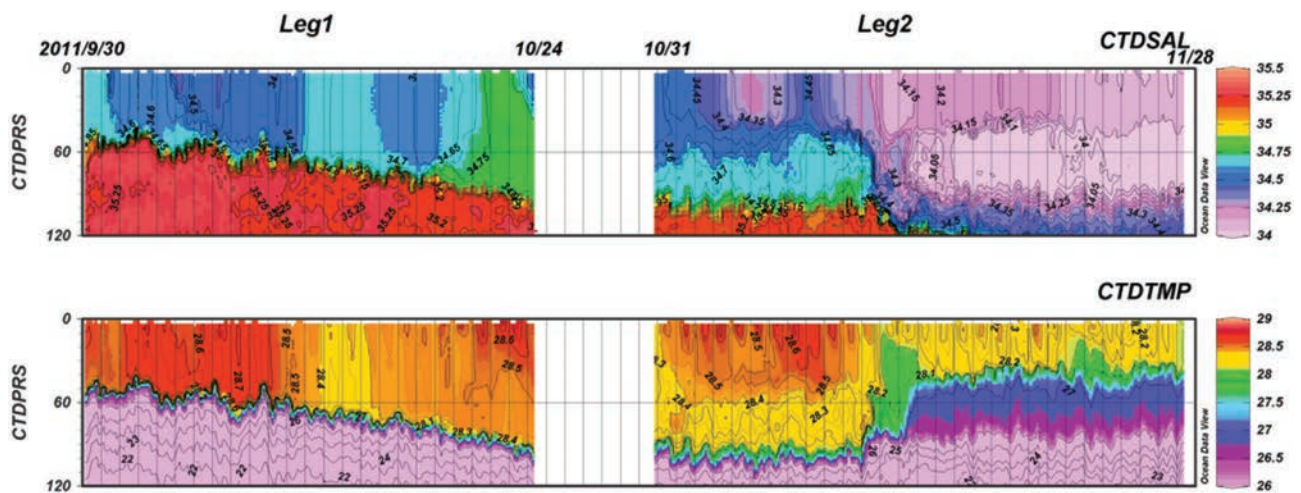


Fig. 10 Time-depth cross section of salinity (upper) and temperature (bottom) obtained by CTD at 8S, 80.5E from the R/V *MIRAI*.

Initiating a New Era of Japan-Indonesia Collaboration –SATREPS-MCCOE Project–

A 5-year international (Japan-Indonesia) project entitled “Climate Variability Study and Societal Application through Indonesian-Japan Maritime Continent COE: Radar-Buoy Network Optimization for Rainfall Prediction” (SATREPS-MCCOE project) has been adopted in April 2009 by the program committee of Japanese Government on Science and Technology Research Partnership for Sustainable Development (SATREPS), supported financially by Japan Science and Technology Agency (JST) and Japan International Cooperation Agency (JICA). The project is carried out by the TCVRP and the Marine Technology and Engineering Center

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(MARITEC) of JAMSTEC, under collaborations with Kyoto University and Kobe University in Japanese side and with Agency for Assessment and Application of Technology (BPPT), Agency for Meteorology, Climatology and Geophysics (BMKG) and National Agency for Aeronautics (LAPAN) in Indonesian side. After signing a Record of Discussions (R/D) between Japanese and Indonesian Governments in January 2010 and a Collaborative Research Agreement (CRA) between JAMSTEC and BPPT in February 2010, the project has been started.

The Indonesian maritime continent (IMC) with warm water pool is the region of the world's most active convective cloud activities and largest rainfall, which maintain and control the global climate. The clouds generate winds, which pump up the global atmospheric circulations and also blow sea waters over the Pacific and Indian Oceans. These ocean-atmosphere interactions lead to global climatic variations such as ENSO and IOD, and resulting rainfall grows up agricultural products and tropical forest absorbing the carbon dioxide. Therefore the better understanding and continuous observations of climate over IMC are inevitably necessary for both scientific understanding and societal sustainability on the global climate. This importance has been recognized mainly by strong scientific collaborations between JAMSTEC and BPPT accumulated in a history for three decades, started under the Agreement between the Government of Japan and the Government of the Republic of Indonesia on Scientific and Technological Co-operation, signed at Jakarta on January 12, 1981.

In order to keep observations of this important region permanently, it must be promoted independently by Indonesia which becomes a G20 country now. For this purpose the SATREPS-MCCOE project will promote establishment of an international research center (MCCOE) by the Indonesian Government (Output 1). The MCCOE will have three functions: observations by radars (Output 2) and buoys (Output 3); data management (Output 4); and researches on regional rainfall (Output 5) and global climate (Output 6). Concerning Output 1, a building is under construction in the National Research and Technology District (PUSPIPTEK) in Serpong (20 km southwest from the central Jakarta) by the Indonesian Government (to be completed in the end of 2012), and a society is under organization between BPPT, BMKG and LAPAN, as well as researchers in universities and other

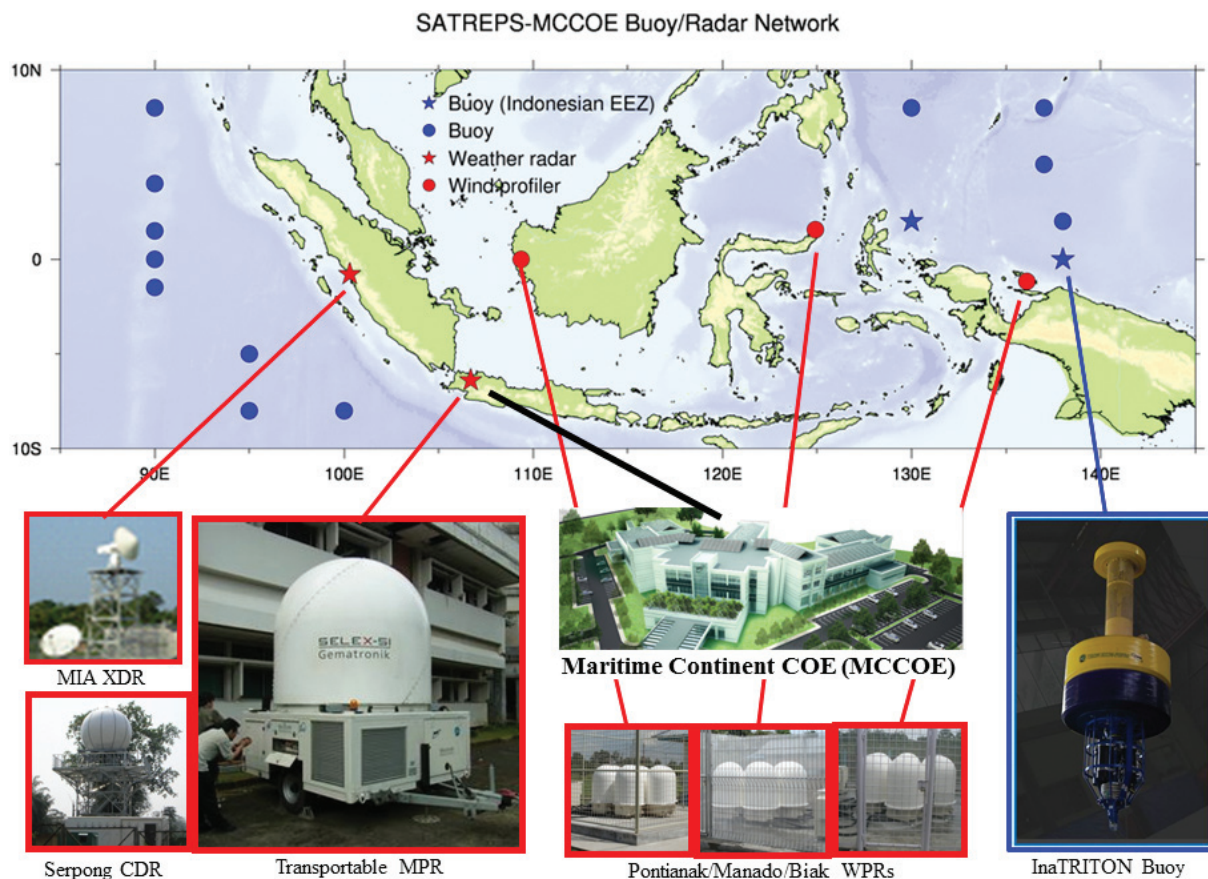


Fig. 11 The MCCOE observation network over IMC, composed of X- and C-band Doppler radars (XDR/CDR), wind profilers (WPRs), a transportable multi-parameter radar (MPR) and an ocean climate buoy (InaTRITON).

agencies. A homepage has been constructed at BPPT: <http://neonet.bppt.go.id/satreps/>

Concerning Output 2, an X-band Doppler meteorological radar (XDR, at Padang) and three wind profilers (WPRs, at Pontianak, Manado and Biak) installed by a Japanese grant (Japanese Earth Observation System Promotion Project or JEPP-HARIMAU, during FY 2005-09) have been transferred to Indonesian Government at the end of FY 2011, after 2-year continuous operation supported by the JICA grant (see Fig. 11). A transportable multi- parameter radar (MPR) has been installed newly under the SATREPS-MCCOE project. Through intense observations for a month in December 2011, the capacity to operate these radars has been successfully built up in Indonesian side.

Concerning Output 3, technology of design, construction, installation and recovery of a climatological buoy (called Ina-TRITON) has been transferred from MARITEC engineers to Indonesian side through trainings in JAMSTEC and PUSPIPTK, as well as on R/Vs of the both countries (*Mirai* and *Baluna Jaya III*). The basic construction of the first Ina-TRITON buoy was almost completed at the end of FY 2011 (see Fig. 12), and it will be installed near Papua Island (an international-network point inside Indonesian EEZ, supported by JAMSTEC until now) in September 2012 by an Indonesian team on *Baluna Jaya III*.

Concerning Output 4, a historical meteorological database, a realtime internet information system on rainfall (called SIJAMPANG), and a quality check system of buoy data have been being constructed. The SIJAMPANG system using the CDR in Serpong and social networks with citizens has been utilized broadly; for example it has been used as a main facility for rainfall watch in Jakarta by Indonesian Government during the 2011-12 rainy season. The historical database and the Ina-TRITON buoy data will be provided to international community.

Concerning Outputs 5 and 6, lectures, workshops and basic researches have been started, and will be continued fully in the next two years (FY 2012-13) of the SATREPS-MCCOE project. Preliminary results published already involve several important results such as strong correlation between ENSO, IOD and rainfall in Jakarta (see Fig. 13). A Indonesian PhD course student is studying radar hydrology under a SATREPS scholarship by MEXT. The SINTEX-F model products are utilized for agricultural application by an Indonesian postdoctoral researcher.

Therefore observational activities over IMC now enters into a new era in which Indonesian scientists will lead to collaborate with Japanese researchers. The establishment of MCCOE at the end of this project (in March 2014) will bring benefit to Indonesia to be a principal country to lead global climate observation and researches as



Fig. 12 The first Ina-TRITON buoy completed by BPPT team (in March 2012).

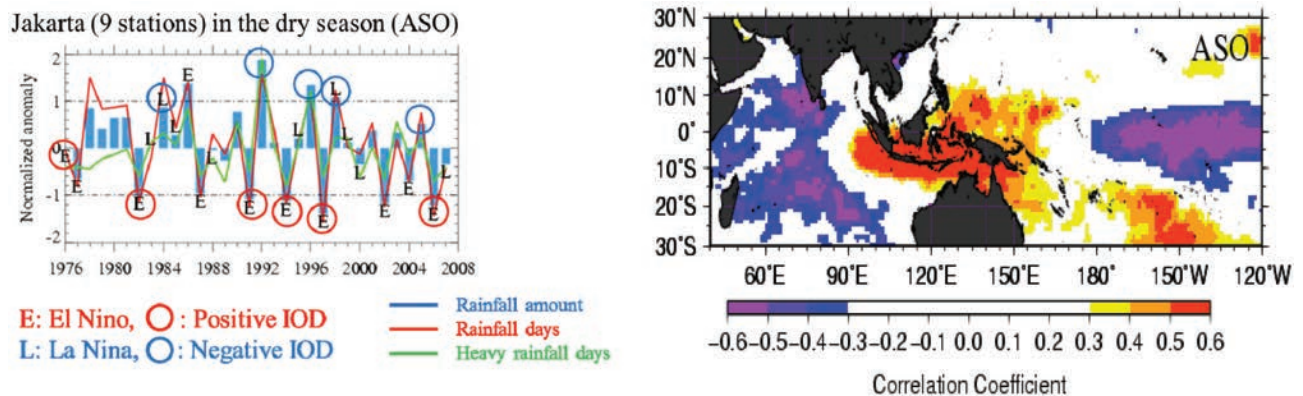


Fig. 13 Strong relationship between rainfall in Jakarta and Indo-Pacific Oceans [Hamada et al., 2012 submitted]. Left: Anomalies of dry-season rainfall and rainy day number in Jakarta labeled with ENSO and IOD. Right: Correlation for dry-season rainfall in Jakarta with sea surface temperature.

well as regional climate observation and researches. To put it another way, this implies that by using Indonesian observation data in future, RIGC researchers will be able to study many advanced subjects such as ocean-atmosphere-land interaction mechanisms and long-time scale variations over and around the Indonesian maritime continent.

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Understanding the Drastic Change in the Arctic and High Latitude Regions

–Northern Hemisphere Cryosphere Research Program–

The aim of the research 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, integrated data analysis based on satellite and data archive, and numerical experiments. Furthermore, to evaluate the influence of Global Warming to the cryosphere, and clarify the role of this region to the global-scale and contribute to the better future prediction. The main research topic are the drastic change occurring in the Arctic Ocean, the surrounding continental region, mainly Siberia, and the response of high latitude atmosphere. The main observation system is described in Fig. 1.

During the 2011FY, as the third year of mid-term (2009~2014), we pursued observations which has been done as monitoring for the changing Arctic Region, and started new observations. Also the analysis works based on past obtained data and usage of other global data have been made to obtain new findings. The following are the main observation and scientific activities in 2011FY, and the main scientific findings are described separately.

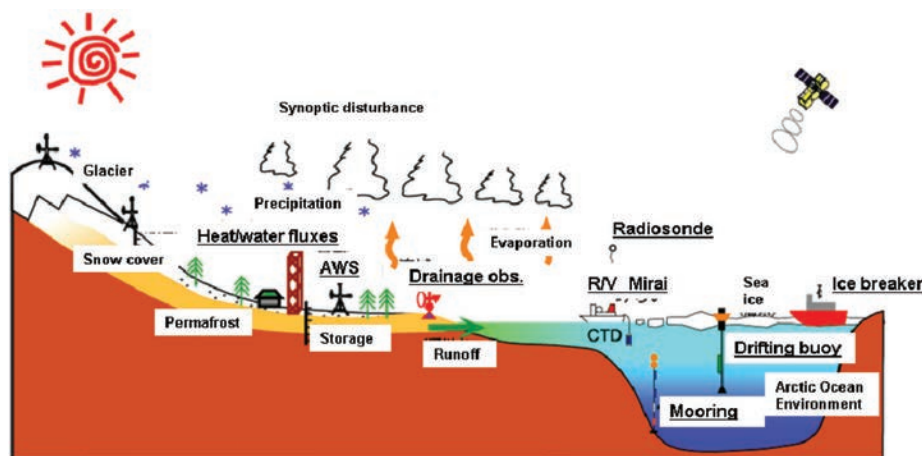


Fig. 1 Main observation structure in the Arctic Region and Eurasia.

- (1) As a routine work POPS (Polar Ocean Profiling System) has been set on the sea ice near the North Pole, and it transmitted ocean, sea ice and atmospheric data worldwide till August.
- (2) Under the cooperation with the German, and Canadian Ice breaker, XCTD observation was made in a wide area in August to October, 2012. Also oceanographic observation and mooring setting was made by joining the cruise of US and Canadian Ice Breakers during September~October, 2011.
- (3) Meteorological/glaciological/hydrological observation at Supersites (Tiksi, Yakutsk, Northern Mongolia) were successfully continued, and a satellite transmission was newly set at Mongolia site.
- (4) Permafrost monitoring (40 sites) in Mongolia which was initiated in 2009, and snow survey in Siberia, Mongolia and Alaska was successfully continued. Implementing method of data-acquisition was changed to local researchers in the Siberia and Mongolia.
- (5) Preliminary operation of new mountain cryosphere research site at Suntar-Khayata Mountains started in September, 2011 and several instruments were set.
- (6) As part of Asia/Arctic Data Archive, past data was registered, and GEN Aerial Photo CD was released as part of Asia CliC activity.
- (7) Energetic analysis of data and publication of papers were made in scientific journals (total: 23) at all teams, and especially 3 following important topics were press-released. "JAMSTEC scientists succeed in observing a detailed structure of Arctic cyclogenesis", "Sea-Ice Variability in the Barents Sea Brings Arctic Warm and Continental Cold- Clues to Coldness in Japanese Winter – "R/V Mirai Survey Reveals Features and Biological Impact of Large Warm-Core Eddy in the Arctic Ocean".

How is the Arctic Ocean environment changing? –Arctic Ocean Climate System Research Team–

In September 2011, minimum sea ice extent in the Arctic Ocean reached the second lowest value ($4.52 \times 10^6 \text{ km}^2$) since 1979. Recently, Arctic sea ice reduction and its impact to not only the Arctic Ocean environments but also global climate change are of interest for both scientists and the general public. Arctic Ocean Climate System Research Team conducted Pan-Arctic field observations in 2011, in collaboration with institutions in U.S., Canada, and Germany (Fig. 2). These observational data will clarify on-going changes of the Arctic Ocean environments related to the sea ice reduction as well as the previous ones.

Recent sea ice reduction in the Arctic Ocean has accelerated the accumulation of freshwater, especially in the Canada Basin of the Arctic Ocean. That caused a decrease in nutrient concentrations in the euphotic zone and thus made there uninhabitable for large phytoplankton. Pacific Summer Water (PSW) is one of the predominant sources of heat, fresh-water, and nutrients. Surface intensified warm-core eddies play an important role to transport PSW from the Chukchi continental shelf into the Canada Basin. Yet, due to a low occurrence of large warm-core eddies, their hydrographic characteristics and impact on marine biological activities remained uncertain. During the Arctic Ocean cruise of R/V *Mirai* in 2010 (September to October; MR10-05), an usually large warm-core eddy was found in the southern Canada Basin and detailed hydrographic surveys were conducted on the eddy ([Nishino *et al.*, 2011]; Fig. 3). Diameter of the eddy was larger than 70 km and the core temperature was much warmer (more than 5°C) than surrounding water temperature (less than 0°C) (Fig. 4A). This large warm-core eddy contained high-ammonium shelf water, could supply the ammonium to the euphotic zone in the southwestern Canada Basin, and might sustain $\sim 30\%$ higher biomass of pico-phytoplankton ($< 2 \mu\text{m}$) than that in the surrounding water in the basin (Fig. 4C and 4D). Such warm-core eddies are likely major nutrient providers to the euphotic zone in the Canada Basin, and their role in phytoplankton growth seems to be more important than before, because a nutrient-poor freshwater is recently accumulated in the euphotic zone due to the sea ice reduction.

In the Eurasian basins of the Arctic Ocean, unusual low ice concentration was observed even in the higher latitude area (Fig. 5). Using observational data from an buoy array of Polar Ocean Profiling System (POPS, Fig. 6) and other ice-drifting buoy, which were deployed near the North Pole in April 2010 and drifted close to the low ice concentration area in summer 2010, a mechanism of the sea ice reduction in the Eurasian basins in summer 2010 were examined [Kawaguchi *et al.*, 2011]. Oceanic heat fluxes to the ice suggest a significant difference

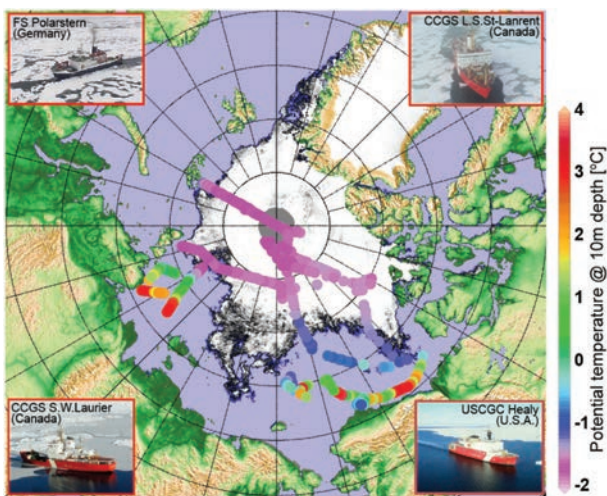


Fig. 2 Distribution of water temperature at 10 m depth, which were observed by U.S., Canadian, and German icebreaker cruise during August and October 2011. Background map shows sea ice concentration at September 9, 2011, when the minimum sea ice extent in 2011 was observed.

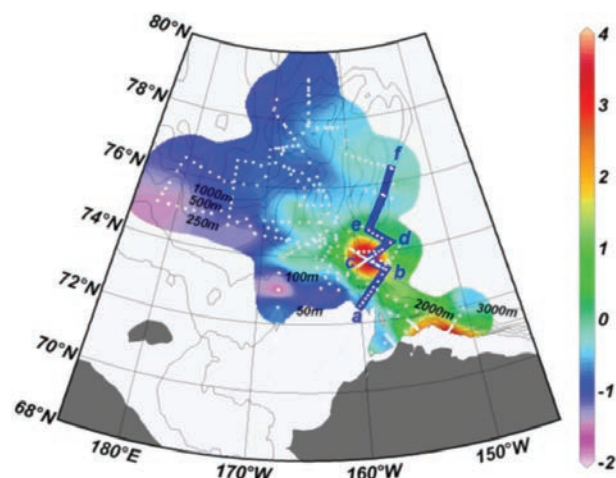


Fig. 3 Temperature distribution at 50 m depth, which data were collected during R/V *Mirai* Arctic cruise in 2010 (MR10-05). The blue lines indicate the locations of the vertical sections illustrated in Figures 3 (A), (C), and (D). [Nishino *et al.*, 2011]

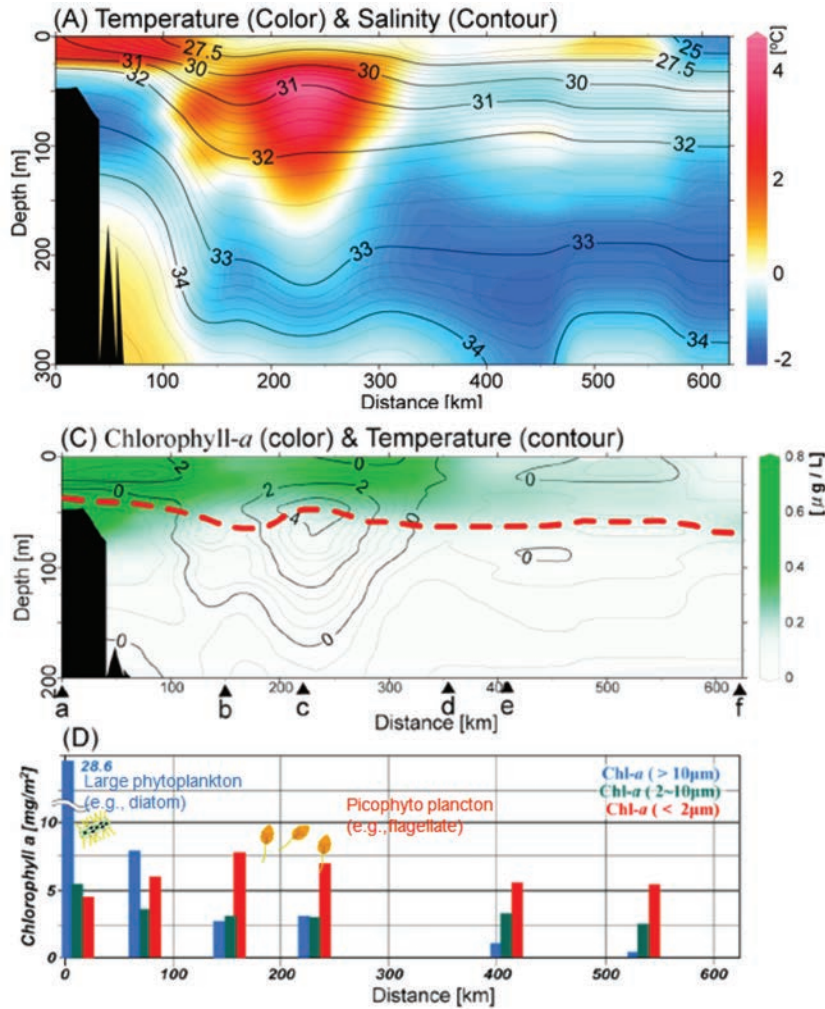


Fig. 4 (A) Vertical section of temperature [degree C] (color) and salinity (contours) across the large warm-core eddy.

Fig. 4 (C) Vertical section of chlorophyll a concentration [mg/L] (color), temperature [degree C] (black contours), and euphotic zone depth (red-dashed contour) across the large warm-core eddy.

Fig. 4 (D) Distributions of phytoplankton biomass [mg/m²] integrated over the water column from the surface to a depth of 50m (approximately the euphotic zone) for phytoplankton chlorophyll a in cells >10 mm (blue bars), cells 2–10 mm (green bars), and cells <2 mm (red bars) across the large warm-core eddy. [Nishino et al., 2011]

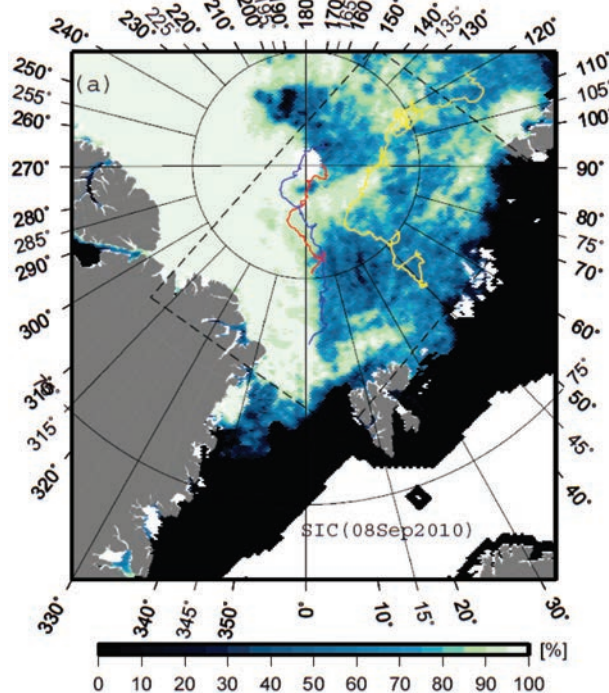


Fig. 5 Track of ice-drifting buoys, overlaid with SSM/I ice concentration on September 7, 2010. [Kawaguchi et al., 2011]

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between fluxes under first-year ice (more than 70 W m^{-2} ; 1.5 m of ice melt) and multi-year ice ($\sim 40 \text{ W m}^{-2}$; 0.8 m ice melt). In addition, extensive low pressure system persisted over the Eurasian basins of the Arctic Ocean in mid-August. Wind-forced ice divergence reduced ice concentration, led to enhanced absorption of incident solar energy in the expanded areas of open water, and thus played an important role of the increase in ice melt.

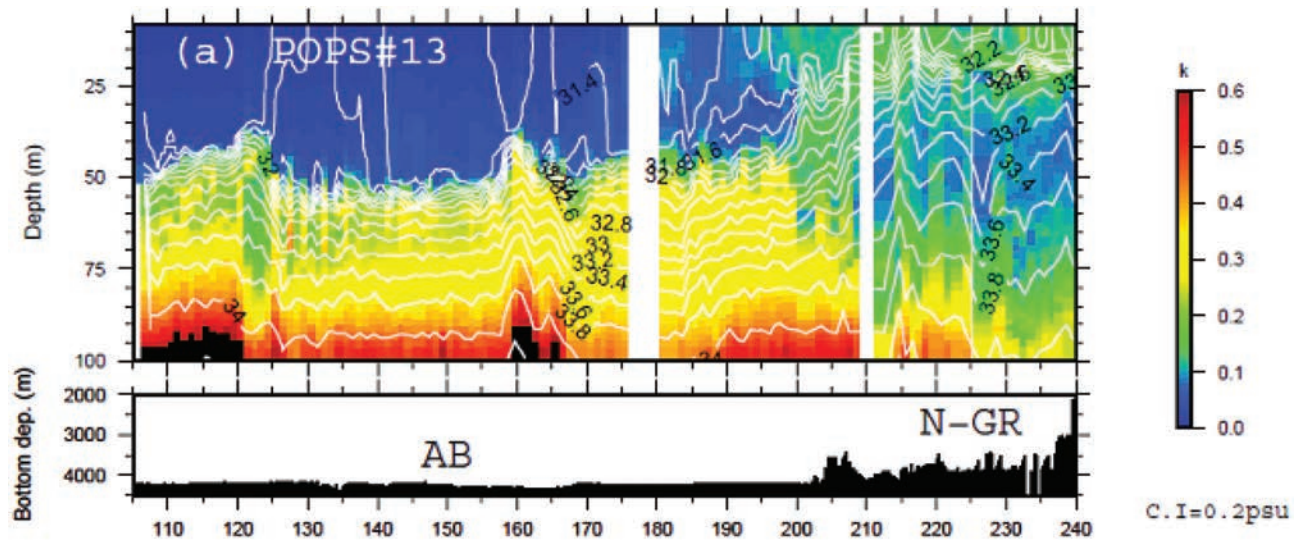


Fig. 6 Oceanographic properties of temperature deviation from freezing point (color) and salinity (contour) along the buoy track. Bathymetry is depicted at the bottom of the panel. Acronyms AB and N-GR denote Amundsen Basin and Nansen-Gakkel Ridge, respectively. [Kawaguchi et al., 2011]

The Fluctuations in Terrestrial Environment

–Terrestrial Environment Change Research Team–

Global warming is in progress around the Arctic after 1990 has caused the change in terrestrial environment in a variety of ways. Global warming, affect the variability snow and ice (glacier and snow cover) is a component water cycle. Global warming will promote the strengthening of the water cycle to increase the amount of variation, such as precipitation, runoff, evapotranspiration, storage, fluctuation period that its faster. Terrestrial environment has a complex change process and the processes of change in chain water cycle, vegetation, snow, permafrost (active layer), and terrain. The important thing is to be monitored for changes in Arctic terrestrial environment, explore the cause and lead to future predictions.

