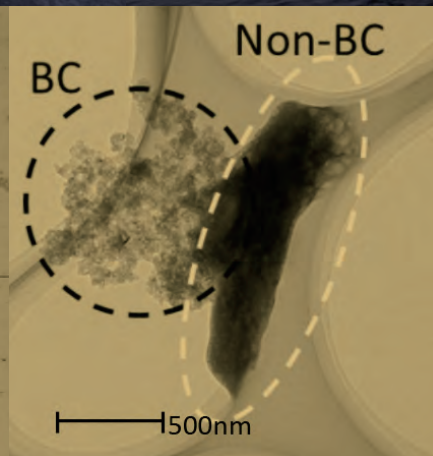
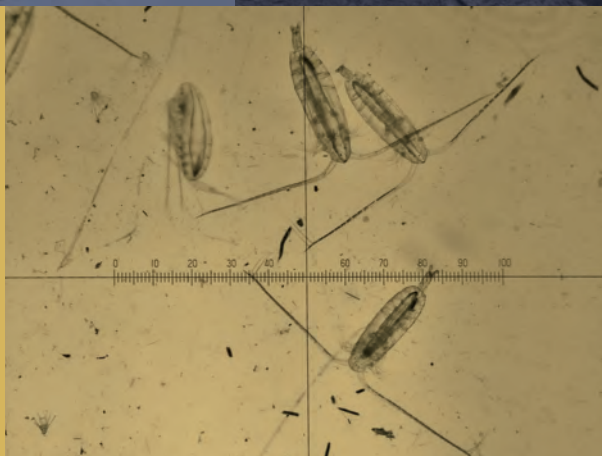
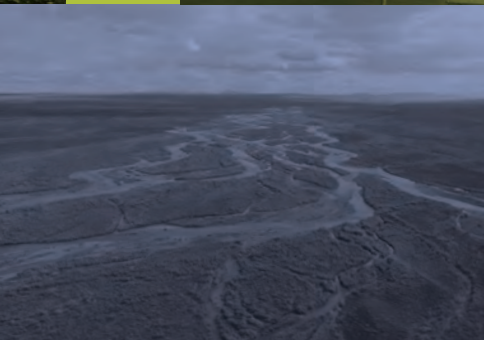


Research and Development on Marine and Global Environmental Change Annual Report FY2016



**Research and Development on Marine and Global
Environmental Change Annual Report FY2016
(April 2016-March 2017)**

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Contents

I. Research Activities and Results

Research and Development Center for Global Change (RCGC)	5
Marine Functional Biology Group / Research and Development Center for Marine Biosciences	17
Application Laboratory (APL)	19
Institute of Arctic Climate and Environment Research (IACE)	25
Department of Coupled Ocean-Atmosphere-Land Processes Research (DCOP)	33
Department of Environmental Geochemical Cycle Research (DEGCR)	39
Department of Integrated Climate Change Projection Research (ICliP) & Project Team for Risk Information on Climate Change	49
Department of Seamless Environmental Prediction Research (DSEP)	59
Department of Biogeochemistry	63
Mutsu Institute for Oceanography (MIO)	67

II. Related Activities

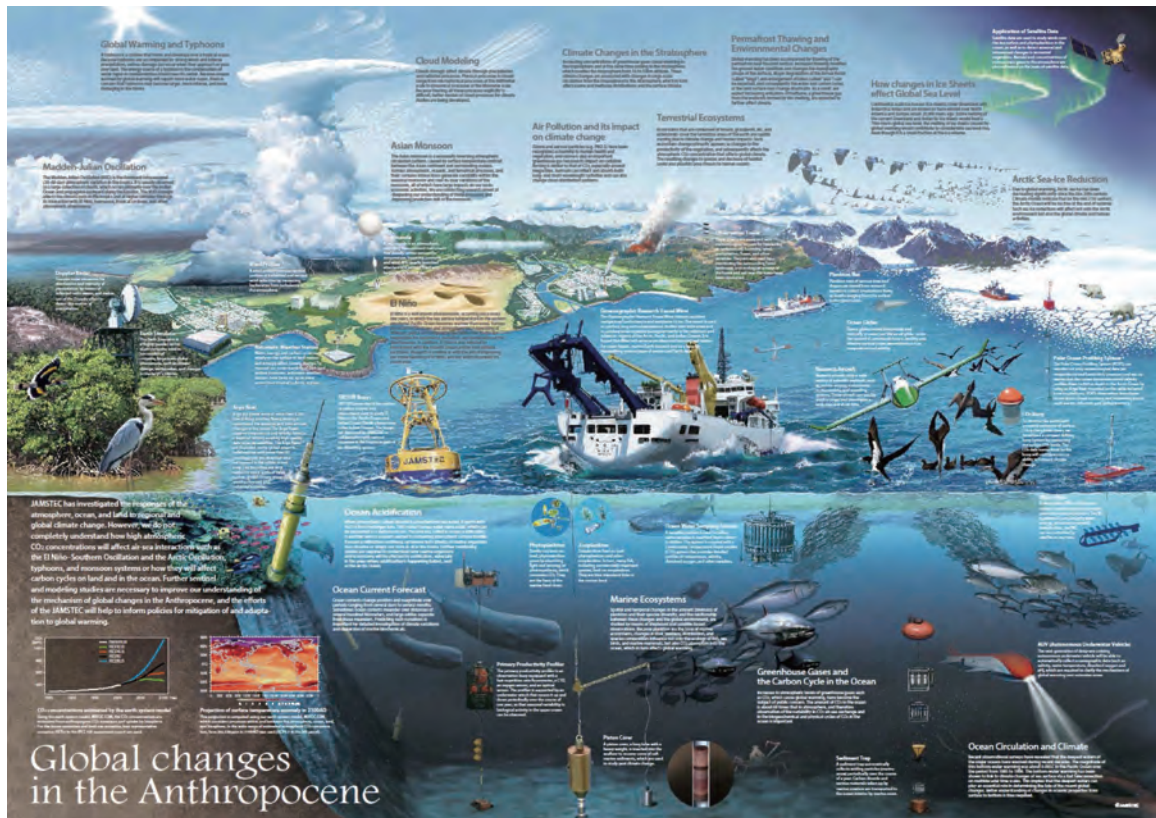
Research Collaboration	71
Funded Research Project	78
Awards	82

I. Research Activities and Results

Changing Oceans

– Research and Development Center for Global Change (RCGC) –

Research and Development Center for Global Change (RCGC) was established in April 2014. The purpose of the center is to explore the oceans to know their state and to detect signal of global environmental changes. The center is consisted of four groups which cover wide area of studies such as physical, chemical, biogeochemical and biological processes in the oceans, tropical climate and sub-arctic environment. Several major achievements in this fiscal year are highlighted as following pages.



Seasonal dynamics of zooplankton in the southern Chukchi Sea

Low zooplankton biomass is one of the key factors contributing to tight pelagic-benthic coupling in the Arctic Ocean, and biomass of Arctic zooplankton is expected to be influenced by climate change. However, the number of documented changes in Arctic zooplankton is low, and baseline information for Arctic zooplankton is poorly understood. To understand the seasonal dynamics of zooplankton in the Chukchi Sea, we use observations from a moored multi-frequency echo-sounder (Acoustic Zooplankton Fish Profiler [AZFP]) from July 2012 to July 2014. The moorings were conducted in Hope Valley in the southern Chukchi Sea (67°42'N, 168°50'W and 68°02'N, 168°50'W; Fig.1), bottom depths of the mooring site were between 52 and 60 m. An upward-looking AZFP was deployed 7 m above the sea bottom and we used acoustic data at 125 and 200 kHz. A CTD and a chlorophyll/turbidity sensor were attached to the AZFP frame for environmental sensing.

Zooplankton biomass, as indicated by backscattering strength, was high during autumn and low in early spring (Fig.2); the seasonal peak in zooplankton biomass did not coincide with the spring phytoplankton bloom. This suggests that the seasonal zooplankton dynamics in the southern Chukchi Sea are less influenced by local growth of zooplankton during the spring phytoplankton bloom and more influenced by advection of zooplankton from the Bering Sea. The differences between volume backscattering strengths at 200 and 125 kHz suggest that the main acoustic scatterers are large zooplankton (euphausiids and *Neocalanus cristatus*) in late summer and autumn and small zooplankton (other copepods) in other seasons. The decrease in acoustic backscatter from

I. Research Activities and Results

Research and Development Center for Global Change

large zooplankton from winter to early summer also suggests the unsuccessful overwintering of advected Pacific zooplankton. The temporal mismatch between zooplankton and phytoplankton production suggests that there is still tight pelagic–benthic coupling in the southern Chukchi Sea.

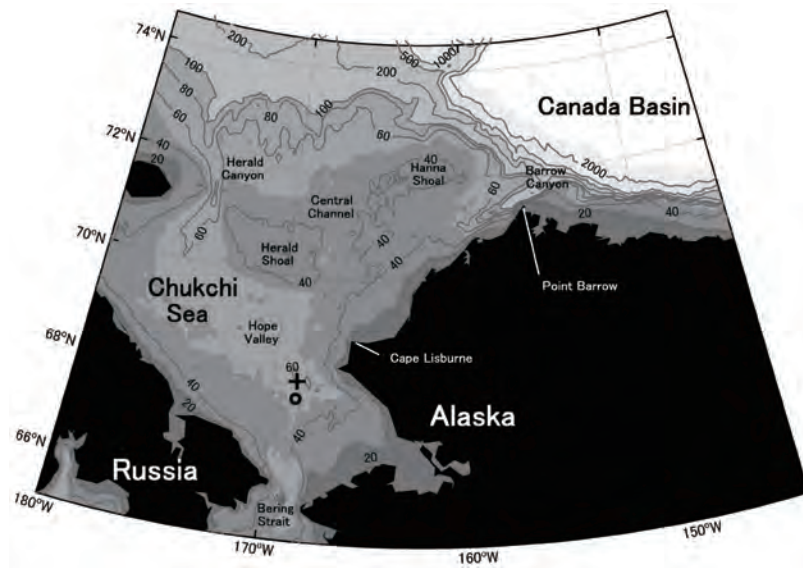


Fig.1 Mooring locations in the southern Chukchi Sea. The open circle shows the location of the first deployment between July 2012 and October 2012, and the cross shows that of the second and third deployments from October 2012 to July 2014.

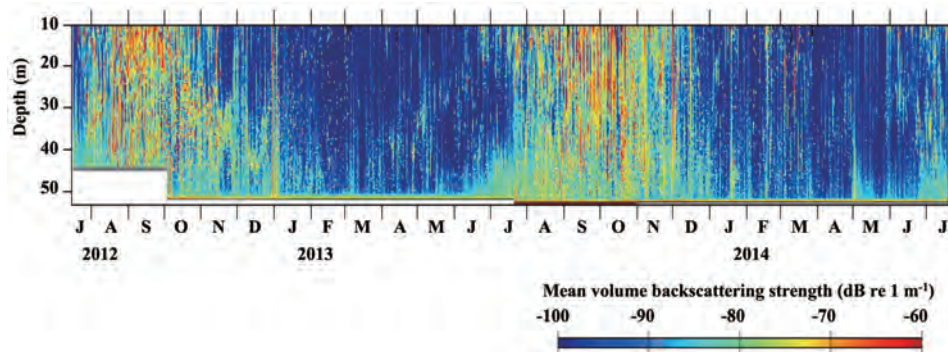


Fig.2 Seasonal change in mean volume backscattering strength observed by using a moored AZFP in the Chukchi Sea.

Transforming typhoon captured by the world-first shipboard polarimetric radar

The research vessel (R/V) *Mirai*, on the way back from the arctic expedition, passed by typhoon Phanfone (2014) undergoing "extratropical transition" (transformation from the tropical cyclone (typhoon) to the extratropical cyclone), as in Fig.3. We onboard scientist performed special observation to capture the detailed internal structure of Phanfone, by frequent radiosonde launches, special observation of onboard weather radar, etc. The weather radar was just upgraded to the world-first shipboard polarimetric radar, to provide the information about the shape of the precipitating particles. The radar data quality were examined by the method in *Geng and Katsumata* [2016].

The observed time series the onboard instruments revealed both dynamic and thermodynamic structure simultaneously in detail for four phases in Phanfone: cirrus shield, warm front, precipitation core, and western flank, as in Fig.4 (a). To the east of the low-pressure center, a "warm front" developed along the mid-latitude baroclinic zone. In the eastern vicinity of the center, heavy precipitation was observed ("precipitation core") at the eastern edge of the remnant of typhoon-originated warm core. The discontinuity between the remnant of warm

core and cold ambient air are captured by the polarimetric radar as in Fig.5, in which the low " ρ_{HV} " layer, which representing the irregular-shaped melting precipitation particles at 0 °C height, are well captured. The polarimetric parameters are converted to 0 °C height as in Fig.4 (b) to show the temperature information in Phanfone in high spatiotemporal resolution to show the frontal structure. These observational results indicates that the remnants of the warm core worked to enhance precipitation through convergence and frontogenesis against cold ambient air. The radar data also indicates that the latent heating/cooling are also suggested to maintain/enhance convection in the "warm front" and "precipitation core". In contrast, the remnant of warm core suppressed convection in the northern/western vicinity of the low-pressure center. Further details are reported in *Katsumata et al.* [2016].

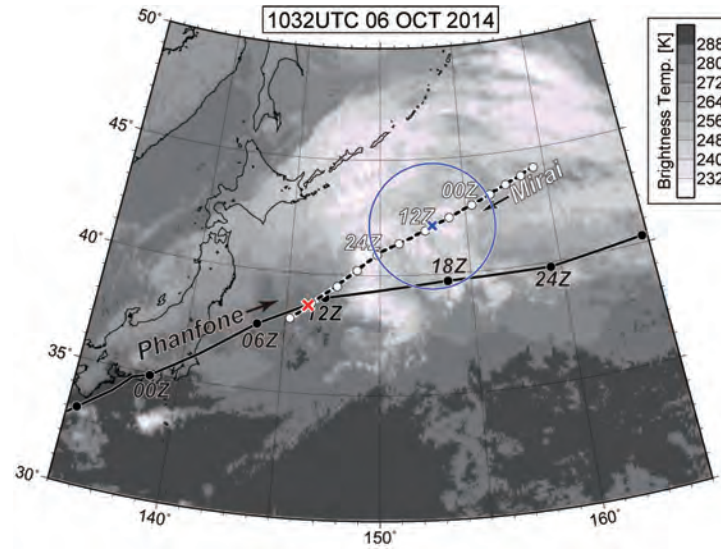


Fig.3 Infrared-channel satellite image around Phanfone, at 1032UTC on 06 Oct. 2014. Solid and broken lines, connecting small circles with timestamp, shows the tracks of Phanfone and R/V *Mirai*. Respectively. The locations of Phanfone and R/V *Mirai* at the time of the image are shown by red and blue crosses, respectively. Blue big circle is the observation range of the weather radar of R/V *Mirai*. [*Katsumata et al.*, 2016]

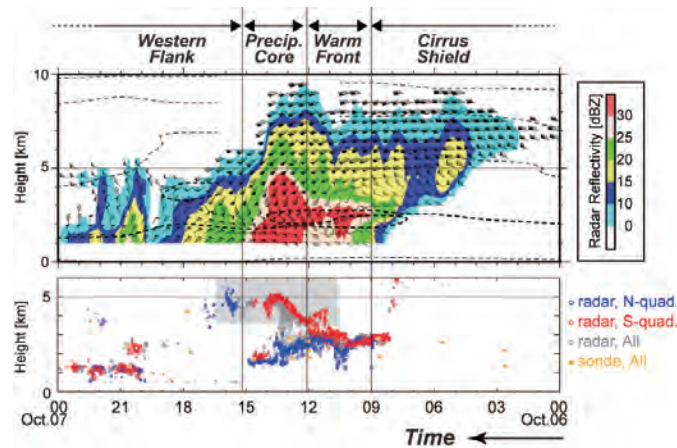


Fig.4 Obtained time-height cross sections of radar-derived parameters. (a) Time-height cross section of radar reflectivity (color) and horizontal wind (barbs). (b) 0 °C height, with dots colored as blue for northern quadrant, red for southern quadrant, gray for other quadrants (west and east), and orange for radiosonde-observed ones. The names at the top indicate the regions within the observed low-pressure system. [*Katsumata et al.*, 2016]

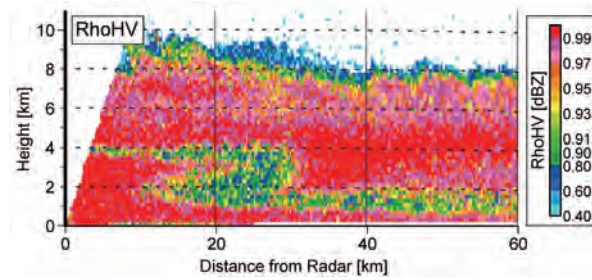


Fig.5 Range-height cross section (so-called "RHI") of the co-polar correlation coefficient (ρ_{HV}), on the azimuth of 315° from R/V *Mirai* at 1317Z on Oct. 06, 2014. [Katsumata et al., 2016]

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Argo-type Observations for Global Change

This research group has been deploying wide variety of Argo-type floats to monitor global open-ocean state and detect environmental changes. They include Deep NINJA and Bio-geochemical (BGC) floats. The former can monitor temperature and salinity profiles of subsurface ocean upper 4,000-m depth. The latter can observe biogeochemical variables inclusive of dissolved oxygen.

Here we show the impact of the data obtained from these floats on a long-term ocean state estimate through observing system experiment. The used OGCM is version 3 of the Geophysical Fluid Dynamics Laboratory (GFDL; NOAA, USA) Modular Ocean Model (MOM3) (Pacanowski and Griffies, 2000). This is a quasi-global model covering the region between 75°S and 80°N. The horizontal resolution is 1° in both longitude and latitude and involves 45 levels. The data synthesis method is based on 4D-Var. An adjoint approach is applied for physical parameters [Osafune et al., 2015], a Green's function approach biogeochemical ones [Doi et al., 2015]. Data synthesis experiments were separately conducted on the Earth Simulator with/without the float data. The targeted floats are Deep NINJA and available BGC floats.

Deep NINJA data can improve the state estimation apart from the deployed region due to forward/adjoint signal propagation. Figure 6a shows the estimate subsurface temperature difference between with/without Deep NINJA data input. The differences in Southern Ocean (Indian sector) and North Pacific regions largely show improvement in the state estimation by long-term Deep NINJA monitoring (Fig.6b). We can see the significant difference subtropical North Pacific where Deep NINJA has not been deployed. This is an advantage of the 4D-VAR data synthesis. Forward and adjoint signal enable to make such “remote” corrections.

Figure 7 shows a result of another comparative experiment in conjunction with BGC floats. Dissolved oxygen difference between with/without BGC float data input is apparent in particular sub-tropic and sub-arctic regions. It should be noted that the difference has well organized pattern since we made optimizations for global parameters. The cost reduced by 3.05%, which reveals that the data input has a subtle impact on the global state estimation.

Although there results possibly depend on data synthesis system, they can provide some contribution to international planning of global Argo-type float network construction, which is now under debate in the Argo research community.

The state estimations are useful datasets for dynamical analysis of global changes not only for physical parameters but biogeochemical parameters. They are open on the website (<http://www.godac.jamstec.go.jp/estoc/>)

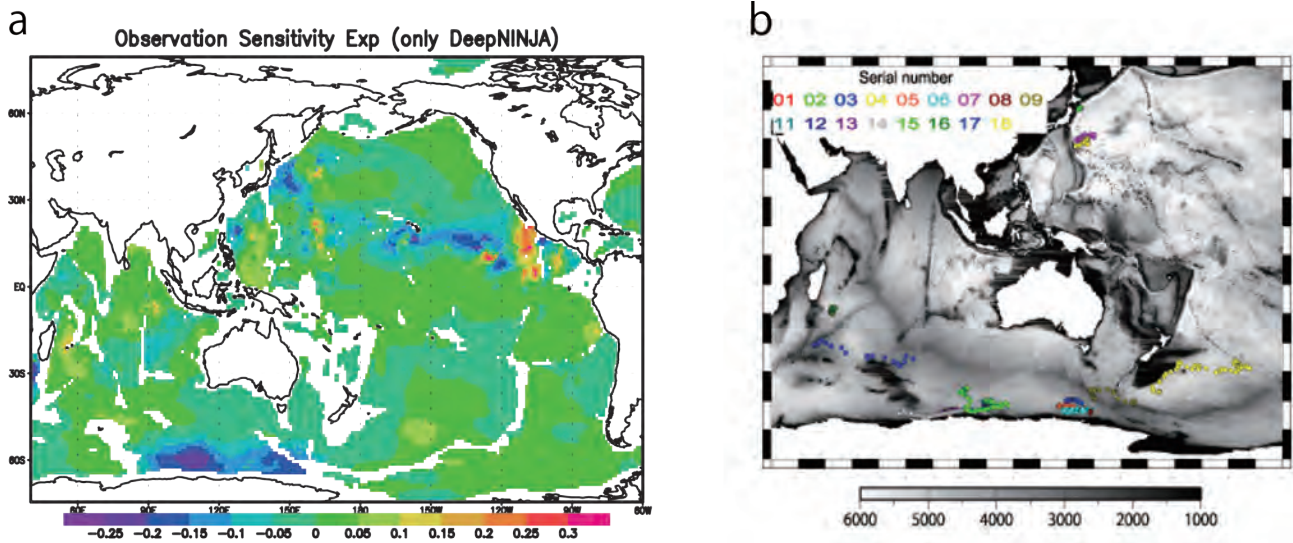


Fig.6 (a) Observation System Experiment result of Deep NINJAs for 2012-2016 state estimation. Difference in the 3000m-depth temperature estimation. The units are K. (b) Deep NINJA trajectories deployed by JAMSTEC.

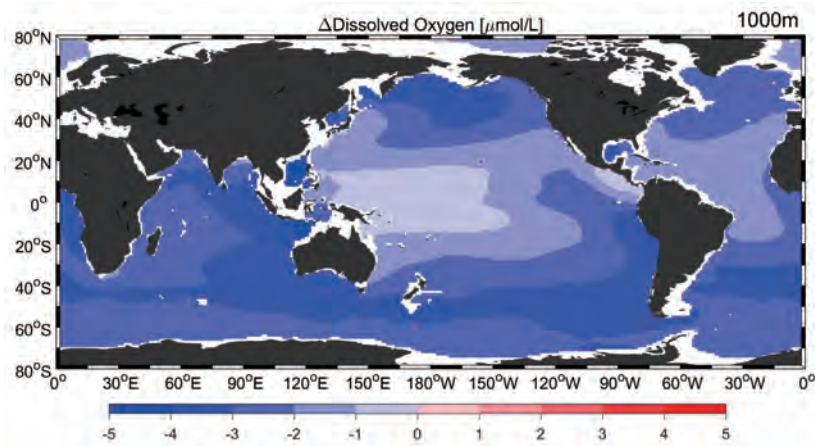


Fig.7 A Observation System Experiment result of BGC float for 1957-2011 state estimation. Difference in the 1000m-depth dissolved oxygen estimation. The units are $\mu\text{mol/L}$.

e/index.html). The newly obtained dataset by applying Deep NINJA and BGC float data is promising one. We will promote climate research by using these dataset.

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Revisiting vertical variations in stoichiometry during oceanic organic matter decomposition

Uniform oceanic stoichiometric ratios for organic matter production and remineralization are generally assumed for large-scale biogeochemical modeling and estimating the oceanic uptake of anthropogenic carbon based on observational data. The stoichiometric ratios used most frequently are the ratios estimated by *Anderson and Sarmiento* [1994] (hereinafter, AS94). They used the nutrient data set obtained in Geochemical Ocean Sections Study (GEOSECS) in order to estimate the stoichiometric ratios. In this study, using the new global nutrient data set (GND13), we re-evaluate basin-wide stoichiometric ratios of remineralization estimated by AS94. For the same latitudinal ranges of the Atlantic, Indian and Pacific Oceans as in AS94, we constructed one or two end-member mixing models on 14 neutral surfaces and estimate the stoichiometric ratios with a probabilistic approach. Unlike the results of AS94, significant vertical variations in the C/P and $-O_2/P$ ratios were found in the Atlantic and Pacific, while the relatively constant stoichiometric ratios with depth are found in the Indian Ocean, similar to AS94 (Fig.8).

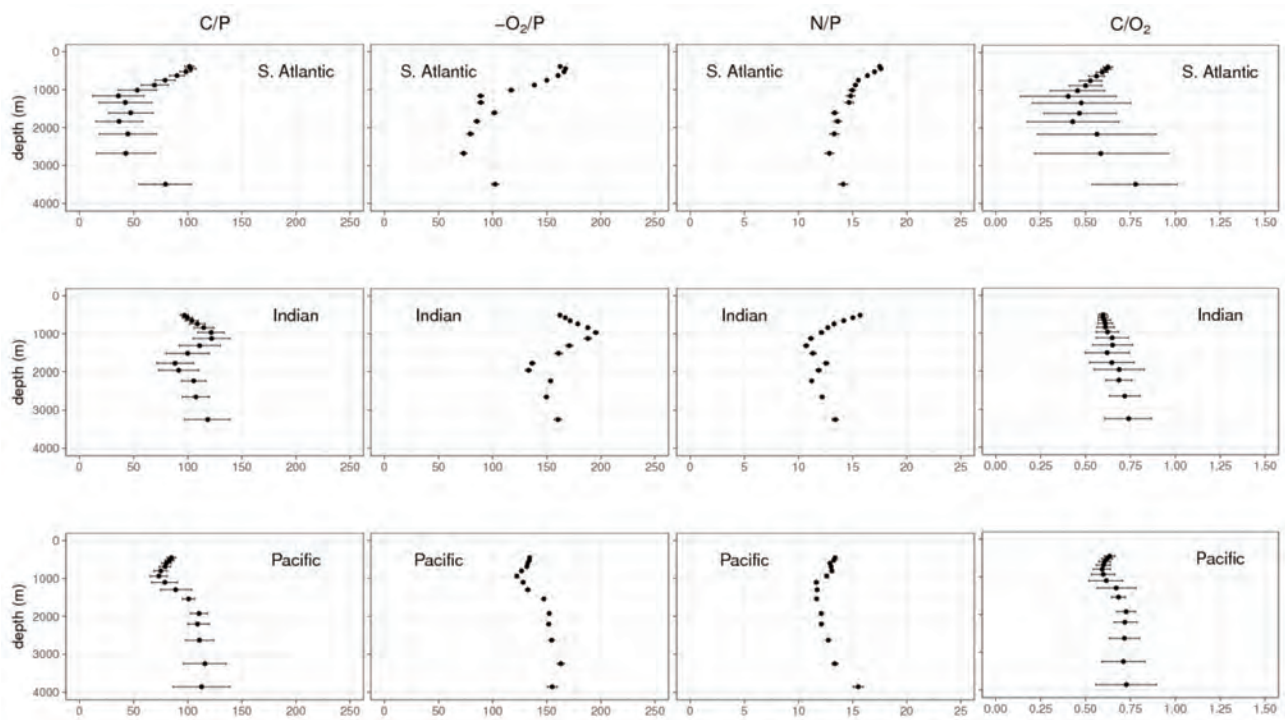


Fig.8 Vertical profiles of C/P (first column), $-O_2/P$ (second column), N/P (third column) and C/ O_2 ratios (last column) of organic matter decomposition with error bars representing 95 % confidence intervals. Upper, middle and lower rows represent the results in the Atlantic, Indian, and Pacific Oceans, respectively.

Recently, chemoautotrophic dissolved inorganic carbon (DIC) fixation in the deep North Atlantic was observed [*Herndl et al.*, 2005; *Reinthal et al.*, 2010]. The DIC fixation might be capable of explaining the decreases in both ratios in the Atlantic. The decrease in the C/P ratios with depth from ~ 100 to 50 requires about 50 % of the remineralized carbon to be consumed within the depth range of about 1000 to 3000 m. Here, we use the export production estimated from the SeaWiFS monthly chlorophyll *a* data in *Shigemitsu et al.* [2016]. With an exponent of -0.8 in the power law dependence of particulate organic carbon (POC) flux [*Martin et al.*, 1987], we calculated the areally integrated POC flux at 1000 and 3000 m to be 288 TgC yr⁻¹ and 88 TgC yr⁻¹, respectively, within the latitudinal range considered in the Atlantic. Thus, the DIC removal rate of about 100 TgC yr⁻¹ via DIC fixation is required within the depth and latitudinal ranges in order to explain the vertical variations in the C/P ratios. The DIC fixation rates in the deep North Atlantic range from 0.1 to 1 $\mu\text{mol m}^{-3} \text{d}^{-1}$ [*Herndl et al.*, 2005; *Reinthal et al.*, 2010]. If we assume the uniform DIC fixation rate of 0.5 $\mu\text{mol m}^{-3} \text{d}^{-1}$ in the domain under consideration, and integrate the rate over the domain (within the depth range of 1000 to 3000 m, and within the

latitudinal range of 50°S to 20°N), we estimate the DIC fixation rate to be 235 TgC yr⁻¹. Thus, we determined that DIC fixation has sufficient potential to remove half the remineralized DIC there.

To realize our results, part of the DIC and phosphate fixed by chemoautotrophs needs to be removed away from the domain under consideration and completely remineralized in the domain, respectively. We hypothesize that the phenomenon is valid by considering the following steps: 1) biomass of some microbes is chemoautotrophically produced by DIC fixation at a rate of more than 100 TgC yr⁻¹ under the some stoichiometric ratio of carbon to phosphorus; 2) the biomass is converted to refractory dissolved organic carbon (DOC) and phosphate/nitrate via microbial carbon pump [*Jiao et al.*, 2013]; and 3) the refractory DOC has longer turnover time than the turnover time of the water mass by advection and mixing on neutral density surfaces under consideration. To date, we have no evidence as to whether organic matter produced by chemoautotrophs via DIC fixation in the deep Atlantic can be converted to refractory DOC, or whether organic phosphorus and nitrogen in the organic matter can be rapidly remineralized to such an extent that phosphate and nitrate there are not affected by the steps. The former seems to be supported by the fact that the buildup of a two amino-acid-like fluorescent DOM was observed in the deep South Atlantic and the turnover time of the fluorescent DOM was estimated to be 379 years [*Catala et al.*, 2015]. The latter seems to be supported by the similar N/P ratios estimated in the Atlantic to those ratios estimated in the Indian and Pacific oceans (Fig.8). The vertical variations in the $-O_2/P$ ratios are considered to become similar to those of the C/P ratios, because most oxygen is consumed by oxidation of organic carbon in respiration. Clearly, further investigations are needed.

Although there are hitherto no observations of DIC fixation in the Indian and Pacific Oceans, the same mechanism we hypothesize in the deep South Atlantic can also apply to the deep Pacific. However, the C/P ratios in the Pacific seem to be unaffected by DIC fixation because the ratios there increase with depth. This might be explained by the relatively shorter turnover time of DIC fixation-derived DOC in the deep Pacific compared with the turnover time of the water mass by advection/mixing on neutral density surfaces under consideration, unlike in the deep South Atlantic. Actually, in the deep Pacific Ocean, the buildup of a two amino-acid-like fluorescent DOM was not observed [*Catala et al.*, 2015]. The same might be true for the Indian Ocean. These should also be investigated in the future.

The C/P and $-O_2/P$ ratios are constant in the Indian Ocean, but increase with depth in the Pacific Ocean (Fig.8). These results indicate that organic matter composition is relatively constant with depth in the Indian Ocean, while more carbon and less phosphorus are remineralized with depth in the Pacific. Here, we calculated the respiration quotient (RQ; C/O₂) (Fig.8), which is the ratio of CO₂ produced to O₂ consumed during respiration, and can be used as an index of the type of organic matter oxidized in respiration. More reduced organic matter, such as lipids and proteins, show low RQ, while more oxidized organic matter, such as carbohydrate, show high RQ [e.g., *Berggren et al.*, 2012]. The estimated RQ in the Pacific gradually increases with depth, suggesting that the proportion of more reduced organic matter in the bulk organic matter gradually decreases with depth. Considering the increases in the C/P and $-O_2/P$ ratios in the Pacific, more reduced organic matter should include phosphorus-bearing phospholipids and nucleic acids and/or proteins.

The present results for the N/P ratios in all the basins are almost all similar and close to the results in AS94 (Fig.8), and would be affected by benthic denitrification as discussed in AS94.

The P/C/ $-O_2$ ratios (mean and 5th to 95th percentile) are estimated to be 1/111(97 to 129)/155(149 to 163) in the depths below 2000 m of the Indian and Pacific Oceans, where DIC fixation and vertical change in organic matter composition have little influence on the stoichiometry estimates.

Our study emphasizes that chemoautotrophic DIC fixation and the effect of change in organic matter composition with depth on the stoichiometric ratios, especially in waters above 2000m, should be considered for large-scale biogeochemical model calculations and estimation of oceanic uptake of anthropogenic carbon from observational data.

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Microbiological process in pelagic ecosystems

– Marine Functional Biology Group /

Research and Development Center for Marine Biosciences –

Microbes play important roles in major biogeochemical processes, such as nutrient cycles and inorganic/organic matter fluxes of the oceans. However the dynamics of microbes are not well considered as parameters in global matter cycle models. To embed the contribution of microbes into a global matter cycle model, it is necessary to determine high-resolution geographical variations of their abundance, production and community composition of functional groups in the global pelagic systems. In this project, we examined both prokaryotic and viral abundance, and prokaryotic activity with depth and across regions to clarify prokaryote-mediated carbon flux mechanisms, and prokaryotic-viral interactions in the pelagic systems.

In FY2016, we conducted water sampling from the water columns in the Southern Ocean along 126 degrees west line from 68 degrees to 52 degrees south during MR16-09 cruise, in order to reveal geochemical and geophysical impacts of this pelagic realm on microbial ecosystems as follows.

- 1) To determine the microbial abundance, diversity and activities throughout the water columns.
- 2) To estimate the impacts of biogeochemical cycles in the epipelagic layer to the abyssopelagic layer.

Microbiological processes throughout water column of the Southern Ocean

Prokaryotes play a major role in marine biogeochemical fluxes. Microbially mediated biogeochemical transformation rate is one of the major research topics in microbial ecology. However the linkages between prokaryotes activity and biogeochemistry in the epi-, meso-, bathy- and abyssopelagic layers are not systematically clarified despite of the efforts that highlighted the role of microbes in the cycling of inorganic/organic matter. In FY2016, we determined both prokaryotic and viral abundance in water samples taken along the water columns in the Southern Ocean transect of MR16-09 cruise (Fig.1). We here highlight a part of results of FY2016 research that distribution pattern of prokaryotic and viral abundance and the relationship among ocean circulation and pelagic microbial ecosystems.

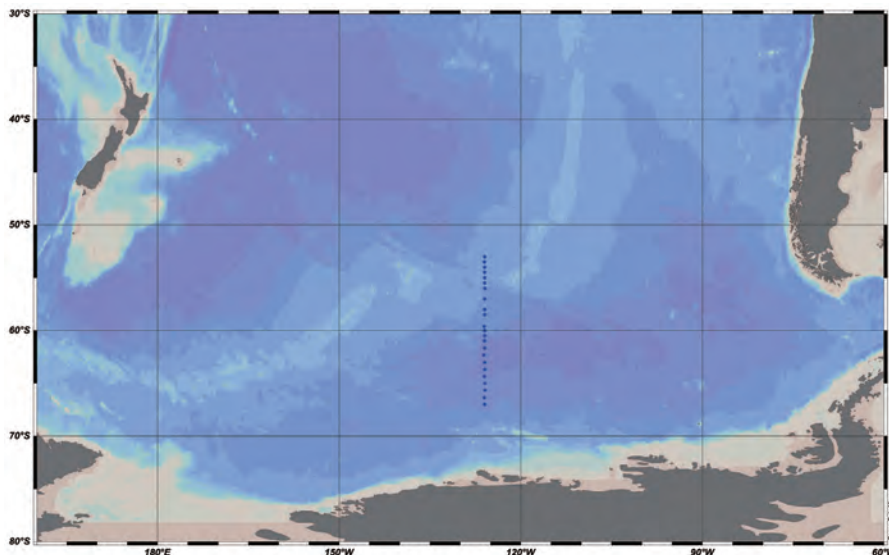


Fig.1 Sampling stations (blue dots) during MR16-09 cruise. This figure was created using Ocean Data View (<http://odv.awi.de/>).

Distribution patterns of both prokaryotic and viral abundance in the surface, meso-, bathy- and abyssopelagic layers of the Southern Ocean along the 125 degrees west.

The results showed that prokaryotic and viral abundance distributions in the epi- (0 – < 200 m), meso- (200 – < 1000 m), bathy- (1000 – < 4000 m) and abyssopelagic layer (> 4000 m) of the Southern Ocean display similar vertical patterns of general pelagic ocean systems.

The abundance of prokaryotes exponentially decreased with depth, from an average of 2.9×10^5 cells mL^{-1} in the epipelagic layer to 1.8×10^4 cells mL^{-1} in the abyssopelagic layer (Fig.2a). Viral abundance decreased with depth from 5.8×10^5 viral particles mL^{-1} in epipelagic layer to 2.3×10^5 viral particles mL^{-1} in abyssopelagic layer (Fig.2b). Viral abundances in the epi-, meso-, bathy- and abyssopelagic layer were variable. Further, decrease of viral abundance with depth is less pronounced than the decrease of prokaryotic abundance leading to higher VPRs in the deep water layers (Fig.2c). We found that VPR in each layer tends to decrease along with the latitude (Fig.2d). Our data revealed that presence distinct patterns of both prokaryote and virus along the depth, and spatial pattern of prokaryotic-viral interactions varied substantially in the Southern Ocean realm.

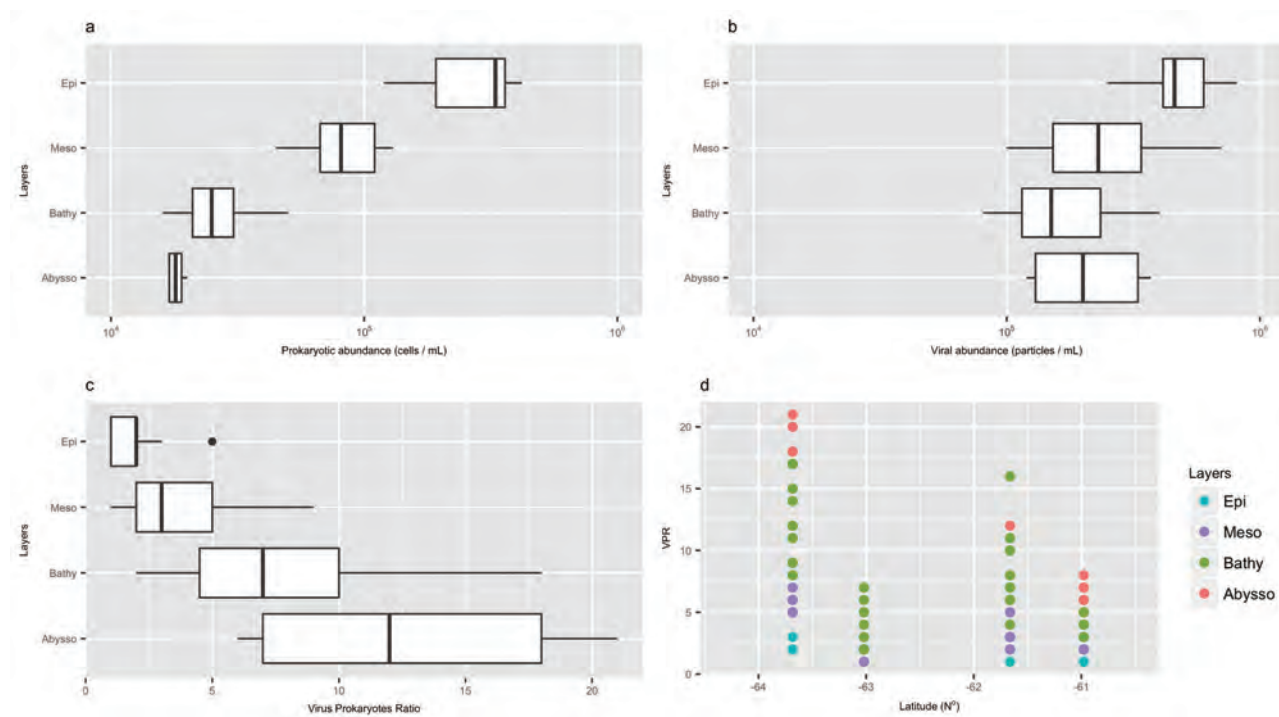


Fig.2 Averaged prokaryotic abundance (a), viral abundance (b) and virus-to-prokaryotes ratios (VPR) (c) in the epi-, meso-, bathy and abyssopelagic layers in the Southern Ocean through the water column. Latitudinal patterns of the VPR in the each depth layers (d).

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Climate and ocean variability prediction and its societal applications – Application Laboratory –

Research and application studies are carried out in the laboratory, with a particular emphasis on improving the predictability of the ocean and climate variation with temporal scales ranging from a few days to a decade. Researchers at the laboratory have been developing various kinds of ocean/climate models, data analysis tools, and data assimilation techniques in the studies of ocean and atmosphere. The accumulated information and discovery of new phenomena from those dedicated research studies help to improve the real-time predictions of ocean and climate variations.

The climate model SINTEX-F has successfully predicted a negative IOD and a weak La Niña/La Niña Modoki in 2016 (Fig.1a) from the beginning of 2016 (<http://www.jamstec.go.jp/aplinfo/climate/?lang=en>). As predicted, the negative Indian Ocean Dipole (IOD) event had developed rapidly in June and July, with the IOD index reaching -1 °C. The event remained strong until October 2016 and then rapidly decayed thereafter. In the tropical Pacific, a weak La Niña/La Niña Modoki had developed in the summer of 2016. The event later turned to a La Niña Modoki, in September/October, when cool SST anomalies in the central equatorial Pacific were flanked by warm anomalies to the east and the west. The ocean prediction system of the lab, the JCOPE, has successfully predicted the Kuroshio path variation involving a small meander occurrence (Fig.1b) in September 2016. It is interesting to watch this development, since these small meanders sometimes cause Kuroshio to the large meander (<http://www.jamstec.go.jp/jcope/>).