In this team, as part of the monitoring, it is going to build the super site and distributed snow traverse route in Alaska and northern Eurasia, permafrost observation network distributed in Mongolia as the southern limit of permafrost, and mountain snow and ice super site in Altay mountain range , determine the year-to-year changes

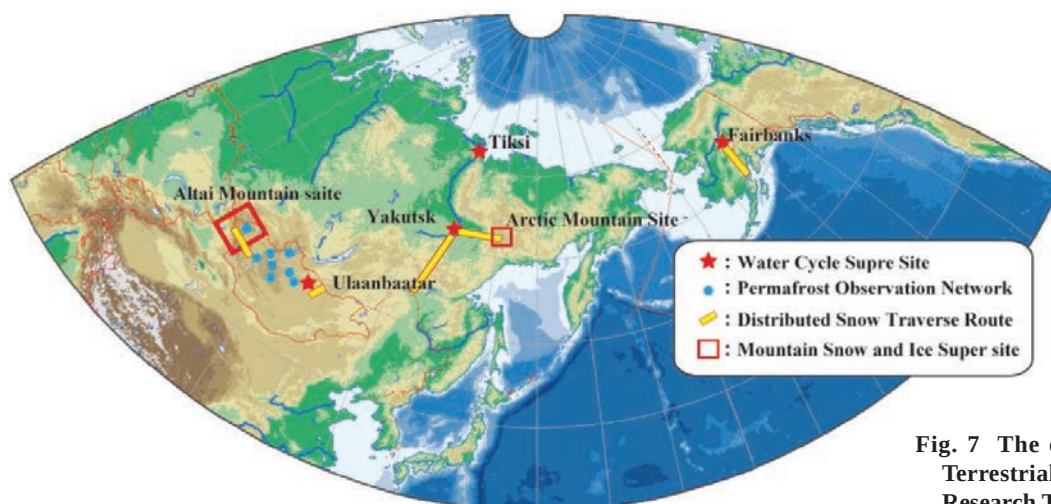


Fig. 7 The observation region by Terrestrial Environment Change Research Team

in the terrestrial environment, to clarify the their change process. (Fig. 7)
The data obtained in these observations are to publish from the cryosphere database. (<http://www.jamstec.go.jp/acdap/>)

Based on these data, published a paper on the process of solidification of the snow conditions [Sugiura *et al.*, 2011] and the decline of the Altai glaciers [Kadota *et. al.*, 2011].

Preliminary study is carried out in September 2011 in Arctic mountain range (Suntar Khayata Mountain range), was the equipment is installed automatic weather stations (Fig. 8). In this region, glacier observation is carried out in 1950 and 2000, the main observation, it is considered state of glacier fluctuations since 2000 and can be understood.

The full-scale study of the next fiscal year, the elucidation of the glacier in the recent and long-term change, such as the major mountainous areas can be expected with the Altai Mountains in Northern Eurasia.

The snow observed meteorological station is located in the lowland, there are few point in high altitude meteorological station that are important to water cycle. To collect snow data for these high altitude observation point, in order to improvement of satellite algorithms and verify the models for the purpose of deriving global distribution is important. It continues to use the traverse route of snow observation in Siberia, Mongolia and Alaska since 2003. Altai mountain range is located at the southern end of the Arctic region is less snow. In the region the snow water equivalent of satellite products is the too large than the observed value, and a satellite products can't be used. In order to clarify the actual conditions of snow cover variability in the region, as an alternative to the satellite products, and then try to reproduce the distribution of snow cover in the region using a regional climate model, we made a comparison with the observed values. Figure 9 (a) shows the distribution of the computational domain and the observation point. It can be seen that the observation points are distributed in high altitude areas. It was found that the output from the comparison of these models (Fig. 9 (b) Black dot line) a and



Fig. 8 Installation of automatic weather station in the Arctic mountain observation sites

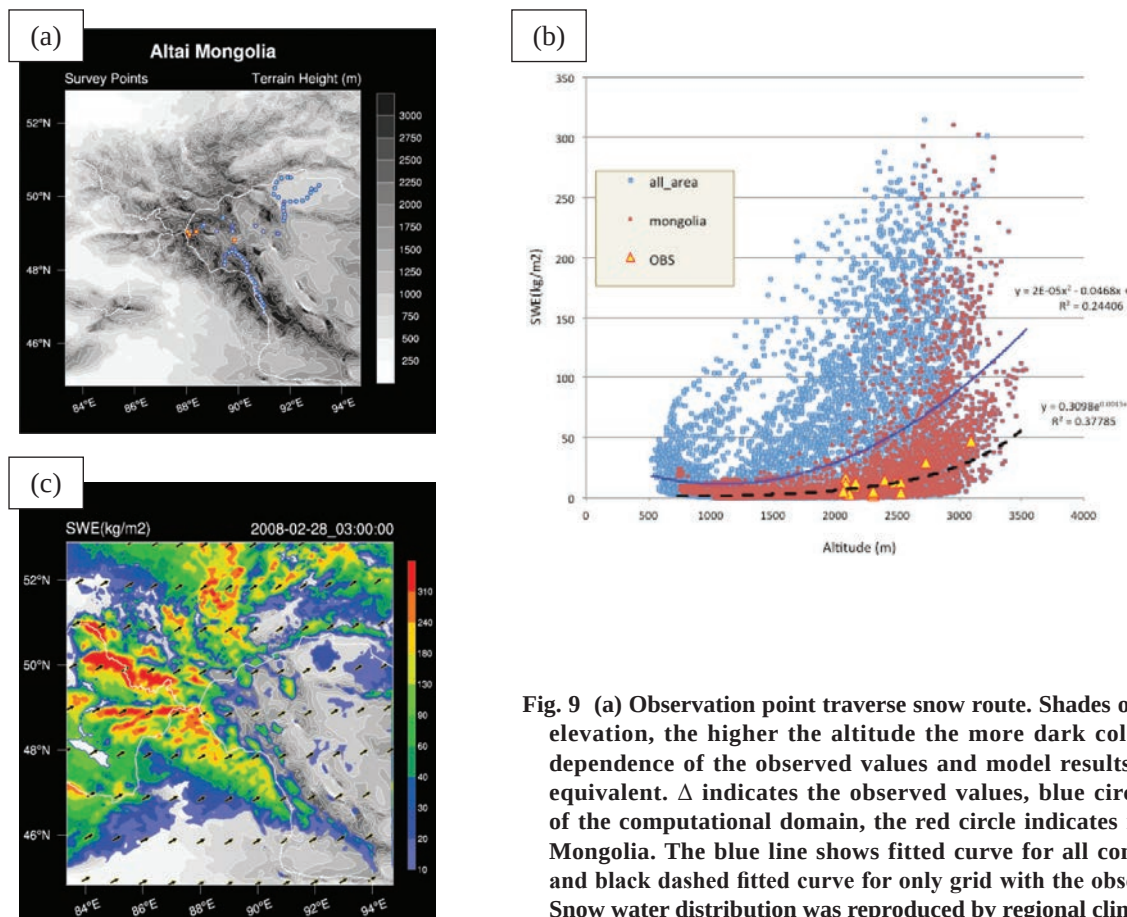


Fig. 9 (a) Observation point traverse snow route. Shades of colors indicate elevation, the higher the altitude the more dark color. (b) Altitude dependence of the observed values and model results of snow water equivalent. Δ indicates the observed values, blue circle indicates all of the computational domain, the red circle indicates model values in Mongolia. The blue line shows fitted curve for all computer domain, and black dashed fitted curve for only grid with the observed values. (c) Snow water distribution was reproduced by regional climate model.

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the observation point (Fig. 9 (b) Δ), it is useful to estimate the regional distribution of snow cover found the effectiveness of the regional climate model.

It was able to determine the snow distribution of Altai mountain range, including high altitude regional climate model results (Fig. 9 (c)) In the Altai mountain range, humid air that comes cross the border by the west wind is a snow storm on the western slopes of the mountainous Altai region, and it is extremely low snowfall in the Mongolian side. This can affect the development situation of glaciers and permafrost in the region.

While snow depth over pan-Arctic terrestrial regions experiencing climatic warming indicates decreasing trend during longer period, the decrease shows significantly different patterns between Eurasia and North America. The spatiotemporal variations of the snow depth were simulated by a land surface model (CHANGE) during the period of 1948–2006 over the terrestrial Arctic regions of $>45^{\circ}\text{N}$. Figure 10 shows interannual variations of air temperature, snow cover extent, and snow depth averaged during January and March. The snow depth was averaged over regions showing the depth of >35 cm, and the cumulated area of the regions was displayed as snow cover extent. Since 1980 when the warming increased, the snow cover extent in both continents decreased responding to the increased temperature. The snow depth in North America also exhibited a significant decrease during the same period, while one in Eurasia showed the annual variation of normal state. This difference seems because the influence of decreasing precipitation and increasing temperature during the winter season on the snow depth was stronger in North America than in Eurasia.

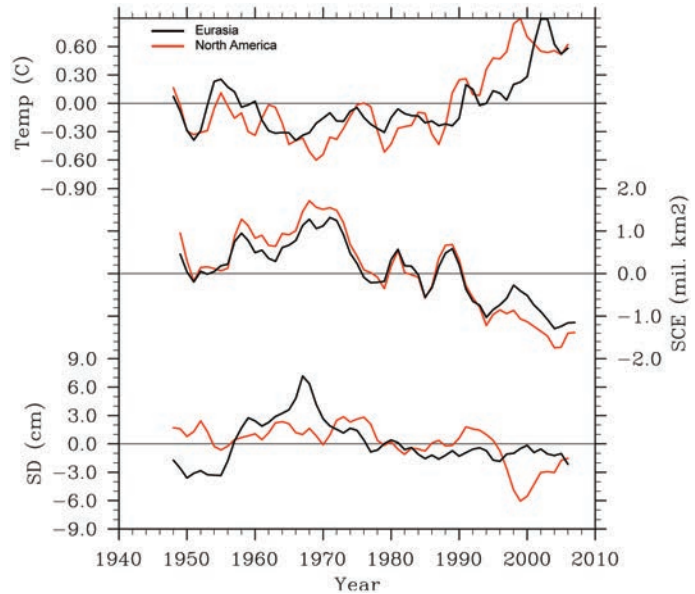


Fig. 10 The yearly deviation of annual mean air temperature (Temp) and snow depth (SD) averaging for regions of >35 cm and accumulated snow cover area (SCE) for the regions in Eurasia and North America.

The roles of the Arctic cyclones on the polar amplification

–Climate Dynamics Research Team–

The Arctic lower troposphere has been warming more than twice as fast as the global average partly due to the decrease in Arctic sea ice and the feedback system. The Arctic temperature amplification has a strong seasonal dependency reaching the strongest in winter and the weakest in summer. One direct trigger is the decrease in sea ice extent during summer, which results in the anomalous absorption of a large amount of solar radiation into the upper ocean, enhancing subsurface ocean warming. During autumn, the meridional heat contrast between the warm ice-free ocean and the cold ice surface becomes large, likely enhancing a baroclinity. However, to date, there is little observational evidence of cyclogenesis along the marginal ice zone. Over the Pacific sector, the recent rapid sea ice retreat has increased observational targets from the sea ice itself to the changes in the ocean and atmosphere. It is now possible for ships that are not ice breakers to reach and observe the Arctic Ocean.

In September 2010, we successfully observed the genesis and development of an Arctic cyclone that occurred near the Arctic marginal ice zone (79.0°N) using the R/V *Mirai* [Inoue and Hori, 2011]. The frontal system traveled southeastward, and grew in a size and intensity comparable to those observed at mid-latitudes within two days (Fig. 11). Our shipboard Doppler radar and intensive radiosonde observations at the marginal ice zone detected an explosive frontal cyclogenesis, with coupling between upper and lower tropospheric vortices. Such direct observations of high-latitude cyclogenesis had never been obtained before. The heat content analysis of the water column before and after the cyclogenesis revealed a 1.5 K decrease in water temperature, resulting in

the southward expansion of the sea-ice margin from 80.0° N to 78° N. The oceanic heat loss during this four-day cyclogenesis event is estimated to be 123 MJ m^{-2} , which is equivalent to the amount of solar radiation absorbed into the ocean during the latter half of September. The in situ observations obtained in this study, offer invaluable clues to a positive feedback loop possibly taking place in the Arctic; where the Arctic cyclone in autumn, induced by summer sea-ice melting, helps transport a large amount of oceanic heat to the atmosphere, warms up the Arctic winter and hinders sea ice formation, resulting in thinner and reduced sea ice extent in summer.

Cyclogenesis at the Arctic marginal ice zone also frequently occurs over the Barents Sea during winter. In this region, warm advection by anomalous winds helps to keep the ocean ice-free and the overlying atmosphere warm. As a result, the polar amplification is especially strong over there. To understand the influence of sea-ice variability over the Barents Sea on the cyclone tracks during winter, Inoue *et al.* [2012] evaluated the downstream response in cyclone activities with respect to the underlying sea-ice variability. The composite analysis including all cyclone events over there revealed that an anticyclonic anomaly prevailed along the Siberian coast during light-ice years over the Barents Sea (dashed line in Fig. 12). This likely caused anomalous warm advections over the northern Barents Sea and cold advections over the Siberia. We call this pattern the warm-Arctic cold-Siberian (WACS) anomaly (Fig. 12). The WACS anomaly resulted from the difference in cyclone paths between heavy- and light-ice years. The lower baroclinicity over the Barents Sea during the light-ice years, which was caused by a weak gradient in sea surface temperature, prevented cyclones from traveling along the Siberian coast. Although the mid-latitude climate is also influenced by other teleconnections, each cyclone path over the Arctic should be worth monitoring for cold-air accumulation over Siberia in short-term forecasts, while the variability of the Barents ice cover has potential predictability for long-term forecasts.

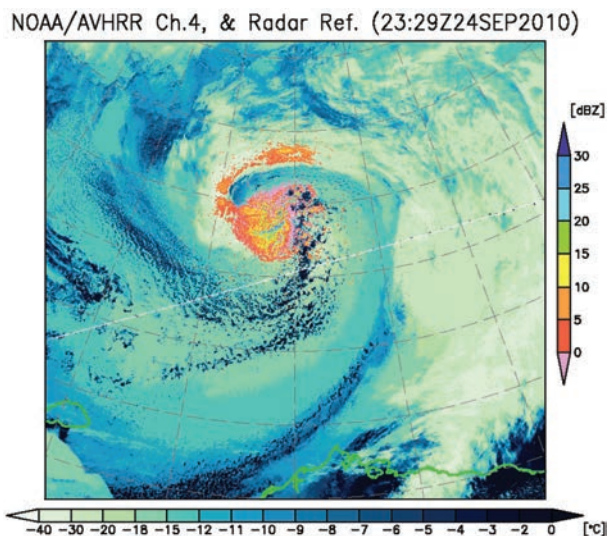


Fig. 11 NOAA/AVHRR infrared image and corresponding radar reflectivity obtained by the ship on 24 September 2010. [after Inoue and Hori (2011)]

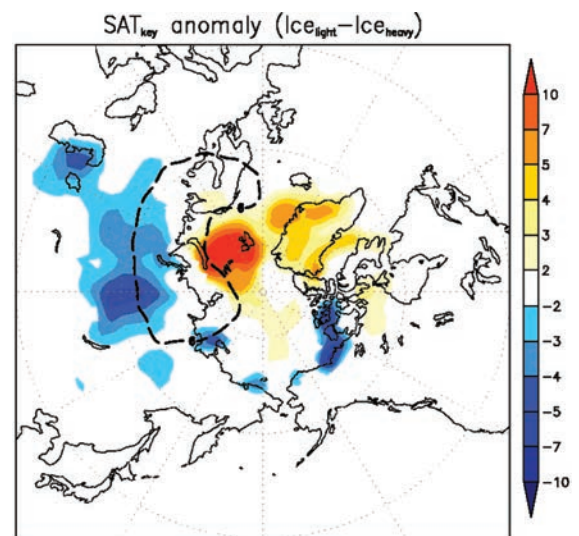


Fig. 12 A difference map of surface air temperature (K) between light- and heavy-ice years. Dashed line denotes SLP anomaly exceeding 6 hPa. [after Inoue *et al.* (2012)]

Publication List

Publication with Peer Review (Published)

- Gueguen, C., F. A. McLaughlin, E. C. Carmack, M. Itoh, H. Narita, and S. Nishino (2011), The nature of colored dissolved organic matter in the southern Canada Basin and East Siberian Sea, *Deep-Sea Res. II*, 58, doi:10.1016/j.dsr2.2011.05.004.
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Publication with Peer Review (Accepted)

Yabuki, H. (2012), Application and metadata format of cryosphere data archive partnership (CrDAP), *CODATA Data Science Journal*, (Accepted)

Ecosystems in Biogeochemical Cycles –Environmental Biogeochemical Cycle Research Program–

Environmental Biogeochemical Cycle Research Program (EBCRP) was established and went through a major reconstruction in FY 2009. Number of the Research Teams was reduced from 8 to 6 in order to put an emphasis to increment inter-team collaborative studies. To facilitate the inter-team collaboration, a program-wide aim and an inter-program collaboration scheme (Fig. 1) were set up at the beginning of the FY2010. In FY2011, to materialize an inter-program collaboration scheme, the EBCRP's umbrella research theme “*Response and feedback of ecosystems and biogeochemical cycles to climate change*” was held up. Under that, the following research sub-themes, i.e., 1) “*Climate change and marine ecosystem and biogeochemical cycles*”, 2) “*Climate change and land vegetation change*”, 3) “*Climate change and green house gases*”, and 4) “*Paleoceanographic reconstruction of ecosystem and biogeochemical cycle change*” were placed. Each Team Leader was encouraged to study more than one sub-theme in collaboration with other research teams within the frame shown in Fig. 1. Additionally, a series of review seminars were given by Invited Principal Scientists to the EBCRP in order to provide opportunities for program members to attain basic knowledge from the Invited Principal Scientists. At the end of FY2011 the EBCRP invited 4 eminent scientists to start discussion on the next 5-year research plan.

Dispersion of radioactive materials from the Fukushima dai-ichi Nuclear Power Plant was an urgent research theme for the EBCRP. We conducted observational and modeling research from very early stage after the accident in collaboration with domestic and overseas research communities.

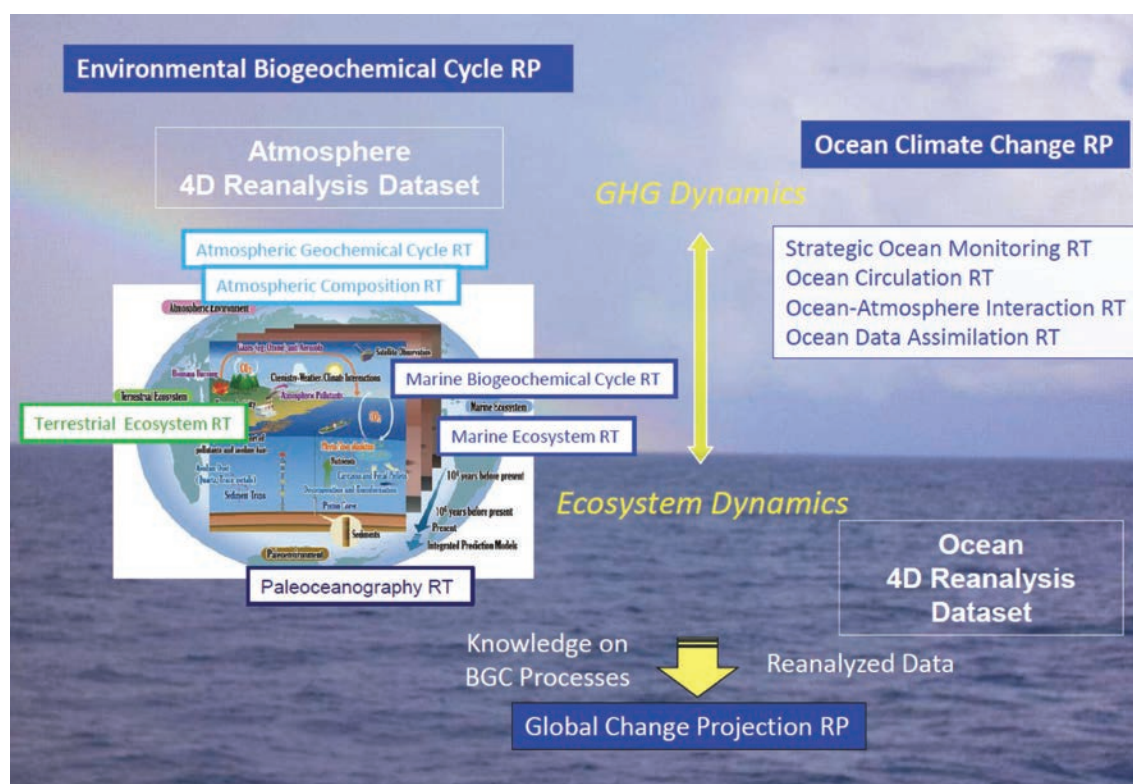


Fig. 1 Aim of the Environmental Biogeochemical Cycle Research Program and schematic diagram of inter-program collaboration with Ocean Climate Change Research Program and Global Change Projection Research Program. The EBCRP aims at providing objective reanalysis data by 4 dimensional data assimilation of greenhouse gasses in the atmosphere and the biogeochemical constituents in the ocean, and mechanistic understandings of the interactions between dynamics of greenhouse gasses 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 Ecosystem and Biogeochemical Cycle Respond to Climatic Forcing?

–Marine Biogeochemical Cycle Research Team–

–Marine Ecosystem Research Team–

Marine Biogeochemical Cycle Research Team and Marine Ecosystem Research Team are conducting studies based on the time-series observation and numerical modeling, respectively, aiming to understand ecosystem-biogeochemical mechanisms linked to physical, chemical and biological processes of various time and spatial scales. Recent retrospective studies have suggested that ecosystem responses 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 on a global scale, there is increasing demand for better understanding of regionally specific mechanisms of variations in ecosystem and biogeochemical cycle. Development of new ecosystem model with better parameterization to be applicable for different regions with different ecosystems is another subject being tackled.

We here highlight accomplishments of FY 2011 research, 1) seasonal variation in primary production and phytoplankton biomass based on the time-series observation in the subarctic and subtropical western North Pacific, and 2) results of the newly developed Optimality-based models on nutrients uptake rate of phytoplankton.

(1) Comparative study of ecosystem and biogeochemistry at the north and south time-series stations

Marine Biogeochemical Cycle Research Team has conducted time-series observation at stations K2 (47°N, 160°E) and S1 (30°N, 145°E) located in the subarctic and subtropical gyres, respectively. From January 2010 to August 2011, 5 times cruises were conducted at both stations, and samples and data covering full seasonality of ecosystem and biogeochemical cycle at both stations were successfully obtained. Regarding to seasonal variability in phytoplankton and primary productivity, the followings were obtained.

a) Species composition and abundance of phytoplankton

To our surprise, proportion of diatom was not high at station K2, where *Prymnesiophytes* and *Thrysophytes* were pre-dominant. At station S1, proportion of diatom increased during “sub-tropical bloom season” (i.e., February), and *Prymnesiophytes*, *Chrysophytes* and *Prochlorophytes* were pre-dominant in other seasons. Abundance of phytoplankton (concentration of chlorophyll *a*: Chl *a*) at station K2 became the annual maximum during summer season and integrated Chl *a* in the euphotic layer was estimated to be 60~80 mg m⁻² (Fig. 2a). On the other hand, Chl *a* at station S1 became the annual maximum during February and March and the integrated Chl *a* in the euphotic layer was about 110 mg m⁻² (Fig. 2a). Although there was seasonal variability in abundance of phytoplankton at both stations, its amplitude was relatively smaller compared to variability of

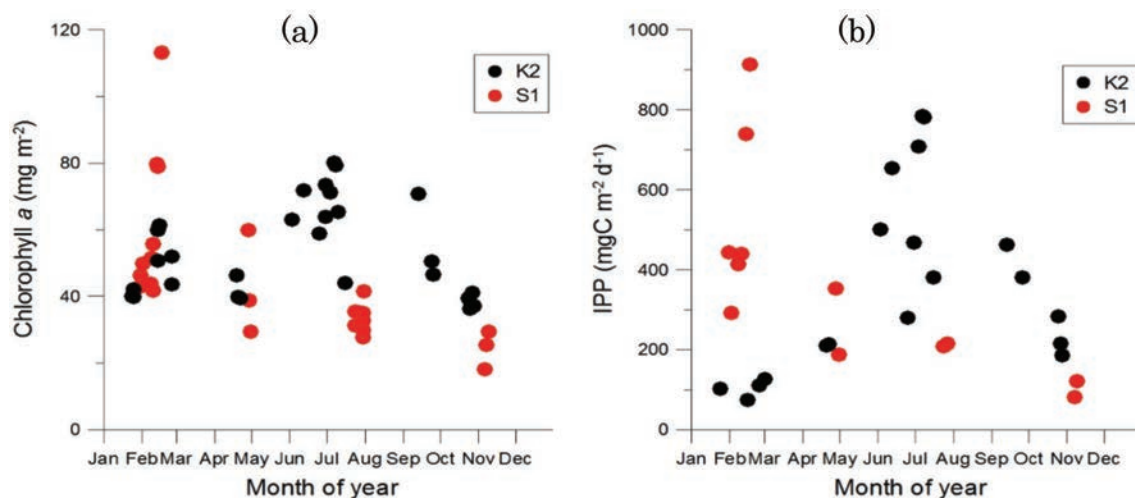


Fig. 2 Seasonal variability in (a) chlorophyll *a* concentration and (b) integrated primary productivity (IPP) at stations K2 and S1. IPP data obtained before 2010 are also shown on (b).

primary productivity.

b) Primary productivity

Primary productivity at station K2 became the annual maximum (integrated primary productivity: IPP, about $800 \text{ mg-C m}^{-2} \text{ day}^{-1}$) in summer and the annual minimum in winter (IPP: about $100 \text{ mg-C m}^{-2} \text{ day}^{-1}$) (Fig. 2b). On the other hand, primary productivity at station S1 became the annual maximum in winter (IPP: about $900 \text{ mg-C m}^{-2} \text{ day}^{-1}$) and the minimum in autumn. Annual mean of IPP at stations K2 and S1 were estimated to be about $311 \pm 188 \text{ mg-C m}^{-2} \text{ day}^{-1}$ and $422 \pm 267 \text{ mg-C m}^{-2} \text{ day}^{-1}$, respectively. Although comparison of these estimations are not necessarily straightforward because annual mean at station K2 was estimated including previous observations while summer season data (probably low data) was not included for estimation of the annual mean IPP at station S1. It is notable that the primary productivity at station S1, where concentration of nutrient in the surface layer is quite low or sometimes depleted, was higher than that at station K2. In future, it should be clarified what kind of mechanisms support high primary productivity at station S1, *e.g.* how nutrients are supplied to the surface / sunlit layer etc. It should be tested whether our shipboard observations represents the ecosystem-biogeochemical processes at the two stations, by analyzing biogeochemical / meteorological / physical oceanographic / satellite data obtained simultaneously.

(2) Interpreting observations and developing better models of plankton growth based on the concept of Optimality.

What is the concept of Optimality-based Models? On the basis of the assumption that natural selection should tend to let organisms optimally adapted to their environments, optimality can be considered a guiding concept for interpreting the behavior of aquatic micro-organisms (plankton) and for developing models to study and predict their behavior. This approach is particularly well suited to plankton because of their long evolutionary history and the ease with which they can be manipulated in experiments. The recent review by Smith et al. (2011) found that many studies made progress based on the assumption that adaptation (of species) and acclimation (of organisms) both tend to maximize growth rate. Compared with mechanistic models not formulated in terms of optimality, this approach has in some cases yielded simpler models with greater generality. This has given new and different interpretations of existing observations.

The optimality-based Model provides a more consistent interpretation of the combined effects of temperature and concentration on nitrate uptake as observed on oceanic cruises, and implies that uptake is more sensitive to temperature than usually assumed (Smith 2010, 2011). With Optimal Uptake (OU) kinetics, $V_{\max}$ (as measured by short-term experiments.) depends on ambient $[\text{NO}_3^-]$ as well as on T . This results in greater inferred T sensitivity, compared to the standard assumption that uptake parameters depend only on T (as applied with Michaelis-Menten [MM] kinetics). This is because given the negative relationship between ambient T and $[\text{NO}_3^-]$ in the near-surface ocean (Fig. 3), when applying OU kinetics these two dependencies tend to counter-act one another for $V_{\max}$. Compared to MM kinetics, with OU kinetics a greater T sensitivity is required to reproduce the same field data, because as T increases $[\text{NO}_3^-]$ tends to decrease, somewhat counteracting the effect of increasing T .