The researchers of the lab have also concluded several high-level studies and published research articles in reputed international journals. Investigations conducted on the association between malaria incidence and spatio-temporal climate variations in northeastern parts of South Africa, suggested that climate anomalies in the tropical Pacific (La Nina) and the southern Indian Ocean (subtropical dipole) bring changes in precipitation and temperature in South Africa, which then affect malaria incidences a few months later [Ikeda *et al.*, 2016]. This study is helping to build a malaria prediction model for the region. In another study, it is reported that the new climate prediction system based on SINTEX-F2 has improved the seasonal predictions compared to SINTEX-F1 [Doi *et al.*, 2016]. The predictability study of the Atlantic Ocean, where model biases are a common problem among the climate models, suggests that improvements in SST and precipitation biases do not necessarily improve the skills to reproduce anomalies of surface wind and precipitation in atmosphere-only simulations (Richter *et al.* 2017). In the context of improvements in JCOPE2-based ocean forecasts, we have published results of a multi-scale three-dimensional variational (MS-3DVAR) scheme that was developed to assimilate high-resolution Himawari-8 sea surface temperature (SST) data for the first time in an operational ocean nowcast/forecast system targeting the Northwestern Pacific [Miyazawa *et al.*, 2017]. Also, using a high-resolution hydrographic dataset a complete structure of the mean and seasonal cycle of the Leeuwin Current System is discussed for the first time [Furue *et al.*, 2017]. A couple of other research studies of our lab are elucidated in the following sub-sections.

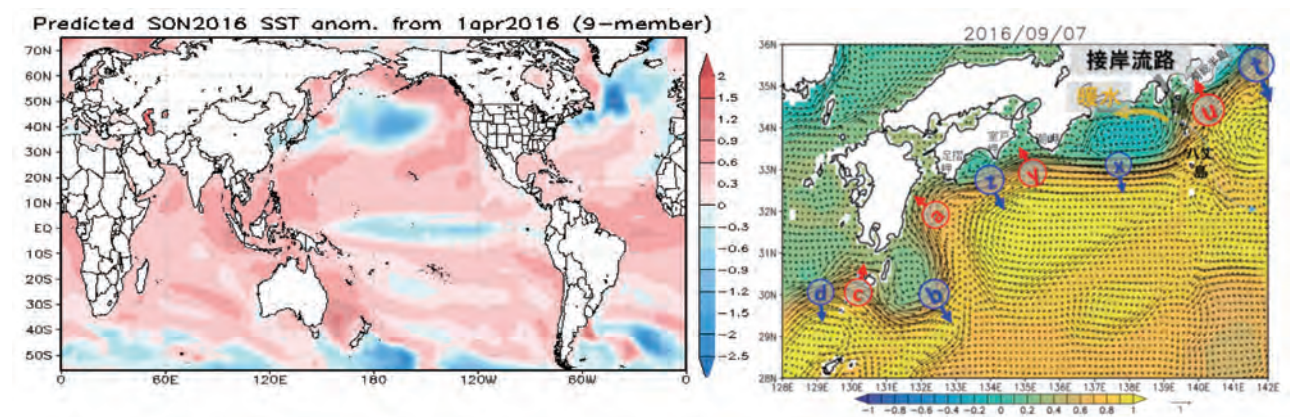


Fig.1 SINTEX-F predicted SST anomalies of September-November 2016 from April 2016 (left) and JCOPE predicted surface current and SST anomalies of September 2016 from August 2016 (right).

Anatomy of Heat Waves over India

South Asia experiences heatwaves during boreal summer season. Most affected regions are in northern India, Bangladesh, and southern Pakistan where the frequency and intensity of heatwaves have increased over the recent decades. In a recent study, *Ratnam et al.* [2016] examined the root causes of these heatwaves over India using observed data. Based on the standard deviation and the leading modes of empirical orthogonal function of the daily maximum temperature, they have classified two types of severe heatwaves; the first type (TYPE 1) occurs over most parts of northern India (Fig 2a) and the second type (TYPE 2) occurs over the coastal regions of southern India (Fig.2c). Nineteen TYPE1 and thirteen TYPE2 events are identified during the study period of 1982-2013. The TYPE1 heatwaves over the north-central India are found to be associated with atmospheric blockings over the North Atlantic. These blockings give rise to cyclonic anomalies west of North Africa in the upper troposphere and the stretching of the vorticity there generates a Rossby wave source of an anomalous wave-train near the entrance of the African Jet. This quasi-stationary wave-train from the north Atlantic can be seen in the 200 hPa streamfunction (Fig.2b). The wave-train has a positive phase over the Indian subcontinent causing an anomalous high-pressure system, which extends to lower troposphere and thereby resulting in conditions favorable for the TYPE 1 heatwaves over India.

The TYPE2 heatwaves are found to be associated with an anomalous Matsuno-Gill response to an anomalous heating in the western Pacific. The Matsuno-Gill response is such that it generates northwesterly anomalies over the landmass in southern India (Fig.2d). This favors winds being drawn away from the land region, thereby diminishing the afternoon sea breeze, that usually helps to ventilate the land temperatures, and hence giving rise to heatwaves over the coastal regions of east coast of India. The inferences from the study will help to improve the forecasts of the heatwaves over India and other regions using the seasonal forecasts based on the SINTEX-F model.

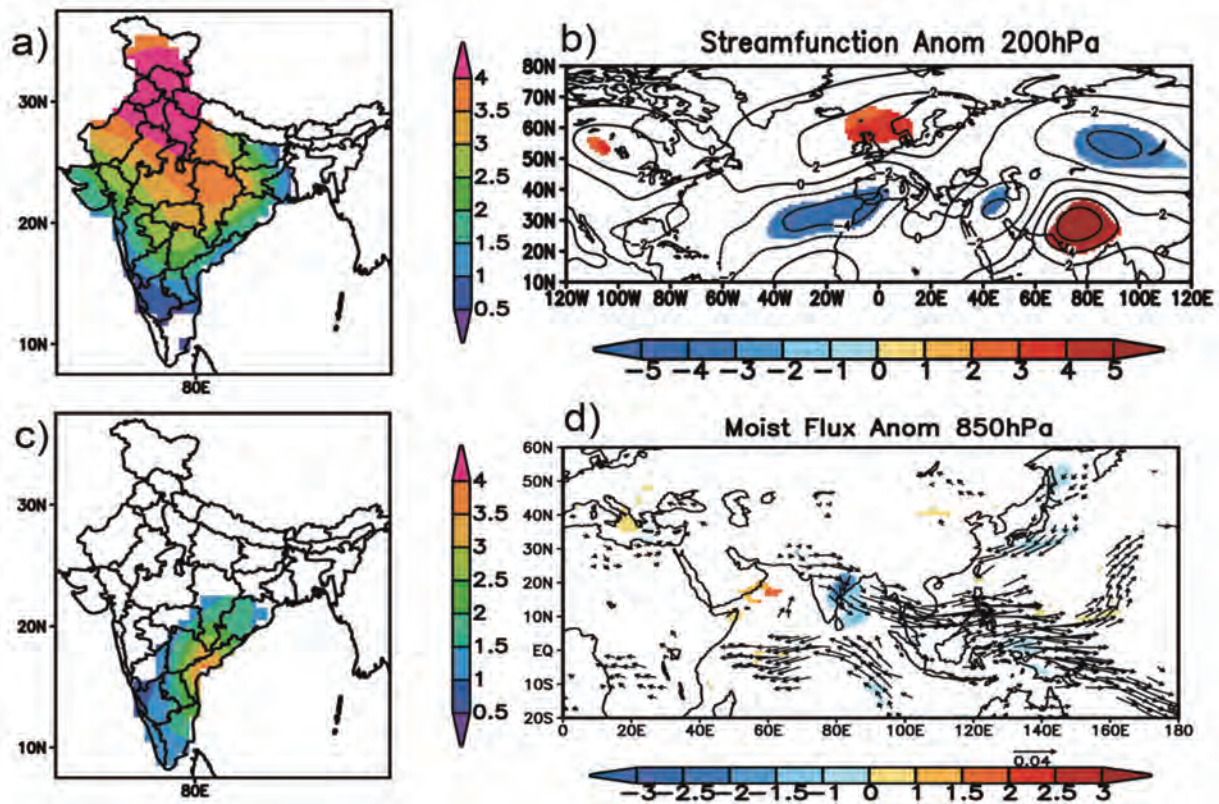


Fig.2 Composites of surface temperatures associated with (a) TYPE1 heatwaves and (b) 200hPa Stream function (shaded) and meridional wind anomalies (contours) for TYPE1 events. Composites of surface temperatures associated with (c) TYPE2 heatwaves and (d) 850hPa moisture flux anomalies for the TYPE 2 heatwaves over India [adopted from *Ratnam et al.*, 2016].

Kuroshio Enhances Bomb Cyclones

The northern Pacific is marked by the occurrence of intense storm systems that typically travel in the direction of the prevailing westerly winds along the so-called storm track. Intense low-pressure systems (also called extra-tropical cyclones) frequently develop along the storm track and are associated with intense wind and rain or snow fall. In some cases, these cyclones intensify rapidly leading to unexpected development of severe weather conditions. These rapidly developing cyclones are called bomb cyclones and have particularly high occurrence over the strong SST gradients (also SST fronts) associated with the Kuroshio and Oyashio currents off Japan. Observational evidence has long suggested a causal link between the SST fronts and bomb cyclones but the exact role of the SST fronts has not been well understood.

The study by *Kuwano-Yoshida and Minobe* [2017] uses a high-resolution atmospheric general circulation model (AGCM) run at the Earth Simulator to address this scientific question. An AGCM is driven by prescribed SST at the lower boundary, which facilitates modifications and sensitivity experiments. In the control experiment (CNTL) observed SST at high resolution (0.25°) are prescribed, which can adequately represent the sharp SST fronts. In the sensitivity test (SMTHK), the SST boundary conditions are smoothed in the region of the northwest Pacific SST fronts. Comparison of CTRL and SMTHK then allows understanding and quantifying the influence of the SST fronts on the storm tracks and bomb cyclones.

The results show that the number of bomb cyclones is drastically reduced in SMTHK (Fig.3), thus lending support to a causal link between SST fronts and explosive cyclones. Key to the strong cyclone energy in CNTL is the surface evaporation that occurs when atmospheric winds blow over the SST fronts. The influence of SST fronts, however, is not confined to the northwestern Pacific. Further analysis of the experiments indicates that the SST fronts also influence the jet stream, a large-scale intense air stream in the upper troposphere, and subsequently the northeastern Pacific. In particular, the SST fronts and the occurrences of bomb cyclones lead to reduced precipitation in the northeast Pacific and along the northwest American coast, but increased precipitation over the central Pacific around the Hawaiian Islands. Thus, the experiments highlight the far-reaching influence of the northwestern Pacific SST fronts.

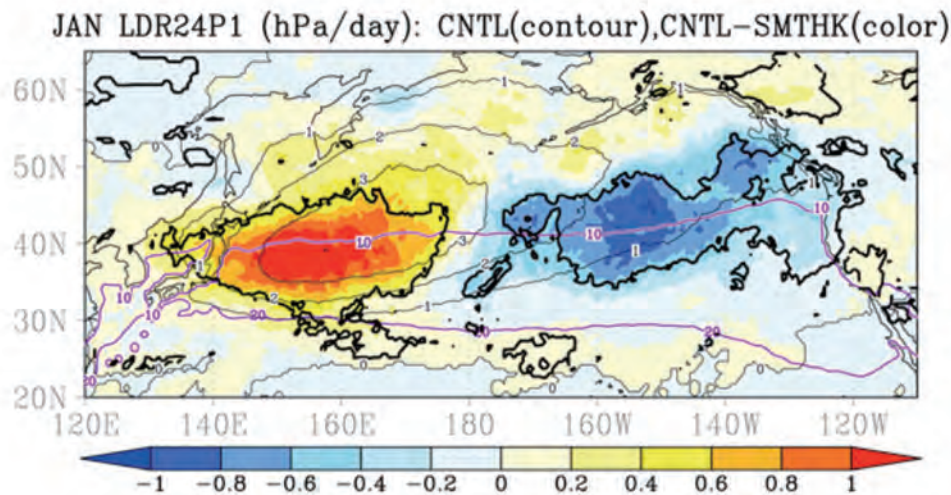


Fig.3 Explosive deepening events in January. Shown here are differences between CNTL and SMTHK (shown in shaded colors; unit: hPa/day) and climate data in CNTL (shown in thin solid lines). The purple line shows sea surface temperature of 10°C and 20°C . The black thick lines indicate areas where differences of explosive cyclone events are statistically significant. Explosive cyclone events are active when the warm color becomes strong and inactive when the cool color becomes strong in CNTL.

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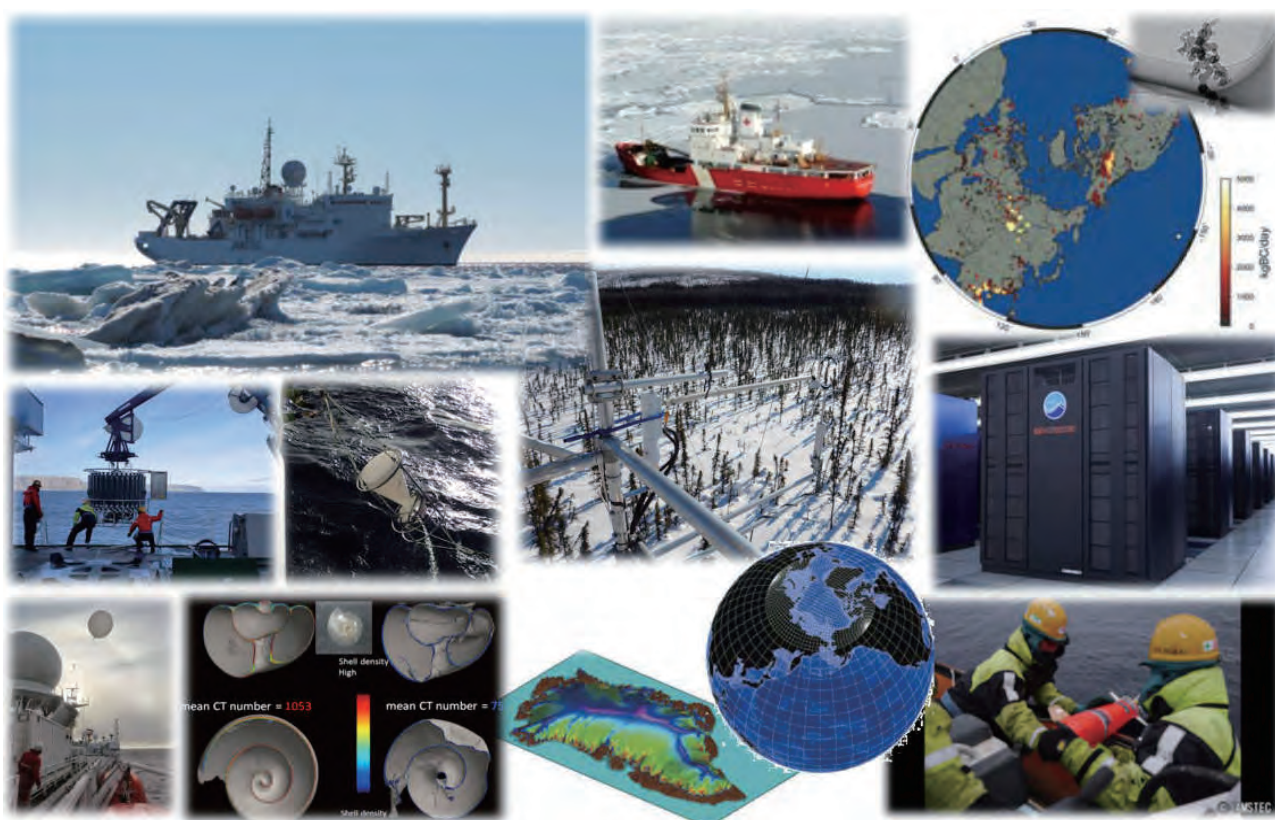
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Changing Arctic

– Institute of Arctic Climate and Environment Research –

The decrease of Arctic sea ice is attributed to the effects of “global warming.” The Arctic is the world region that is warming the most. Warming in the Arctic will proceed at least twice as fast as the world average. Such rapid change will not only reduce sea ice, but also drive the melting of permafrost, glaciers, and ice sheets. Further, this is having impacts on not only the Arctic Ocean and its surrounding region, but also on oceans and countries around the world, including Japan. Change in the Arctic climate will bring about change in the ecosystems of marine organisms living there. In fact, changes occurring in the Arctic Ocean, where the effects of global warming are quickly manifested, could at some time occur in the world’s other oceans. Arctic problems are no longer confined to countries bordering the Arctic Ocean; so, we must think of these problems as global, affecting the whole world. The Japan Agency for Marine-Earth Science and Technology (JAMSTEC), which had been conducting Arctic research since the 1990s, established the Institute of Arctic Climate and Environment Research (IACE) in April 2015 to further expedite its Arctic research and to broadly benefit international society.



Mapping of the air–sea CO₂ flux in the Arctic Ocean and its adjacent seas: Basin-wide distribution and seasonal to interannual variability

The Arctic Ocean and its adjacent seas are thought to act as a sink for atmospheric CO₂ because of the high solubility of CO₂ in its low-temperature waters. Furthermore, as global warming progresses, melting of sea ice will increase the area of open water in the Arctic, thus enhancing the potential for the oceanic uptake of CO₂ from the atmosphere. However, the basin-wide distribution and seasonal to interannual variability of the CO₂ fluxes in the Arctic had not been clarified because of the sparseness of CO₂ measurements in this very heterogeneous area. We produced 204 monthly maps of the air–sea CO₂ flux in the Arctic north of 60°N, including the Arctic Ocean and its adjacent seas, from January 1997 to December 2013 by applying, for the first time, a self-organizing map (SOM) technique to the partial pressure of CO₂ (pCO₂) in the surface water estimation in the Arctic.

I. Research Activities and Results

Institute of Arctic Climate and Environment Research

Using the mapped result, we investigated the basin-wide distribution and seasonal to interannual variability of the CO₂ fluxes. Figure.1 shows 17-year annual means of (a) CO₂ flux, (b) sea ice concentration, (c) wind speed, and (d) air–sea pCO₂ difference ($\Delta p\text{CO}_2$). The estimated annual CO₂ uptake by the Arctic Ocean was 180 TgC yr⁻¹. The CO₂ influx was strong in the Greenland/Norwegian Seas (>15 mmol m⁻² day⁻¹) and the Barents Sea (>12 mmol m⁻² day⁻¹), and in the Chukchi Sea (~10 mmol m⁻² day⁻¹). From the examination the effects of wind speed, SIC, and $\Delta p\text{CO}_2$ on the seasonal changes in the CO₂ flux, the CO₂ influx was strongest in winter in the Greenland/Norwegian Seas and the Barents Sea because of strong winds, and in summer in the Chukchi Sea because of the sea-ice retreat.

Figure.2 shows area-mean interannual variations of the CO₂ flux (upper panels), sea ice concentration, wind speed, and $\Delta p\text{CO}_2$ (lower panels) in (a) the Greenland/Norwegian Seas and (b) the Barents Sea from January to March, and (c) the Chukchi Sea from September to November. Interannual variation of the CO₂ flux was large (~ 10 mmol m⁻² day⁻¹) in the Greenland/Norwegian Seas and the Barents Sea in early winter, and in the Chukchi Sea in late summer. The CO₂ influx in the Greenland/Norwegian Seas and the Barents Sea was large in 2002, 2006, and 2011, mainly because of stronger winds in those years, while the CO₂ influx in the Chukchi Sea varied with the SIC change. The interannual variation of $\Delta p\text{CO}_2$ affected the interannual variation of the CO₂ flux at longer time scales. Figure.3 shows 17-year trends in (a) CO₂ flux, (b) sea ice concentration, (c) wind speed, and (d) $\Delta p\text{CO}_2$. The trend in the CO₂ flux was negative (i.e., uptake by the ocean was increasing) in the Greenland/Norwegian Seas and northern Barents Sea, and positive (i.e., uptake was decreasing) in the southern Barents Sea. These trends corresponded well to that of the $\Delta p\text{CO}_2$ trend.