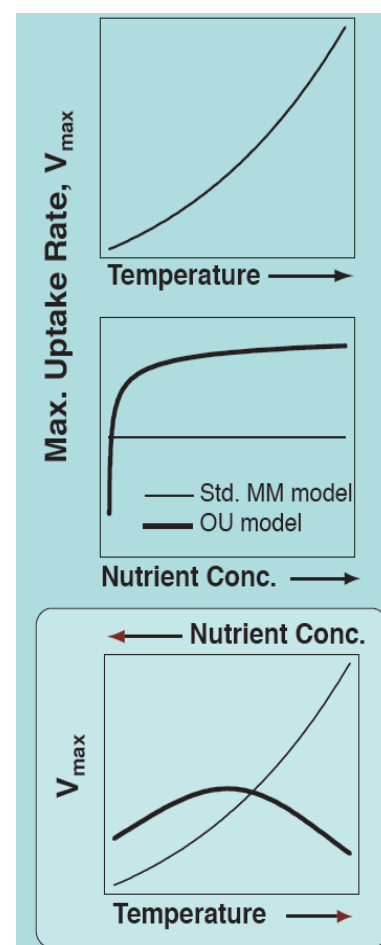


Fig. 3 Variation of Maximum nutrient uptake rate ($V_{\max}$) of phytoplankton in relation to temperature and nutrient concentration for both OU-based (thick line) and MM-based (thin line) models.

For a data set for nitrate uptake in the North Atlantic, Smith (2011) found $Q_{10} = \sim 3$ based on OU kinetics vs. $Q_{10} = \sim 2$ based on MM kinetics. This result implies that phytoplankton may be just as sensitive to T as heterotrophic bacteria, in contrast to the typical assumption that bacteria are more sensitive. If the T sensitivity of heterotrophs were greater than that of autotrophs, warming of the near-surface ocean would cause a net release of CO_2 (degradation), but if the sensitivities are the same there will be no net effect (Fig. 4)

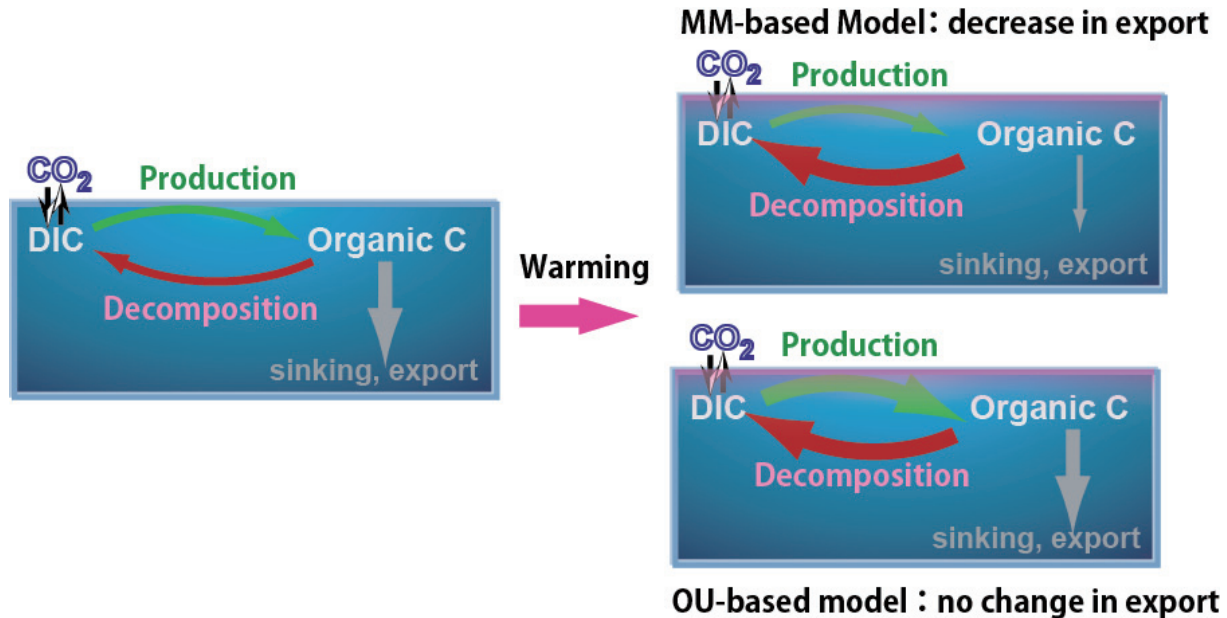


Fig. 4 Comparison of predicted results on changes in primary production rate, decomposition rate, and vertical carbon export in the future warming scenario, MM-based Model vs. OU-based Model.

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How Does the Vegetation in Boreal and Tropic Regions Vary?

–Terrestrial Ecosystem Research Team–

Terrestrial ecosystem Research Team 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) Bidirectional reflectance distribution function observation of boreal forest

Spectral reflectance of land surface generally has the dependency on the illumination angle and the viewing angle. This characteristic is called bidirectional reflectance distribution function (BRDF). Since the sensor “Second-generation Global Imager (SGLI)” of the satellite “Global Change Observation Mission (GCOM) -C”, which will be launched in the future, has the function to observe the land surface from three viewing angles, *in situ* land surface BRDF will be required for the interpretation and validation of the SGLI measurement.

In fiscal year 2011, an observational study on BRDF of boreal forest was carried out successively from fiscal year 2010. A black spruce forest that is located in the Poker Flat Research Range (PFRR) of University of

Alaska Fairbanks (UAF) was targeted. This forest is extensive and homogeneous, and therefore, suitable for the acquisition of *in situ* values for satellite remote sensing. This forest also plays an important role in the JAMSTEC-IARC Collaboration Study (JICS) as the super site. A 17m observational tower was constructed in the black spruce forest for various purposes of observation in terms of hydro-meteorological, ecological, and remote sensing studies. Because the height of trees around the tower is below 10m, observation of BRDF of the black spruce forest is possible from the top of the tower.

BRDF observations were conducted on July 7, 2010 (no snow season) and March 17, 2011 (snow season). The reflectance of the forest in the principal plane (PP, vertical plane parallel to solar insolation azimuth) and orthogonal plane (OP, vertical plane normal to solar insolation azimuth) was measured by a spectroradiometer (MS-720, Eko Instruments, Japan) from the top of the tower, being changed the viewing angle from 20 to 70 degree (off-nadir angle) with 5 degree interval.

The result is shown in Fig. 5. The BRDF in PP in no snow season showed bowl-shape profile and the backscatter was larger than the forward scatter in both visible and near infrared bands. By contrast to snow season, the reflectance in PP was considerably larger than that in the no snow season due to the existence of the snow and the forward scatter was larger than backscatter. The normalized difference vegetation index (NDVI) showed larger value in forward scatter area than that in backscatter area in no snow season. NDVI was very small in snow season due to the large reflectance of the snow cover.

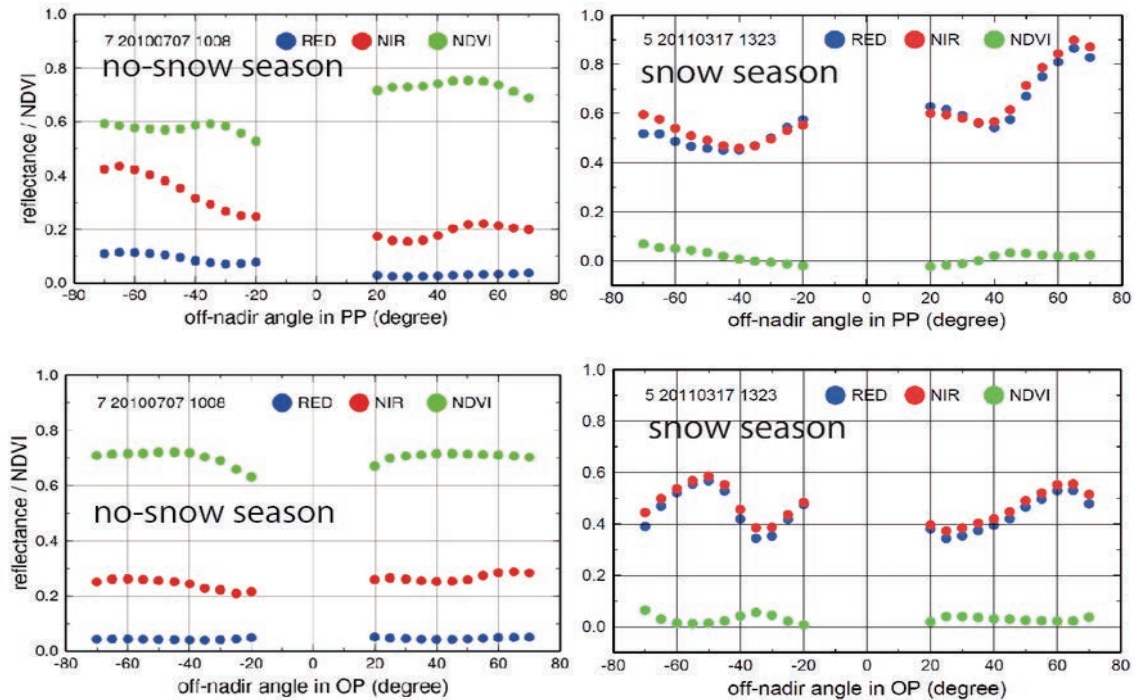


Fig. 5 The BRDF of red and near-infrared bands and NDVI of the black spruce forest in PFRR of UAF. The panels in left row indicate the BRDF at 10:12AKDT on July 7, 2010 (no snow season), while the panels in right row indicate the BRDF at 13:30 on March 17 (snow season). The top and bottom panels exhibit the BRDF profile on the principal and orthogonal planes, respectively.

(2) Forest canopy observation by fish-eye camera shows clear seasonal pattern

To observe the canopy surface seasonality and the sky condition, we installed an automatic digital fisheye camera system composed of a digital camera (Coolpix 4500, Nikon, Japan), a fisheye lens (FC-E8, Nikon, Japan), and a controller (SPC31A, Hayasaka Rikoh, Japan). In the black spruce forest in PFRR, one camera system was pointed downward (forest canopy and land surface) from the top of the tower and the other camera system was pointed upward from the ground to the sky.

We examined the relationship between seasonal change of the forest canopy and land surface in pictures of the camera system and that of Terra/MODIS-observed daily NDVI data without cloud contamination in 2010 and 2011 (Fig. 6). Although this site is fully covered with the evergreen coniferous tree, black spruce, NDVI

I. Research Activities and Results

Environmental Biogeochemical Cycle Research Program

showed a bell-shaped seasonal pattern. This may be caused by the seasonality of the forest floor vegetation and the snow cover in the winter season. Thus, we acquired the ground truth for the satellite remote sensing of the seasonal pattern of ecosystem structure and function in an open-canopy boreal forest by using *in situ* pictures.

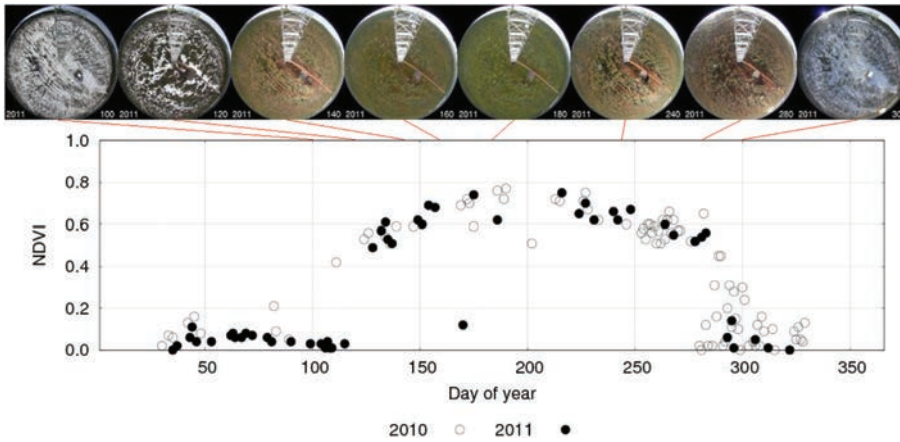


Fig. 6 Seasonal patterns of the Terra/MODIS-observed daily NDVI data without cloud contamination in 2010 and 2011 at the Poker Flat Research Range. Typical fish-eye images of the canopy surface are presented at the top of the figure.

(3) Leaf Area Index change of Siberian forest

In eastern Siberia, we continued working on the estimation of the overstory leaf area index (LAI) where larch is a dominant species. In our approach, we used SPOT/VEGETATION satellite data. As larch is a deciduous needle leaf species, its overstory LAI can be estimated by the seasonal increase in the satellite vegetation index, assuming that the difference of the satellite signals between pre-foliation and foliated stages can be attributed to the overstory LAI changes. The relationship between satellite vegetation index and overstory LAI was calibrated by the three dimensional plant canopy radiative transfer model (FLiES). Using this method, we estimated the monthly larch overstory LAI from 1998 to 2011 (Fig. 7), and found that the mean maximum LAI over east Siberia increases by 0.0099 yr^{-1} , suggesting a warming trend in Siberia could enhance the growth of larch although more detail analysis will be necessary to see how this trend is exactly related to the climate change.

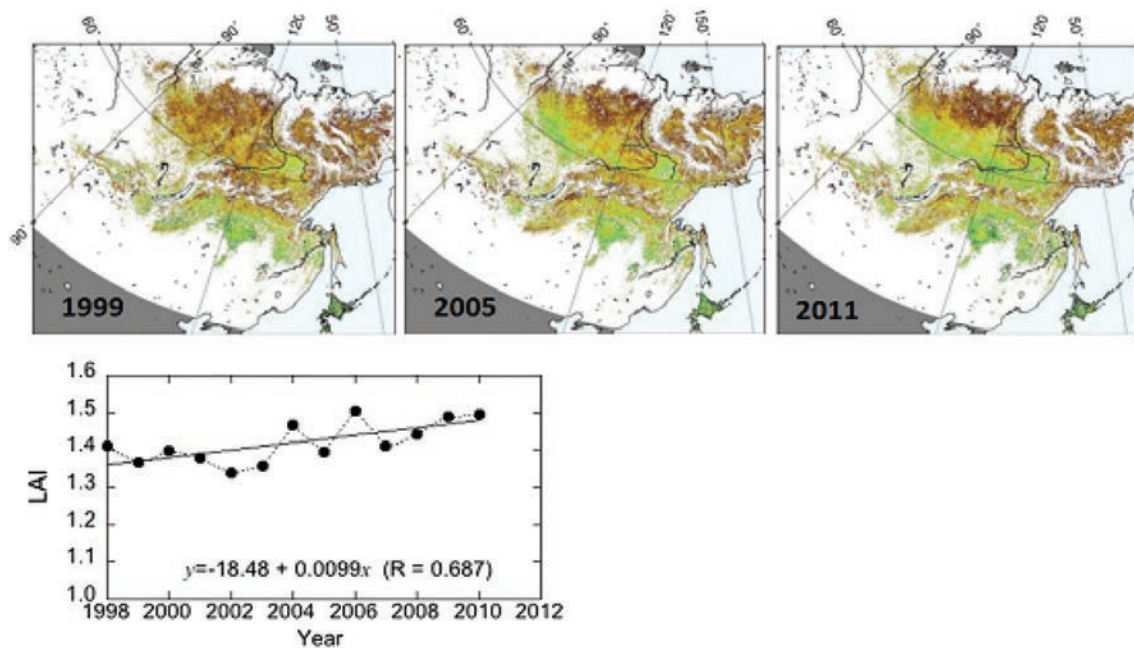


Fig. 7 Larch overstory leaf area index (LAI) estimated by SPOT/VEGETATION satellite data. The relationship between satellite vegetation index and overstory LAI was calibrated by the three dimensional plant canopy radiative transfer model (FLiES). The map shows the June, 1999, 2005, 2011. The bottom figure shows a decadal trend of the maximum LAI.

(4) Land use change in Sarawak, Malaysia

In tropics, an observational study on the tropical forest in Sarawak (Borneo Island), Malaysia was conducted. In Sarawak, large areas of the tropical forest have been deforested, and developed for the plantation such as oil palm etc. The deforestation and plantation modify carbon budget between land and atmosphere, and in addition, influence on ecosystem function and biodiversity of the tropical forest. Since they will possibly cause a loss of ecosystem services in a long view, intensive studies are required.

We began study on the land cover change in Sarawak by remote sensing in FY2011. High resolution satellite-derived images (ALOS/AVNIR2, ALOS/PALSAR, SPOT5, TerraSAR-X) were acquired, while a preliminary field survey was conducted in Sarawak. Fig. 8 exhibits the image of ALOS/PALSAR and TerraSAR-X from which we can identify the land cover types.

The ground-truth information for satellite images was collected by the preliminary field survey by driving a car around Miri and Sampadi areas. The latitude and longitude of oil palm plantation areas were recorded with their photographs were taken so that the tree spacing and height can be estimated.

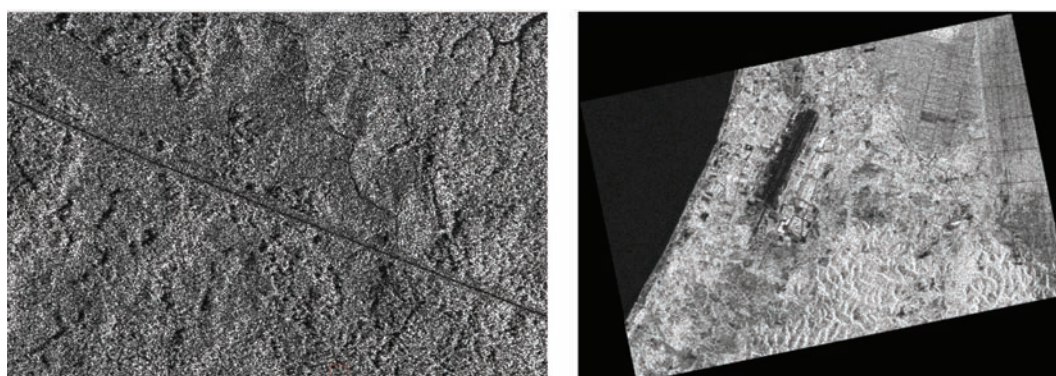


Fig. 8 Images of microwave synthetic aperture radar (SAR) around Sampadi by TerraSAR-X (left) and around Miri by ALOS/PALSAR (right). Plantation areas can be found in the region under the straight west-east road in TerraSAR-X image. Also in ALOS/PALSAR image, they are found in its eastern part as the area with a grid-like pattern. The rectangular black area near the center of ALOS/PALSAR is the run way of the Miri International Airport.

Exploring atmospheric chemistry and transport processes

–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 1) improvement in the retrievals from MAX-DOAS, a ground-based remote sensing technique, 2) transport analysis of aerosols from the Asian continent to Japan, and 3) estimation of emission rate distributions of short-lived species using our data assimilation system, as major accomplishments in FY2011.

(1) Eight-component retrievals from ground-based MAX-DOAS observations

We established an improved analysis method of the UV/vis spectra derived from MAX-DOAS (Multi-Axis Differential Optical Absorption Spectroscopy) observations, to retrieve lower-tropospheric vertical profile information for 8 quantities, including HCHO (formaldehyde) and CHOCHO (glyoxal), related to biosphere-atmosphere interactions. In the past, aiming mainly at contribution to GEOSS, we deployed several MAX-DOAS instruments over Japan, China, Korea, and Russia and on Research Vessels *Kaiyo* and *Mirai*, to derive NO₂ and aerosols (at 476 nm) using a narrow spectral window (460-490 nm). This time, we made use of a wider wavelength band (310-515 nm) to extend our analysis to include HCHO, CHOCHO, H₂O, SO₂, O₃, aerosol at 357 nm, as well as NO₂ and aerosols at 476 nm, and optimized the retrieval algorithms for each quantification.

Our analysis was made on spectra obtained during the CINDI campaign, a semi-blind intercomparison activity of MAX-DOAS observations, held in the Netherlands in 2009. Fig. 9 shows time series of the 8 components in the altitude range of 0-1 km. They showed close agreement with independent data sets, such as NO₂ observations on the ground and at the tower (altitude = 200 m) and those derived from a regional atmospheric chemistry model CHIMERE, suggesting adequacy of the observations and the developed algorithm. During the observations, episodes with high concentrations of HCHO and SO₂ were found, likely caused by chemical transformation from isoprene emitted from terrestrial biosphere and by ship emissions, respectively. We plan more detailed analysis on HCHO and CHOCHO in the future, to study relationships between atmospheric organic species and the ecosystem.

(2) Transport analysis of aerosols combining observations in China and Japan

We made detailed analysis of the observational data obtained from an intensive field campaign performed at Rudong (32.26°N, 121.37°E), Jiangsu Province, China, in May-June 2010. Fig. 10 shows an analysis of temporal variations in mass concentrations of PM_{2.5} (aerosol particles whose diameters are less than 2.5 μm), in combination to those observed at Fukue Island (32.75°N, 128.68°E), located ~700 km east, across the East China Sea. From backward trajectory analyses, we identified that the same air masses were observed at the two sites on three occasions, with delays of 1-2 days, respectively. We compared the chemical signatures (e.g., trace metals) of the aerosol particles in the particular air masses before and after the transportation. At Fukue, from the feature of high V/Mn ratios, the high PM_{2.5} concentrations on 19 May were attributed to heavy oil combustion. Such source information is useful for the establishment of a solid countermeasure strategy. We plan to extend our analysis by combining the observational results with model simulations, toward the goal to quantify aerosol transport flux from the continent to the western North Pacific, via the Pacific Rim region including Japan.

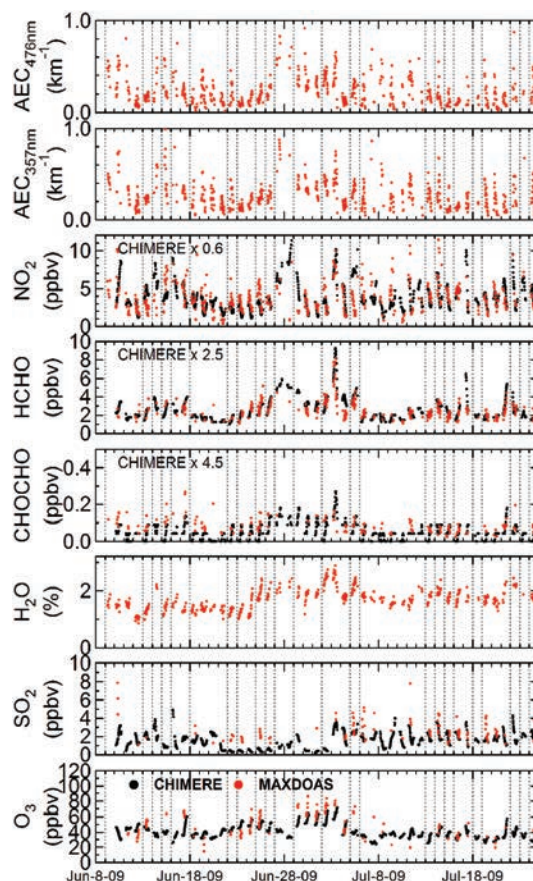


Fig. 9 Time series of the 8 components retrieved from MAXDOAS observations (red) for the 0–1 km layer. Also shown in black are values calculated by the CHIMERE model.

Fig. 10 Time series of PM_{2.5} mass concentrations at Rudong and Fukue. Three episodes of air mass transportation were identified.

(3) Estimation of global surface flux of short-lived chemical species using a data assimilation system and satellite observations

Our data assimilation system was applied to estimate global nitrogen oxides (NO_x) emission using satellite-based OMI (Ozone Monitoring Instrument) tropospheric NO₂ columns (DOMINO project) and our online global chemical transport model (CTM), CHASER. Our data assimilation system, established in FY2009 and was basically applied for long-lived species such as CO₂ until FY2010, was updated to include chemical reactions

such as photolysis and gaseous, liquid-phase, and heterogeneous reactions in the atmosphere using a chemical transport model CHASER. CHASER is a global chemical transport model fully-coupled with meteorological and radiative models; it also serves as an atmospheric chemistry module of the Earth System Model jointly developed by JAMSTEC, the University of Tokyo, and National Institute for Environmental Studies (NIES).

NO_x is one of the important precursors of ozone, which is of major concerns with respect to global warming and air quality issues. NO_x has both anthropogenic and natural sources. Anthropogenic sources of NO_x include fossil and bio - fuel combustion and industry. Natural sources of NO_x include soil, biomass burning, and lightning emissions. The uncertainty of NO_x emission is still large when its horizontal distribution and temporal variation are concerned. In the data assimilation, the emission rates are adjusted to reduce the discrepancy between the model and observation, while the advantages of the nature of online CTM are fully utilized.

To constrain the surface emission of NO_x using our data assimilation system, we used the Dutch OMI tropospheric NO₂ (DOMINO) data provided by the Tropospheric Emission Monitoring Internet Service (TEMIS). Since the sensitivity of nadir measurements varies with height, detailed retrieval information such as the averaging kernel provided in the DOMINO product was taken into account during the assimilation process. As *a priori* emission, we have used the EDGAR (Emission Database for Global Atmospheric Research) version 3.2 for the anthropogenic sources, the GFED (Global Fire Emissions Data base) version 2.1 for global biomass burning emissions, and the GEIA (Global Emissions Inventory Activity) for soil emissions, respectively. Anthropogenic emissions over East Asia were replaced by the REAS (Regional Emission inventory in Asia) version 1.1, which was developed by JAMSTEC and NIES. To improve simulation, we applied pre-defined functions for the diurnal variations of the surface NO_x emissions for individual sources (e.g., anthropogenic and soil sources).

For the validation of our assimilation system, the global distribution of NO₂ column and vertical profiles have been compared with independent observational data derived from other satellite-based instruments such as SCIAMACHY (Scanning Imaging Absorption spectroMeter for Atmospheric CHartographY), an aircraft-based campaign INTEX-B (Intercontinental Chemical Transport Experiment Phase B), and from a lidar system operated during the DANDELIONS (Dutch Aerosol and Nitrogen Dioxide Experiments for Validation of OMI and SCIAMACHY) campaign. The emission correction greatly improved the agreement between the simulated and observed NO₂ fields.

Fig. 11 shows the difference between the *a priori* and *a posteriori* emissions over East Asia region. It clearly suggests that the emission rate from eastern China needs to be increased from 3.1 TgN yr⁻¹ to 5.0 TgN yr⁻¹ to reproduce observations. The distribution of the *a posteriori* emission is quite similar to that from newer bottom-up emission databases such as EDGAR 4.1 and GFED 3.1. For more precise estimation of atmospheric NO₂ distribution, we are planning to estimate the impact of lightning on NO_x emission in FY2012.

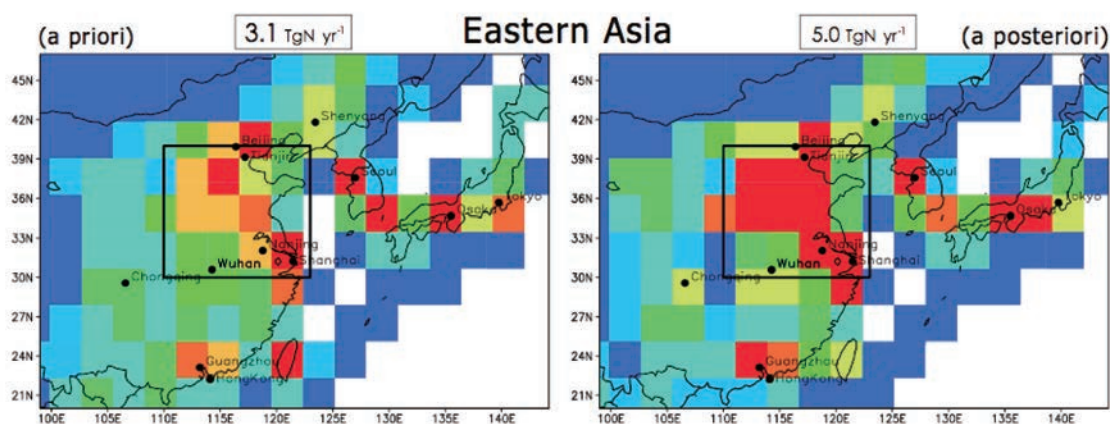


Fig. 11 Regional distributions of NO_x surface emissions over East Asia region from the *a priori* emission (left) and the *a posteriori* emission (right) of our assimilation system.

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, and 2) their responses to climate changes during the past thousand to several tens of thousand years that was not influenced by human activity. The strategy is to extend observational data toward the past by reconstructing climate variations with high time resolution by using paleo proxies recorded in marine sediments. Here, we report a new result of the sea surface temperature changes in the Okhotsk Sea and adjacent North Pacific during the Last Glacial Maximum and the following deglaciation periods published by Harada *et al.* [2012]. This is a part of special volume entitled “Climate change dynamics of present and past in the North Pacific and its northern marginal seas” edited by Harada, N. *et al.*, Deep Sea Res. II, 61-64, 2012 and has been selected as a key research article, which means the top Earth and environmental Science Research, by the Earth Emphasis (<http://earthemphasis.com/>).

Climate linkage between the Pacific and Atlantic Oceans recorded in SST changes over the past 20,000 yr.

The mid- to high-latitude region of the western–central North Pacific—including the Kuroshio–Oyashio transition area and marginal seas (the Okhotsk, Japan, and Bering Seas)—is a key area for understanding present-day climate variability of the eastern Asian continent [Yasuda, 2003]. Glacial to interglacial changes in the surface circulation and hydrography of this area probably affected the climate of the Asian continent and of Japan [Chinzei *et al.*, 1987]. Although syntheses based on compilations of reconstructed last glacial maximum (LGM) and deglacial SSTs for the North Pacific [Kiefer and Kienast, 2005] and the Multiproxy Approach of the Reconstruction of the Glacial Ocean Surface (MARGO) project [MARGO Project Members, 2009] for the global ocean have been published recently, variations in mixed-layer temperatures in the mid- to high-latitude region of the western–central North Pacific and its marginal seas have not been well studied on glacial–interglacial timescales. Therefore, the purpose of this study was to clarify the interaction between atmospheric circulation, the sea-surface environment, and circulation in the intermediate–deep ocean in the western–central North Pacific and its marginal seas in response to local and remote forcings during the last glacial to deglacial period. We estimated sea surface temperatures (SSTs) in the western Okhotsk Sea during the last glacial maximum (LGM) and the last glacial termination from measurements of the alkenone unsaturation index ($U^{K'_{37}}$) in piston core sediments (Fig. 12), which reveal the climate response of this region to different types of climate forcings.

During the LGM, alkenone SSTs in the Okhotsk Sea were relatively warm (no figure shown). These and similarly warm alkenone SSTs found at many other sites in the western North Pacific may reflect a shift in the season of biomarker

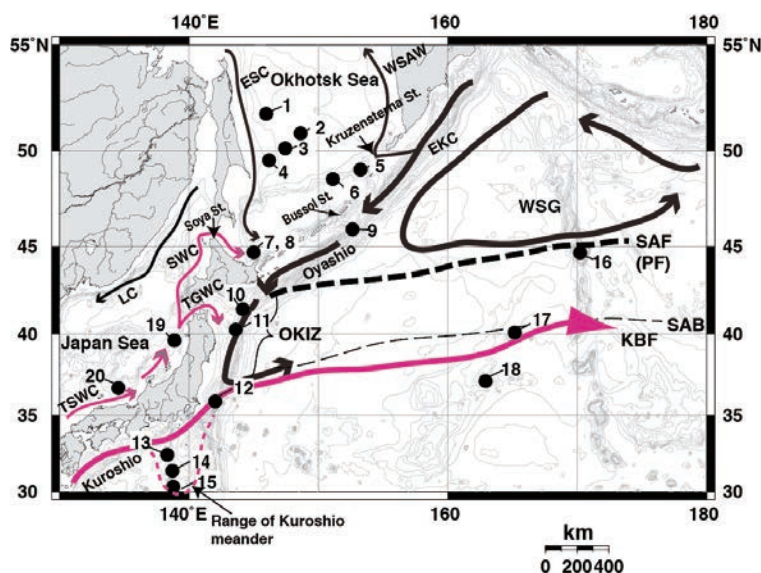


Fig. 12 Map of sediment core locations in the western–central North Pacific and the Okhotsk and Japan Seas (black circles). Numbers indicate the sediment core sites. Arrows show the average direction of flow of surface waters, with pink and black arrows indicating warm and cold currents, respectively. EKC, East Kamchatka Current; WSAW, Western Subarctic Water; ESC, East Sakhalin Current; SWC, Soya Warm Current; TSWC, Tsushima Warm Current; TGWC, Tsugaru Warm Current; OKIZ, Oyashio–Kuroshio interfrontal zone; WSG, Western subarctic gyre; SAF, Subarctic front; PF, Polar front; SAB, Subarctic boundary; KBF, Kuroshio Bifurcation front.

production from early summer and autumn to midsummer during the LGM as a result of the expansion of the season of sea-ice cover. During the deglaciation, mean alkenone SSTs during H1 and the YD in the Okhotsk Sea were not necessarily “cold”, and those during the B–A were not always “warm”, compared with those in other periods. In contrast, the temperatures were relatively lower during the H1 and the YD and warmer during the B–A at sites in the western North Pacific. The conditions in the western North Pacific implies that the alkenone SST changes during the deglaciation were related to atmospheric circulation and, in particular, to northward and southward migrations of the westerly jet axis associated with northward and southward migrations of the Asian summer monsoon front.

Empirical orthogonal function (EOF) analysis of alkenone SSTs at 14 sites from the North Pacific suggested substantial cooling between 20 and 14 cal kyr B.P during the deglaciation at 11 sites (Fig. 13). This dominant EOF mode suggests either an overall seasonal bias in alkenone SSTs or potential shifts in the Haptophyceae production season. As a second scenario, an EOF analysis of longer term alkenone data for this region suggests that EOF1 follows the precessional cycle of fall insolation at 45°N with increased insolation during the LGM and minimum insolation around 13 kyr BP. If the shift in the production season of alkenones is irrelevant to the argument, it could be argued that the alkenone data track fall temperature variations throughout the entire analysis period, and that warming during the fall season can be explained by strengthened surface stratification. The second EOF mode (EOF2) of variability indicated a deglacial warming trend punctuated by millennial-scale cold events, associated with reorganizations of the Atlantic Meridional Overturning Circulation. The SST pattern corresponding to this EOF mode is indicative of millennial-scale meridional shifts of the axis of the westerly jet, which may have affected heat transport across the Kuroshio. Reconstructed temperature changes, in particular in the Okhotsk Sea, provide insight into the conditions that modulated the ventilation history of intermediate waters in the North Pacific.

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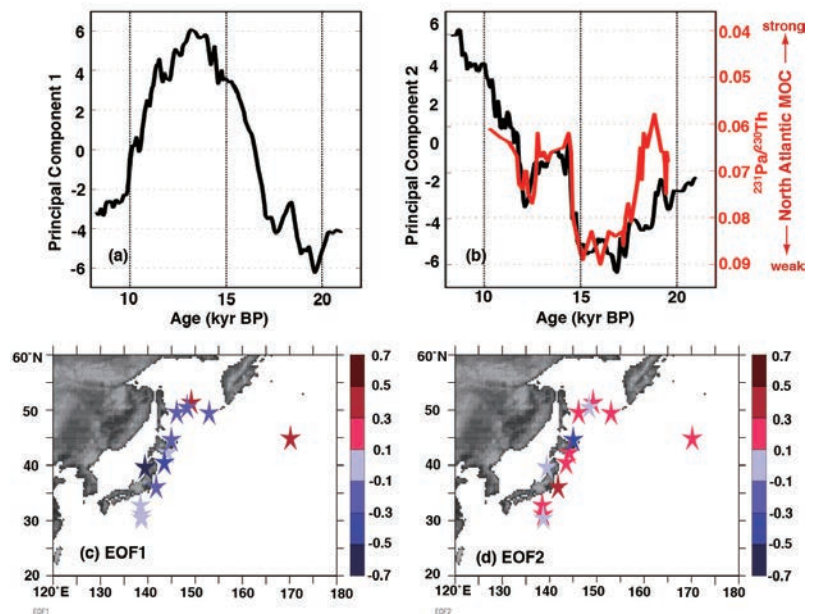


Fig. 13 Empirical orthogonal function (EOF) analysis of alkenone-derived temperatures throughout 22–8 kyr BP. (a) First principal component; (b) second principal component, along with changes in the North Atlantic meridional overturning circulation (MOC) estimated by the sedimentary activity ratio of $^{231}\text{Pa}/^{230}\text{Th}$ [McManus et al., 2004]; (c) and (d) EOF spatial patterns corresponding to the first and second principal components, respectively. The color scale indicates the loading of the EOF pattern. To obtain the magnitude of the EOF pattern and its evolution in time in degrees Celsius, the principal component must be multiplied by the EOF loadings.

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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:

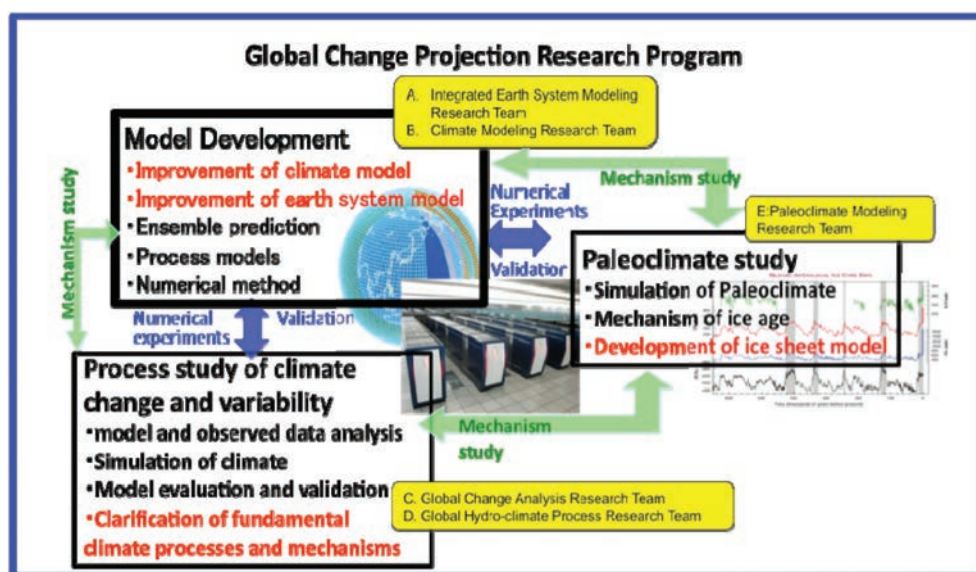


Fig. 1 Research teams and targets of Global Change Research Program.

- * Integrated Earth System Modeling Research Team led by Dr. Michio Kawamiya performs global warming projection experiments by using an advanced earth system model with interactions between climate change and biogeochemical processes, in order to provide information which could contribute to long-term global warming mitigation policies.
- * Climate Modeling Research Team led by Dr. Tatsushi Tokioka is engaged in developing a better climate model through improving processes included in it, such as cumulus parameterization and planetary boundary layer. This team is also engaged in developing a data assimilation system for a coupled atmosphere and ocean system based on a climate model.
- * Global Change Analysis Research Team led by Dr. Akira Noda undertakes studies using various methods of climate analysis. The outputs from global climate model simulations which have been performed in universities and research institutes around the world are analyzed and evaluated using observational data. Additionally, the uncertainty is considered in climate change projection using the latest model results.
- * Global Hydro-climate Process Research Team led by Dr. Tetsuzo Yasunari conducts diagnostic and modeling studies of regional to global scale hydro-climate processes using satellite data, local to global in-situ hydro-climatological data, global re-analyses data and climate models, to improve predictions of hydrological and hydro-climate processes of the climate system.
- * Paleoclimate Modeling Research Team lead by Dr. Ayako Abe aims to reveal the mechanisms of past climate changes that the earth has experienced on various time scales, through numerical experiments of paleoclimatic events, using climate models. These experiments also contribute to verification and improvement of the climate model for future projection.

Research highlights from each team in the fiscal year 2011 are shown in the following sections. The

global warming CMIP5 experiments for the IPCC AR5 were performed under the Innovative Program of Climate Change Projection for the 21st Century funded by the MEXT and its results were reported separately, so that only some relevant works are mentioned here.

Shaping Future Scenarios through 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)

Using a terrestrial ecosystem model VISIT and an earth system model MIROC-ESM, impacts on carbon emission due to land-use change are evaluated under multiple RCP scenarios including those of climate change. RCP Land Use Harmonization data are used as land-use change scenario; in particular, data with 0.5 degree resolution for primary and secondary land, cropland, pasture and city are utilized. For MIROC-ESM, the data are mapped onto the T42 Gaussian grid. Emissions estimated with VISIT are obtained from concentration-driven climate projection data by MIROC-ESM. Those with MIROC-ESM are estimated as differences between carbon fluxes in an experiment with land-use fixed at 2005 and one with varying land-use. The result shows that, even under the same land-use scenario, there are significant differences between fluxes depending on the model used and experimental settings such as incorporation of climate change effects. It is suggested that the key for estimating emission due to land-use change is formulation of processes for a forest to re-grow after abandonment of a cropland etc. Also examined are impacts of land-use change on climate. It turned out that whether the net impact of land-use change is warming or cooling differs among different RCP scenarios depending on relative strengths of the cooling effect due to albedo decrease and the warming one due to CO₂ emission (Fig. 2).

Under the scenarios such as RCP2.6 and RCP8.5 where cropland and pasture extend, the warming effect surpasses the cooling one. Under RCP6.0 where vegetation recovery is evident, the impact on surface temperature through biogeophysical processes (e.g., changes in albedo and evapo-transpiration) due to land-use change has a complex spatial structure; it is possible that a significant cooling occurs regionally because of vegetation increase after abandonment of cropland and pasture in southern Africa and mid- and low-latitudes of South America.

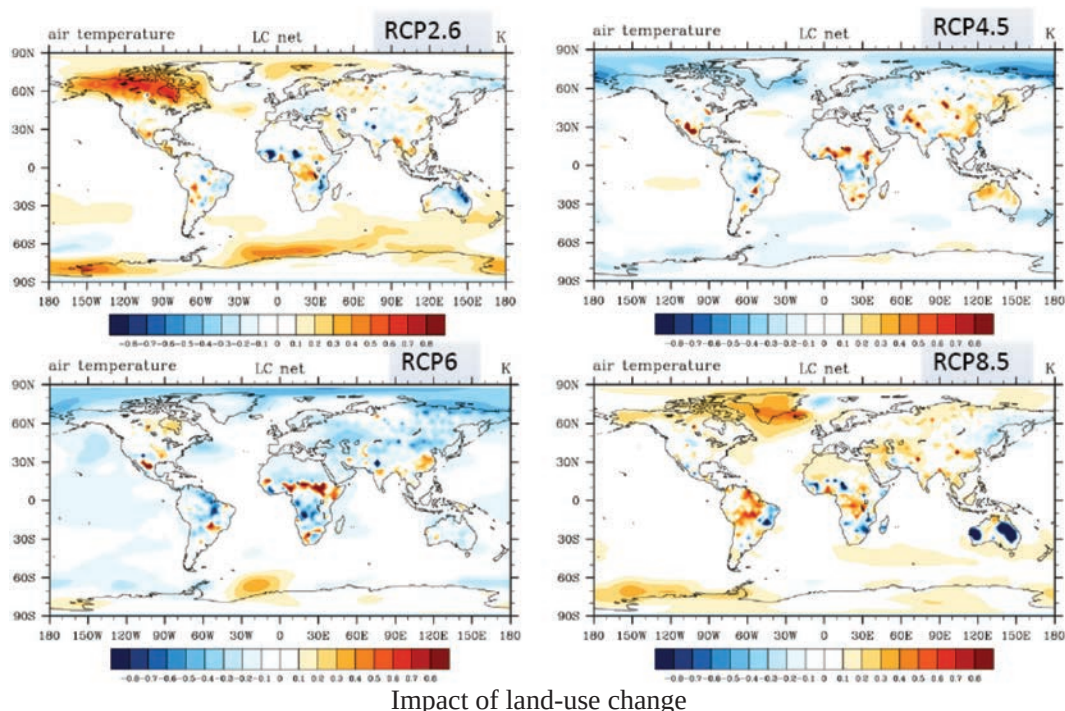


Fig. 2 Impact of land-use change on surface temperature in experiments under RCP scenarios. (upper-left) RCP2.6, (upper-right) RCP4.5, (lower-left) RCP6.0 and (lower-right) RCP8.5.

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

The main purpose of this subject is to support users of climate projection data outside the climate modeling community. On top of the services based on a common data format used internationally, those based on the format specific to Data Integration and Analysis System (DIAS) are provided. Climate projection data produced in Japan are uploaded to DIAS first and then distributed worldwide through Earth System Grid (ESG) with DIAS being one of the data nodes of ESG. DIAS-specific supports are beneficial for data users because DIAS provides its own integrated data analysis environment in which users can efficiently manipulate climate projection data.

More specifically, a converter utility is developed between meta-data formats for ESG and DIAS. Using the converter, DIAS meta-data for more than 400 thousand files are produced from CMIP5/CF meta-data adopted in ESG, based on experiments for future projection and 20th century climate reproduction obtained by an earth system model (MIROC-ESM and MIROC-ESM-CHEM) and a high resolution coupled climate model (MIROC4h and MIROC5). Data transfer to impact assessment researchers is supported including datasets of 500GB not compliant with CMIP5/CF meta-data. A computer environment is set up for converting a dataset with non latitude-longitude grid system to that with latitude-longitude one. A quick visualization software is installed so that datasets can be confirmed before and after the grid conversion (Fig. 3).

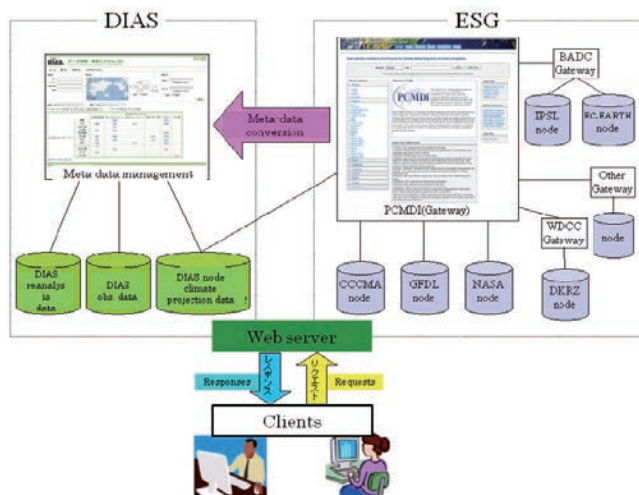


Fig. 3 Data manipulation environment in Earth System Grid (ESG) and Data Integration and Analysis System (DIAS) interfaced by a meta-data converter between them.

Development of a New Data Assimilation and Prediction System Based on a Climate Model

–Climate Modeling Research Team–

(1) Development of a data-assimilation and prediction system based on a coupled atmosphere and ocean model with an ensemble Kalman filter

A data assimilation and prediction based on an ensemble technique may be useful not only for short-term predictions like a weather forecast but also for long-term predictions like a seasonal to decadal climate prediction. In addition, the data assimilation in a coupled atmosphere-ocean system for the long-term prediction is challenging because of difficulties caused by a wide range of intrinsic time scales in the system.

In this study, we have developed a system of ensemble data assimilation and prediction, based on an ensemble Kalman filter (EnKF) (Fig. 4). This system aims improvements of decadal climate predictions and the implementation of a long-term objective analysis, using an atmosphere-ocean coupled model MIROC developed by JAMSTEC, Atmosphere and Ocean Research Institute (AORI) and National Institute for Environment Sciences (NIES). Both atmospheric and oceanic observations can be assimilated in our system.

As the first step of testing this system, mimic observations generated by MIROC were used, and we confirmed that our system works as expected (Fig. 5). As the next step, real oceanic observations were assimilated

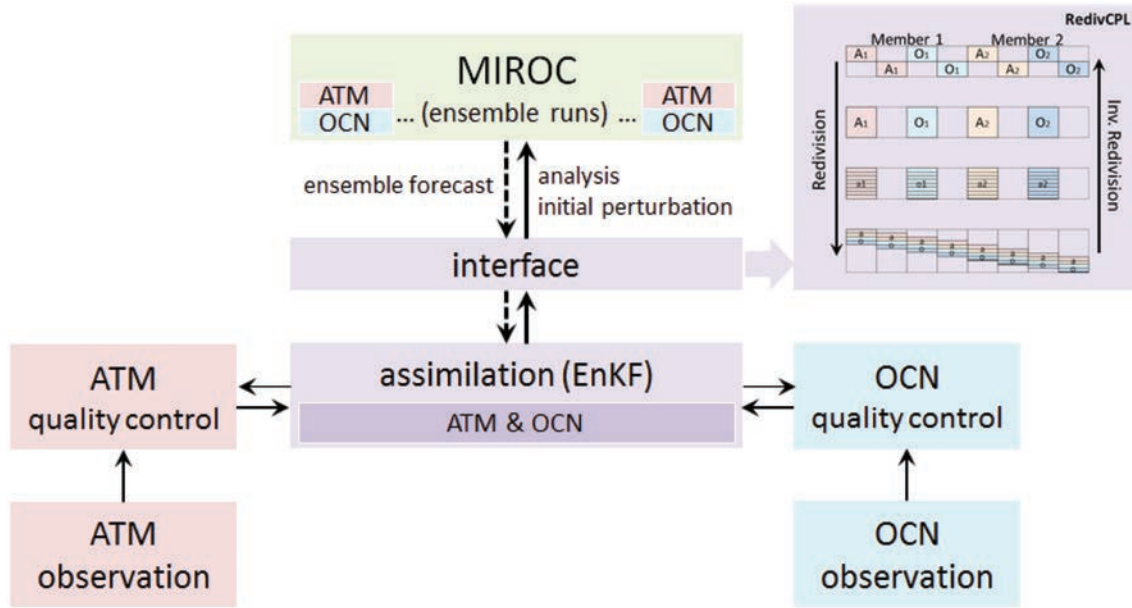


Fig. 4 A schematic diagram of the ensemble assimilation system in MIROC.

with the introduction of quality control procedures for input data to eliminate artificial observation errors. The result indicates that the assimilation with the use of surface oceanic observations only gives fairly good skill compared with that where full observations were used (Fig. 6). We plan to test our system further with the use of real observations of both ocean and atmosphere to investigate the effectiveness of our system in data assimilation of a coupled atmosphere-ocean system.

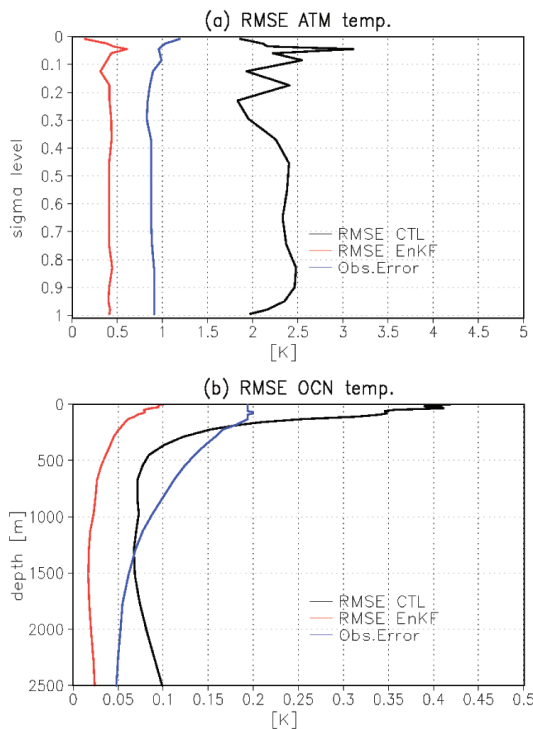


Fig. 5 RMSE (root-mean-square error) with EnKF (red), RMSE without EnKF (black), and the standard deviation of the observation error (blue). Top and bottom panels indicate atmospheric and oceanic temperatures, respectively.

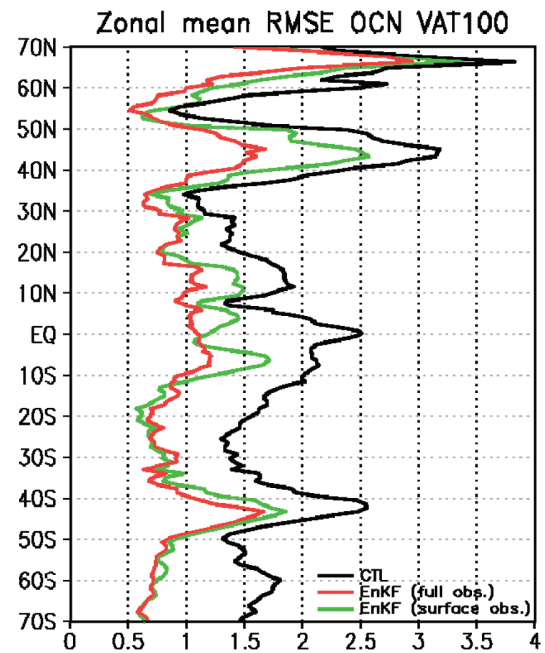


Fig. 6 Zonal mean RMSE of the oceanic temperature averaged vertically. RMSE with EnKF by full observations (red), RMSE with EnKF by surface observations (green), and RMSE without EnKF (black).

(2) Simulation of Kelvin-Helmholtz wave for improving stably stratified planetary boundary layer parameterization

Planetary boundary layer parameterization has been improved substantially by the new scheme MYNN proposed by *Nakanishi and Niino* [2009]. However it has become clear that performance of the scheme still is not satisfactory when the planetary boundary layer is stable, probably due to qualities of observed data used in the parameterization. The purpose of this study is to simulate the so called Kelvin-Helmholtz (KH) waves directly with possible improvements of parameterization in stable case in mind. A large-eddy simulation model is used for this purpose. The governing equations are normalized by half the depth H_0 of the shear layer, half the velocity difference U_0 across the shear layer, and half the temperature difference ΔT_0 across it. Vertical profiles of the basic-state horizontal wind and potential temperature are given by

$$U(z) = \tanh(z), \quad (1)$$

$$\Theta(z) = \tanh(z) + \Gamma z + \Theta(0), \quad (2)$$

where $\Gamma \geq 0$ is the dimensionless gradient of potential temperature external to the shear layer and $\Theta(0) = \Theta_0/\Delta T_0$ the dimensionless reference temperature. The size of the computational domain is set to twice the wavelength of the fastest growing mode of the KH instability, which is determined from a linear stability analysis. A uniform grid spacing of 0.1 is used in all directions. The Richardson numbers Ri at the center of the shear layer for two simulations are selected to be 0.1 and 0.06.

For $Ri = 0.1$, KH billows that have a two-dimensional structure appear first, and then secondary billows occur on braids between the KH billows, which are associated with the increase of the baroclinic production of the horizontal vorticity equation. After that, convection is developed inside the KH billows by the buoyancy production, and the flow is shortly changed into three-dimensional turbulence.

For $Ri = 0.06$ (see Fig. 7), after KH billows appear ($t = 66$), two billows come close to each other and

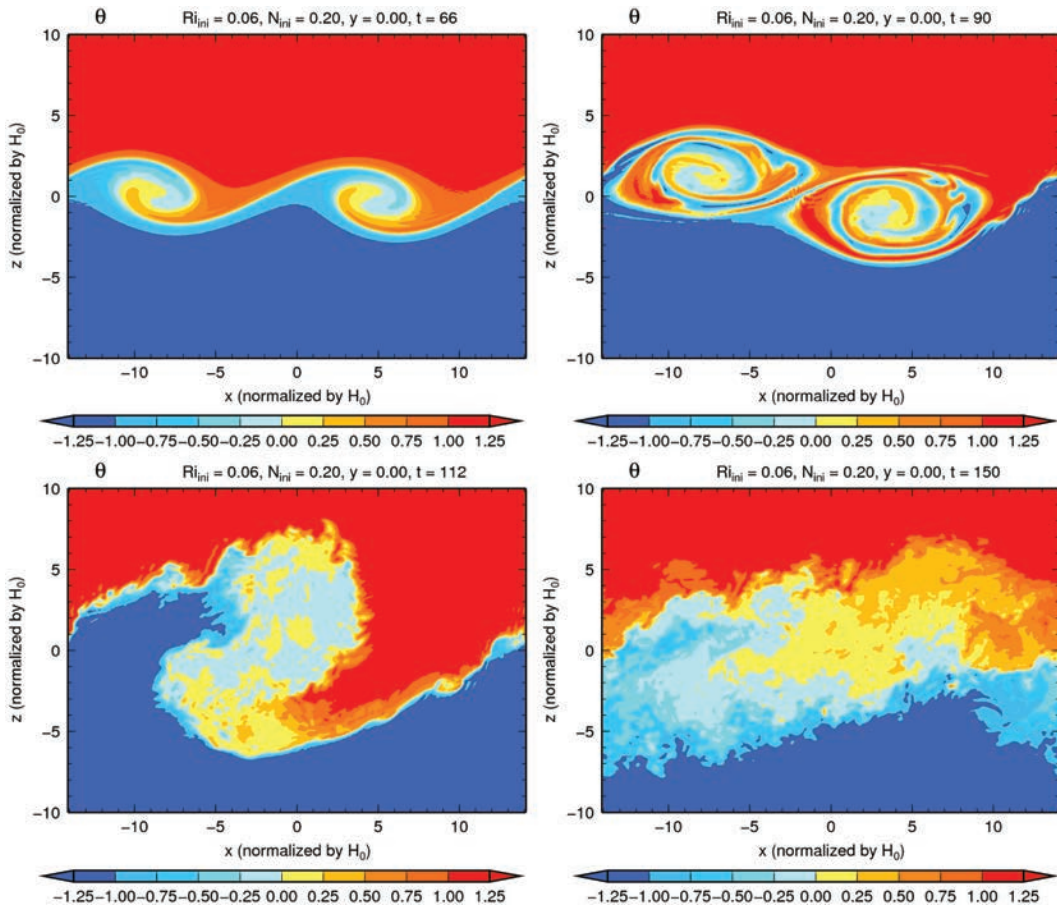


Fig. 7 Vertical distributions of potential temperature in the transition of the KH instability for $Ri = 0.06$. t represents the dimensionless time: $t = 66$ (upper left panel), $t = 90$ (upper right panel), $t = 112$ (lower left panel), and $t = 150$ (lower right panel).

form a subharmonic vortex pairing ($t = 90$). The resulting large billow breaks ($t = 112$), and the flow is shortly transferred into turbulence ($t = 150$).

The vertical fluxes of momentum and heat vary considerably with these transitional phenomena. We plan to examine the performance of a turbulence closure model, MYNN, for the reproduction of the fluxes and to improve it, if necessary.

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

(1) The effects of changes in sea surface temperature and CO₂ concentration on the quasi-biennial oscillation

The quasi-biennial oscillation (QBO) is a quasi-periodic oscillation in the equatorial stratosphere. The QBO has significant remote effects ranging from the North Pole to the South Pole and from the lower stratosphere to the upper mesosphere. There is no evidence that any of the models employed in the IPCC AR4 model inter-comparison simulated a stratospheric QBO. *Kawatani et al.* [2011] investigated the effects of anticipated 21st-century global climate changes on the QBO using a high-resolution version of the MIROC-AGCM. In the experiment for late 21st-century conditions, the QBO period becomes longer and the QBO amplitude becomes weaker than those in the late 20th-century simulation. The downward extension of the QBO into the lowermost stratosphere is also curtailed in the late 21st-century run. These changes are driven by a significant increase in the mean upwelling in the equatorial stratosphere, and the effect of this enhanced mean circulation overwhelms counteracting influences from strengthened wave fluxes in the warmer climate. The future QBO changes studied by *Kawatani et al.* [2011] included the effects of both increased CO₂ concentration and higher SST. It would be interesting to investigate how the changes in the QBO found by *Kawatani et al.* [2011] are individually affected by SST change and CO₂ increase. The main purpose of this study is to clarify the individual effects of CO₂ and SST on changes in the QBO associated with differences in several physical quantities such as precipitation, mean zonal wind, residual mean circulation, and wave forcing (*Kawatani et al.* 2012).