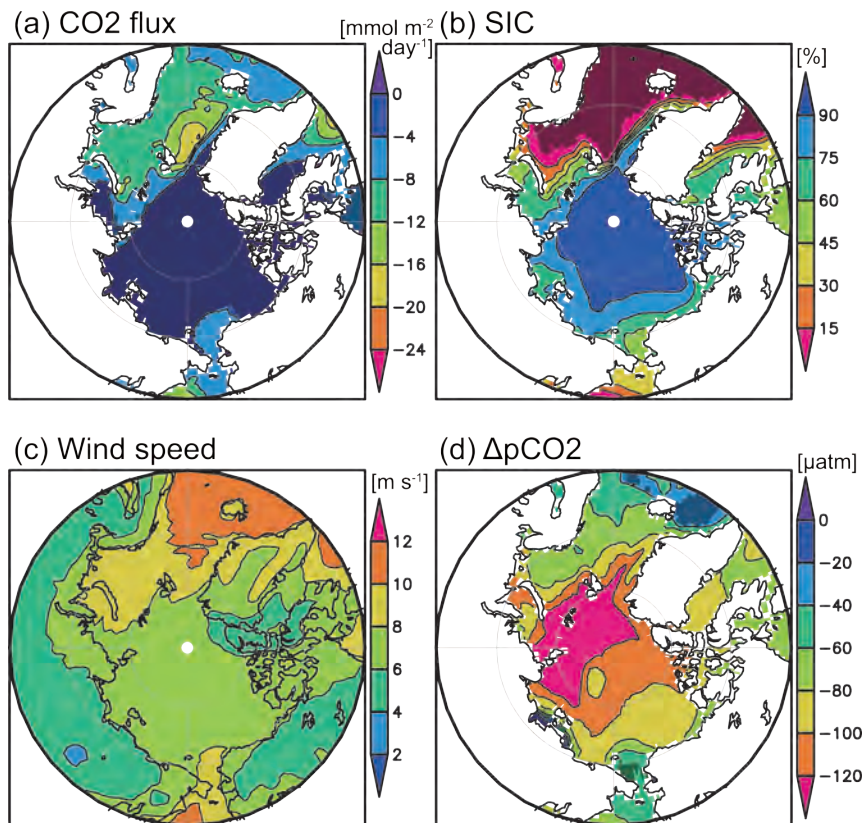


Fig.1 Seventeen-year annual means of (a) CO₂ flux, (b) sea ice concentration, (c) wind speed, and (d) air–sea pCO₂ difference ($\Delta p\text{CO}_2$).

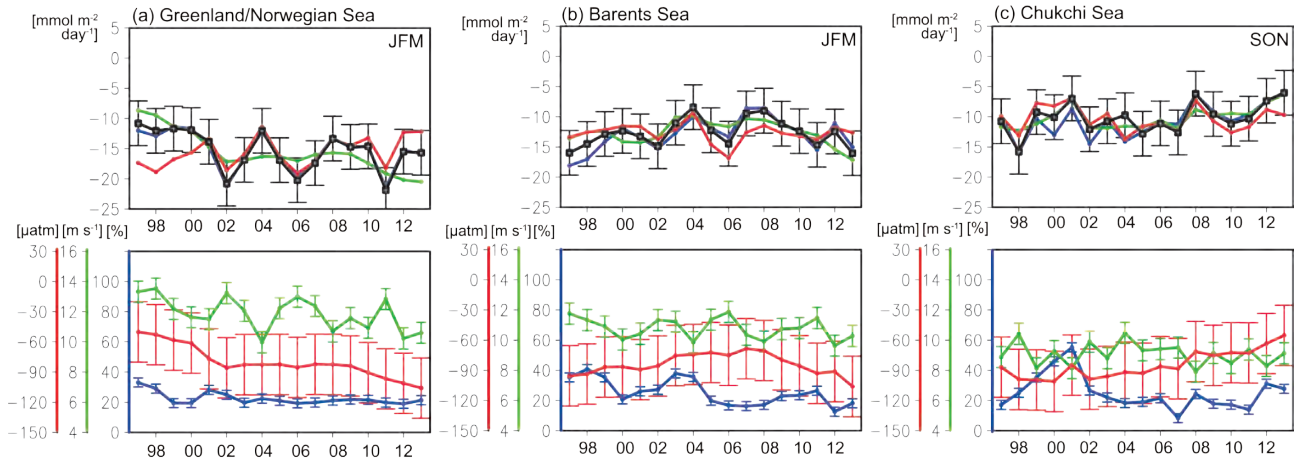


Fig.2 Area-mean interannual variations in (a) the Greenland/Norwegian Seas and (b) the Barents Sea from January to March, and (c) the Chukchi Sea from September to November. The upper panels show interannual variations in the CO₂ flux (black, standard; blue, SIC constant; green, wind constant; red, ΔpCO₂ constant) in each region, and the lower panels shows interannual variations in sea ice concentration (blue), wind speed (green), and ΔpCO₂ (red).

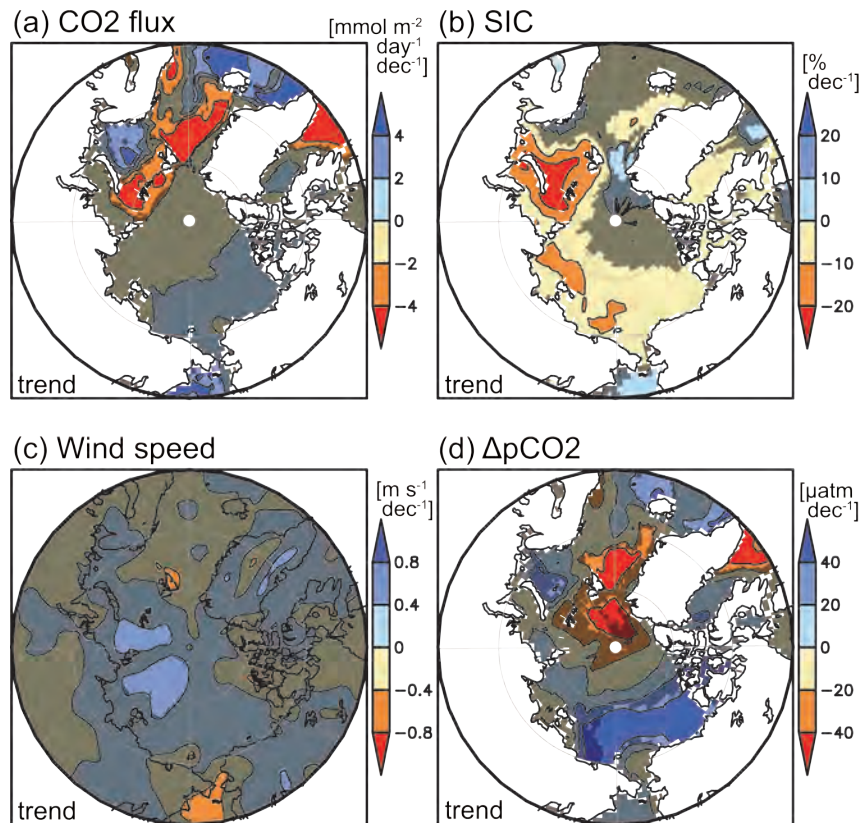


Fig.3 Seventeen-year trends in (a) CO₂ flux, (b) sea ice concentration, (c) wind speed, and (d) ΔpCO₂.

Climate model simulations proved that reduction of Arctic sea ice caused increase in Arctic cloud for the late 20th century

Satellite observations have shown that Arctic sea ice has decreased gradually since the 1980s. A further reduction in Arctic sea ice is likely to result from future global warming. In turn, the reduction in sea ice can accelerate surface warming in the Arctic region through various feedback processes. A major feedback process in climate change is the ice-albedo feedback, in which reduced sea ice decreases the global albedo and increases shortwave radiation entering the climate system. This feedback is likely to occur in high-latitude regions, where snow cover and sea ice are seasonally extended. In addition, other processes such as ocean heat

I. Research Activities and Results

Institute of Arctic Climate and Environment Research

uptake, atmospheric stability, and low-level cloud response may require further attention to better understand the Arctic warming mechanism. The reduction in sea ice also involves other feedback processes in the Arctic region. Previous studies have suggested that extended periods of open ocean resulting from reductions in sea ice increase Arctic cloud cover and enhance Arctic amplification. The cloud cover change resulting from sea ice loss is under debate. The Arctic cloud cover changes resulting from reduced sea ice in climate model simulations should be informative for understanding the mechanism underlying future changes in Arctic clouds and Arctic warming.

In this study, firstly, we analyze historical simulations using a coupled atmosphere–ocean general circulation model, i.e., MIROC5, which was used in the Coupled Model Intercomparison Project Phase 5 (CMIP5). Historical simulations are performed from 1850 to 2005 using anthropogenic forcings recommended by the CMIP5 project. A large negative trend was found for Arctic sea ice in the MIROC5 simulations in summer and fall during the period 1976–2005, although small negative trends in the winter and spring were found in limited regions. The temporal trend in the simulated Arctic cloud cover was positive in fall, winter, and spring, reaching a maximum in October (Fig.4).

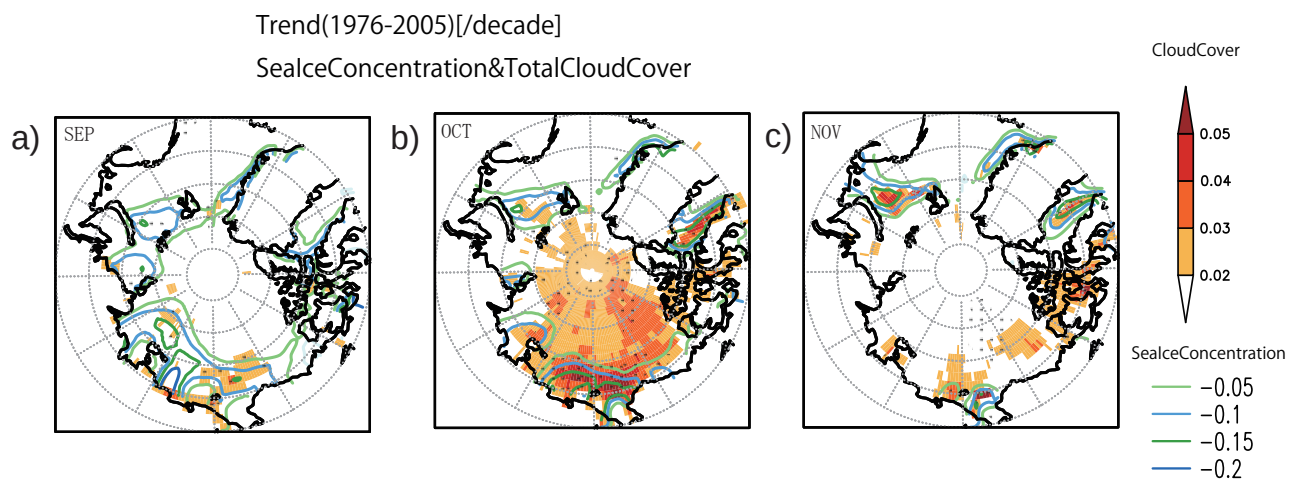


Fig.4 Geographical map of the simulated linear trend in the total cloud cover (shaded) and sea ice concentration (contours) in (a) September, (b) October, and (c) November during the period 1976–2005. The units are decade⁻¹. Dots indicate that the linear trend is not zero at the 95% significance level. (Fig.5 in Abe *et al.*, 2016 was modified.)

To further examine the effect of reduced sea ice on Arctic cloud cover, we conducted systematic sensitivity experiments with MIROC5 atmospheric GCM (AGCM). In the sensitivity experiments, the Arctic cloud cover under different combinations of sea surface temperature (SST) and sea ice conditions in the 1980s and 2000s was compared. Additionally, the impact of changes in other forcings, such as greenhouse gases, aerosols, and land use, from the 1980s to 2000s on the Arctic cloud cover were examined. Table 1 shows the SST, sea ice, and other forcing conditions. These experiments used climatological monthly mean SST and sea ice data, which were obtained from historical MIROC5 simulations. The SST and SIC in the 1980s were averaged over the period 1976–1985 in the historical simulations. Both the SST and SIC in the 2000s comprised additive data from the 1980s and changes for the following 20 years, which were estimated using the linear trend from 1976 to 2005 in the historical simulations. The geographical maps of cloud cover in October for the CTL and ALL2000 experiments and the differences between each experiment and CTL are shown in Fig.5. Increases in cloud cover are remarkable in the SIOF2000 and ALL2000 experiments, particularly in the grids with large sea ice reductions (Fig.5d and f). These indicate that the large increases in cloud cover are due to sea ice reduction. In contrast, there is no remarkable increases in cloud cover in the OF2000 and SSTOF2000 (Fig.5c and e), where the sea ice reductions was not included. These results strongly imply that the sea ice reduction caused the increased cloud cover. Additionally, cloud cover increased in October when sea ice was reduced, even if the SST had remained unchanged since the 1980s (Fig.5d). Furthermore, changes in SST and other forcing conditions (except for sea ice) from the 1980s to 2000s did not increase cloud cover (Fig.5c and e). These results agree with the results from the historical MIROC5 simulations. Therefore, we could conclude that the increased Arctic cloud cover was caused

by the sea ice reductions at least in the MIROC5-AGCM simulations.

Table 1 Sea surface temperature (SST), sea ice, and other forcing conditions in the sensitivity experiments with MIROC5-AGCM. Other forcings include land use, greenhouse gas concentrations, aerosol emissions, and total solar irradiance. Data in the 1980s indicate an average over the period 1976-1985, and the data in the 2000s combine data for the 1980s and changes for the following 20 years, which were estimated using the linear trend from 1976 to 2005 in the historical simulations. (Table 1 in Abe *et al.*, 2016)

Exp. name	Sea ice (SI)	SST	Other forcing (OF)
CTL	1980s	1980s	1980
OF2000	1980s	1980s	2000
SSTOF2000	1980s	2000s	2000
SIOF2000	2000s	1980s	2000
ALL2000	2000s	2000s	2000

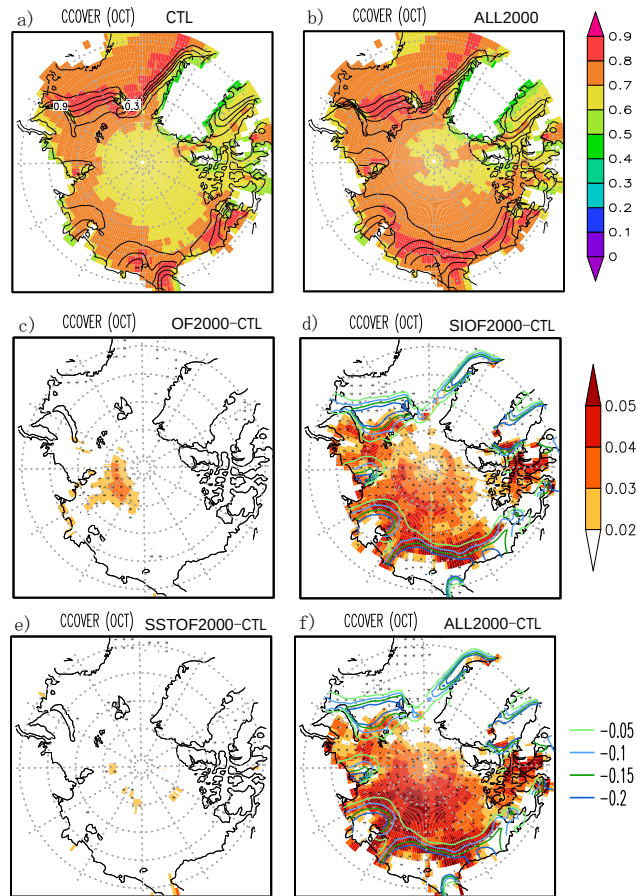


Fig.5 Geographical map of the total cloud cover (shaded) and sea ice concentration (contours) in October in the sensitivity experiments and the differences between experiments. (Fig. 6 in Abe *et al.*, 2016)

Successful Shooting of Sub-Arctic Sea by Small Prototype AUV

In-situ observations at the ice edge and under sea ice are essential for Arctic research. With the expectation of enabling such observations effectively, development of Autonomous Underwater Vehicles (AUVs) for Arctic observations is currently underway worldwide. But, we have not experienced in development and operation on the AUV for Arctic Ocean observation. In 2015, we have started to develop a small AUV in order to accumulate know-how in operation of AUV for Arctic Ocean. In 2016, we launched prototype AUV which is named “RAIV” (Retrievable Arctic Icy edge observation Vehicle). The length of RAIV is ab.2 meters and weight is ab 30kg in air. Maximum depth is 200m. RAIV equipped two thrusters for underwater navigation and yaw control, and an oil bladder for pitch control. The rated thrust power is ab.3[N] per one unit. Cruising speed is controlled 3.6km/h. Endurance is about 60 hours. Iridium satellite communication system is used for data

I. Research Activities and Results

Institute of Arctic Climate and Environment Research

transmission. Magnetic compass is used for heading control.

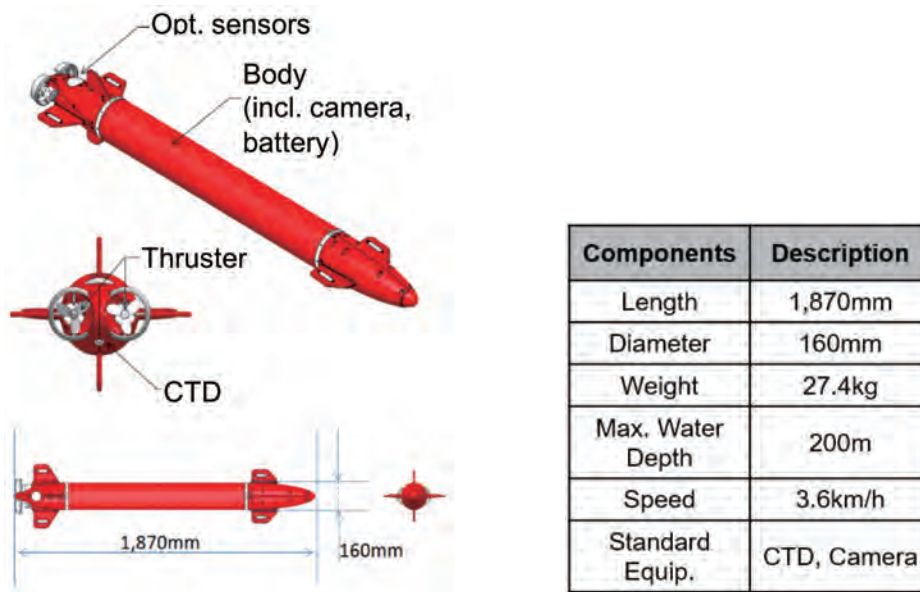


Fig.6 External drawing and specification of “RAIV”

During the Arctic expedition by R/V *Mirai* in August – October, 2016, RAIV succeeded in autonomous navigation under sea ice for the first time among Japanese researchers. This field test led to successful measurements of seawater temperature, salinity and other features in the sea-ice area as well as video shooting under the ice.

JAMSTEC will develop new underwater positioning technology to improve the scientific significance of observation under sea ice.

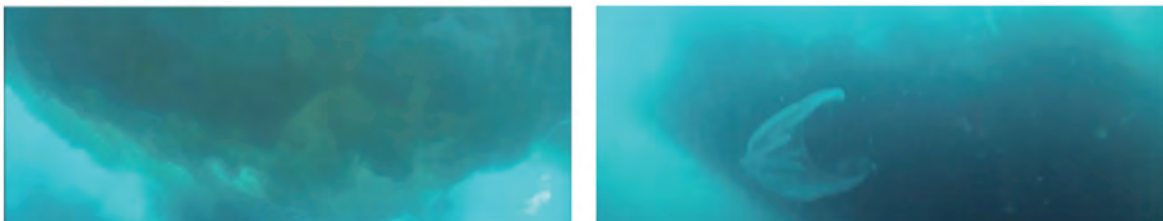


Fig.7 Underwater images recorded just below sea ice by RAIV. Comb jelly is visible at right image.

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Chasing what's happening in the tropics

– Department of Coupled Ocean-Atmosphere-Land Processes Research –

The Maritime Continent (MC) and adjacent seas host a source of the global atmospheric circulation owing to the huge amount of heat release from cumulus convections. Since this region is characterized with complicated topography with steep mountains and surrounding warm waters, interactions among ocean, land, and atmosphere are thought to play a critical role in regulating weather and climate systems, which have impacts onto not only the tropics but also higher-latitudes. Our research goal is to improve our understanding of weather and climate in this region through observations from the viewpoints of ocean-atmosphere-land interactions. In particular, we have set to conduct two major activities during this mid-term (FY2014 - 2018). One is the international field campaign called “Years of the Maritime Continent (YMC)”, and the other is the boreal summer monsoon study.

The YMC is a 2-year international project which engages to conduct field campaign starting from July 2017. Its ultimate goal is to expedite the progress of improving understanding of local multi-scale variability of the MC weather-climate system and its global impact. Currently over 70 institutes/universities from 20 countries and regions are expected to join the campaign. Its field campaign consists of long-term measurements and several intensive observations focusing on specific scientific topics such as diurnal cycle of rain and the Madden-Julian oscillation. As part of the YMC, we have proposed to conduct intensive observations around west coast of Sumatra Island, Indonesia from November 2017 through January 2018. In addition, under the framework of the YMC, we have already conducted a pilot study as pre-YMC in 2015.

As for the monsoon study, we have conducted observations in Viet Nam, Philippines, and Palau by deploying long term measurement systems or conducting continuous observations based on the collaboration with local agencies. In addition, we plan to conduct special intensive observations for studying the boreal summer monsoon focusing on two points; stratosphere-troposphere interaction and boreal summer intraseasonal oscillation in July - August 2018, partly as part of the YMC.

Figure 1 shows major observation sites, where we deploy our observation facilities.