We used the MIROC-AGCM with T106L72 resolution. This experiment does not include non-stationary gravity wave parameterization. Hence, the simulated QBO is driven by explicitly resolved waves in the model. *Kawatani et al.* (2011) conducted two types of runs with 90-year integration: (1) control run (present climate run) with present SST + sea ice and present CO₂; (2) future SST + sea ice and future CO₂ (future climate run). We conducted further two types of runs; (3) future SST + sea ice and present CO₂ (FS run); and (4) present SST and future CO₂ (FC run). In this paper, data from runs (1) to (4) are analyzed, and “differences” are defined by subtracting the present run from each of the future, FS, and FC runs.

Figures 8a-d show a time–height cross section of the monthly and zonal-mean zonal wind over the equator in the present, future, FS, and FC runs for 45 years. In the present climate, an obvious QBO-like oscillation with a period of approximately 2 years is apparent (Fig. 8a). The QBO wind variations extend down to approximately 60–80 hPa. In the FS run, the 0 ms⁻¹ lines of the westerly phase of the QBO extend down to ~50 hPa (Fig. 8c). The amplitude of the QBO becomes smaller, especially in the lower stratosphere. On the other hand, in the FC run (Fig. 8d), the westerly phases of the QBO extend down to ~70 hPa. Zonal wind variation associated with the QBO component around 70–100 hPa is slightly larger than that in the present run. In the future climate, the 0 ms⁻¹ lines of the westerly phase of the QBO extend down to ~50 hPa and sometimes to 20–30 hPa (Fig. 8b). The QBO in the future climate becomes more irregular.

Figures 8e-h show the frequency power spectra of the zonal-mean zonal wind at the equator as a function of height. In the present run, the most dominant period of the QBO is 24 months. The relatively strong variances extend to ~70 hPa. In the FS run, the dominant QBO periods are from 25 to 27 months. In the FC run, the dominant periods are 25 months. As a result, the QBO in the future run has a broad range of periods around 22–33 months and a very large variance around at 25 and 27 months, with a third peak of 29 months.

When compared with the present run, precipitation increases around the equatorial region in the FS run

and decreases in the FC run, resulting in increased and decreased wave momentum fluxes, respectively. In the mid-latitude lower stratosphere, westward (eastward) wave forcing anomalies form in the FS (FC) run. In the middle stratosphere off the equator, westward wave forcing anomalies form in both the FS and FC runs. Corresponding to these wave forcing anomalies, the residual vertical velocity significantly increases in the lower stratosphere in the FS run but decreases to below 70 hPa in the FC run, whereas residual upward circulation anomalies form in both the FS and FC runs in the middle equatorial stratosphere. Consequently, the amplitude of the QBO becomes smaller in the lower stratosphere, and the period of the QBO becomes longer by about 1–3 months in the FS run. On the other hand, in the FC run, the QBO extends farther downward into the lowermost stratosphere, and the period becomes longer by 1 month.

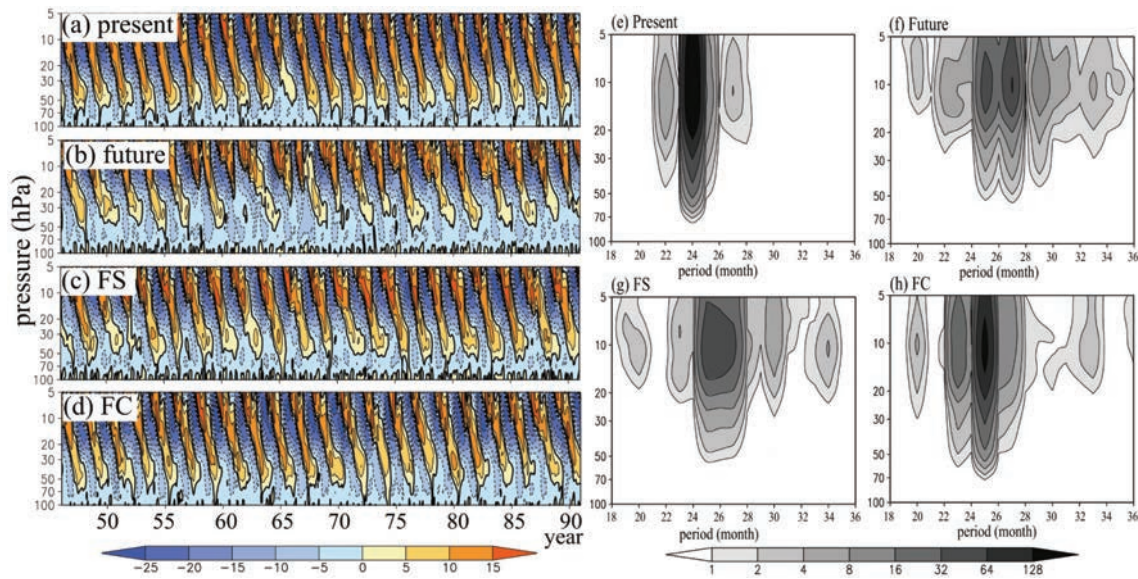


Fig. 8 Time–height cross section of the monthly and zonal-mean zonal wind over the equator in the (a) present, (b) future, (c) FS, and (d) FC runs. Frequency power spectra of the zonal-mean zonal wind at the equator as a function of height in the (e) present, (f) future, (g) FS, and (h) FC runs.

(2) Characteristics of Intense Rainfalls over Southwestern Japan in the Baiu Season in the CMIP3 20th Century Simulation and 21st Century Projection

This study examined features of intense rainfalls over southwestern Japan in the Baiu season (June and July) in the 20th Century Climate in Coupled Models (20C3M) and 21st Century projection (Special Report on Emission Scenarios [SRES] A1B) used by 18 climate models that contributed to the World Climate Research Programme’s Coupled Model Intercomparison Project phase 3 (CMIP3).

Characteristics of daily precipitation over an area of $5^\circ \times 5^\circ$ within $30\text{--}35^\circ\text{N}$ and $130\text{--}135^\circ\text{E}$ obtained by 20th century climate simulation were compared with observed precipitation data for a 3-year period (1997–1999). The studied area includes four meshed subareas of $2.5^\circ \times 2.5^\circ$. The four-area averaged daily precipitation and the maximum precipitation in the four areas were analyzed. The order statistics of the maximum precipitation indicated a very wide difference from model to model. To measure the temporal and spatial concentration of precipitation,

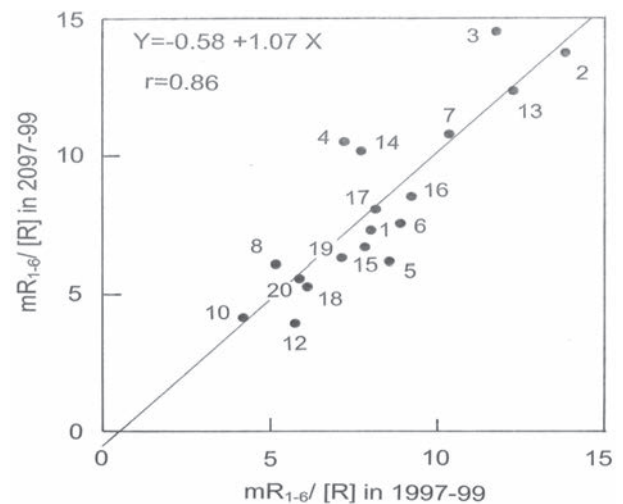


Fig. 9 Comparison of “concentration ratio” simulated by the 18 models for 1997–1999 (in the x-axis) with these projected for 2097–2099 (in the y-axis). The numeral attached to the small circle indicates the sequential number of the models.

“concentration ratio,” defined as (the average of the first- to sixth-largest maximum precipitation) / (time–area averaged precipitation) was examined. Although a few models reproduced a reasonable concentration ratio comparable to observations, many other models did not reproduce a reasonable ratio. Models of medium and high horizontal resolution with the Arakawa–Schubert cumulus scheme tended to reproduce a reasonable concentration ratio. Models that simulate a realistic Baiu frontal precipitation zone were able to simulate a proper concentration ratio.

Features of the intense rainfalls in the 21st century climate projection by the models were examined for June and July over a 3-year period (2097–2099). The characteristics of the models in regard to the intense rainfalls in the 20th century simulation were commonly found in the 21st century projections. Because the difference among the models was too large with respect to the intense rainfalls, the change in intense rainfalls under the climate changes in the 21st century cannot be definitely determined by CMIP3 models.

Global Hydro-Climate Processes in Changing Climate

–Global Hydro-climate Process Research Team–

(1) Evaluation of refined soil freeze/thaw processes in MIROC by offline simulations and observational data

Freezing ground, including permafrost and seasonally-frozen ground, is found in more than half of the Northern Hemisphere (NH). The changes in soil freezing/thawing, or the subsurface thermal conditions, are a local phenomenon, but can have large impacts on climate and life on the global scale through physical, dynamical, and ecological pathways. Despite its potential impacts, the freeze/thaw processes have not sufficiently incorporated in large-scale climate models, including the MIROC GCM and the MATSIRO land surface model. The investigations until the previous year demonstrated the needs of improvement in the conventional scheme in MATSIRO for plausible and realistic simulations, that is:

- 1) Total depth of soil column and thickness of each soil layer (esp. near the surface). The conventional scheme has 5 layers for 4 m depth.
- 2) Vertical profile of soil layer, especially consideration of organic soil layer.
- 3) Evaluation of thermal and hydrological physical property values. In the conventional scheme, effect of ground ice and unfrozen water were not omitted.

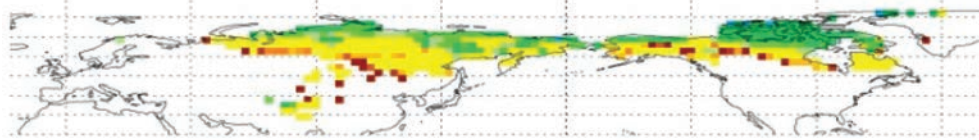
We conducted a series of global-scale offline simulations (i.e., not coupled with the atmospheric GCM) for the period of 1948–2000 using the refined MATSIRO regarding the above three issues on freeze/thaw processes. The forcing data were taken from the meteorological observations, and the spatial and temporal reconstructions were evaluated with the independent observational data.

Active layer (top layer thawed in summer; AL) is the area where principal hydrological and ecological activities take place in the permafrost regions. Realistic reproducibility of its thickness (ALT) and seasonal change is a key to simulate the physical climate, and to evaluate the ecological impacts of the subsurface changes. The maximum ALT simulated by the refined scheme (Fig. 10b) improved the previously overestimated results (Fig. 10a), and compare well to the observed ATL distribution (Fig. 10c) by the international Circumpolar Active Layer Monitoring (CALM) project.

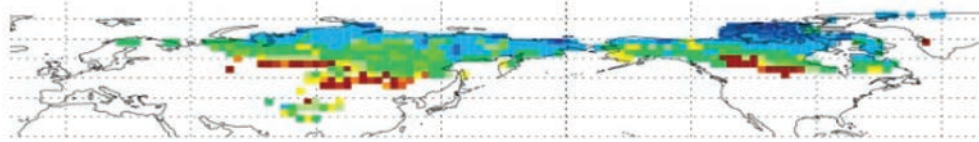
Understanding and determination of vertical and horizontal distribution of ground ice is important for water resource management, as well as for societal hazard evaluation such as subsidence due to melting. It has been indicated that the simulated ground ice amount by the conventional scheme was underestimated due to insufficient evaluation of the seasonal amplitude of the thermal property (i.e., thermal conductivity, heat capacity). The refined scheme simulated larger amount of ground ice north of the mid latitude (not shown), which is more consistent with the current understanding. Quantitative validation by direct or remote-sensing observations is left for future research.

It was also found that the differences in soil temperature and moisture led to systematic different surface conditions such as winter snow accumulation (not shown) and summer heat fluxes (sensible heat in Fig. 11a),

a) 4m soil. No Organic layer. Conventional scheme



b) 14m soil. Organic layer. Refined scheme



c) Observed values by CALM

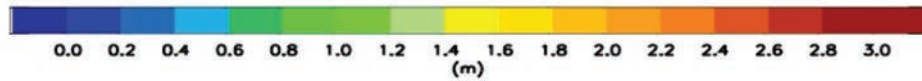
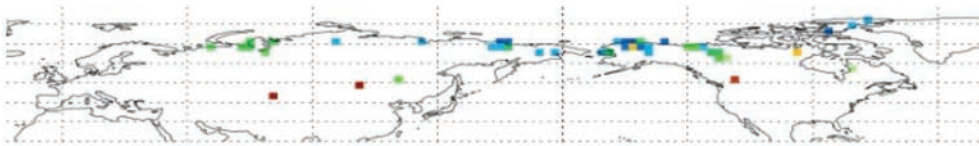
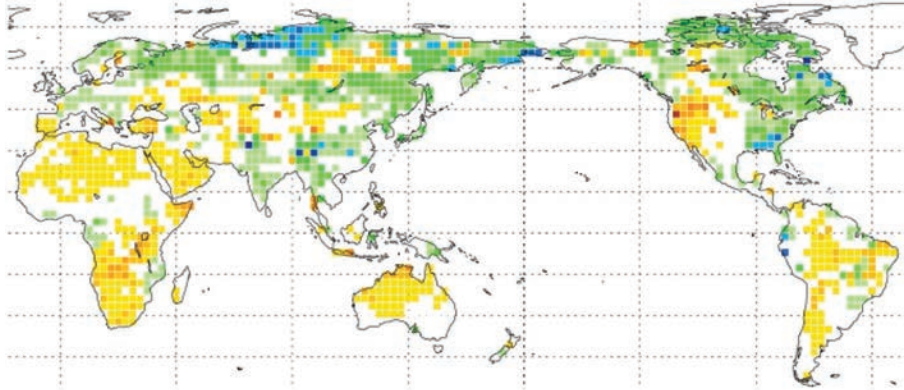


Fig. 10 Distribution of maximum active layer thickness. Simulated by a) the conventional model (4m soil, no organic layer, old thermal/hydrological parameterization), and b) the refined model (14m soil, top organic layer, improved parameterization). C) observations by CALM.

a) Sensible heat flux July (Conventional-refined)



b) Latent heat flux July (Conventional-refined)

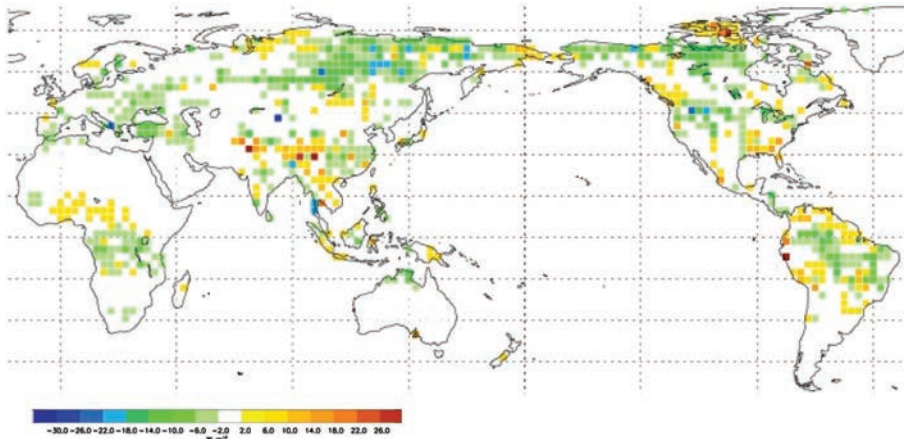


Fig. 11 Comparison of July eddy heat flux at surface for a) sensible heat and b) latent heat.

and latent heat in Fig. 11b)) on the large scale. This implies that the improvement of representation of soil and its processes can influence the simulations of the surface and lower atmosphere through changes in the surface conditions and heat/water fluxes, as well as directly the subsurface thermal/hydrological states. This issue will be examined by the online simulations planned to conduct in the next year. The interactions with the ecological processes will also be the topic of future research.

In parallel to refinement of the model codes, the observational research have been conducted in Alaska, Japan and the Antarctica as the domestic and international collaborative works to understand the climatic characteristics of snow/soil physical properties. This will offer the ground-truth foundation of the model improvement and validations to be done in the next years.

(2) ENSO-Monsoon variability in MIROC5

Verifying and tracing the performance of a coupled global climate model (CGCM) are indispensable for its continuous improvement. These efforts can also provide valuable information from which scientific community gains confidence in utilizing a CGCM for various purposes. In this regard, the present study evaluated the fidelity of the prime examples of the forced response (global monsoon), internal feedback process (El Niño), and their year-to-year coupling simulated by MIROC5 in comparison with MIROC3med, MIROC3hi, and the CGCMs participating in the third phase of the Coupled Model Intercomparison Project (CMIP3).

The climatological annual mean and cycles of precipitation and 850-hPa winds, the key components to demarcate global monsoon domain, are reproduced better in MIROC5 than in MIROC3. As a consequence, the former considerably outperforms the latter and is generally superior to the CMIP3 CGCMs in replicating the intensity and domain of global monsoon precipitation and circulations. The maximum covariance analysis (MCA) shows observational evidences that a significant fraction of the interannual global monsoon rainfall variability is in concert with El Niño (Fig. 12a-12b). The multi-model results indicate that such linkage is robust across the contemporary CGCMs and, more importantly, the fidelity of the global monsoon precipitation significantly relies on the realism of the tropical SST. In particular, MIROC5 simulates better the spatial patterns of the interannual

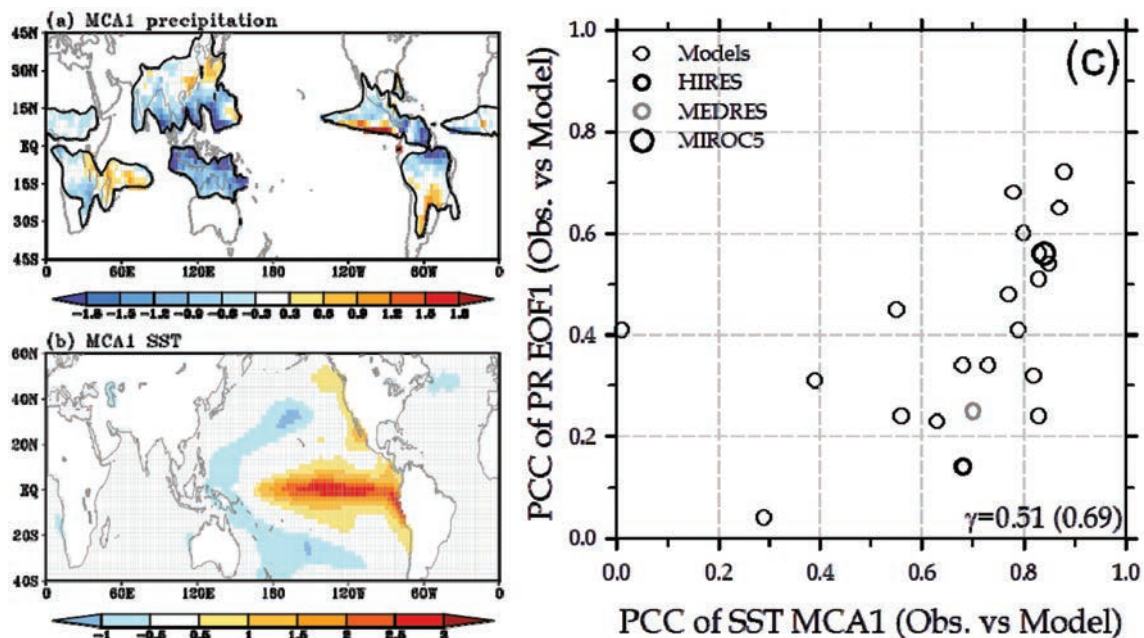


Fig. 12 (a)-(b) Observed spatial patterns of interannual ENSO-monsoon coupling obtained from the first leading mode of the maximum covariance analysis (MCA1). The PR MCA1 in (a) is nearly identical to the PR EOF1 (figure not shown), indicating the remote control of ENSO on global monsoon variability. (c) Pattern correlation coefficients (PCCs) between the observation and CGCM simulations for PR EOF1 (ordinate) and SST MCA1 (abscissa). The PCC for PR EOF1 is linearly related to PCC for SST MCA1 with a regression coefficient of 0.51 (0.69 without one outlier at middle left), suggesting that the fidelity of the global monsoon rainfall depends upon the reality of the tropical SST. Also of note is that MIROC5, the latest version of MIROC, is superior to its previous versions of MIROC3hi and MIROC3med, denoted as HIRES and MEDRES, respectively.

tropical SST swing as compared with MIROC3, which yields a more realistic representation of interannual global monsoon precipitation (Fig. 12c).

The improved reproducibility of MIROC5 bodes well for its use of future climate projection. Although CGCMs have been extensively used to predict future climate changes, assessing the accuracy of the models' projection is hampered due to the limited knowledge of the highly complex climate system. Thus the fidelity of a CGCM's performance for current climate variations is alternatively considered a measure of its capability to project the future. In this context, near-term to century-long predictions of MIROC5 would be more reliable. Especially, the forthcoming international collaboration, such as CMIP5, calls for intergraded efforts from around the world to meet the need of both the scientific community and the public. The results in Kim *et al.* [2011] suggest that MIROC5 will be able to contribute to such efforts as a credible member.

Simulations of Paleoclimate by GCMs and Ice Sheet Model

–Paleo-climate Modeling Research Team–

(1) Impact of arithmetic asymmetries on simulated thermodynamical ice-sheet evolution.

Interaction between thermodynamic processes and dynamic processes with in ice-sheets is very important for ice-sheet evolution. A positive feedback mechanism between the ice-sheet temperature and the velocity has much impact on the ice-sheet flow, which has been presented theoretically as 'creep instability' [Clarke *et al.*, 1977] and 'Binge/purge theory' [MacAyeal, 1993]. Since these interaction/feedbacks play a significant role, e.g., on ice-sheet instability under global warming condition, or on ice-sheet oscillation reconstructed by paleo proxies, they are one of the big subjects for ice-sheet modeling.

Calov *et al.* [2010] presented an intercomparison of nine different ice-sheet models, including IcIES developed as collaboration between JAMSTEC and Univ. of Tokyo. The main objective of the paper is to demonstrate how far the contemporary large-scale ice-sheet models can reproduce such internal oscillations known as Heinrich events, by comparing of the strength and frequency of the simulated oscillations under idealistic configuration. One important result of them is that six of nine models showed some deviations from mirror symmetry imposed by the boundary conditions. Calov *et al.* [2010] presented possible causes of the breaking of symmetries, however, impact on the simulated amplitude and/or periodicities by the breaking of symmetries are not discussed, which is discussed by this work. One reason of the breaking of symmetries is limited accuracy to store numbers in computers, which is already showed in Calov *et al.* [2010]. Different arithmetic order of an equation may result in different answer in computers with limited accuracy due to the 'loss of trailing digits' problem, even if the equation is identical analytically. Small differences among the answers on analytically identical grids may accumulate during the long-term simulation enough to be visible to break the symmetries. These errors originate in the limited accuracy of computers to represent numbers, which is inevitable in principle, however, we can guarantee the identical representation of numbers by computers when the corresponding analytic formulation is identical just by careful handling of the order in which numerical operations are carried out, without an artificial method. This study reexamines the experiment of Calov *et al.* [2010] by two variation of IcIES: one in which all the arithmetic order are carefully constructed to preserve the symmetry, and the other in which all the equations are analytically identical to the former model but intentionally constructed to induce an asymmetric result just by changing the arithmetic order. Figure 13 shows the simulated ice-sheet oscillation using the two variations of the models. A significant difference is found in the time evolution of ice-sheet volumes between the two results, where the global behavior focused in the experiment (in this case, the periodicities and amplitude of ice sheet) is significantly affected.

It can be concluded, that the small perturbation triggered by arithmetic asymmetry in numerical models may accumulate sufficiently to entirely damage the validity of the simulation. This study shows that it is imperative to apply a symmetric scheme to maintain overall symmetries in the simulation of ice-sheet evolution, however, it is difficult to judge whether the numerical asymmetries presented here also may influence results of numerical ice sheet models computing ice sheet dynamics with realistic, and thus highly asymmetric, topography

and other boundary conditions. Despite this, it is still preferable to avoid as many numerical pitfalls as possible, in particular by using the arithmetic symmetry algorithms introduced in this study, in order to understand the ice-sheet evolution.

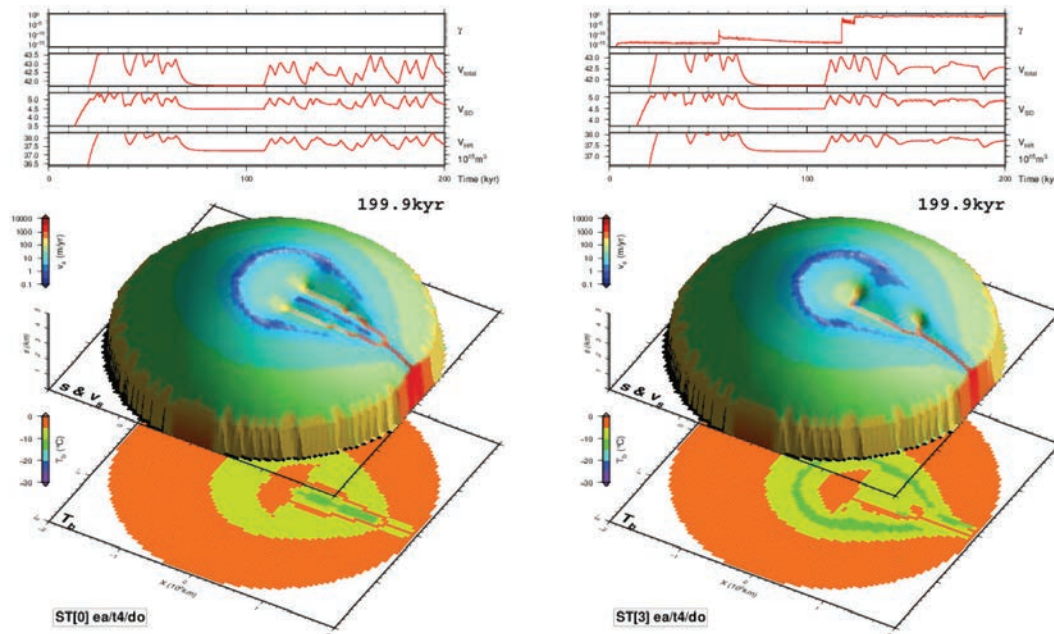


Fig. 13 Ice-sheet simulation under an idealized configuration: The left panel is the result obtained from a model with preservation of symmetry and the right is that from a model without it just by changing the arithmetic order. A snapshot of the basal temperature (bottom), ice sheet topography and velocity (middle) and the time evolution of ice sheet volumes (top) are shown. V_{tot} is the change in the total ice sheet volume during 200,000 years. The characteristics of the simulated oscillation are completely different; the latter model shows very minor oscillation.

(2) Modelling Uncertainty in Modeling Forecast

We investigated the reliability of various ensembles of climate model simulations at the Last Glacial Maximum using a sea surface temperature data synthesis. Reliability is a key concept in probabilistic prediction and predictions are described as reliable if the predicted probability of an event equals the frequency of its occurrence, over a large set of instances. One standard test of ensemble reliability is to evaluate the rank histogram, also known as Talagrand diagram. Computing the rank histogram, and checking for uniformity provides a necessary condition for an ensemble prediction system to be reliable, but it should be noted that it is not by itself a sufficient one. We also took into account the issue of uncertainty in the observational data. If the truth is sampled from the same distribution as the ensemble members, then the inevitable presence of this observational error will result in the observations themselves tending to have a somewhat broader distribution than the ensemble members. A standard method to account for this which we employ here is to simply add equivalent (randomly generated) perturbations onto the model outputs.

We analyzed two multi-model ensembles, created through the Paleoclimate Model Intercomparison Projects (PMIP1 and PMIP2), plus one ensemble created by varying parameters within a single model, using data from the Multiproxy Approach for the Reconstruction of the Glacial Ocean Surface (MARGO) sea surface temperature data synthesis. The zonally averaged output from the models are shown in Fig. 14. We found that while the two multi-model ensembles pass our simple tests of reliability, the single model ensemble does not perform so well. We showed that accounting for observational uncertainty in the MARGO database is of prime importance for correctly evaluating the ensembles. The results including the data error estimate are shown in Fig. 15. Perhaps surprisingly, the inclusion of a coupled dynamical ocean (compared to the use of a slab ocean) does not appear to cause a wider spread in the sea surface temperature anomalies, but rather causes systematic changes. For example, some evidence of this is apparent in Fig. 15(b). On further analysis, we find that in PMIP2 more is heat transported north in the Atlantic. There is weak evidence that the sea surface temperature data may be

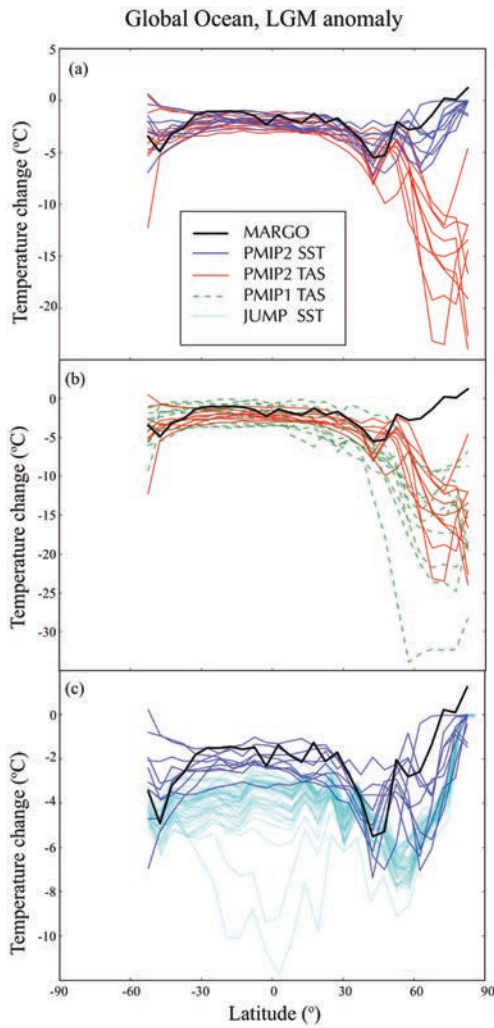


Fig. 14 The LGM anomaly for PMIP2 SST, PMIP2 TAS and PMIP1 TAS, and the MARGO data: The PMIP model output is interpolated onto the MARGO grid. The zonal means are made by averaging only over the grid boxes for which there are MARGO data. Characteristic differences between the ensembles are evident, with PMIP2 being generally narrower than PMIP1 and showing different behavior around 30-60N, indicative of a difference sea-ice distribution. The JUMP ensemble shows variation in magnitude, but it also shows less variation in the latitudinal pattern across the ensemble.

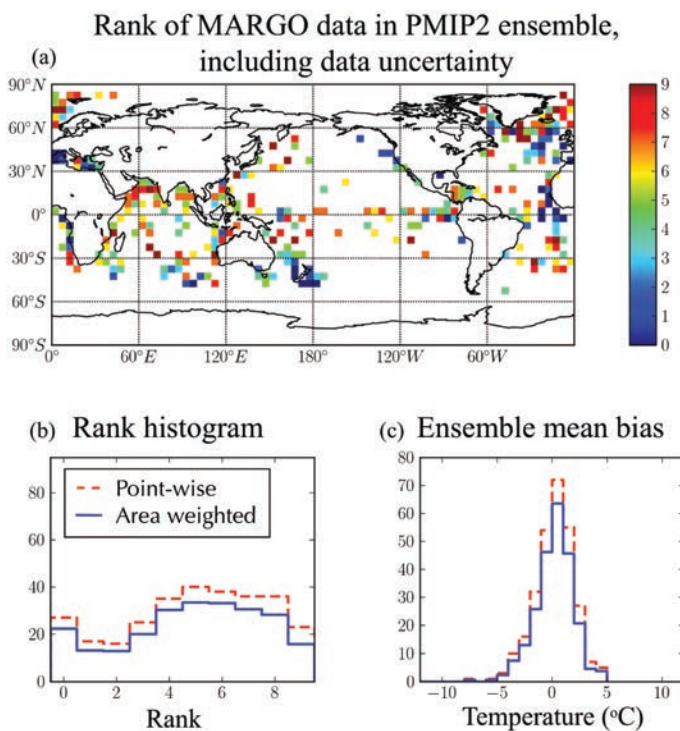


Fig. 15 (a) The rank of the MARGO data in the PMIP2 SST for the whole globe. (b) Area-weighted rank histogram of the ranks in plot (a). High rank (red on the color scale) indicates that MARGO is warmer at the LGM than the ensemble. (c) The histogram of the difference between the PMIP2 SST ensemble mean and the MARGO data for each data point in plot (a). Both area-weighted and point-wise rank histograms are shown. The uncertainties in the MARGO data are taken into account.

more consistent with meridional overturning in the North Atlantic being similar for the LGM and the present day. However, the small size of the PMIP2 ensemble prevents statistically significant results from being obtained on this issue. Increasing the robustness of these results would also be helped by having available data representative of a range of variables including in the ocean at depth rather than only the surface, and initiatives are underway to increase the scope of ocean data syntheses.

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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, with 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, are dominant signals in the Indo-Pacific basin, whose influences are observed not only in the tropical regions but also in other regions outside of tropics via atmospheric teleconnections. Local air-sea interactions and ocean processes in oceanic frontal zones are important aspects that control climate variations in mid-latitudes. Location of Kuroshio path is affected by meso-scale eddy activities and instability of currents. Accurate prediction of such variations and dissemination of predicted information in an appropriate way will be highly beneficial for the 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 air-sea coupled models, together with analyses of available observed and reanalysis datasets.

We contributed further advancements of our understanding on the processes in the climate and ocean systems. Using SINTEX-F1 and other coupled general circulation models, impacts of El Niño and El Niño Modoki on climate variations over Asia and Europe and an origin of model biases in the tropical Atlantic Ocean are investigated. Analyses for the case of hot summer over Europe indicate that some of the blocking highs that are responsible for a regional dipole in the extreme summer temperatures of Europe are associated with teleconnections arising from the tropical climate variations in the Indo-Pacific sector. Air-sea interactions over oceanic frontal zones in mid-latitudes and predictability of ocean conditions in such regions are among the hot issues we are focusing on in recent years. We found there is significant predictability, with lead time of about three years, in speed of Kuroshio axis in the Kuroshio extension region due mainly to westward propagation of oceanic Rossby waves from the central Pacific Ocean. Regional impacts of oceanic fronts in East China Sea and near Agulhas Current are also investigated through analyses of reanalysis datasets and sensitivity experiments using a regional coupled ocean-atmosphere model. Multi-scale operational ocean forecasting model is utilized to study impacts of Stokes drift associated with surface waves on surface currents and upper-ocean mixed-layer variations. We also continue improvements of SINTEX-F to optimize the model performance on the Earth Simulator and of JCOPE model by including the ensemble Kalman filter method for data assimilation component and by adding a material transport and dispersion component.

Basic study on application of climate prediction data for socio-economic benefits is one of our key activities. Combining outputs from climate models 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 continued and promising results emerged from preliminary experiments on a bias correction method.

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 in the following sections.

Chasing origin of climate variation predictability –Low-latitude Climate Predictability Research Team–

Role of surface wind and land precipitation in model biases of the tropical Atlantic

Most coupled general circulation models (GCMs) perform poorly in the tropical Atlantic in terms of climatological seasonal cycle and interannual variability. Most conspicuously, the models fail to simulate the development of the equatorial cold tongue in boreal summer, which leads to a warm sea surface temperature (SST) bias in the eastern equatorial Atlantic and a reversal of the zonal SST gradient along the equator relative to observations. The reasons for this poor performance are investigated in a suite of sensitivity experiments with the Geophysical Fluid Dynamics Laboratory (GFDL) coupled GCM [Richter *et al.*, 2011]. The experiments show that a significant portion of the equatorial SST biases in the model is due to weaker than observed equatorial easterlies

during boreal spring (see Fig. 1 for a description of one particular experiment). Due to these weak easterlies, the tilt of the equatorial thermocline is reduced, with shoaling in the west and deepening in the east. The erroneously deep thermocline in the east prevents cold tongue formation in the following season despite fairly strong upwelling.

It is further shown that the surface wind errors are due, in part, to deficient convection over equatorial South America and excessive convection over equatorial Africa, which already exist in the uncoupled atmospheric GCM. Additional tests indicate that the precipitation biases are highly sensitive to land surface conditions such as albedo and soil moisture. This suggests that improving the representation of land surface processes in GCMs offers a way of improving their performance in the tropical Atlantic.

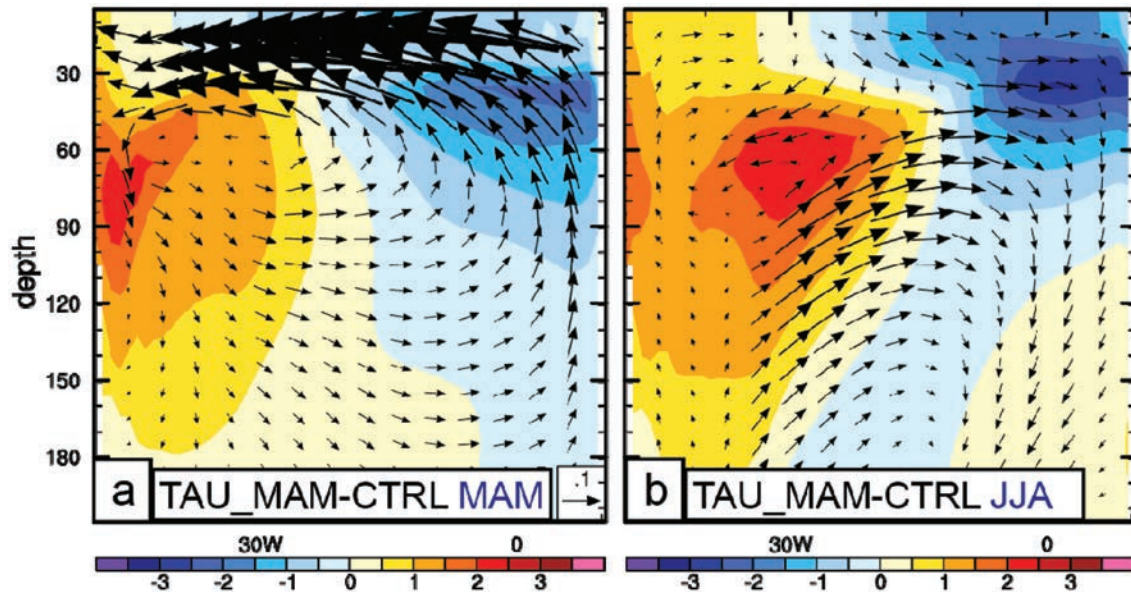


Fig. 1 Differences between a sensitivity experiment (“TAU_MAM”) and the control simulation (CTRL) in terms of ocean temperature (shading; K), and zonal and vertical ocean velocity (arrows; reference 0.1 m/s; vertical component scaled by 1.0E3) averaged between 1S-1N along the equator for (a) boreal spring (MAM), and (b) boreal summer (JJA). The figures show the effect of replacing model-generated wind stress with values from an observed climatology. The wind stress modifications are performed in boreal spring (MAM) only and limited to the equatorial Atlantic region 1S-1N, with linear blending with model-generated wind stress from 1-10N and 1-10S. Eliminating the equatorial wind stress bias in MAM clearly intensifies upwelling in the eastern equatorial cold tongue region and also strengthens the westward equatorial surface current. This is accompanied by about 2K cooling just below the surface, relative to CTRL. In JJA, when the wind stress is not corrected, upwelling is somewhat weaker than in CTRL. Nevertheless, the total vertical velocity is upward and brings the cold water generated in MAM to the surface, thus reducing the warm SST bias in the eastern equatorial Atlantic.

A regional model coupled to mixed-layer simulates better rainfall for southern Africa

Much of the southern Africa (SA) receives its precipitation during the austral summer (December to February; DJF) and any large variability in the seasonal rainfall has impacts on the economy of the region. The precipitation variations over SA can be partly explained by SST variations in the surrounding oceans, viz. the southern Indian Ocean and the south Atlantic Ocean. The variations in the SST are also known to affect the frequency and position of the rain bearing synoptic scale systems and hence the seasonal rainfall. It is, therefore essential to correctly specify the spatial and temporal variations in the SST to the dynamical models to simulate the intraseasonal and interannual variations in climate of southern Africa.

We have used the Weather Research and Forecasting (WRF) regional model to simulate the climate of southern Africa during the austral summer [Ratnam *et al.*, 2011]. The dynamical downscaling using the two-tier approach is limited by availability of the spatial and temporal distributions of the SST and also errors in the forecasted SSTs. To overcome these limitations we have coupled the WRF regional model to a simple mixed layer ocean model. Fig. 2b shows the precipitation bias in the simulation of the stand-alone WRF model, which indicates positive bias over most parts of southern Africa except for Tanzania and Mozambique. Fig. 2c shows

that WRF coupled to a simple mixed layer ocean model could realistically simulate the climate of southern Africa with slight negative biases over Tanzania and Mozambique. The plot of the difference in precipitation between the coupled and uncoupled cases (Fig. 2d) shows improvements in the simulation of the mean precipitation over most parts of southern Africa. If we define a day to be dry (wet) when it receives less (more) than 1mm (5mm) of rain, a one-tier approach with coupled WRF model improves the simulation of the number of dry/wet days and hence the improvement in the seasonal mean.

The results show that the one-tier approach of simulating the climate of southern Africa is superior compared to the two-tier approach of specifying the observed/forecast SSTs. Also, the one-tier approach with the simple mixed-layer model effectively reduces the complicity of finding good SST predictions for the regional downscaling and prediction experiments.

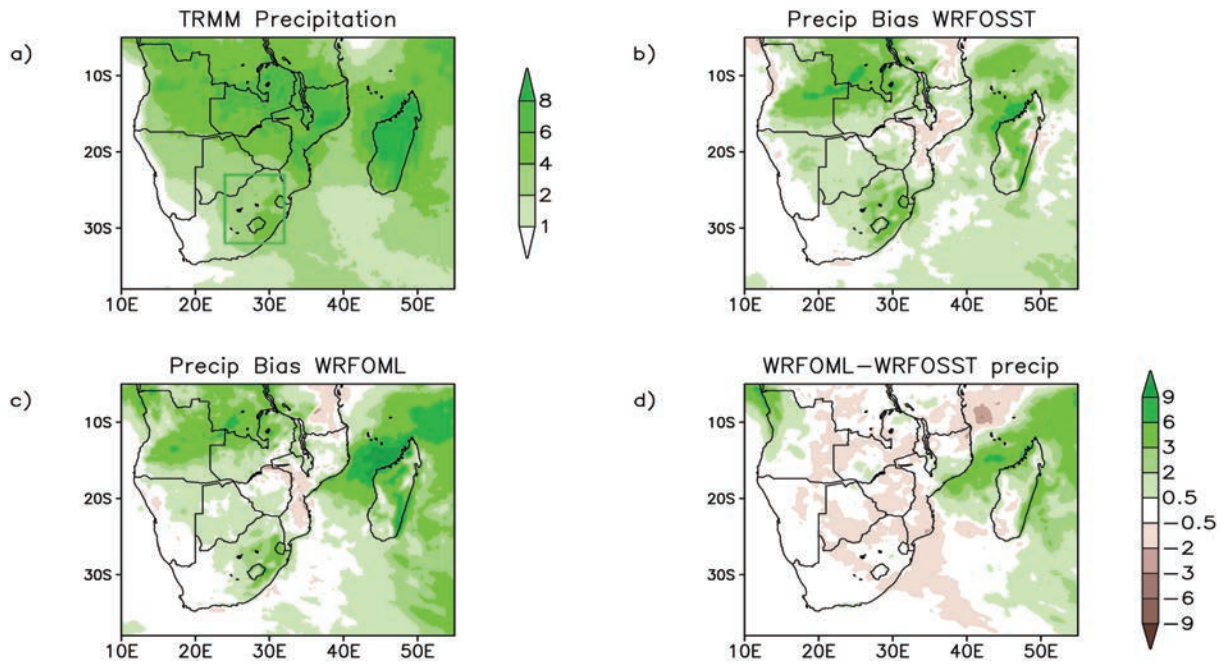


Fig. 2 a) Observed TRMM precipitation (mm/day), b) WRF simulated bias, and c) precipitation bias simulated by WRF coupled to a simple mixed-layer ocean model. d) Difference in simulated precipitation between c) and b).

Three-year-lead predictability of the Kuroshio Extension jet –Mid- and High-latitude Climate Predictability Research Team–

Potential predictability of interannual variability in the Kuroshio Extension (KE) jet speed attributed to the westward propagation of wind-driven oceanic Rossby waves is investigated through prediction experiments and long-term hindcast integration with an eddy-resolving ocean general circulation model (OFES) under the perfect-model assumption. Though based on the small number of the experiments due to limited computational resources available, our experimental results suggest some predictability not only in broad-scale sea surface height anomalies (SSHAs) but also in anomalous KE jet speed associated with meridionally-confined frontal-scale variability. Specifically, more than half of the variance in the 13-month running mean KE jet speed can be explained by the ensemble mean of the forecast integrations even in the third year (Fig. 3). The predictability of the KE jet speed and crucial importance of Rossby wave propagation to it thus revealed have been confirmed in the 61-year-long hindcast integration as significantly high correlation ($r = 0.68$) between the smoothed interannual variability in KE jet speed and SSHAs over the central North Pacific [30° - 34° N, 170° E- 175° W] three years earlier (Fig. 4). Though limited in their availability, the satellite observed SSHA data and the geostrophically derived KE jet speed are also correlated if the same time lag is assigned. These results mean that although KE jet is known to include intrinsic variability, there is also some predictable component.

The warm KE releases abundant heat and moisture into the atmosphere, implying significant impact of

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KE on the atmospheric circulation and KE's potential importance in air-sea interactions. We have confirmed in the historical observational data and an ocean-atmosphere coupled model that SST anomalies caused by meridional shift of KE and another SST front to its north can force a basin-scale anomaly pattern of the atmosphere with the anomalous intensity of the surface Aleutian Low. Additionally, recent studies have suggested that decadal changes in the speed of the Kuroshio and an upstream portion of KE can influence natural mortality of infant Japanese sardine, which is known to yield several orders of interdecadal variability in its mass. Prediction of the path and intensity of KE is thus of social and scientific importance, and this study contributes to the research project Population Outbreak of Marine Life (POMAL) by the Agriculture, Forestry and Fisheries Research Council of Japan.

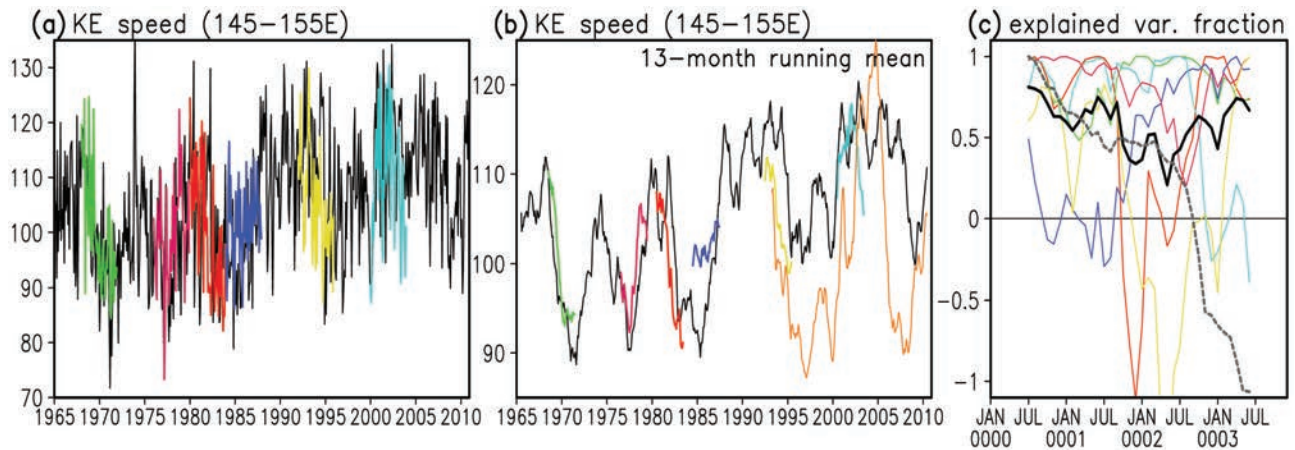


Fig. 3 (a) Time series of the KE jet speed (cm sec^{-1}) averaged over $[145^{\circ}\text{--}155^{\circ}\text{E}]$, based on the OFES hindcast integration (black) and six forecast experiments (colors). (b) Same as (a), but 13-month running mean is applied to reduce influences of eddies. (c) Time series of the corresponding fraction of variance explained by the forecast experiments represented by $1 - (\text{forecast errors})^2 / (\text{signal variance})$ in the KE jet speed in (b). Thick black curve is for the ensemble mean, and grey is for the persistence.

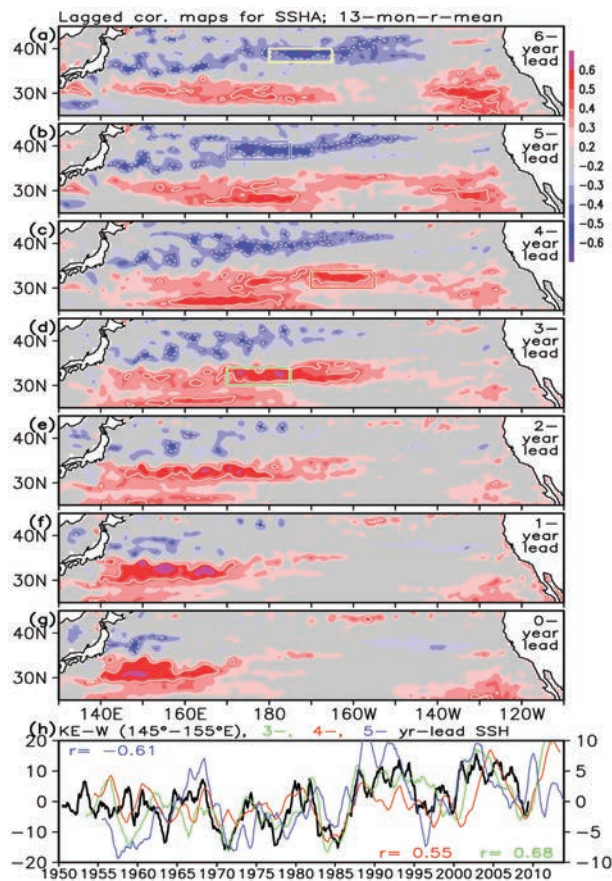


Fig. 4 (a-g) Lag correlation maps of SSHAs with the mean KE jet speed averaged between 145° and 155°E as the reference index. SSHAs lead the index by (a) 6, (b) 5, (c) 4, (d) 3 (e) 2, (f) 1, and (g) 0 years. (h) Time series of the KE jet speed (black; left axis), and 3 (green)-, 4 (red)-, and reversed 5 (blue)-year-lead SSHAs averaged over $[30^{\circ}\text{--}34^{\circ}\text{N}, 170^{\circ}\text{E}\text{--}175^{\circ}\text{W}]$, $[30^{\circ}\text{--}34^{\circ}\text{N}, 170^{\circ}\text{--}155^{\circ}\text{W}]$, and $[37^{\circ}\text{--}41^{\circ}\text{N}, 170^{\circ}\text{E}\text{--}175^{\circ}\text{W}]$, plotted with the green, red, and blue rectangles in panels d, c, and b, respectively.

Open and coastal seas interactions represented by an ensemble Kalman Filter –Ocean Downscaled Prediction Research Team–

Recent progresses in downscale modeling have allowed us to simulate interactions between open ocean and coastal seas, including highly variable and spatially anisotropic phenomena due to coexistence of multi-scale processes. To develop an advanced data assimilation method for better representation of such open and coastal seas interactions, we investigated the feasibility of the ensemble Kalman filter (EnKF) focusing on reproducibility of oceanic conditions south of Japan [Miyazawa *et al.*, 2012]. We adopted the local ensemble transformation Kalman filter algorithm based on 20-member ensemble simulations of the parallelized Princeton

Ocean Model (the Stony Brook Parallel Ocean Model) with horizontal resolution of $1/36^\circ$. By assimilating satellite sea surface height anomaly, satellite sea surface temperature, and in situ temperature and salinity profiles, we reproduced the Kuroshio variation south of Japan for the period from 8 to 28 February 2010. EnKF successfully reproduced the Kuroshio path positions and water mass property of Kuroshio as observed. It also captured the variation of the steep thermohaline front in the Kii Channel due to intrusion of the Kuroshio water, suggesting efficiency of EnKF for detection of open and coastal seas interactions with highly complicated spatiotemporal variability (Fig. 5). Detailed examination of the results indicates that unpredicted variations in particular areas and their responsible phenomena can be identified. The efficiency of EnKF is attributed to seamless representation of the forecast error covariance from meso- to sub-mesoscales. This study is the first attempt of the application of EnKF for the Kuroshio variations and shows significant potential of the method for ocean state estimation, analysis, and prediction.

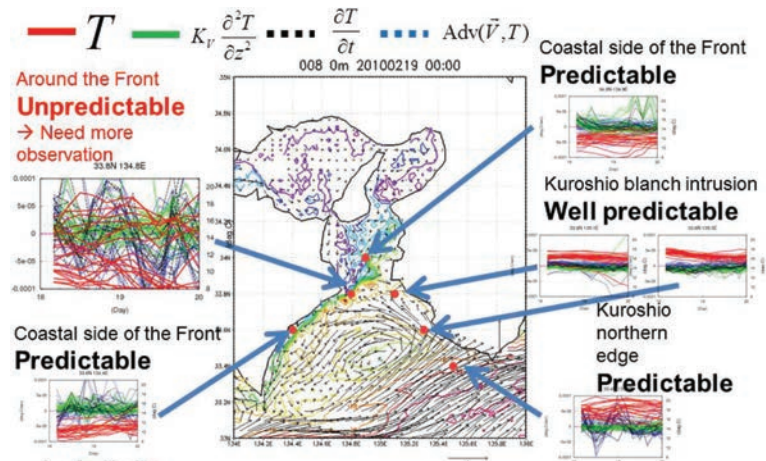


Fig. 5 Predictability of the Kii Channel front variations indicated by the ensemble Kalman Filter. A central figure shows the surface flow (vectors) and temperature (contours) of an ensemble forecast member. Time sequences of ensemble heat budgets on selected five points are also shown.

Critical review on the energy balance of ACC and successful reproductions of documented episodic events by a newly developed nonhydrostatic model

–Climate Variation Informatics Research Team–

In order to determine the maintenance mechanisms of the Antarctic Circumpolar Current (ACC), we have investigated the budget of the annual mean kinetic energy (KE) in a high-resolution (0.1-deg) semi-global ocean simulation. The analysis is based on a separation of the mean KE using the barotropic (i.e., depth averaged) and baroclinic (the residual) components of velocity. An energy diagram is rederived to show that the work of the barotropic component of the horizontal pressure gradient (HPG) is connected to the work related to the joint effect of baroclinicity and bottom relief (JEBAR), and then to the budget of potential energy (Fig. 6). The working rates of wind forcing on the barotropic and baroclinic circulations in the Southern Ocean are 191 and 352 gigawatts, respectively. It is found that the work of the wind forcing on the barotropic component of the simulated ACC is canceled by the combined effect, in equal measure, of the work of the barotropic HPG and the work of dissipative processes for mean KE. This result makes a significant contribution to the discussion on the depth-integrated momentum balance of the ACC. The barotropic KE is dissipated by the effects of bottom frictional stress, lateral frictional stress, and the Reynolds stress, of which more than half is attributed to an unexpectedly

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large contribution from biharmonic horizontal friction. Future studies should pay more attention to the role of biharmonic friction used in high-resolution numerical models.

We have also investigated the possible impact of the Indonesian Throughflow (ITF) on tidally generated internal waves in Lombok Strait and examine the energetics of these disturbances (Fig. 7). Using a two-dimensional nonhydrostatic numerical model which takes into account the variable width of the strait region, two main experiments have been performed, one without and one with an idealized ITF component in the upper layer flowing southward toward the Indian Ocean. These correspond to conditions in boreal winter and summer, respectively. Both experiments show trains of internal solitary-like gravity waves (ISWs). Overall, ISWs are more numerous on the north side of the sill where the narrower channel in effect amplifies the disturbances. In both experiments about 3.9 GW of energy is injected into barotropic and baroclinic tidal currents, of which about 2.6 GW is radiated away by internal gravity waves. The ITF regulates the way that the radiated energy is partitioned between the two sides of the sill. Without the ITF (boreal winter), the northward radiated energy flux is greater in magnitude than that radiated to the south. However, when the ITF is present (boreal summer), the northward radiated energy flux is smaller in magnitude than that radiated to the south. This result suggests that the vertical mixing is enhanced on the Java Sea side in boreal winter, and is enhanced on the Indian Ocean in boreal summer.

Oceanic nonhydrostatic dynamics becomes important when horizontal wavelengths become shorter than 5 km (which is the typical depth of sea floor), as is shown by previous studies focusing on tidal internal waves. We have found that ISW trains can be also generated by typhoons. We have performed two separate hindcast

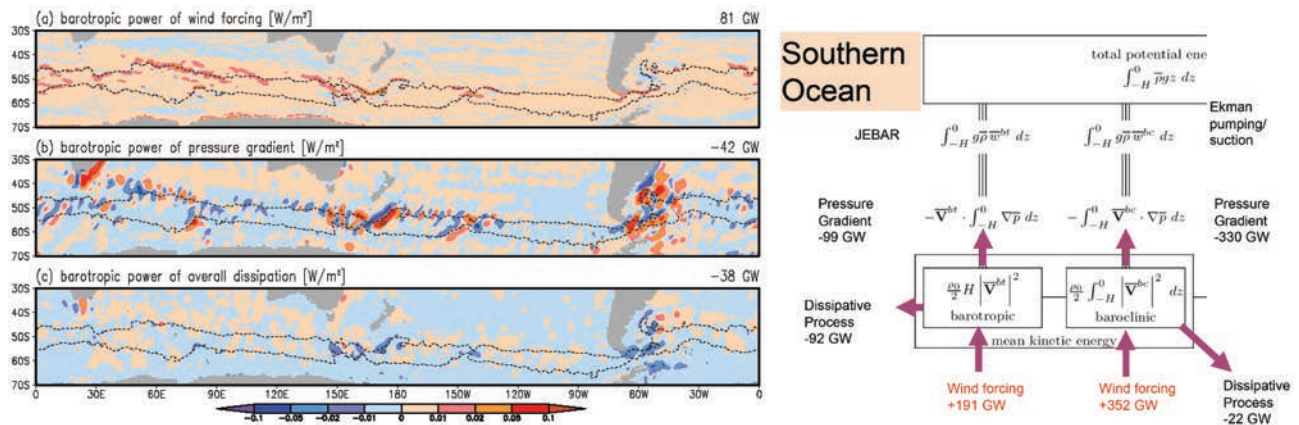


Fig. 6 Diagnosis of energy conversion rates in the Antarctic Circumpolar Current simulated by a high-resolution ocean general circulation model. The horizontal distribution of the depth-integrated rates (left), and the volume budget in the Southern Ocean (right).