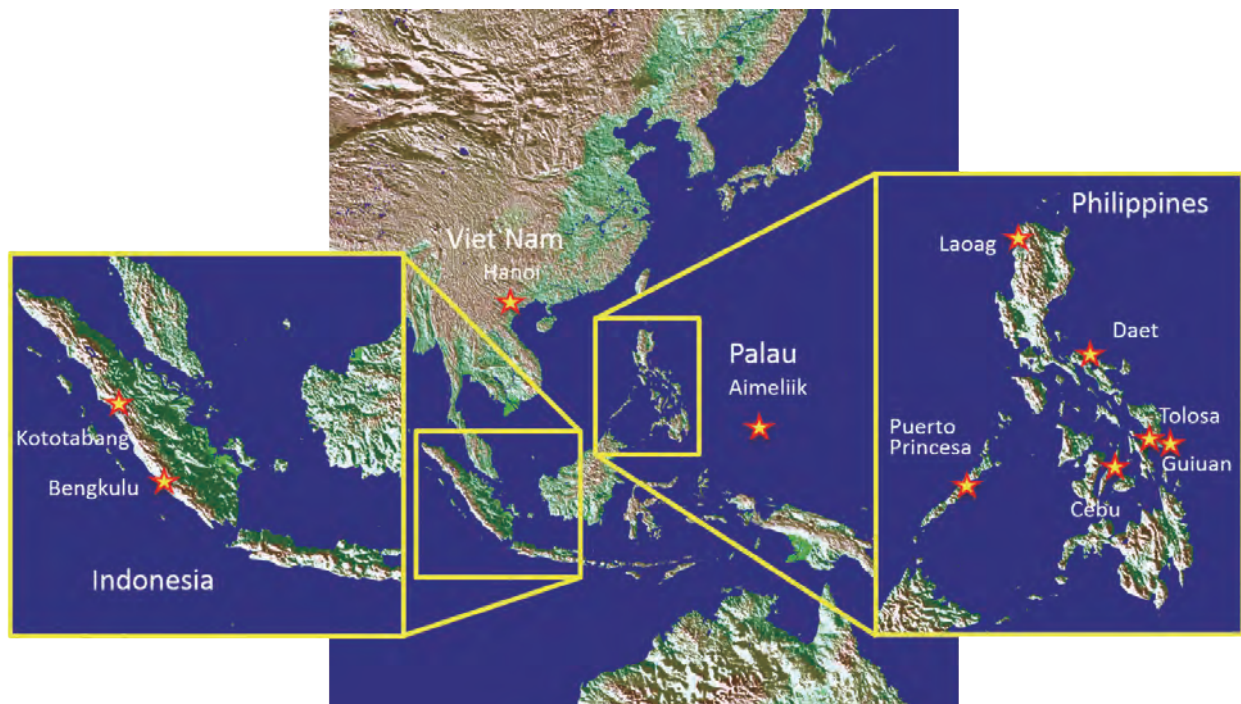
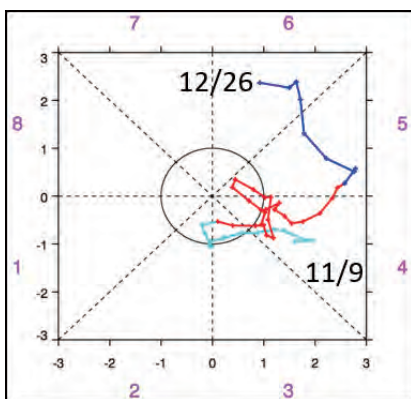


Fig.1 Major observation sites (red stars), where DCOP deploys their instruments or conducts intensive observations.

Diurnal cycle of rain and the MJO

As noted in the previous section, the Years of the Maritime Continent (YMC) is designed to take place from July 2017 for two years for improving our understanding and prediction of the weather-climate system over the Maritime Continent (MC) region and its global impact. During the campaign period, several intensive observations coordinated under the framework of YMC are planned in addition to the long-term monitoring by the MC local agencies. JAMSTEC has several plans of intensive observations and its first campaign is done at the west coast of Sumatra Island, Indonesia. However, such coordination and conducting observations may encounter unforeseen difficulties. In addition, 2-year period is still insufficient to understand local phenomena as it may be affected by large/longer-scale phenomena such as El Niño. By considering these factors, we conducted a pilot study for the YMC, and we call it as pre-YMC campaign. Its scientific purpose was to study diurnal cycle of rain and the Madden-Julian Oscillation (MJO), which is usually developed over the Indian Ocean and propagates eastward, and their interaction. This field campaign was conducted in Sumatra, Indonesia from November through December 2015. While we deployed land-based radar/special radiosonde sites in Bengkulu from November 9 through December 25, we also deployed the R/V *Mirai* off Bengkulu to study precipitation mechanism and their propagation characteristics during November 21 to December 17. Observations captured the atmospheric features in the transition phase from inactive to active for convection associated with the MJO. Figure 2 shows the real-time multivariate MJO index [Wheeler and Hendon, 2004], and it is evident that the MJO convection developed over the central Indian Ocean and propagated eastward, and its convective center arrived over Bengkulu around December 13. Figure 3 shows the precipitation observed by the radars of the R/V *Mirai* and BMKG land station, and they are shown as a function of distance from the coast line. It is obvious that convection associated with diurnal cycle developed in the coastal region (roughly 30-km from the coast line) around 15-17 LST, and then propagates offshore-ward and reached over the *Mirai* around 21 LST. In particular, this feature is evident prior to the MJO convection arrival on December 13 (red solid line). This indicates their interaction between diurnal cycle rain and the MJO. The changes of diurnal cycle feature before/after the passage of the MJO convective center can be found in various parameters. Figure 4 shows precipitation, specific humidity, zonal and meridional wind components measured at the ground surface as a function of nominal day and local time in a day. As indicated by thick solid line on December 13, their features are drastically changed. Before December 13, sea breeze (south-westerly) dominates during 09-15 LST, and then it moistened during 12-18 LST, and precipitation are observed in the evening (15-21 LST). However, such diurnal cycle became unclear after December 13.

Interaction between diurnal cycle of rain and the MJO could be found in various forms. For example, Wu *et al.* [2017] studied the torrential rain observed over Bengkulu on December 12 and noticed that torrential rain was caused as a result of combination of westward moving diurnal convection and the leading edge of the westerly wind associated with the MJO (not shown here).



Based on the results of these features, observation plan for the YMC in 2017 has been reviewed. For example, to study the behavior of diurnal convection, the R/V *Mirai* will be stationed about 100km off Bengkulu, so that its radar can cover the offshore-ward convection from the coast to open ocean region. In addition, more frequent radiosonde sounding will be carried out to capture the inner structure of propagating convective systems.

Fig.2 RMM Index. No. 3 in pink indicates the location of eastern Indian Ocean, while 4 and 5 indicate western and eastern Indonesian Maritime Continent regions.

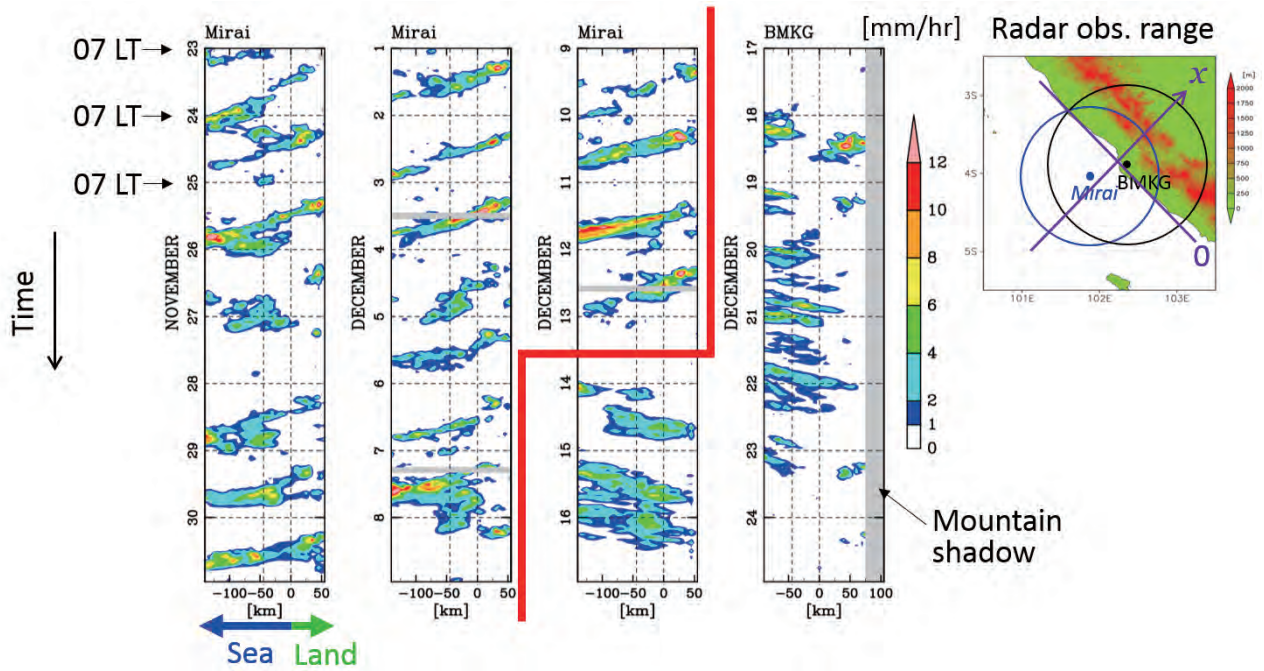


Fig.3 Time series of radar-estimated precipitation as a function of distance from the coast line and time.

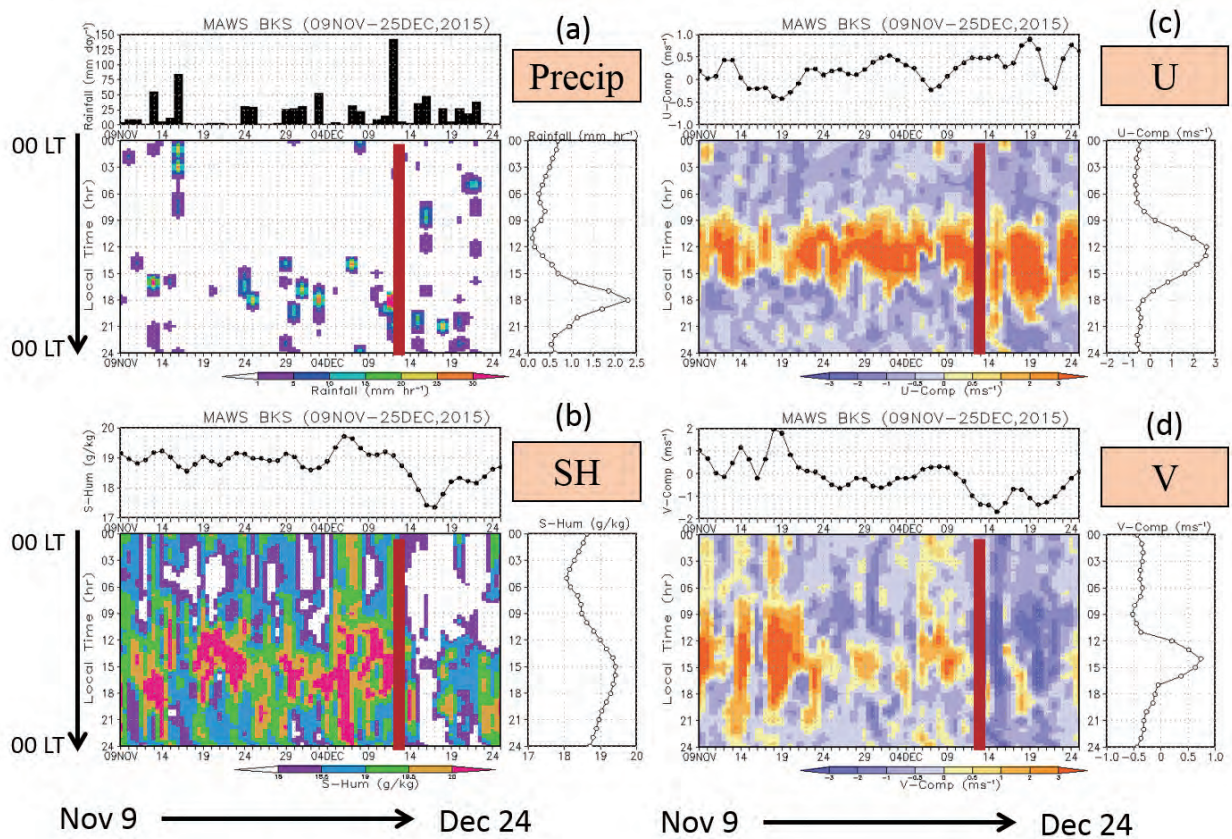


Fig.4 Surface meteorological observations as a function of day and local time in a day for (a) precipitation, (b) specific humidity, (c) zonal, and (d) meridional wind components.

I. Research Activities and Results

Department of Coupled Ocean-Atmosphere-Land Processes Research

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Exploring key geochemical cycles across atmosphere, land, and ocean related to global environmental change

– Department of Environmental Geochemical Cycle Research –

Various geochemical substances, as well as water and energy, are cycled across the atmosphere, land, and ocean, interacting with the climate and environment of the earth. For example, carbon dioxide (CO₂), the most important greenhouse gas (GHG) released mainly from anthropogenic fossil fuel combustion (FFC), is absorbed and sequestered by the land and ocean, moderating the increase in the atmospheric CO₂ concentration and thereby the speed of climate change.

Ocean and land ecosystems play an important role in the dynamics of the sequestration. The processes involved are complex; for example, supply of nutrients to the ecosystems and various types of environmental conditions affect strongly. Moreover, CO₂ is not the only species important for the climate change; In addition to CO₂, aerosols generated from wildfires and human activities, and methane (CH₄) from anthropogenic sources as well as paddy fields/wetlands strongly influence the earth's climate and environment.

As such, our current challenge is to better elucidate the detailed processes and dynamics of emission, transport, and accumulation (deposition), as well as the transformation of these important substances in the atmosphere, land, and ocean, based on *in-situ* observations, satellite data, and numerical modeling, towards better prediction of our future.

The FY2016 was the third year of the current midterm plan of the Japan Agency for Marine-Earth Science and Technology (JAMSTEC). As the research progressed, our new target of studies involved interactions of sub-systems (e.g., atmosphere-land and ocean-land interactions). Our department members with expertise in different research fields interacted in an efficient way to address the new challenges. For this purpose we coordinated two types of seminars (discipline-based and interdisciplinary, both were open to all JAMSTEC members); they fostered in-depth discussion and provided opportunities to disseminate scientific information.

Here, two topics are highlighted, regarding CO₂ source/sink attribution and the influence of riverine inflow on the ocean ecosystems, from the full spectrum of the departmental research results during the FY2016.

Refinement of global and China carbon budgets by joint analysis of CO₂ and CH₄ inversion fluxes

Carbon dioxide (CO₂) and methane (CH₄) are the two most significant greenhouse gases (GHGs) in terms of their contribution to the radiative forcing (RF) increase since the preindustrial era (circa. 1750). According to the IPCC 5th Assessment Report, emissions of CO₂ and CH₄ together contribute 50% and 28%, respectively, of the total RF increase of 3.38 W/m² due to the GHGs alone. Thus, a call for voluntary emissions reduction of these two gases have been made first under the Kyoto Protocol (1996), and subsequently Intended Nationally Determined Contributions (INDCs) are urged under the Paris Agreement (2015). Both CO₂ and CH₄ have natural and anthropogenic sources intermingled on the Earth's surface. About half of the anthropogenic CO₂ emissions due to fossil fuel consumption and cement production (FFC) are taken up by the land and ocean ecosystems, while CH₄ is predominantly emitted from the Earth's surface and lost by chemical reactions in the atmosphere. Therefore, tracking their sources and sinks separately in the Earth's environment is extremely challenging but urgent in order to monitoring, reporting and verification (MRV) of GHG emission budget at national level. The atmospheric inverse modeling, so called top-down approach, is an effective way to estimate global and regional GHG emissions by using an atmospheric transport model and precise measurements of GHG concentrations.

I. Research Activities and Results

Department of Environmental Geochemical Cycle Research

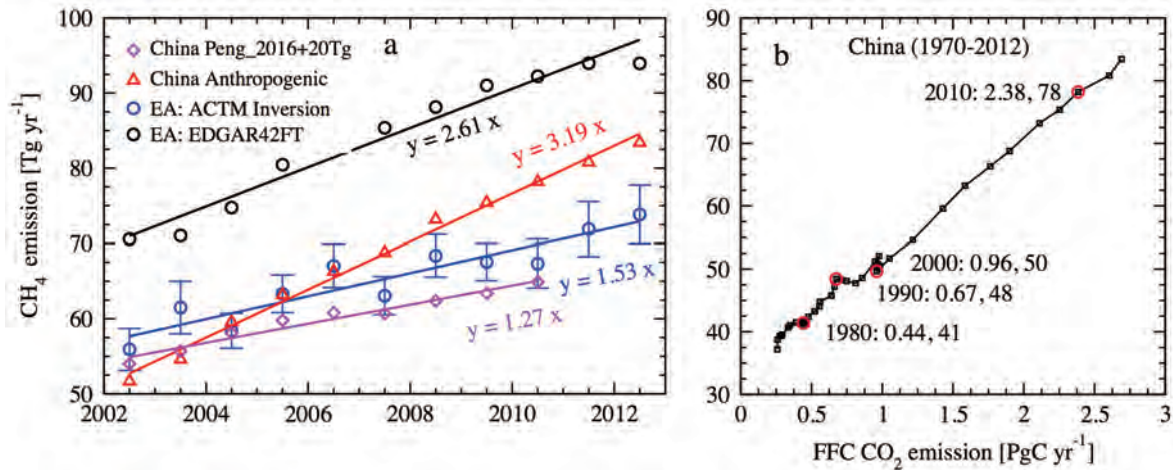


Fig.1 (a) Comparisons of CH₄ inversion results (black: a priori; blue: a posteriori) for the East Asia (EA) region, and the a priori anthropogenic emissions for China. The linear fits to the annual mean values are shown as lines, with slopes being marked along the fitted lines. Recent inventory based CH₄ emissions are plotted for a comparison [Peng *et al.*, 2016]. **(b)** The linear relationship of anthropogenic CO₂ and CH₄ emissions for China over the period of 1970–2012. Adapted from Saeki and Patra [2017].

The inverse modeling of CO₂ assumes FFC emissions are a known quantity, and estimates the “residual” land sources/sinks (flux). FFC emissions are considered better known, compared to the more variable land fluxes, because these are calculated from better known industrial indicators. Any bias in the FFC emissions would thus introduce a systematic bias in estimation of the residual land fluxes by inverse modelling. A top-down model assessment from seven inverse models found that annual CO₂ sink in East Asia (China, Japan, Korea and Mongolia) increased between 1996–2001 and 2008–2012 by 0.56 PgC, with large implied uncertainty from FFC emissions [Thompson *et al.*, 2016]. No plausible explanation could be put forward for such a large increase in East Asian CO₂ uptake over a short time period. An effort to validate the top-down CO₂ fluxes using independent aircraft CO₂ observations did not provide conclusive results as the simulated concentrations fairly matched the observed vertical gradients between the surface and middle troposphere as well as the concentrations near the surface layer for a large range (~1 PgC/yr) of residual CO₂ flux over East Asia alone. In contrast, we found the inversion results of CH₄ emissions could be successfully validated using independent aircraft observations over Japan [Patra *et al.*, 2016]. Note here that the CH₄ loss in atmosphere is modelled using well-calibrated concentrations of OH, O¹D and Cl. Our results suggested an overestimation of East Asian CH₄ emissions and increase rate by the inventories (Fig.1a).

Here we introduce a new approach by using the CH₄ inversion results to refine the increase rate of FFC CO₂ emission inventory for East Asia [Saeki and Patra, 2017]. Since the anthropogenic emissions of both CO₂ and CH₄ increase linearly in the emission inventory (Fig 1b), we apply a scaling factor of 0.59 derived from the CH₄ inversion results, to FFC CO₂ emission increase rate for the period 2003–2014, with the base year of 2002 (referred to as FFC CH₄scl). The application of this CH₄-inversion-derived scaling factor to the CO₂ emission increase rate assumes constant CH₄/CO₂ emission ratio over the periods of our analyses. The increase in emissions of both CO₂ and CH₄ from East Asia is linked to the Chinese coal industry; CH₄ is emitted during the coal mining, while emissions of CO₂ occur during the consumption of coal primarily in power plants and industrial combustions.

Figure 2 shows the comparisons of FFC CO₂ emissions (top row) and residual land fluxes (bottom row) for China and the global totals. We find the FFC CO₂ emissions as per the CDIAC inventory method are always higher compared to the CH₄scl and the consumption-based International Energy Agency (IEA) inventories. A fairly compensatory land CO₂ fluxes are estimated for the East Asia region. This compensatory effect can also be seen in the CO₂ emission and sinks trends being opposite in phase during 2002–2012 [ref. Saeki and Patra, 2017]. A biased higher (lower) FFC CO₂ emission leads to an artificially stronger (weaker) biospheric CO₂ sink over a given land region. The global total and East Asian CO₂ flux changes due to CO₂ fertilization and climate as simulated by the TRENDY2 global dynamic vegetation models (DGVMs) also confirm no significant increase in

carbon uptakes, contrary to the residual land sink increases for the CDIAC FFC CO₂ emissions. The forest carbon storage rates based on the country statistics of land use and land cover also suggest no significant change in carbon sequestration in the East Asia region [Calle *et al.*, 2016].

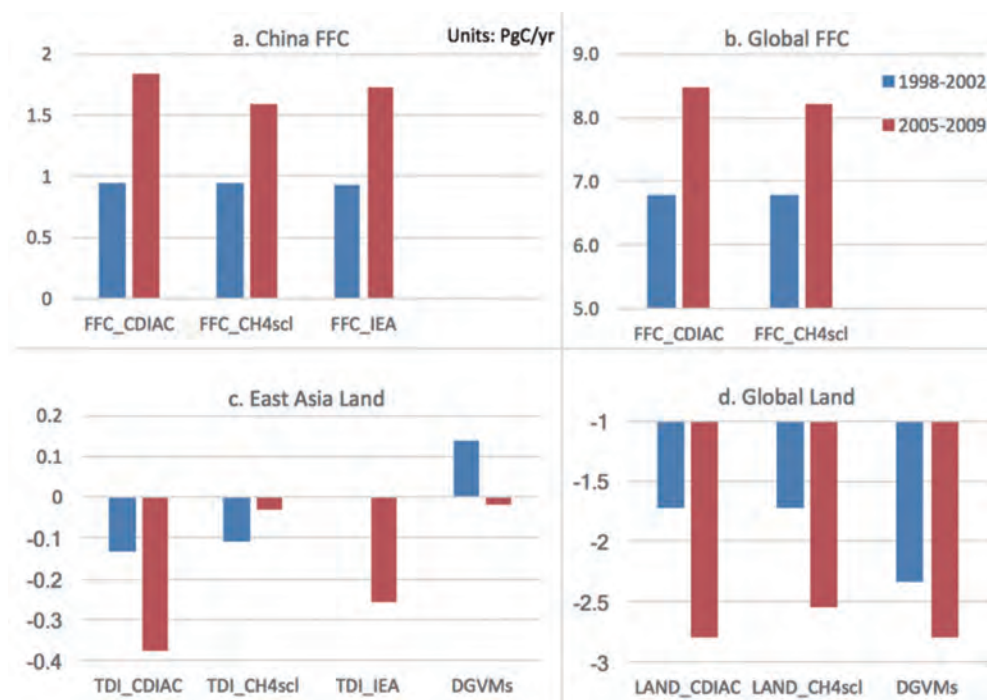


Fig.2 Effect of FFC CO₂ emissions on regional carbon budget of East Asia (left column) and the global land (right column). 5-yr mean CO₂ fluxes simulated by the TRENDY2 and Global Carbon Project [GCP; Le Quéré *et al.*, 2017] are also shown for a comparison.

Further, the land CO₂ sink bias due to uncertainties in FFC CO₂ emission greatly influence our understanding of the global and regional carbon budgets. Figure 2b,d show global CO₂ FFC emission and land sinks obtained from the GCP have the biggest increases from 1998–2002 to 2005–2009. The residual land sink increase is largely inconsistent with that simulated by the DGVMs. This inconsistency is further magnified for the China FFC emissions and the East Asian CO₂ sink increase (Fig.2a,c). The land sink increases for FFC CH4scl are in better agreements with those simulated by the DGVMs. Our results raise questions on the validity of steep increase FFC CO₂ emissions during 2002–2011, a stabilization during 2012–2016 and a proposed increase in 2017, and thereby the trends in residual land carbon sinks [Le Quéré *et al.*, 2017].

Impact of El Niño on phytoplankton biomass in the southern South China Sea through river discharge variability

The impact of El Niño/La Niña events was discerned on phytoplankton biomass abundance indexed by chlorophyll-a concentration (Chl-a, a measure of ocean biological production) in the southern South China Sea or coastal ocean northwest of Borneo Island. The report is based on a paper by Siswanto *et al.* [2017], but more focused on the coastal ocean described above (Fig.3).

The Sea-viewing Wide Field-of-view Sensor (SeaWiFS)-derived Chl-a data (from <https://oceancolor.gsfc.nasa.gov/>) within the period from September 1997 to December 2010 were used. The monthly sea surface temperature anomaly in the Niño3.4 region (from <http://www.cpc.ncep.noaa.gov/data/indices/sstoi.indices/>) was used as the El Niño/La Niña index (Niño3.4). River discharge was estimated by means of the global river hydrodynamical model CaMa-Flood which was forced by runoff calculated by the land surface model MATSIRO under JRA-25 reanalysis-based atmospheric boundary conditions [Kim *et al.*, 2009; Yamazaki *et al.*, 2013]. The Rajang-Kapit River flow was modeled and used as a proxy of river flows from other main rivers in the

I. Research Activities and Results

Department of Environmental Geochemical Cycle Research

northwestern Borneo.

November–December Chl-a mean (1997–2010) in the coastal ocean northwest of Borneo during non-El Niño years was high than that during El Niño years (Fig.3a,b). This can be seen more clearly in terms of Chl-a anomaly derived by subtracting Chl-a during El Niño from that during non-El Niño years (Fig.3c). The coefficient of correlation (r) between Chl-a anomaly and the Rajang-Kapit River discharge anomaly in the coastal ocean northwest of Borneo was significantly positive (Fig.3d), indicating that Chl-a variation is largely determined by land-derived nutrients discharged by river flows. A similar result was also recently mentioned by Sun [2017] who included all main rivers in the northwestern Borneo.

In general the Rajang-Kapit River discharge anomaly inversely varied with Niño3.4 (Fig.3e). This is understandable because low (high) rain rate anomaly in Malaysia tends to enhance during El Niño (La Niña) though there is a spatial dependency [Tanggang *et al.*, 2017]. Therefore this work concludes that the decline in Chl-a in the coastal ocean northwest of Borneo during El Niño event is likely attributed to a decline in the supply of land-derived nutrients associated with low rain rate anomaly.

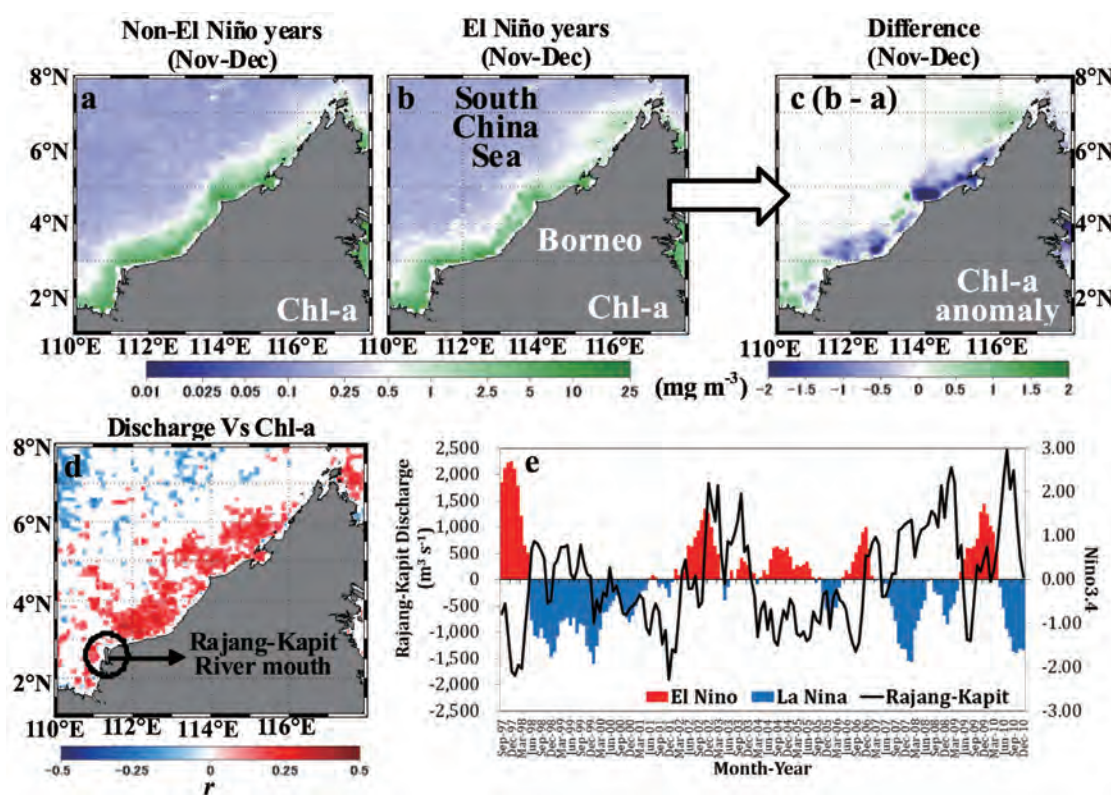


Fig.3 Spatial variation of mean Chl-a (November – December from 1997 to 2010) during non-El Niño years (a) and during El Niño years (b). Panel (c) shows Chl-a difference (b – a). Panel (d) shows the spatial variability of the coefficient of correlation (r) between Chl-a anomaly and Rajan-Kapit River discharge anomaly. Panel (e) shows time series of Niño3.4 and the Rajang-Kapit River anomaly time series from September 1997 to December 2010. White area and black circle in (d) indicate the area with insignificant r and the Rajang-Kapit River mouth, respectively.

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Toward Comprehensive Projection of Global Change

– Department of Integrated Climate Change Projection Research & Project Team for Risk Information on Climate Change –

Department of Integrated Climate Change Projection Research works on researches on mechanism for oceanic and atmospheric variations including water and biogeochemical cycles, and assessment of human impacts on those variations. Our main research tools include an atmosphere-ocean coupled model dealing with physical variables such as temperature and precipitation, and an earth system model (ESM) incorporating oceanic and terrestrial biogeochemical dynamics important for formation of the global environment. Activities also include observational research on permafrost, in order to develop a land process module to be a part of the ESM. It is hoped that our researches lead to contribution to the society in addition to improved understanding on how the nature works.

JAMSTEC has been undertaking "Program on Risk Information on Climate Change" funded by Ministry of Education, Culture, Sports, Science and Technology (MEXT) since FY 2012 by establishing a dedicated project team. Based on the protocol for global change projection experiments being discussed by scientists from across the world (CMIP6 protocol), we perform projection experiments using the models developed at JAMSTEC. This annual report includes results obtained under this program.

This year, we made an analysis on the impacts of anthropogenic aerosol and degradation of soil organic carbon in the permafrost on evaluating relation between cumulative emission of anthropogenic carbon and consequent temperature rise. The work on soil organic carbon in permafrost led to publication of five scientific papers through participation in an international project for model intercomparison.

The climate model MIROC has been improved toward the next cycle of the Intergovernmental Panel on Climate Change (IPCC) Assessment Report. Improvements include sophistication of the aerosol transport sub-model and revision of radiation processes. Further, the model has been tuned and tested in a preliminary experiment, which showed improved reproducibility on features such as warming trend and internal climate variations. It can be said that preparation for the next IPCC cycle has been completed and that the model is ready for production runs.

Possible changes in the dynamics of typhoons have been examined using NICAM, the global cloud system resolving model. Composite analysis has been made based on simulation data for three individual typhoons, revealing that the internal structure of typhoon would indeed be modified. The changes detected in the simulation results include strengthening of tangential wind velocity on the outer cloud wall. Thus, scientific achievements have been successfully obtained in accordance with the mid-term plan.

Identification of processes in climatic system that affect socio-economic scenarios

From analysis of climate stabilization experiments (Fig.1), uncertainty in soil decomposition in the permafrost regions was found to be large. We therefore should note the uncertainty in discussing the relationship of anthropogenic carbon emission and rise in global mean surface air temperature. In addition, scenarios of non-CO₂ emissions, e.g. anthropogenic aerosol, are also considered to give influence to the stabilization of climate change.

We participated in an international model inter-comparison project on the response of permafrost to climate change. Figure 2 is among the five papers published by the project.

We also analyzed the impact of changing the aerosol reduction scenario in RCP6.0 to climate (Fig.3).

As these are the processes that will have large impact on climate change projections, and also have large uncertainty, quantifications of their impact is timely and of significant scientific importance at an international level. Model outputs for permafrost is submitted to an international model inter-comparison project. As provision of information to the society, we were engaged in editorial supervision of a book for the general public and cooperation to a TV program of the NHK Special "Mega crisis" series.

I. Research Activities and Results

Department of Integrated Climate Change Projection Research

Moreover, our works included additional input of the soil temperature database as well as procedure for data release, and preparation of the forcings and code modifications for the Last Millennium experiment with our Earth system model. Outputs for them were the nation-wide database of the soil temperature and the frost penetration depth, and the forcing dataset for the Last Millennium experiment.

For those works, we did not have significant delay nor efficiency degradation, and based on them we consider that we did not have any significant problems in the structure and the methodology of implementation.

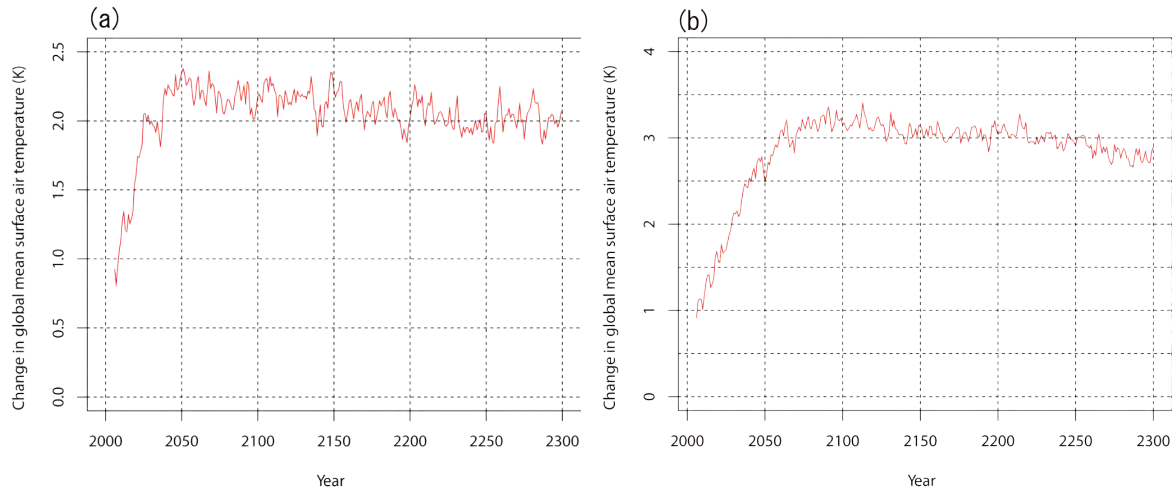


Fig.1 Result of climate stabilization scenario experiments
(a): 2 °C, (b): 3 °C

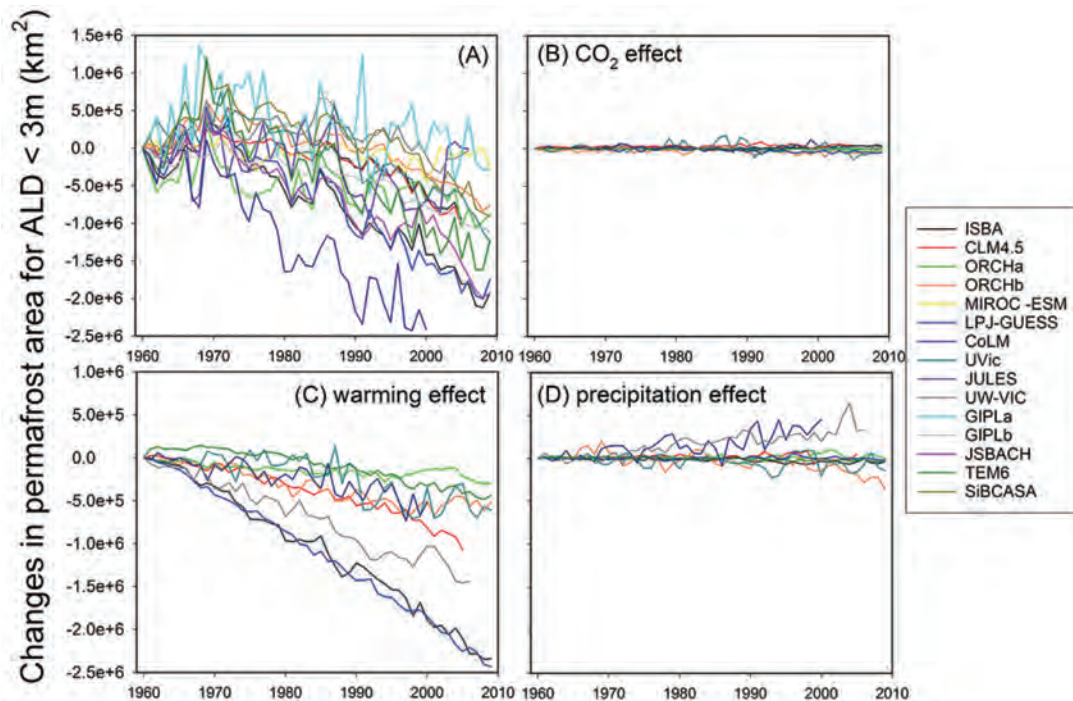


Fig.2 Response of permafrost to climate change [McGuire et al., 2016, GBC]
Permafrost area from 1960 to 2009 (A) and the contribution from changes in atmospheric carbon dioxide concentration (B), temperature (C), and precipitation (D) from 1960 to 2009 to simulated changes in permafrost area.

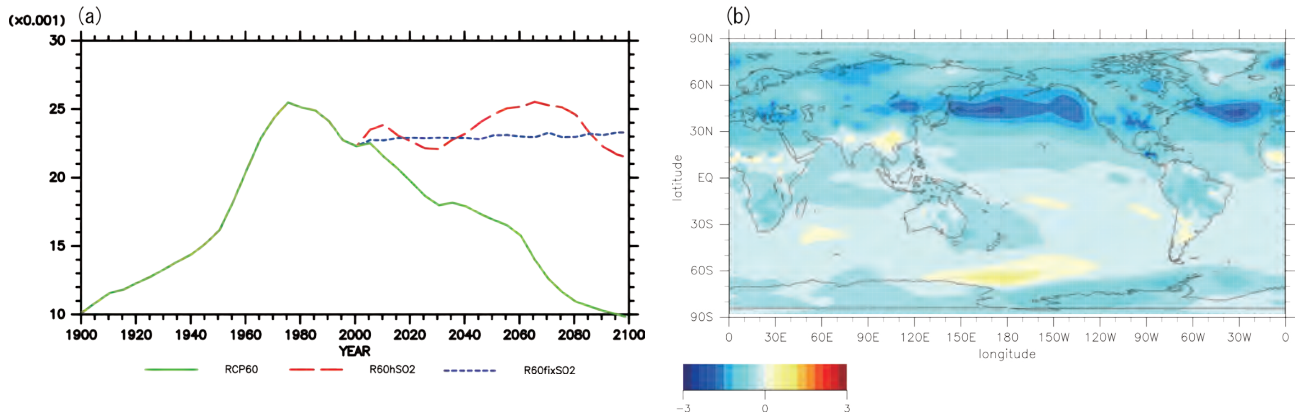


Fig.3 Impact of changing the aerosol reduction scenario in RCP6.0 to climate [Abe et al., in prep]
(a) aerosol emission scenario compared here, (b) difference of summer temperature between the cases where future SO₂ emission is reduced and not reduced.

Development and evaluation of the climate MIROC6 for the IPCC-AR6

We have developed the climate model MIROC6 for the purposes of contribution to the IPCC-AR6 and providing information on climate changes which could be used for political decision makings. In this fiscal year, model configuration has been frozen after implementing additional aerosol species in the aerosol transport module and tuning of radiation transfers, and preliminary climate simulations after 19th century have been done. The global-mean surface air temperature simulated in MIROC6 is consistent with observations (Fig.4). As for intrinsic climate variations, which influences the climate over Japan, Madden-Julian Oscillations (Fig.5), the summer and wintertime East Asian Monsoon, for example, are better represented in MIROC6 than in MIROC5 which is an official model for the previous IPCC. Because representation of intrinsic climate variations is important in climate predictions on seasonal-to-decadal timescales, it is expected that errors in climate predictions using MIROC6 might be smaller than in those with the previous climate model.

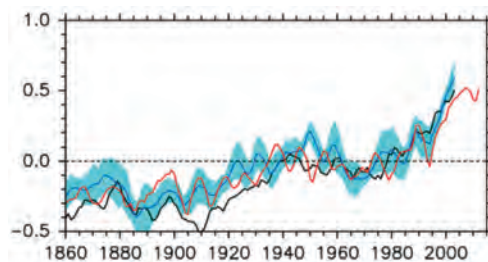


Fig.4 Time-series of the global-mean surface air temperature for observations (black line), MIROC6 (red), and MIROC5 (blue).
Anomalies are with respect to the climatological mean in 1961-90. A 5-yr running mean filter is applied.