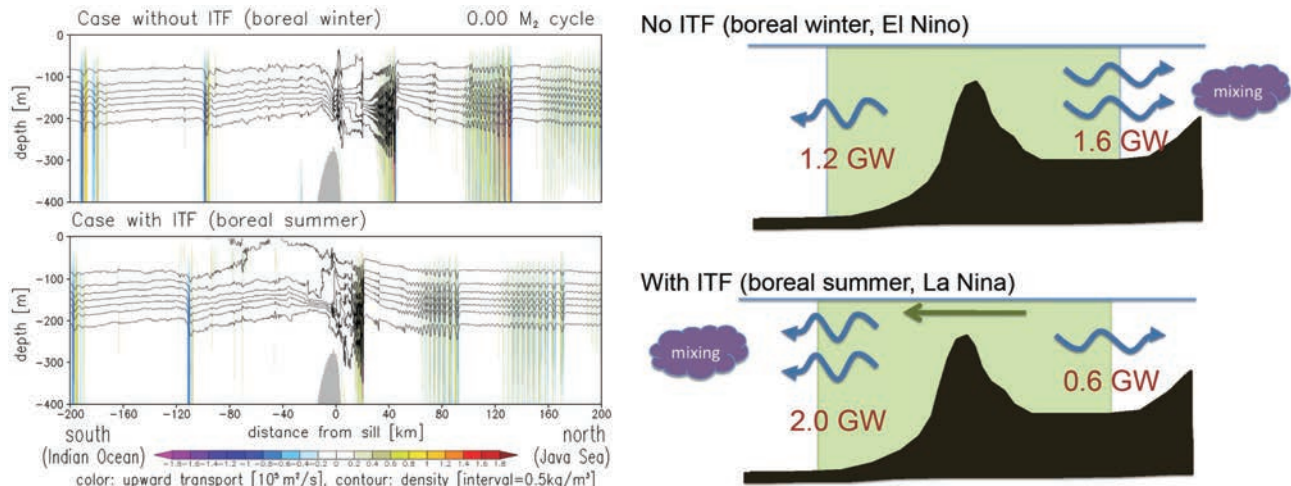


Fig. 7 Comparisons of cases without and with the ITF. Left: snapshots of the vertical component of velocity (color) and density (contour). Right: illustration of the energy radiation by internal gravity waves that leads to the vertical mixing.

simulations for typhoon Choiwan 2009, one with nonhydrostatic pressure in the ocean component of the model and one without it, using a coupled atmosphere-ocean nonhydrostatic three-dimensional model. Choiwan passed the Ogasawara Islands on 20 September 2009. The cyclonic wind stress of the typhoon induces divergent ocean flows at sea surface, resulting in the doming of thermocline that radiates away as internal gravity waves. Simulated internal gravity waves are significant to the east of typhoon, and propagate at the speed of waves in the first baroclinic mode. Gradually ISW trains with waves about 5-10 km in length and about 1 hour in period are formed in the nonhydrostatic run (Fig. 8). Such saturation of wave frequency is consistent with the dispersion relation of nonhydrostatic internal gravity waves. No ISW is formed in the hydrostatic run where the leading edge of waves is too significant and there is no tail of wave trains. The effect of ISWs needs to be taken into account in the parameterization of the vertical mixing in the deep ocean.

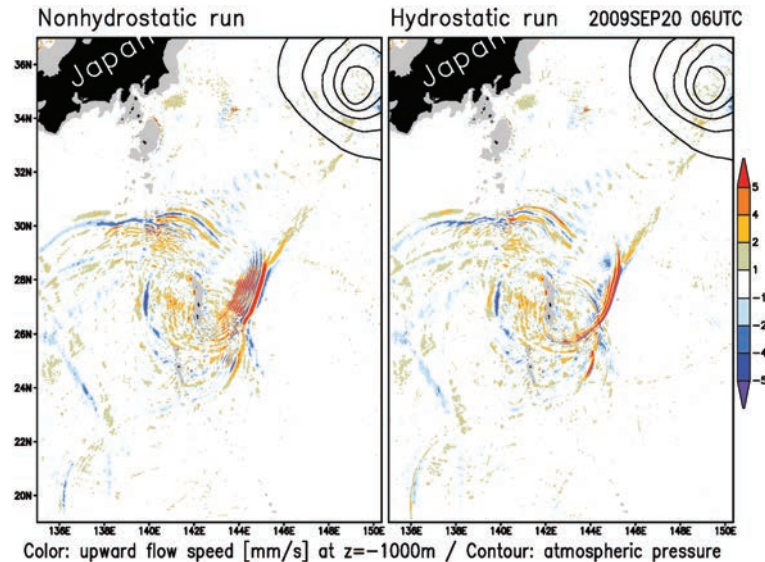


Fig. 8 Horizontal distributions of the vertical component of velocity at 1000 m depth [color, mm/s] and sea surface pressure [contour interval = 5 hPa] in the nonhydrostatic run (left) and the hydrostatic run (right).

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Higher resolution and lower uncertainty –Advanced Atmosphere-Ocean-Land Modeling Program–

To make adaptation plans to the climate change, we need to know how change in occurrence of heavy rainfall, typhoons and extremely high temperature in the scale of nations, prefectures or even cities. For example, we might project that a sharp decline in the volume of water resources in the future. In order to mitigate the shortage of water resources, a new reservoir may be required. The cost of building a new reservoir for the adaptation is extremely high and it will take long term. Such adaptation plans would be difficult if the uncertainty of the projection is too large. In fact, this uncertainty still exists in the prediction of climate change. In addition, climate projections are spatially blurred because of low horizontal resolution of the climate models. These make the policy makers difficult. They need more detail information in their regions of responsibility.

The aim of this program is to contribute to the projection of global climate change as well as weather prediction using a very high-resolution numerical atmosphere-ocean-land model. The higher spatial resolution often reduces the scientific uncertainty. So far, small-scale spatial variations and processes are simplified by using some parameterizations in a low-resolution model. Very high spatial resolution models can calculate physical processes without any parameterizations. To achieve this objective, there are six teams working together. Below is the summary of the results and brief descriptions of three high-light studies in them.

Global Cloud-Resolving Modeling Research Team studied the resolution dependency of the diurnal variation of tropical precipitation. It is well known that numerical models often difficult to accurately simulate the diurnal cycle of precipitation. The accuracy of the diurnal cycle was investigated as shown later in detail. Advanced Ocean Modeling Research Team improved the coordinate system, the time integration scheme and the parameterizations of physics in their oceanic general circulation model. Cloud, Precipitation and Radiation Process Research Team studied the mechanism of the organization of cumulus convections with MJO using a mesoscale convection resolution model as described later. Land Surface Modeling Research Team investigated the difference in snow water in the area along the Sea of Japan coast between 1980s and 1990s using a regional numerical model. They found snow water was decreased, but precipitating was not. Snow melting was more prominent especially in February during 1990s. Regional Climate Modeling Research Team investigated the uncertainty of the downscaling of change in snow water associated with the climate change in Japan. The uncertainty caused by regional climate model is smaller than that of CGCMs, but difficult to ignore. Tropical Atmosphere-Ocean Observation and Modeling Research Team supported observation terms of CINDY2011 (Cooperative Ocean Experiment on Inter-seasonal Variability in the Year 2011) by the weather forecast using a numerical model (Regional NICAM).

Resolution dependency of Diurnal variation of Tropical precipitation –Global Cloud-Resolving Modeling Research Team–

Tropical convection plays a primarily role in driving the atmospheric circulation over the globe, and a better numerical representation of their behavior is an urgent task for better predictability of NICAM simulations, including basic characteristics of tropical precipitation systems appropriately, such as their diurnal variation. A limitation of conventional global atmospheric models (GCMs) comes from due mainly to their cumulus parameterization that diagnoses vertical transport of mass and heat artificially, which can cause potential biases on cloud behavior [e.g., Lee *et al.*, 2007; Hara *et al.*, 2009].

To overcome the deep-rooted issue in the field of the present climate research with GCMs, our research team has conducted innovatively high-resolution global simulations that free from impacts by a cumulus convection parameterization and compute individual cloud motions explicitly. Addresses of these outcomes have led to better understanding of a development mechanism of Madden-Julian Oscillations, major tropical disturbances that affect strongly on yearly tropical weather systems [e.g., Miura *et al.*, 2007, 2009]. Moreover, we have also made efforts on elucidating potential advantages in going forward a study using high-resolution

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simulations that require huge computational resources. In this fossil year, as a course of the mission mentioned above of this research team, *Noda et al.* [2012] analyzed detailed characteristics of the diurnal variation in tropical precipitation simulated in 14-km and 7-km mesh NICAM (R14 and R7, respectively).

Figure 1 shows global distributions of surface precipitation simulated by NICAM. Both R7 and R14 perform well in simulating the spatial characteristics, such as regions of intense precipitation over the Inter-Tropical Convergence Zone (ITCZ), including the African continent and the South Pacific Convergence Zone (SPCZ); however, the models overestimate precipitation over the Indian Ocean, among other areas, and underestimate precipitation over India, Southeast Asia, and central South America. The excessive surface precipitation is less pronounced in R7 for areas such as the Indian Ocean, SPCZ, and ITCZ of the Atlantic Ocean.

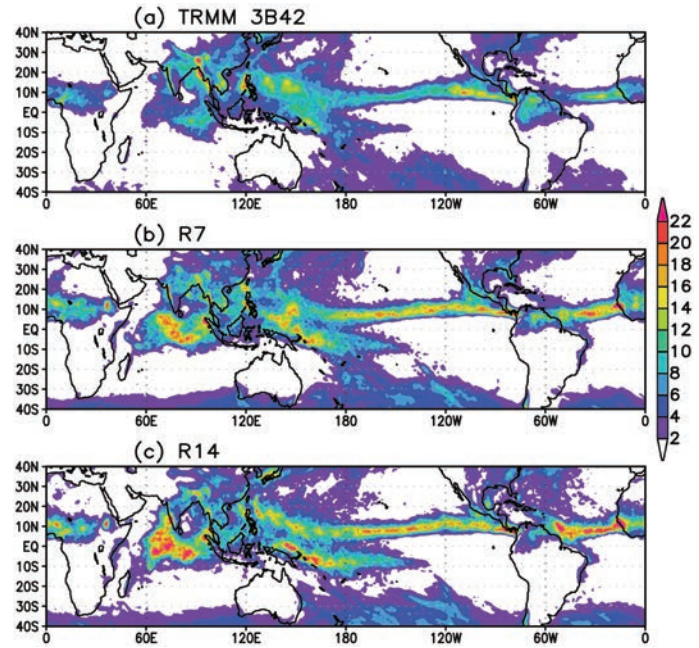


Fig. 1 Comparison of surface precipitation in (a) TRMM 3B42, (b) R7, and (c) R14. The data are averaged over June–August 2004. Simulation data were linearly interpolated in space from the original resolutions (i.e., 14 km and 7 km) to 1° data. The unit is mm dy^{-1} .

Figure 2 shows diurnal variations in surface precipitation within the tropics (10°S – 10°N). Over land (Fig. 2a), both models show a delay in the phase of diurnal variations. R14 shows maximum and minimum values at 2100–2400 local time (LT) and 1200–1500 LT, respectively, which are about 6 hrs later than those in the TRMM result. R7 shows a phase delay of about 3 hrs. It has been often reported the earlier development of the maximum of tropical precipitation in conventional GCMs [e.g., *Lee et al.*, 2007]. In contrast, the diurnal variation of precipitation in a GCM without cumulus convection parameterization, NICAM, behaves quite differently. The NICAM result shows that the diurnal cycle of surface precipitation can be steady improved with the model resolution. This fact indicates a great advantage to promote a study of higher-resolution modeling. The resolution dependence is more prominent over land than over ocean. *Sato et al.* [2009] also pointed out a similar resolution dependency based on NICAM data about a boreal winter season; however they did not mention its underlying

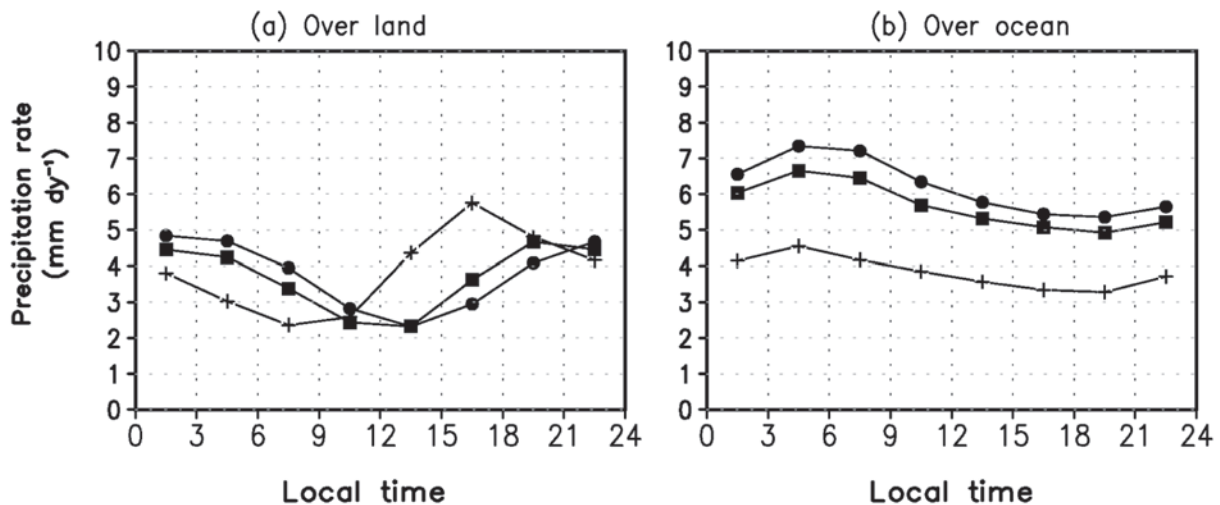


Fig. 2 Temporal changes in surface precipitation (mm dy^{-1}) over (a) ocean and (b) land in the tropics ($\pm 10^{\circ}$ of latitude). Lines with '+' symbols represents data from TRMM 3B42. Lines with circles and squares represents data from R14 and R7, respectively.

mechanisms. Over ocean (Fig. 2b), TRMM data show maximum and minimum values at 0300–0600 local time (LT) and 1800–2100 LT, respectively. The diurnal variation in surface precipitation in R7 is similar to that in R14, and both models perform well in reproducing its phase, although the overestimation of mean values is an important issue that requires improvement (Fig. 1).

In order to understand the interesting finding regarding the horizontal resolution observed between ocean and land, we first analyzed the controlling mechanism of the modeled diurnal precipitation, based on the R7 data (an analysis of the R14 data yielded similar results, and is therefore not presented here). Figure 3 shows time–height plots of vertical velocity and moist static stability (h_s) over land and ocean, respectively. The term “anomaly” indicates the residual from the temporal mean at each height. Over land, the anomaly of h_s turns to positive during the period 0700–1100 LT, due to the development of a convective boundary layer (BL) by solar insolation. This vertical mixing occurs mainly via subgrid-scale turbulence (parameterization), and is large at the boundary beneath 2 km above ground level (AGL), the layer near the BL top. After 1700 LT, the anomaly of vertical velocity develops vertically, eventually showing strong positive values ($>0.06 \text{ m s}^{-1}$) after 1800 LT, indicating the development of nighttime deep convection. These results show that vertical transport of moist air in the BL to the layer around the BL top is a key factor in the subsequent intense convection over land.

It is recognized well that daytime heat supply from a BL to a free atmosphere is strongly linked to evening deep convection and consequent surface precipitation [e.g., *Yang and Slingo*, 2001; *Lee et al.*, 2007]. An interesting piece of evidence in this regard, as obtained from the present results, is that the maximum surface precipitation over land occurs at 1800–2100 LT (Fig. 2a), when vertical vapor transport in the BL is at a maximum (represented by the anomaly of increasing h_s vertically with time; Fig. 3a).

Over ocean, the anomaly of h_s in the free atmosphere shows clear diurnal signals as a result of daytime radiative heating and nighttime cooling. The diurnal variations in h_s are much weaker than those over land. The stability changes that occur in the free atmosphere over ocean are in good agreement with diurnal surface precipitation in this region. The picture presented above is consistent with the results of conventional GCM studies [e.g., *Randall et al.*, 1991; *Lee et al.*, 2007], and presumably indicates the robustness of the fundamental mechanisms that drive modeled diurnal variations in tropical precipitation. The anomaly of vertical velocity over ocean below 2 km AGL shows a phase change similar to that of diurnal variations in surface precipitation

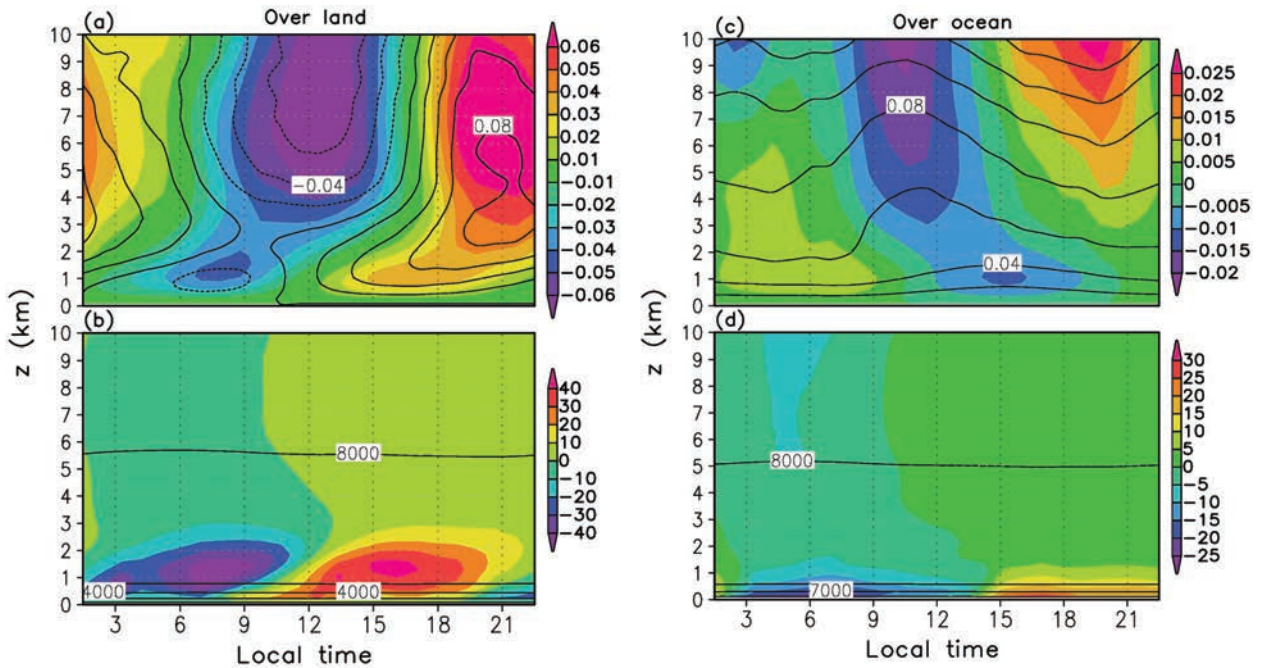


Fig. 3 Time–height plot of (a) vertical velocity (solid contours; m s^{-1}) and deviation from the daily mean (colors), and (b) moist static energy (solid contours; kJ kg^{-1}) and deviation from the daily mean (colors) over land in the tropics ($\pm 10^\circ$ of latitude). Contour intervals in (a) and (b) are 0.02 m s^{-1} and 2000 kJ kg^{-1} , respectively. (c) and (d) are the same as (a) and (b), except over ocean.

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(Fig. 2b); i.e., the period showing an updraft motion in early morning (downdraft motion) corresponds to the period of maximum (minimum) precipitation.

Next, we compared the size distributions of precipitating areas in R14 and R7 (Fig. 4) to clarify the underlying mechanisms that cause the marked difference in the maxima of surface precipitation in R7 and R14. For R7 over land, small precipitating areas (<100 km) gradually develop after sunrise, reaching a maximum value by 2100 LT. Subsequently, the contribution of these areas decreases, and that of areas with a radius of 0–50 km decreases by 0600 LT. The change in the size distributions from 1400 LT to 0600 LT reflects the nighttime evolution of deep convective clouds (cf. Fig. 3a). Clear diurnal signals are also evident in R14 (Fig. 4b); however, the temporal changes apparent in the histogram are relatively monotonic: the maximum range of area sizes in R14 always occurs at an area size of 50–200 km, whereas that in R7 varies over time. Consequently, the diurnal variations are weaker in R14, depending on area size. A comparison of the size distributions of precipitating areas in R7 and R14 over ocean (Fig. 4c and 4d) shows relatively small differences in their diurnal variations; even in R7, the maximum range of area sizes throughout the day is 0–100 km.

Finally, to further understand the role of small precipitating areas in controlling tropical precipitation in the tropics, we compare the size distributions of 3-month means of surface precipitation in Fig. 5. The frequency occurrence of the size distribution of surface precipitation over land in R7 (solid bars in Fig. 5a) shows that areas with radii of 0–100 km contribute most to surface precipitation, with a gradual decrease with increasing radius. For R14 (dashed bars in Fig. 5a), larger contributions are made by areas with radii of >50 km. Similar characteristics of surface precipitation are seen over ocean (Fig. 5b), although with larger amplitudes than those over land, showing that the role of small precipitating areas is more important in R7 than in R14, in terms of determining the total amount of surface precipitation.

The present result shows evidence of better predictability of basic nature of tropical convection (diurnal cycle) especially over land, in a higher-resolution GCM. The reason is a better representation of small-scale clouds that start to develop after sunrise from a convective BL. Over ocean, both R7 and R14 results agree well with the observation. The reason is that precipitation over ocean is primarily controlled by temperature changes of the free atmosphere due to radiation. The radiative process depends less on horizontal resolution,

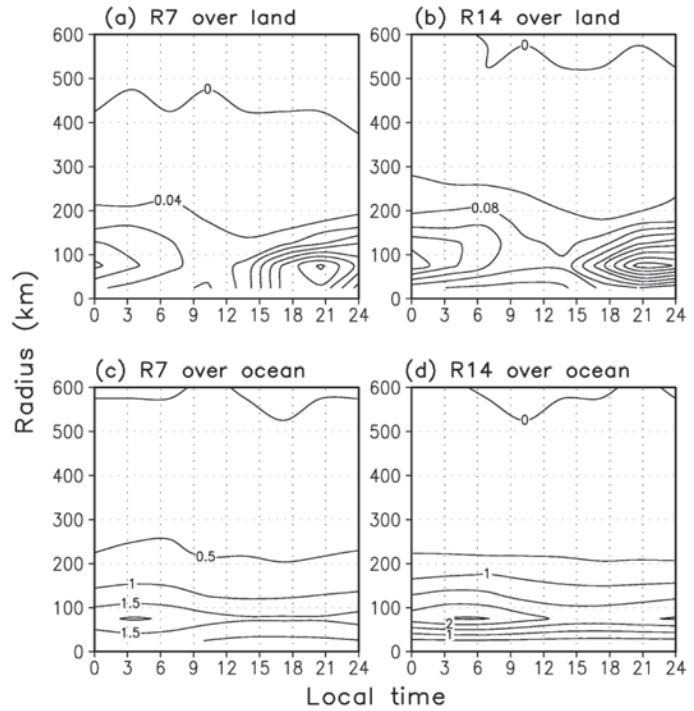


Fig. 4 Temporal changes in the size distribution of precipitating areas over the tropics. Data are shown for (a) R7 and (b) R14. The histograms were constructed by sampling the data at radii intervals of 50 km. (c) and (d) are as for (a) and (b), except for over ocean. The unit is $\text{mm hr}^{-1} \text{ km}^{-1}$.

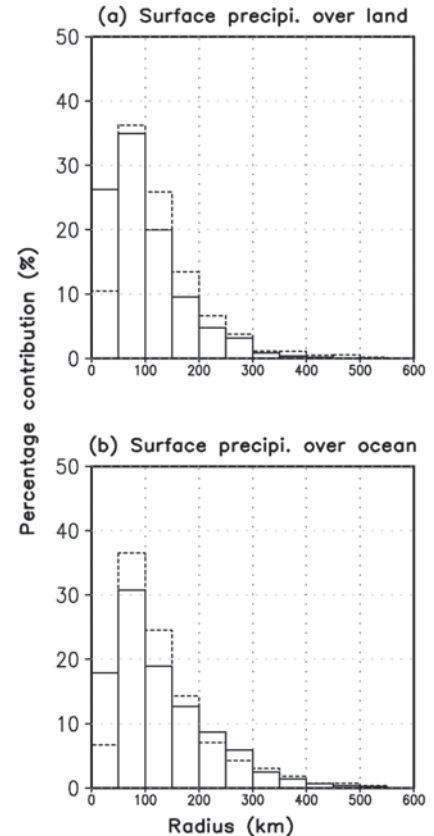


Fig. 5 Percentage contribution to precipitating areas over (a) land and (b) ocean in the tropics with different radii.

and as a result both R7 and R14 show a similar diurnal cycle in surface precipitation.

For future study to improve predictability of NICAM, continuous efforts should be required to evaluate how much higher-resolution model affects on behavior of simulated convective activity and associated precipitation. Moreover, another important issue to be addressed is predictability of detailed local circulations oscillated by land-sea contrast. It is well-known that different heat capacity among adjacent land and ocean areas, along with inhomogeneity of topography, modulates development timing of precipitation systems [e.g., *Chen and Houze, 1997*], which should provide nonnegligible impacts on climatological precipitation from region to region. An innovatively high-resolution model such as NICAM will first make it possible to simulate such detailed meso-scale systems over the global domain. Therefore subsequent studies that assess on predictability of such regional precipitation are also required in future.

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Toward a better understanding of the Madden-Julian oscillation –Cloud, Precipitation, and Radiation Process Research Team–

The Madden-Julian oscillation (MJO) is one of the most important phenomena in the tropics, and a number of observational, theoretical and numerical studies have been made in these 50 years. However, it is still not properly understood. This study presents some results from numerical experiments under simplified (idealized) conditions as a step toward its full understanding; the effects of the land-orography remain to be studied as the next step.

The model used in this study is a mesoscale-convection-resolving model (MCRM) that intends to resolve mesoscale convection MC, which is the basic organized form of cumulus convection, and incorporates the effects of cumulus convection as the subgrid-scale. In order to save computer time (and study efficiently), a 0.2 degree (about 20 km) grid is used in the spherical coordinate model. The MCRM is designed so that a coarse grid of 5-20 km can be used owing to inclusion of the subgrid-scale effects of convection.

The latitudinal distribution of the sea surface temperature (SST) in the tropics is important to MJO; the SST corresponding to the observed is imposed. Since subtropical highs are also important to MJO, strong gradient

of the SST is imposed in the mid-latitudes so that baroclinic instability can occur. Under this condition, tropical cyclones as well as MJO form realistically on the equatorial side of subtropical highs.

A warm pool in the northwestern Pacific and Indian Ocean is very important to MJO. In this study, one elliptical (long in the longitudinal direction) warm pool is imposed. A maximum SST anomaly T_A and the longitudinal scale are parameters that specify the intensity and shape of the warm pool. Seven numerical experiments are performed by changing these parameters. One of the important features of this study is that long-period (320-560 days) time integrations are performed to get the general property and its variability. This is in contrast to short-period (mostly, less than 100 days) time integrations in past studies.

This study intends to understand three aspects of MJO. The first is the period of MJO. Although many researchers have referred to MJO as a 30-60 day oscillation, it seems that the typical period is 40-50 (60) days. This study intends to understand why the period of MJO is not about 30 days but rather 40-50 days. Figure 6 shows results obtained in the case without any warm pool ($T_A = 0$). The mixing ratio of rainwater near the surface, the surface pressure, and the zonal velocity at 925 hPa (averaged for 5S-5N) are shown. It can be seen that Kelvin wave with wavenumber 1 is pronounced and its period is about 30 days, which is shorter than that of MJO. Figure 7 shows results for the case of $T_A = 2.0$ K. In this case, periods of 40-60 days are dominant. The deviations of the surface pressure and the zonal velocity from the time average are also shown (the third and fifth panels). These panels indicate that the eastward propagation speed of Kelvin wave is slowed down near the warm pool area (centered at 120 E). This contributes to longer periods of MJO. In addition to Kelvin waves, a standing oscillation mode exists in the warm pool area. This mode enhances Kelvin waves, and it is also affected by Kelvin waves. Another important result is that the period of MJO does not increase monotonically with increasing intensity of the warm pool (T_A). When the warm pool has a moderate intensity, the period (time interval of high pressure in the warm pool area) takes a wide range from 20-60 days. This is due to complicated interaction between the two modes; Kelvin waves and the standing oscillation.

The second concern of this study is better numerical simulation and understanding of super cloud cluster (SCC), where SCC is defined as a synoptic-scale convective system (SCS) with an eastward-propagating speed of about 5 ms^{-1} in and near the warm pool area. Observed SCC has two features. (1) SCC consists of a few cloud clusters (CC) that move westward. (2) SCC propagates eastward as an envelope of CCs. These features are qualitatively well simulated by the MCRM, although quantitative simulation remains to be studied. In the present model, each CC consists of a few mesoscale convective systems (MCSs), where MCS is an organized form of MC. A new MCS forms to the west of an old MCS. The low-level air in the trade easterlies turns toward equatorward with westerly component, and contributes to the formation of the new MCS to the west of the old MCS.