I. Research Activities and Results

Department of Integrated Climate Change Projection Research

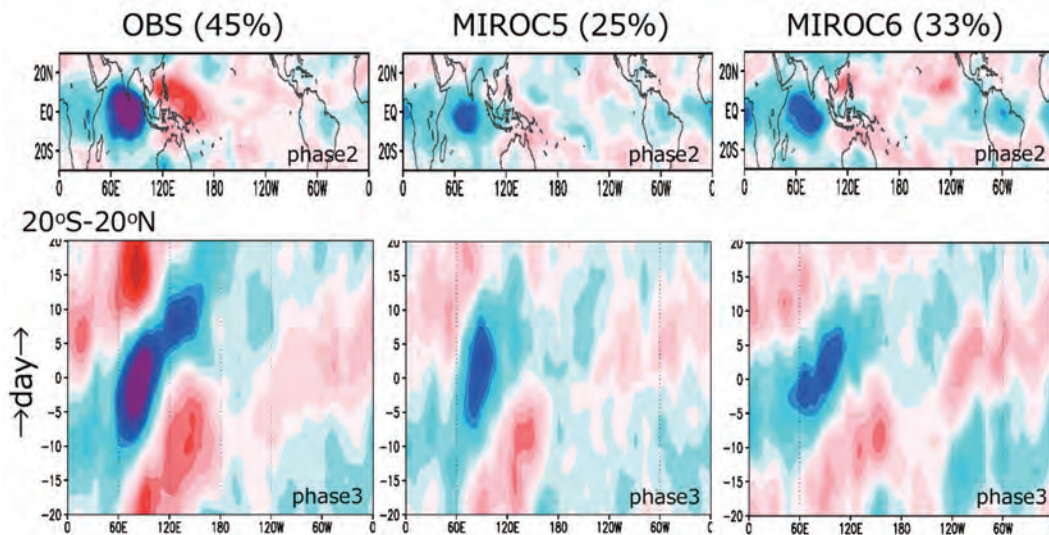


Fig.5 Time evolution of Madden-Julian Oscillation in observations (left), MIROC5 (middle), and MIROC6 (right). Signals of MJO are extracted based on *Wheeler and Hendon [2004]*. Variable in the figure is the outgoing longwave radiation at the top of the atmosphere.

Development of a new Earth system model with explicit climate–carbon/nitrogen cycles interactions

By introducing new parameterizations and component models into a climate model, a new Earth system model that has explicit climate-carbon/nitrogen interactions has been developed, and it is confirmed that the model can stably run on our HPC system over than a few centuries (with pre-industrial condition). This model enables us to simulate global nitrogen cycles in addition to global carbon cycle that have been already included in the former version of the model. Thus, the new model can simulate soil nutrient limitation on plant growth and resultant CO₂ uptake, and the limiting process has been confirmed to be working in its sensitivity analysis. This suggests that nitrogen cycle can make impact on climate by regulating carbon cycle, and the new model has possibilities to create scientific findings to make more accurate climate projections. Furthermore, the new model considers the process of nitrogen transportation from land to ocean, and it is confirmed in the simulations that riverine N can make impacts on the marine ecosystem activities (Fig.6). Since marine biogeochemistry in the model includes Fe, P, O cycles in addition to that of C and N, it can be a useful tool to analyze and understand global biogeochemistry and ocean ecosystem dynamics.

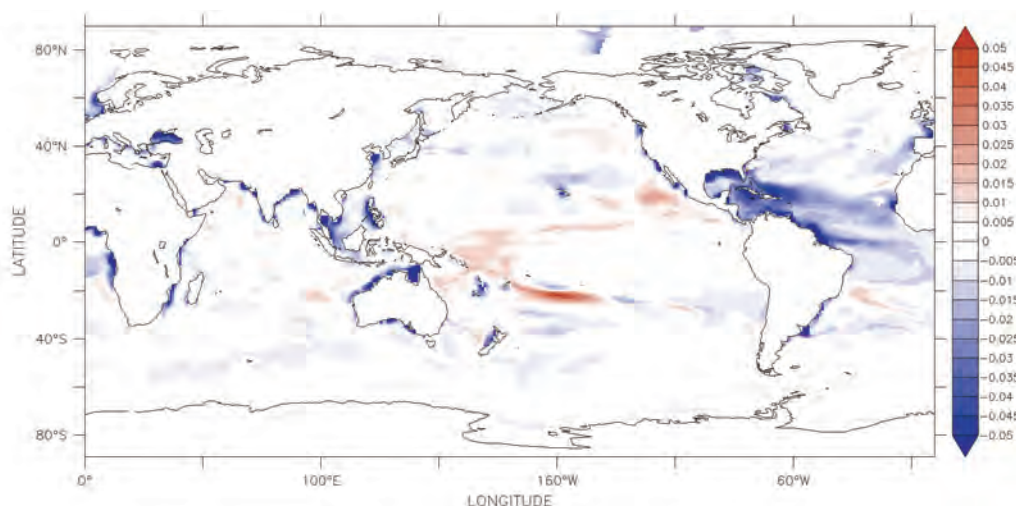


Fig.6 Impact of nutrient transportation by river on marine ecosystem, simulated by the new Earth system model: by taking difference of a) with and b) without riverine N transportation simulations.

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Structural changes of tropical cyclones due to global warming evaluated from NICAM simulations

We conducted NICAM simulations for present and warmer climate conditions with a horizontal grid size of 14 km to investigate structural changes of tropical cyclones (TCs) due to global warming. A composite analysis of TCs in the same categories of intensity between the two climate states shows larger (smaller) tangential wind velocity outside (inside) eyewall clouds. The mechanism of this change is caused due to both the increased diabatic heating in the eyewall clouds and the deepened tropospheric height. More diabatic heating warms the atmosphere there, which lowers pressure under it. As a result, lower pressure locally under the eyewall clouds causes a greater (smaller) pressure gradient outside (inside) the eyewall clouds, and thus the stronger (weaker) tangential wind velocity there. We conclude that the change of the exact location of diabatic heating, i.e., a slope of eyewall clouds, is important for this effect. More details are described in Yamada *et al.* [2017].

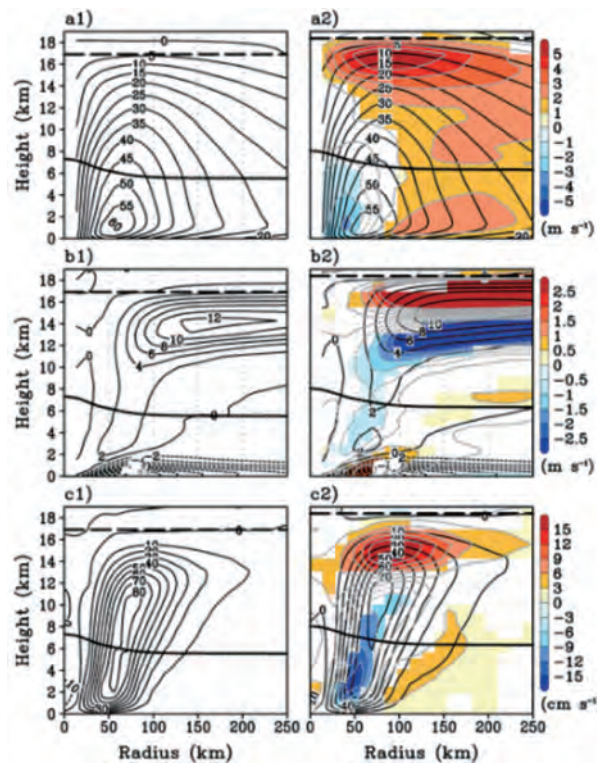


Fig.7 Height-radius cross sections of mean TC structure for the category of intensity C4 ($920(\text{hPa}) \leq P_c < 945(\text{hPa})$) in the present climate simulation. Left panels show the horizontal wind velocity (m/s) (a) in the tangential direction and (b) in the radial direction, (c) mean vertical velocity (cm/s). Right panels are the same as in the left, except for the result of warmer atmospheric experiment. Color shades with grey contour lines show changes due to global warming. Thick solid and thick broken lines show tropopause height and zero-degree height, respectively.

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Tropical cyclogenesis process simulated by a global 3.5-km mesh model – Department of Seamless Environmental Prediction Research –

Tropical cyclone (TC) is a typical phenomenon that cause meteorological disaster in Asian countries. Accurate prediction of the track and intensity of TCs are socially demanding, and the “Research to Operation” with this issue is highly expected. In particular, prediction of TC genesis is a tough problem because of its complexity under a broad range of scale-interactions among large-scale variabilities such as the Asian monsoon or the Intraseasonal Oscillation (ISO) [O(1000 km)], and mesoscale systems such as the eyewall clouds which comprise the inner core of the TCs [O(10 km)]. A global nonhydrostatic model, “Nonhydrostatic Icosahedral Atmospheric Model (NICAM)” [Sato *et al.*, 2014], which is capable of simulating various scales of cloud and precipitation phenomena in a uniform framework, forms a basis of our seamless environment prediction model. NICAM has been used for pioneering researches using state-of-the-art super computers including the Earth Simulator. In the FY2016, we investigated a leading process a tropical cyclogenesis case by global 3.5-km mesh simulations using the NICAM on the Earth Simulator [Nasuno *et al.*, 2016].

Genesis process of Typhoon Fengshen [2008], which occurred over the Philippine Sea in June [Yamada *et al.*, 2012], was studied. Figure 1a shows the large-scale fields several days before the TC genesis. The onset of western Pacific monsoon and the activation of the ISO caused large-scale moistening and a large-scale cyclonic gyre in the lower troposphere. The lower-tropospheric gyre extended upward through the latent heat release (Fig.1a, shading) and merged with a middle tropospheric trough (Fig.1a, contour lines), providing a favorable environment for establishment of the TC inner core (deep upright vortex). A precursor vortex of Fengshen, traveling across the Pacific and reached the western Pacific, was intensified under this environment by successive formation of deep convection near the vortex center, and develop into typhoon with a deep upright inner core (Fig.1b, c). We also confirmed the importance of the large-scale convective activity and the large-scale gyre associated with the ISO by sensitivity experiments; when these were weakened, TC genesis and development were significantly delayed (not shown).

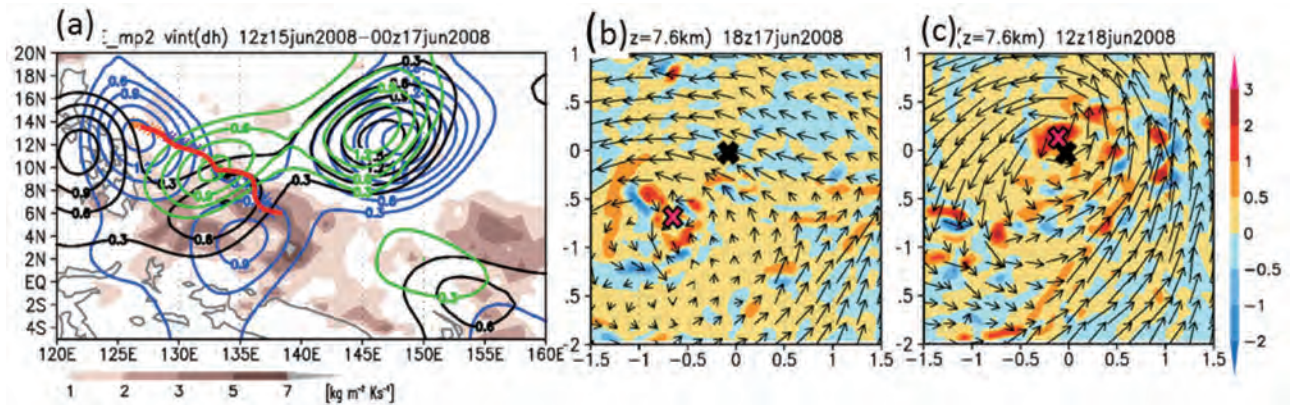


Fig.1 (a) Vertically integrated latent heating rate (shade) and middle tropospheric daily mean vorticity (contours; blue on 16 June, black on 17 June, and green on 18 June, 2008) in the global 3.5-km mesh simulation. Red line indicates the track of Fengshen. Zoomed plots of the simulated relative vorticity (color) and wind vectors at (b) 1800 UTC 17 June and (c) 1200 UTC 18 June, 2008 at $z = 7.6$ km around the center of the precursor vortex of Fengshen. Black and red crosses indicate the vortex center at $z = 1.5$ km and $z = 7.6$ km, respectively. (Fig.3c and Fig.6a, b of Nasuno *et al.* [2016] with modifications)

Fengshen is known by sever track biases in the operational forecasts [Cooper and Falvey, 2008] (i.e, northward biases; Fig.2a, blue lines). The northward biases were significantly reduced in the global 3.5-km mesh simulation in the present study, and we investigated the reason for that by vorticity budget analysis. In the global 3.5-km mesh simulation, upward motion and associated formation of positive vorticity were successively found to the west of the TC center (Fig.2b). In contrast, the operational forecast produced much weaker upward motion around the TC center because of the coarse mesh size (Fig.2c). This caused underproduction of the vorticity formation to the west, and resultant northward track biases in the presence of northward vorticity advection by the

I. Research Activities and Results

Department of Seamless Environmental Prediction Research

steering flow [Yamada *et al.*, 2016]. The improvement in the TC track simulation by increasing horizontal model resolution is a meaningful outcome, which had not been initially aimed. Interestingly, a systematic improvement in the TC track simulations in 7-km mesh models than in a 20-km mesh model was also found in the “global 7-km mesh nonhydrostatic model intercomparison project for improving typhoon forecast (TYMIP-G7)” [Nakano *et al.*, 2017].

Recently, increase in horizontal resolution in global models is accelerated worldwide. However, global simulations using finer than 5 km mesh is still mostly in preliminary stages, and few in-depth investigations on the mechanisms of phenomena had been made. Our studies described above serve as a basic step toward forthcoming model improvements and understanding of the multi-scale phenomena. As a next step, we plan to extend our target to observational cases in the international campaign “Years of the Maritime Continent” (2017-2019), under synergy between observation and modeling.

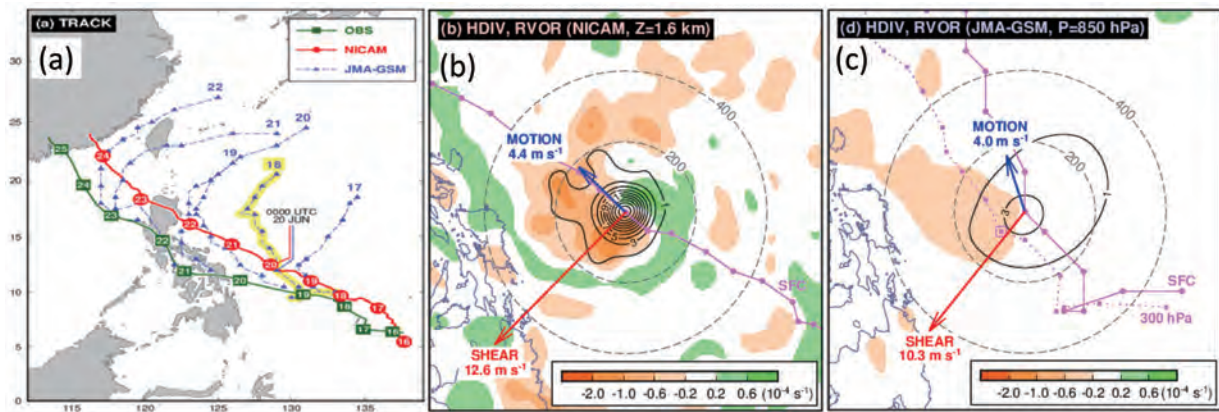


Fig.2 (a) Track of Fengshen [best track (green), the global 3.5-km mesh model (red), the JMA global model (blue)]. Vertical velocity (color) and relative vorticity (contour) in (b) the global 3.5-km mesh model and (c) the JMA global model in the lower troposphere at 0000 UTC 20 June, 2008. (Fig.1a, Fig.2b and 2d of Yamada *et al.* [2016])

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- Hashino, T., M. Satoh, Y. Hagihara, S. Kato, T. Kubota, T. Matsui, T. Nasuno, H. Okamoto, and M. Sekiguchi (2016), Evaluating Cloud Radiative Effects simulated by NICAM with A-train. *J. Geophys. Res. Atmos.*, *121*, 7041–7063, doi:10.1002/2016JD024775.
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- Yamada, H., T. Nasuno, W. Yanase, and M. Satoh (2016), Role of the vertical structure of a simulated tropical cyclone in its motion: A case study of Typhoon Fengshen (2008), *Scientific Online Letters on the Atmosphere*, *12*, 203–208, doi:10.2151/sola.2016-041.

Understanding of marine nitrogen cycle based on stable isotope analysis and modeling

– Department of Biogeochemistry –

The purpose of this group is to understand key processes and regulation mechanisms of nitrogen cycle including nitrous oxide (N_2O) in the ocean. For this purpose we made various kinds of water sampling for nitrogen isotope analysis and measured nitrogen isotope ratios of each component of marine nitrogen cycle (Fig.1), such as phytoplankton, chlorophylls, nitrate, ammonium, particulate organic nitrogen, nitrous oxide, and so on, with our elemental analyzer–isotope ratio mass spectrometer specifically modified to analyze small samples. By using these measured values, we developed marine ecosystem isotope models (Green part in Fig.1) to comprehensive and quantitative understand the marine nitrogen cycle. Furthermore, based on these marine ecosystem isotope models, we had developed a one-dimensional marine ecosystem isotopomer model in the last year, which can predict sea-to-air N_2O emissions directly. In this year we newly added ammonia compartment to predict the impact of ocean acidification on sea-to-air N_2O emission. We are planning to further extend to a global ocean model, and conduct global warming experiments with our model in the future.

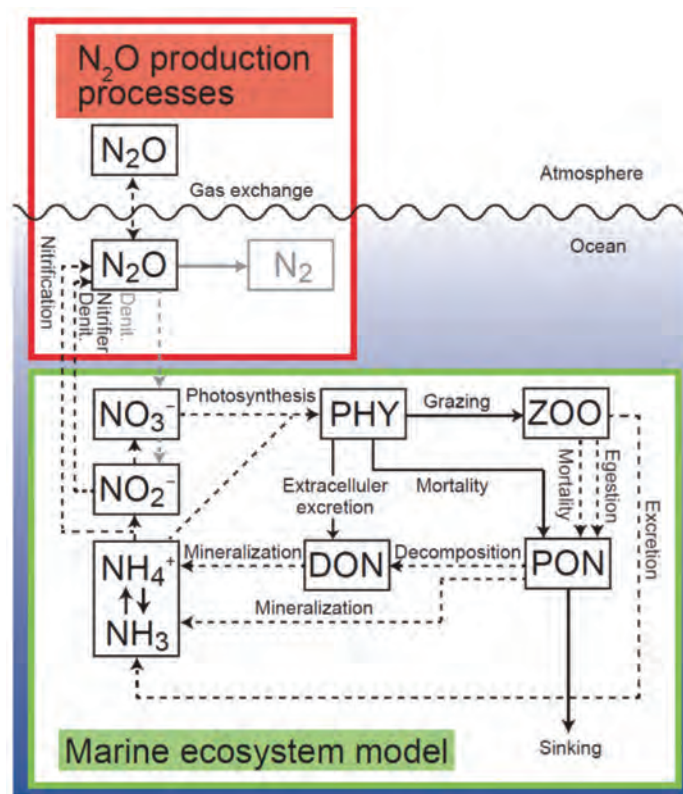


Fig.1 A schematic representation of the marine ecosystem isotopomer model, which consists of a marine ecosystem model based on *Yoshikawa et al.* [2005] and the N_2O production processes with nitrogen isotopomers based on *Yoshikawa et al.* [2016]. The symbols NO_3^- , NO_2^- , NH_4^+ , NH_3 , PHY, ZOO, PON, and DON represent the nitrate, nitrite, ammonium, ammonia, phytoplankton, zooplankton, particulate organic nitrogen, and dissolved organic nitrogen concentrations, respectively. The ammonia is newly added. The dashed and solid arrows indicate nitrogen flows with and without isotopic fractionation, respectively. The gray arrows indicate processes not represented in this study.

Insight into nitrous oxide production processes in the western North Pacific based on a one-dimensional marine ecosystem isotopomer model

Nitrous oxide (N_2O) is a greenhouse gas that also destroys the stratospheric ozone. Therefore, it is important to estimate accurately the global N_2O budget in order to better understand the factors that influence atmospheric N_2O concentrations, to develop global warming countermeasures, and to protect the ozone layer. Because estimates of total N_2O emissions vary widely (from 8.1–30.7 Tg N yr⁻¹ [IPCC, 2013]), it is necessary to reduce the uncertainty in the estimate of each emission source. Previous models have indirectly predicted marine N_2O emissions from the apparent oxygen utilization (AOU), based on the observed inverse relationship between the dissolved oxygen and N_2O concentrations in the ocean [Suntharalingam and Sarmiento, 2000; Jin and Gruber, 2003; Schmittner and Galbraith, 2008; Rickels et al., 2010; Zamora and Oschlies, 2014]. A model that simulates ammonium oxidation, nitrite reduction, and N_2O reduction explicitly and separately had yet to be reported in the literature.

The two main types of marine N_2O production are ammonium oxidation during nitrification and nitrite reduction during nitrifier denitrification and denitrification. The main marine N_2O consumption process is N_2O reduction during denitrification. Different microbes with distinctive substrates and enzymes mediate each of these processes. Hence, the N_2O production rate for each process has a different environmental dependency. N_2O isotopomers, the differences in the abundance of $^{14}\text{N}^{15}\text{N}^{16}\text{O}$ and $^{15}\text{N}^{14}\text{N}^{16}\text{O}$ (site preference [SP]) and the average nitrogen isotope ratio [$\delta^{15}\text{N}$] are useful tracers to distinguish the various N_2O production processes and have been used in different oceanic environments [e.g., Toyoda et al., 2002; Popp et al., 2002; Yamagishi et al., 2007]. To accurately estimate current and future marine N_2O emissions, we developed a model, which explicitly includes these processes by evaluating observed nitrogen isotope/isotopomer values.