The third concern is how MC, MCS, SCS and LCS (large-scale convective system), which constitute the hierarchical structure of MJO, behave realistically in the MCRM. Although the hierarchical structure is well simulated qualitatively, the time scales of MC and convective systems remain to be better simulated.

When one studies tropical phenomena (such as MJO) in which moist convection plays an important role, the importance of latent instability (positive buoyancy of rising air or CAPE) should be discussed with particular interest. However, it appears that most of past studies have not been concerned with its importance. Rather, the

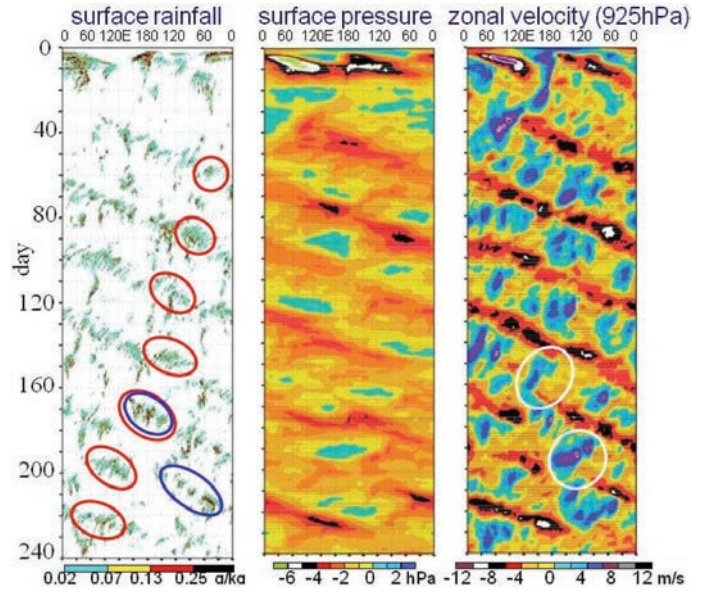


Fig. 6 Hovmöller diagram (longitude-time section) for low-level rainwater mixing ratio, surface pressure, and zonal velocity at 925 hPa in a numerical experiment without warm pool ocean.

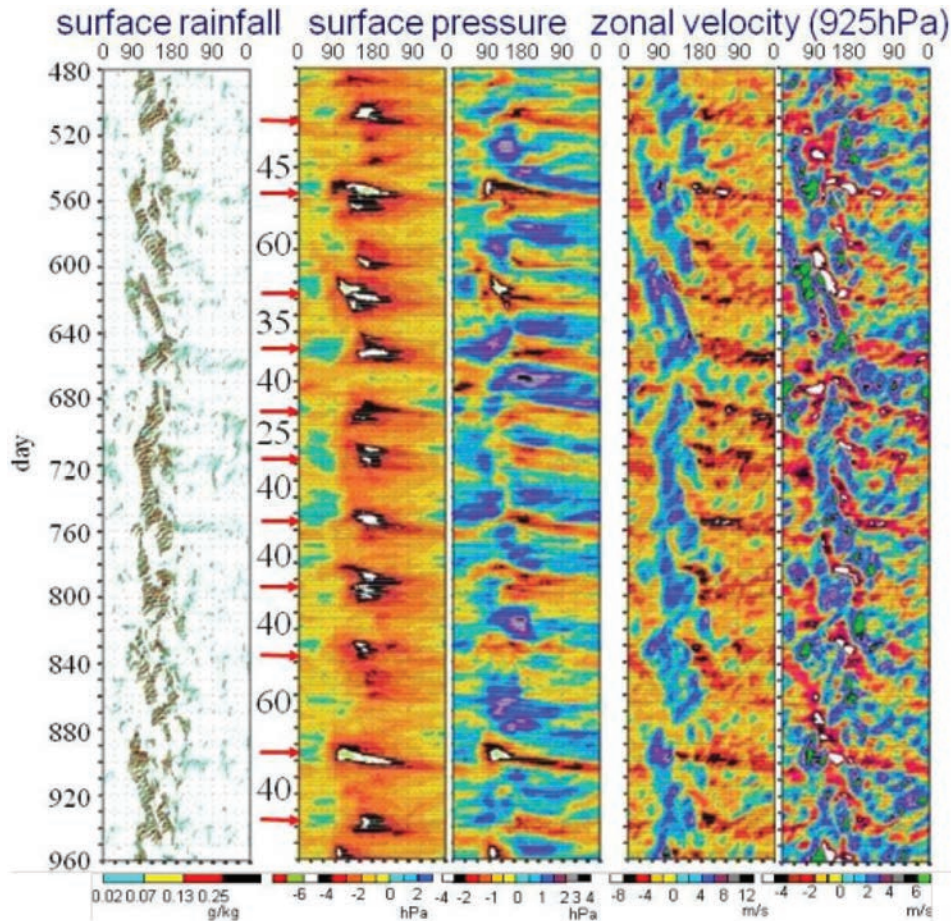


Fig. 7 Hovmöller diagram for low-level rainwater mixing ratio, surface pressure, its deviation from the time average, zonal velocity at 925 hPa, and its deviation from the time average in a numerical experiment that includes a warm pool with a maximum anomaly of 2 K.

importance of water vapor field above the boundary layer has been emphasized by many researchers in recent years. In connection with this, the importance of convective moistening in a numerical model has been suggested; that is, a model has to realistically represent convective processes that moisten the entire atmosphere in order to simulate the MJO. The present climate models have not simulated this feature, whereas the MCRM used in this study has simulated this feature well in numerical experiments in these 20 years, and also in this study. The upper-right panel of Fig. 8 shows that the relative humidity at 700 hPa is higher in the active convective area. This feature also holds for 500 hPa (not shown). On the other hand, the relative humidity at 900 hPa (lower-right panel) is higher to the east of the active convective area. The latent instability (lower-left panel) is strongest in the convective area. It appears that these features are also realistic.

A paper from this study has been published as Yamasaki [2011, *Advances in Meteorology*]. A review on MJO and wave-

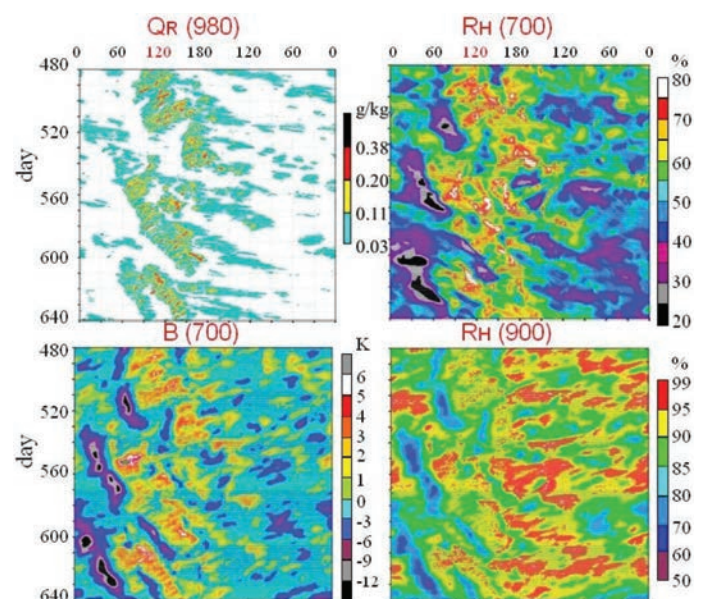


Fig. 8 Hovmöller diagram for low-level rainwater mixing ratio, buoyancy that rising air acquires at 700 hPa (a measure of latent instability), and relative humidities at 700 hPa and 900 hPa.

CISK studies in these 50 years is also given, with an emphasis on the differences between the author's view and other researchers'.

Validation of Pseudo Global Warming method for regional climate projection –Regional Climate Modeling Research Team–

Global warming could cause the decrease in snowfall and snow cover in the future. The Regional Climate Modeling Research Team has been focused on the future changes in snow cover using high-resolution regional climate model [Hara *et al.*, 2008]. We developed the Pseudo Global Warming downscaling (PGW-DS) method which uses the difference between present and future climates projected by the global climate model (GCM). The PGW-DS can reduce the biases of GCMs in the present climate and simulate the future changes in regional climate with high resolution. The method, on the other hand, assumes the similar variability, such as daily disturbances and inter-annual variability, between the present and future climates. The validation of the PGW-DS for the future snow cover changes has not been investigated. Our team applies the PGW-DS to the past snow cover changes and investigate the possibility of snow cover projection. Here, we call the PGW-DS as the Pseudo Climate Simulation downscaling (PCS-DS) in the past simulation.

We focused on the decrease in snow cover observed in Hokuriku region from the 1980s to the 1990s. Hokuriku region is one of the heaviest snow areas in the world. More than seven-meter snow depth is observed over the mountainous areas. On the other hand, the coastal area of the Sea of Japan is a warm snowfall area, where the winter mean surface air temperature is higher than 0 °C. In this area, variations of the snowfall and snow cover have a correlation with the variation of the surface air temperature rather than with that of precipitation, indicating that the snow cover is vulnerable to global warming due to an increase in greenhouse gases. In the late 20th century, it is pointed out that the temperature rise resulted in the reduction of the snow cover in Hokuriku region. The snow cover is, on the other hand, influenced by both the climatic air temperature change and short-term extratropical cyclones activities, i.e., perturbation changes. We conducted the PCS-DS to investigate the impacts of the climatic changes and the perturbation changes on the snow cover changes between the 1980s and the 1990s. The comparison between the PCS-DS and realistic present climate simulation shows the impact of the climatic changes separately since the PCS-DS includes only the climatic changes in the atmospheric conditions.

Numerical experiments were conducted using a nonhydrostatic numerical model, the Advanced Research Weather Research and Forecasting (WRF) modeling system Version 3.2.1. Two-way nested grid systems were adopted. The grid intervals in coarse and nested fine grid systems were 18 km and 4.5 km, respectively. We used the Kain-Fritsch scheme as the convective parameterization and the WSM6 as the microphysics in both domains. The land surface process is calculated by the Noah-LSM. We performed a control experiment using the six-hourly NCEP/NCAR Reanalysis Project (NNRP) dataset from 1980 to 1989 (CTL80s) and from 1990 to 1999 (CTL90s). We performed the PCS-DS in the 1990s (PCS90s). In the initial and lateral boundary conditions of the PCS90s, the differences of the 10-year monthly mean NNRP data between the 1980s and the 1990s were added to the six-hourly NNRP dataset in each month in the 1980s. In other words, the PCS90s consists of the mean atmospheric fields in the 1990s and the perturbation in the 1980s. In addition, we performed the Pseudo Perturbation Simulation in the 1990s (PPS90s) assuming the mean atmospheric fields in the 1980s and perturbation in the 1990s.

The interannual variation of maximum snow depth (SNDmax) is well simulated by the CTL80s and the CTL90s in Hokuriku region; the correlation coefficient is 0.945, with a 95 % significant level according to the student t-test. The SNDmax, however, is underestimated in heavy snow years in the 1980s. The CTL80s shows about 50 cm of snow over the coastal areas of Ishikawa and Toyama Prefectures and 100 cm - 200 cm of snow over the coastal area of Niigata Prefecture (Fig. 9a). The CTL90s shows that a decrease in SNDmax of about 20 % relative to the CTL80s is simulated over the coastal areas, while a slight increase in SNDmax of about 6.9 % is simulated over the mountainous area (Figs. 9b and 9c). The control experiments show the different changes in SNDmax between the coastal and mountainous areas.

Figure 9d shows the ratio of the difference in SNDmax between the CTL80s and the PCS90s relative to

the CTL80s. Large decreases in SNDmax are found over the coastal area in the PCS90s, which are comparable to those in the CTL90s (Fig. 9c). The PCS90s simulated approximately 1 °C higher air temperature at screen height than the CTL80s did. Since the CTL90s and the PCS90s show negligible changes in precipitation over the lowland (Table 1), a decrease in snowfall and an increase in snowmelt due to warming are main factors of the snow cover changes over the coastal area. In contrast, over the mountainous area with an altitude higher than 1,500 mASL, the PCS90s shows a decrease in the SNDmax (-3.1 %), while the CTL90s shows the increase in the SNDmax (6.9 %). On the other hand, the PPS90s assuming the mean atmospheric fields in the 1980s and perturbation in the 1990s shows no changes in the SNDmax over the lowland and the increase in the SNDmax over the highland. These results mean that the changes in the mean atmospheric fields, especially, the mean temperature rise, are main factors of the snow cover decrease over the coastal area, while changes in both the mean atmospheric fields and the perturbation contribute to the snow cover changes over the mountainous area.

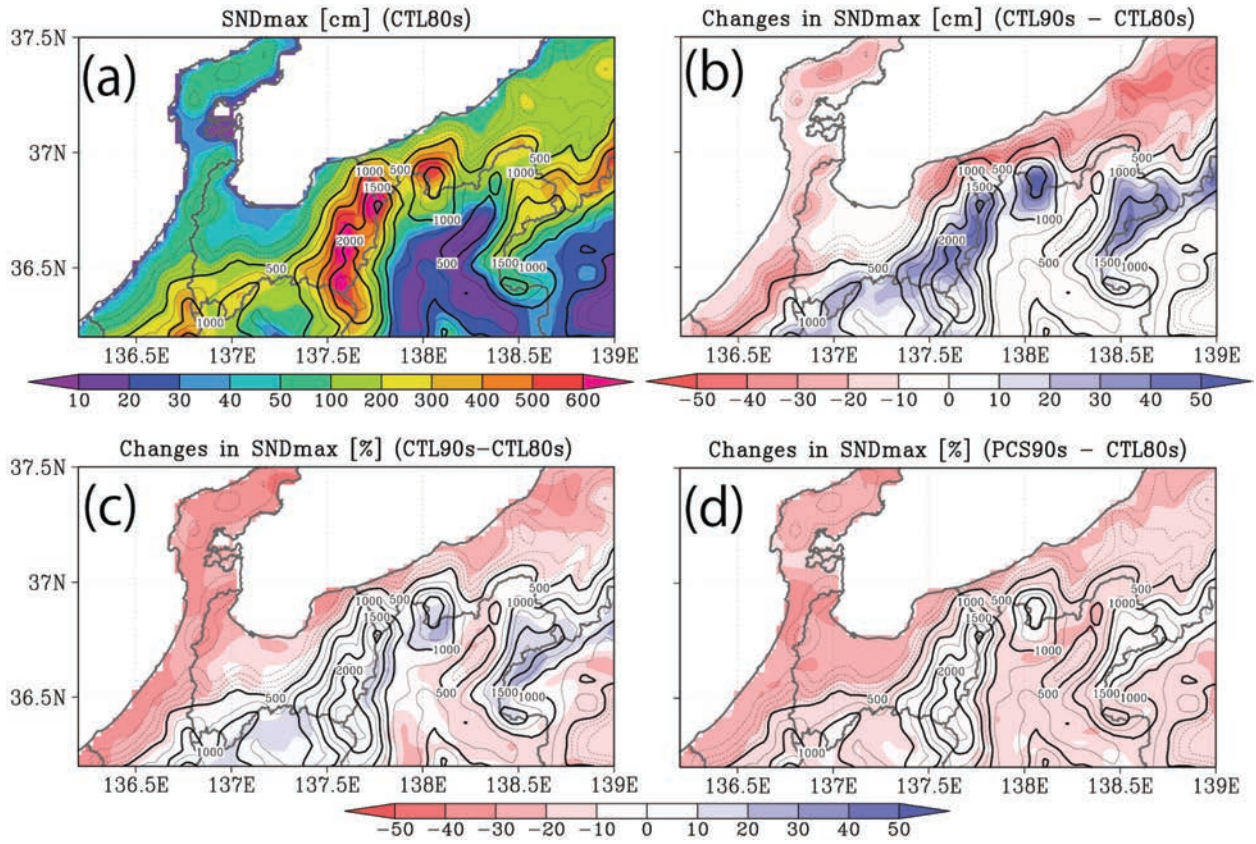


Fig. 9 Distributions of (a) the maximum snow depth (SNDmax) simulated by the CTL80s, (b, c) differences in the SNDmax between the CTL80s and the CTL90s, and (d) a difference between the CTL80s and the PCS90s. (c, d) The differences are shown as percentages (%) relative to the CTL80s. Warm and cool colors represent lower and higher SNDmax than that in the CTL80s, respectively.

	Atmospheric fields		Lowland (lower than 500m)		Highland (higher than 1500m)	
	Mean fields	Perturbation	SNDmax	precipitation	SNDmax	precipitation
			DIFF(%)	DIFF(%)	DIFF(%)	DIFF(%)
CTL80s	1980s	1980s	*	*	*	*
PCS90s	1990s	1980s	-19.9	0.6	-3.1	8.9
PPS90s	1980s	1990s	0.0	0.7	10.6	5.3
CTL90s	1990s	1990s	-19.8	-1.13	6.9	0.3

Table 1. Simulated SNDmax and the differences in SNDmax and precipitation during the winter (December, January, and February) between CTL80s and the other experiments. DIFF means the ratio of the difference between each experiment and the CTL80s relative to the CTL80s.

Our results indicate that the near-future snow cover changes would be projected by considering the mean temperature changes over the coastal area, meaning that the PGW-DS method could be valid for the projection of snow cover changes. On the other hand, the changes in both the mean atmospheric fields and the perturbation, such as the frequency of extratropical cyclone, should be considered to project the snow over changes over the mountainous area. Lastly, our study implies that the thermal advection changes caused by the perturbation changes could affect the air temperature in the model domain, which may affect the snow cover changes. In the PCS-DS and PGW-DS methods, the effects were neglected. Further studies are needed to improve the PGW-DS method.

Our results contribute to the Research Program on Climate Change Adaptation (RECCA) by Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan.

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II. Related Activities

Research collaboration

1. Domestic research collaboration

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

Theme:

- 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:

- 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: 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

(6) Fisheries Research Agency (FRA)

Theme: Observational Research on Air-Sea Interaction around the Oyashio Front

Program: Ocean Climate Change Research Program

(7) 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

II. Related Activities

Research collaboration

(8) Kyoto University

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

Program: Tropical Climate Variability Research Program

(9) Arid Land Research Center, Tottori University

Theme: Hydrological Processes in Grassland Ecosystems in Mongolia and Kazakhstan

Program: Northern Hemisphere Cryosphere Program

(10) Kobe University

Theme: Dynamical Analysis of Wide Scale Ocean Current Variations affected by the Open Sea Conditions and the Strategy of the Environmental Conservation in the Set Inland Sea

Program: Climate Variation Predictability and Applicability Research Program

(11) Research Institute for Humanity and Nature (RIHN)

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

(12) 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

(13) National Agriculture and Food Research Organization (NARO) / National Research Institute for Earth Science and Disaster Prevention (NIED) / Akita University

Theme: Domestic Observations on the Surface/Sub-surface Hydrological and Thermal State

Program: Global Change Projection Research Program

(14) Marine Works Japan Ltd. (MWJ)

Theme: Development of a Reference Material for Density Measurement of Seawater

Program: Ocean Climate Change Research Program

(15) The Tsurumi-seiki Co., Ltd. (T.S.K)

Theme: Research for Realization of a Practical Profiling Float for Deep Ocean Observation

Program: Ocean Climate Change Research Program

(16) 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
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)

II. Related Activities

Research collaboration

(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 Organisation (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), Germany

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 JFY2011 regarding Joint Activities at the International Arctic Research Center (IARC)
Program: Northern Hemisphere Cryosphere Program / Environmental Biogeochemical Cycle Research Program / Global Change Projection Research 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 Atmospheric Composition Change related to Environmental and Climate 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
Program: Environmental Biogeochemical Cycle Research Program

(7) Lhasa Section of the Institute of Tibetan Plateau Research, Chinese Academy of Sciences, 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 Atmospheric Composition Change related to Environmental and Climate Change
Program: Environmental Biogeochemical Cycle Research Program

II. Related Activities
Research collaboration

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

Theme: 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 Paleoceanography, 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: Implementing Agreement 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), Mongolia

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), Mongolia

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

Program: Northern Hemisphere Cryosphere Program

(15) A.M. Obukhov 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) V.E. Zuev Institute of Atmospheric Optics (IAO), Siberian Branch of 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 for Biological Problems of the Cryolithozone (IBPC), Siberian Branch of 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) Melnikov Permafrost Institute (MPI), Siberian Branch of 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 Sciences, 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) Sir Alister Hardy Foundation for Ocean Science (SAHFOS), UK

Theme: Implementing Agreement on Research Cooperation of Long-term Variation in Lower Trophic Level Ecosystems based on the Continuous Plankton Recorder (CPR) Survey in the North Pacific

Program: Environmental Biogeochemical Cycle Research Program

(22) Center for Climate, Agroclimate and Marine Climate, the Agency for Meteorology, Climatology and Geophysics of the Republic of Indonesia (BMKG), Indonesia

Theme: Implementing Agreement on Collaborative Research for Cooperative Indian Ocean Experiment on Intraseasonal Variability in the Year 2011 (CINDY2011)

Program: Tropical Climate Variability Research Program

Funded research projects

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

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

Funding institution: Japan Science and Technology Agency (JST)

Program: Advanced Atmosphere-Ocean-Land Modeling Program

(2) Integrated Research on Climate Change Scenarios to Increase Public Awareness and Contribute to the Policy Process; 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

(3) Integrated Research on Climate Change Scenarios to Increase Public Awareness and Contribute to the Policy Process; 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

(4) Integrated Research on Climate Change Scenarios to Increase Public Awareness and Contribute to the Policy Process; 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

(5) Integrated Research on Climate Change Scenarios to Increase Public Awareness and Contribute to the Policy Process; 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

(6) Scientific Analysis of Regional Air Pollution and Promotion of Air Pollution Management in East Asia Considering Co-benefits; 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

(7) Quantitative Studies on the Cycles of Some Global Warming Gases and Related Materials through their Isotopomers; 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

- (8) **Integrated Impact of Vegetation and Aerosol Changes on Asian Monsoon Climate; 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
- (9) **Development of a Next Generation System for Monitoring the Atmospheric Environment and Estimating the Emission Inventory of Related Species; 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
- (10) **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
- (11) **Mechanism Elucidation and Future Forecast on the Decreasing Trend of Dissolved Oxygen Concentrations in the Deep Water of the Japan Sea; 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
- (12) **Archiving of GPS Water Vapor Data for Global Warming Assessment (FY2011-2013)**
Fund: Environment Research and Technology Development Fund (ERTDF)
Funding institution: Ministry of the Environment
Program: Advanced Atmosphere-Ocean-Land Modeling Program
- (13) **Development of Evaluation Method of Ecosystem Services to Find Good Balance between Climate Change Prevention and Biodiversity Conservation; Study on Assessment of Ecosystem Functions by Satellite Remote Sensing (FY2011-2013)**
Fund: Environment Research and Technology Development Fund (ERTDF)
Funding institution: National Institute for Environmental Studies (NIES)
Program: Environmental Biogeochemical Cycle Research Program
- (14) **Integrative Observations and Assessments of Asian Biodiversity; Mapping and Spatio-Temporal Change Detection of Biodiversity and Ecosystem Service/Function by Remote Sensing (FY2011-2015)**
Fund: Environment Research and Technology Development Fund (ERTDF)
Funding institution: Tohoku University
Program: Environmental Biogeochemical Cycle Research Program
- (15) **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

II. Related Activities
Funded research projects

(16) 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) / Japan International Cooperation Agency (JICA)

Program: Tropical Climate Variability Research Program

(17) 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); Research Program on Climate Change Adaptation (RECCA)

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

Program: Advanced Atmosphere-Ocean-Land Modeling Program

(18) 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); Research Program on Climate Change Adaptation (RECCA)

Funding institution: Graduate School of Environmental Studies, Nagoya University

Program: Advanced Atmosphere-Ocean-Land Modeling Program

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

Fund: Initiative for Strategic Adaptation to Climate Change (ISACC); Research Program on Climate Change Adaptation (RECCA)

Funding institution: School of Engineering, The University of Tokyo

Program: Advanced Atmosphere-Ocean-Land Modeling Program

(20) Research of Transportation of Artificial Radioactive Nuclides by Sinking Particles in the Ocean (FY2011-2012)

Fund: J-RAPID

Funding institution: Japan Science and Technology Agency (JST)

Program: Environmental Biogeochemical Cycle Research Program

(21) Climatic Changes and Evaluation of their Effects on Agriculture in Asian Monsoon Region (FY2011)

Fund: "Green Network of Excellence" (GRENE) Program; Environmental Information Project

Funding institution: Graduate School of Agricultural and Life Sciences, The University of Tokyo

Program: Tropical Climate Variability Research Program

(22) Ecosystem Studies on the Arctic Ocean Declining Sea Ice (FY2011-2015)

Fund: "Green Network of Excellence" (GRENE) Program; Arctic Climate Change Research Project

Funding institution: National Institute of Polar Research (NIPR)

Program: Northern Hemisphere Cryosphere Program

(23) 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

(24) North Atlantic-North Pacific Comparison of Long-term Ecosystem Change based on the International Initiative of Marine Ecosystem Monitoring (FY2011-2012)

Fund: Bilateral Programs

Funding institution: Japan Society for the Promotion of Science (JSPS)

Program: Environmental Biogeochemical Cycle Research Program

(25) 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 (JSPS)

Program: Global Change Projection Research Program

(26) Greenhouse Gas Budgets of South and Southeast Asia (FY2011-2013)

Fund: Annual Regional Call for Proposals (ARCP)

Funding institution: Asia-Pacific Network for Global Change Research (APN)

Program: Environmental Biogeochemical Cycle Research Program

(27) Multi-Scale Climatology of Coastal Heavy Rainbands over the Indonesian Maritime Continent using Satellite and Ground Based Radar Observations (FY2011)

Fund: Precipitation Measuring Mission (PMM) Science Research Announcement

Funding institution: Japan Aerospace Exploration Agency (JAXA)

Program: Tropical Climate Variability Research Program

(28) Validation of GCOM-W Product using in-situ Observation Data over the Ocean (FY2011-2013)

Fund: Global Change Observation Mission (GCOM) Research Announcement

Funding institution: Japan Aerospace Exploration Agency (JAXA)

Program: Ocean Climate Change Research Program

(29) A Study on Ensemble Snow Data Assimilation in North-East Eurasian Region (FY2011-2013)

Fund: Global Change Observation Mission (GCOM) Research Announcement

Funding institution: Japan Aerospace Exploration Agency (JAXA)

Program: Global Change Projection Research Program

(30) Production of Wave and Ocean Current Reanalysis Data (FY2011-2012)

Fund: Research and Development of the Renewable Energy Conversion including Utilization of Atmospheric and Oceanic Phenomena, Focusing on Implementation of Oceanic Power Generation Systems

Funding institution: The University of Tokyo

Program: Climate Variation Predictability and Applicability Research Program

Awards

- **The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology: the Young Scientists' Prize**

Dr. Jing-Jia Luo (Climate Variation Predictability and Applicability Research Program)

Climate Prediction Research with an Advanced Climate Model (April, 2011)

- **The Best Poster Award of the 52th Annual meeting of Japan Society for Atmospheric Environment**

Dr. Fumikazu Taketani (Environmental Biogeochemical Cycle Research Program)

Measurement of PM_{2.5} at Fukue Island at Japan in Spring 2010 (September, 2011)

- **“Okada Prize” of the Oceanographic Society of Japan**

Dr. Yusuke Okazaki (Environmental Biogeochemical Cycle Research Program)

A Study on the North Pacific Paleoceanography (September, 2011)

- **Young Scientist Award in Atmospheric Chemistry**

Dr. Hitoshi Irie (Environmental Biogeochemical Cycle Research Program)

Synergistic use of Satellite and Ground-based Observations to Study Spatio-temporal Distributions of Air Pollutants (October, 2011)

- **Encouraging Prize of Senshu-kai, Alumni Association, Tohoku University Department of Physics**

Dr. Takuya Hasegawa (Tropical Climate Variability Research Program)

Study on Upper Ocean Heat Content in the Equatorial Pacific Ocean. (October, 2011)

- **“Yamamoto-Syono Award” for outstanding papers of the Meteorological Society of Japan**

Dr. Yoshio Kawatani (Global Change Projection Research Program)

The Roles of Equatorial Trapped Waves and Internal Inertia-gravity Waves in Driving the Quasi-biennial Oscillation. Part I: Zonal Mean Wave Forcing. Part II: Three-Dimensional Distribution of Wave Forcing (November, 2011)

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

Dr. Kozo Nakamura (Advanced Atmosphere-Ocean-Land Modeling Program)

Reconsideration of Conditional Instability -Static Stability of a Saturated Air Parcel in an Unsaturated Environment- (November, 2011)

Dr. Hirofumi Tomita, Dr. Masaki Sato (Advanced Atmosphere-Ocean-Land Modeling Program)

A Three-Dimensional Icosahedral Grid Advection Scheme Preserving Monotonicity and Consistency with Continuity for Atmospheric Tracer Transport (November, 2011)

- **SOLA Award for outstanding papers of the Meteorological Society of Japan**

Dr. Jun Inoue, Dr. Masatake E. Hori, Dr. Takashi Kikuchi (Northern Hemisphere Cryosphere 1Program)

Intercomparison of Surface Heat Transfer Near the Arctic Marginal Ice Zone for Multiple Reanalyses: A Case Study of September 2009 (March, 2012)

- **Harunire Award**

Dr. Maki Noguchi (Environmental Biogeochemical Cycle Research Program)

Outstanding Achievements in Marine Research: Food-web Analysis for Lower Trophic Marine Ecosystem using Nitrogen and Carbon Stable Isotopes (March, 2012)



RIGC/JAMSTEC

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