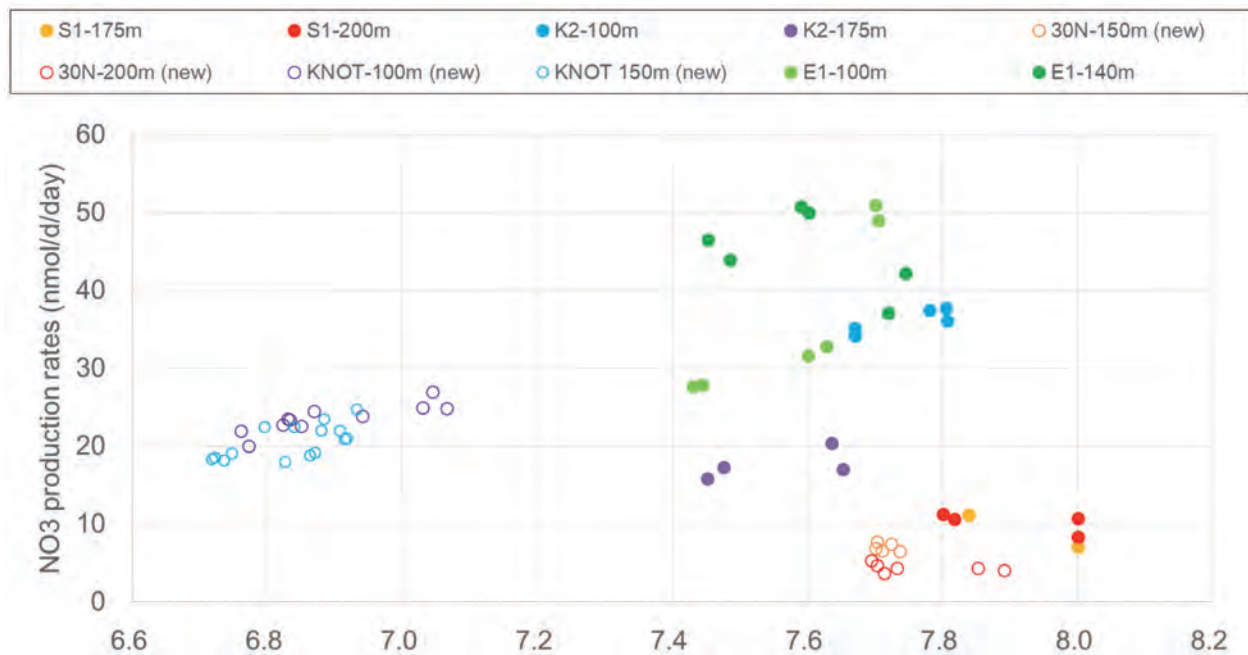


Fig.2 The observed ammonia oxidation rates when pH was experimentally reduced in the western subtropical (S1 and 30N) and subarctic (E1, K2, and KNOT) North Pacific [Breider et al., in prep.].

We had developed a one-dimensional marine ecosystem isotopomer model in the last year [Yoshikawa et al., in prep]. In this year an ammonium (NH_3) compartment with pH and temperature dependent terms were employed on our model to predict the impact of ocean acidification on sea-to-air N_2O emission. Figure 2 shows the ammonia oxidation rates when pH was experimentally reduced in the western subtropical and subarctic North Pacific. The acidification reduced ammonia oxidation rates at almost all stations. As the $\text{NH}_3/\text{NH}_4^+$ equilibrium is pH-sensitive and ammonia-oxidizing bacteria (AOB) and archaea (AOA) use preferentially NH_3 rather than

NH_4^+ , nitrification reaction might be partly inhibited under reduced pH. Our model was successfully simulated the reduction of nitrification rate under experimental acidification. The reduced pH by 0.4 decreases nitrification rate by 10-20 nmol/L/day and also decreases N_2O concentration up to 2 nmol/L in the high-nitrification depth of the bottom of mixed layer from summer to winter. As a result, the reduced pH decreases the marine N_2O emission from 40.4 to 37.8 mgN/m²/yr (6% reduction).

In this year we applied the marine N_2O isotopomer model to an aerobic ocean environment. The next step in improving the estimate of the global ocean N_2O emission will be the addition of denitrification processes to our model and the application of the model to oxygen-deficient zones.

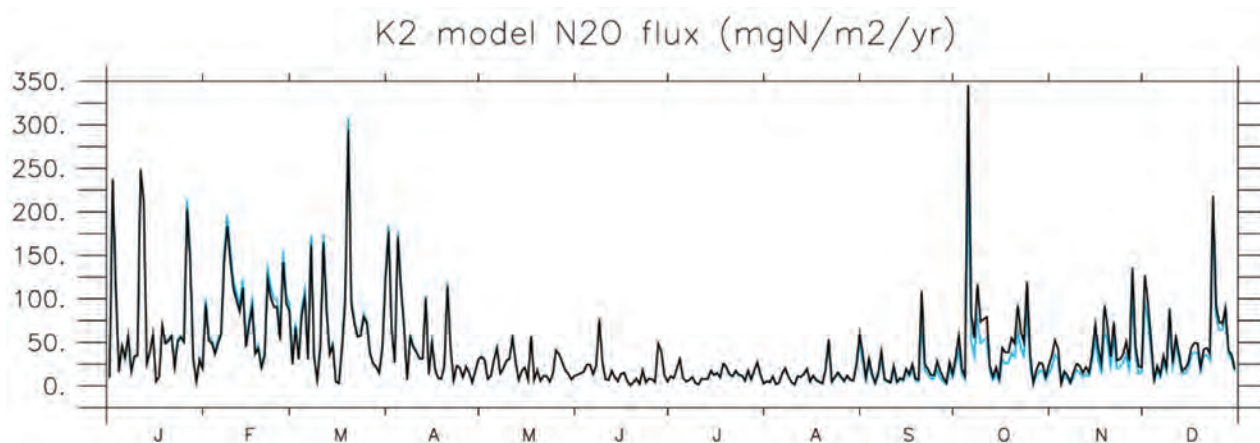


Fig.3 Simulated seasonal variations of sea-to-air N_2O emission flux at station K2. The black and blue lines show the fluxes in the control case and the reduced pH case, respectively.

Publication List

Publication with Peer Review (Published)

- Honda, M. C., M. Wakita, K. Matsumoto, T. Fujiki, E. Siswanto, K. Sasaoka, H. Kawakami, Y. Mino, C. Sukigara, M. Kitamura, Y. Sasai, S. L. Smith, T. Hashioka, C. Yoshikawa, K. Kimoto, S. Watanabe, T. Kobari, T. Nagata, K. Hamasaki, R. Kaneko, M. Uchimiya, H. Fukuda, O. Abe, and T. Saino (2017), Comparison of carbon cycle between the western Pacific subarctic and subtropical time-series stations: highlights of the K2S1 project, *Journal of Oceanography*, doi:10.1007/s10872-017-0423-3.
- Kajino, M., M. Ishizuka, Y. Igarashi, K. Kita, C. Yoshikawa, and M. Inatsu (2016), Long-term assessment of airborne radiocesium after the Fukushima nuclear accident: re-suspension from bare soil and forest ecosystems, *Atmospheric Chemistry and Physics*, 16(20), 13149–13172, doi:10.5194/acp-16-13149-2016.
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Research of Coastal Environment Change

– Mutsu Institute for Oceanography –

The aims of research program of the Mutsu institute for oceanography (MIO) are to investigate coastal environment changes and to understand biogeochemical cycle in coastal area which area might be affected by the global warming and the increasing carbon dioxide concentration. For this purpose, MIO is conducting observational studies around the eastern Tsugaru Strait under the collaborative agreements with the Hokkaido University and the Aomori Prefectural Industrial Technology Research Center.

Methods of our main researches are the measurement of surface current speed and direction using High frequency ocean radar system (HF radar), and the hydrographic observation in the eastern area of Tsugaru strait. The hydrographic observation by the training ship of Hokkaido University was started in 2009 and it has been conducted about 4 times a year. The surface water temperature off Sekinehama port which requested from the Aomori Prefectural Fisheries Experiment Station is measured from 2002 to distribute to fishermen. The high frequency observation was also added on the pier of Sekinehama Port to detect seasonal and annual environmental changes after we observed the cold Oyashio Water in 2014.

The HF radar has been installed and operated since April 2014. The current pattern maps obtained from HF radar are distributed to fishermen and others through web site, MORSET (MIO Ocean Radar data Site for Easter Tsugaru Strait, <http://www.godac.jamstec.go.jp/morsets/e/top/>) from September 2015. In the end of FY 2016, we started distributing the current map which drawn current pattern on the isobath diagram.

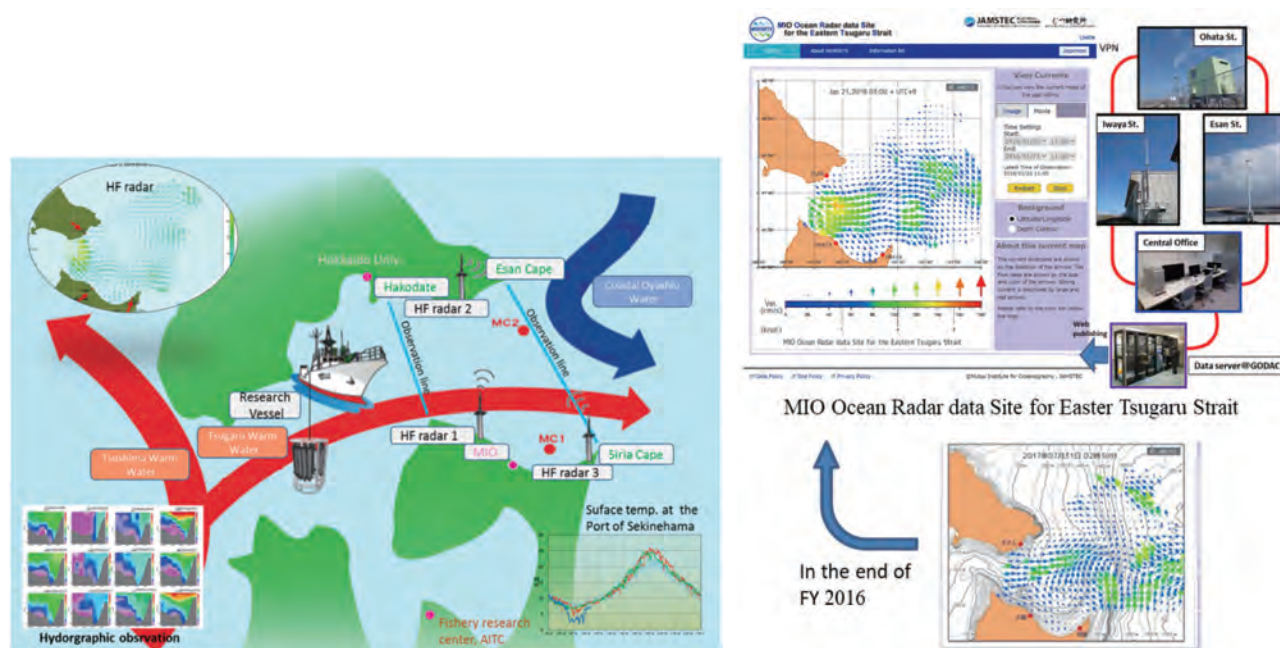


Fig.1 Schematic of MIO research program and web site of MORSETS

II. Related Activities

Research collaboration

1. Domestic research collaboration

(1) Institute of Low Temperature Science, Hokkaido University

Theme: Study of mechanism to sustain primary productivity and biogeochemical cycle in the subarctic North Pacific including its marginal seas such as Okhotsk and Bering Seas

Program: Research and Development Center for Global Change

(2) National Institute for Environmental Studies (NIES)

Theme: Improvement of observation using shipboard lidar for water vapor, cloud and aerosol over ocean

Program: Research and Development Center for Global Change

(3) Kyushu University, Institute for Advanced Study

Theme: Deposition of aerosol particles on the North Pacific and the Arctic region

Program: Research and Development Center for Global Change

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

Theme: Evaluation of a densitometer based on refractive index measurement

Program: Research and Development Center for Global Change

(5) The Tsurumi-seiki Co., Ltd.

Theme: A study on development of the next-generation deep profiling float equipped with the high-accuracy dissolved oxygen sensor

Program: Research and Development Center for Global Change

(6) JFE Advantech Co., Ltd.

Theme: Evaluation of pressure dependency of the dissolved oxygen sensor used for the next-generation deep profiling float

Program: Research and Development Center for Global Change

(7) Research Institute for Sustainable Humanosphere, Kyoto University / Metro Weather Co., Ltd.

Theme: Observational study of wind characteristics over ocean using shipboard Doppler lidar

Program: Research and Development Center for Global Change

(8) Institute of Tropical Medicine, Nagasaki University (NEKKEN)

Theme: Establishment of an Early-warning System for Infectious Diseases in Southern Africa Incorporating Climate Predictions

Program: Application Laboratory

(9) Kyoto University Graduate School of Advanced Integrated Studies in Human Survivability (GSAIS)

Theme: Advanced Ocean Modeling Combined with River Discharge Information

Program: Application Laboratory

(10) Kobe University

Theme: Studies on Model Expression to Better Describe Atmospheric Ozone Behavior Using Observations as Target

II. Related Activities

Research collaboration

Program: Department of Environmental Geochemical Cycle Research

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

Theme: Domestic Observations on Thermal and Hydrological States on and Below Surface

Program: Department of Integrated Climate Change Projection Research

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

Theme: Improvement of mesh meteorological data accuracy using a regional climate model

Program: Department of Seamless Environmental Prediction Research

(13) San-Ei Gen F.F.I., Inc.

Theme: Studies on the traceability of crucumin based on isotopic compositions

Program: Department of Biogeochemistry

2. International research collaboration

A. Interagency agreement (*extracted based on the areas of cooperation related to Research and Development on Marine and Global Environmental Change)

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

Theme:

- Arctic Research
Program: Institute of Arctic Climate and Environment Research
- Physical Oceanography and WOCE Hydrographic Lines Revisits
Program: Research and Development Center for Global Change
- Biogeochemistry and the Carbon Cycles
Program: Mutsu Institute for Oceanography
- Extra-tropical Ocean-Atmosphere variability and predictability
Program: Application Laboratory

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

Theme:

- Study of Ocean General Circulation and Climate
Programs: Research and Development Center for Global Change, and Application Laboratory
- Research into Marine Biogeochemical Cycles
Program: Research and Development Center for Global Change

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

Theme: Climate Change in Relation to Dynamics of Marine Ecosystem and Biogeochemical Cycles
Program: Department of Environmental Geochemical Cycle Research

(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 and IndoOS (Scientific and Technology Development Cooperation)
Program: Research and Development Center for Global Change
- 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: Research and Development Center for Global Change
- Arctic Observation and Research
Program: Institute of Arctic Climate and Environment Research
- CO₂ and other Autonomous Biogeochemical Sensors and Platforms including autonomous surface vehicles and autonomous underwater vehicles
Program: Research and Development Center for Global Change
- Computer Modeling for Global Environment Research
Program: Department of Integrated Climate Change Projection Research
- Ocean Acidification Observation and Research
Program: Research and Development Center for Global Change

II. Related Activities

Research collaboration

(5) University of Hawaii (UH), USA

Theme: Study on Climate Change and Variability in the Asia-Pacific region

Program: Application Laboratory

(6) University of Alaska Fairbanks (UAF), USA

Theme:

- Greenhouse Gas Dynamics of Boreal Forest and Tundra Ecosystems Vulnerability to Arctic Warming

Program: Department of Environmental Geochemical Cycle Research

- Arctic Ocean Observation Research

Program: Institute of Arctic Climate and Environment Research

- Northern Fresh Water Cycle and Changing Atmospheric Pattern

Program: Department of Environmental Geochemical Cycle Research

(7) The National Oceanography Centre (NOC) and The University of Southampton (UoS), UK

Theme:

- Geology and Geophysics (Palaeoceanography)

Program: Department of Biogeochemistry

- Physical Oceanography (The Argo Programme, Global Ocean Circulation)

Program: Research and Development Center for Global Change

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

Theme:

- Tropical Ocean Climate Observational Studies

Program: Research and Development Center for Global Change

- Climate Dynamics Research over the Maritime Continent

Program: Department of Coupled Ocean-Atmosphere-Land Processes Research

(9) The Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia

Theme:

- Heat, Carbon and other Material Transports through Ocean Circulation and their Variability

- Planktonic Community Comparisons, including those of the Continuous Plankton Recorder, in Australasian and Japanese regions

- Ocean Modelling and Data Assimilation

- Real-time Monitoring of the Global Ocean, including Polar and Deep-water Extensions

- Indo-Pacific Ocean and Atmosphere Dynamics

Program: Research and Development Center for Global Change

(10) 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: Institute of Arctic Climate and Environment Research

(11) Korea Institute of Ocean Science and Technology (KIOST), Korea

Theme:

- Western Pacific Ocean Circulation and Air-Sea Interaction
Program: Research and Development Center for Global Change
- Nonlinear Wave Interaction
Program: Application Laboratory

(12) Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI), Germany

Theme:

- Polar Research and Technology
Program: Institute of Arctic Climate and Environment Research
- Atmospheric Research
Program: Application Laboratory

(13) L'Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER), France

Theme:

- Ocean Monitoring
Program: Research and Development Center for Global Change
- Simulation Research with the Earth Simulator
Program: Application Laboratory

(14) Council of Scientific and Industrial Research – National Institute of Oceanography (NIO), India

Theme:

- Upper Ocean Dynamics and Air-Sea Interactions in the Tropical Indian Ocean
- Ocean Biogeochemistry in the Indian Ocean and Impact on Ocean Climate
Program: Research and Development Center for Global Change

(15) The Agency for Meteorology, Climatology and Geophysics of the Republic of Indonesia (BMKG), Indonesia

Theme: Marine Meteorology and Climate Studies over the Maritime Continent

Program: Department of Coupled Ocean-Atmosphere-Land Processes Research

(16) Institute of Marine Research (IMR), Norway

Theme: Marine Research (e.g. Carbonate chemistry and Biogeochemistry, Ocean dynamics and Climate variability)

Programs: Research and Development Center for Global Change, and Institute of Arctic Climate and Environment Research

(17) The Ministry of Earth Sciences (MOES), India

Theme:

- Observation System for Ocean Climate Variability
Program: Research and Development Center for Global Change
- Modeling of Climate Variability and its Application
Program: Application Laboratory

B. Research cooperation agreement between each research program and foreign institute on specific theme

(1) University of Alaska Fairbanks (UAF), USA

Theme:

- Greenhouse Gas Dynamics of Boreal Forest and Tundra Ecosystems Vulnerable to Arctic Warming
- Observational Research of Black Carbon in Alaska relevant to Climate and Environmental Changes in the Arctic

Program: Department of Environmental Geochemical Cycle Research

(2) University of Hawaii (UH), USA

Theme:

- Sub-seasonal Predictability of Tropical and Extratropical Climate Modes
Program: Application Laboratory
- High-resolution Atmospheric Modeling and Diagnosis
Program: Department of Seamless Environmental Prediction Research
- Mid-Latitude Ocean-Atmosphere Variability
Program: Application Laboratory
- Climate/biogeochemical Interactions in the North Pacific during the past 18,000 Years
Program: Research and Development Center for Global Change
- Unraveling the Coupled Air-Sea Interaction Processes in CFES in Shaping the Monsoon-Indian Ocean Basic States
Program: Application Laboratory

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

Theme: Pan-Arctic Climate Investigation

Program: Institute of Arctic Climate and Environment Research

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

Theme:

- Research Collaboration in Climatology, Meteorology, and Hydrometeorology over Indonesian Maritime Continent
Program: Department of Coupled Ocean-Atmosphere-Land Processes Research
- Tropical Ocean Climate Observational Studies
Program: Research and Development Center for Global Change

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

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

Program: Department of Environmental Geochemical Cycle Research

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

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

Program: Department of Environmental Geochemical Cycle Research

- (7) **Advanced Environmental Monitoring Research Center (ADEMRC), Gwangju Institute of Science and Technology, Korea**
Theme: Research Cooperation of Atmospheric Composition Change related to Environmental and Climate Change
Program: Department of Environmental Geochemical Cycle Research
- (8) **Universidad de Concepción (UDEC), Chile**
Theme: Basic Research on Paleoceanography, Biogeochemistry, Biology, Physical Oceanography and Geophysics in the Coastal Area off Chile
Program: Research and Development Center for Global Change
- (9) **Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) of the Department of Science and Technology (DOST), The Philippines**
Theme: Monsoon Experiment in the Republic of the Philippines
Program: Department of Coupled Ocean-Atmosphere-Land Processes Research
- (10) **Aero-Meteorological Observatory of National Hydro-Meteorological Service (AMO/NHMS), Vietnam**
Theme: Research Collaboration on Asian Monsoon Observation over Vietnam
Program: Department of Coupled Ocean-Atmosphere-Land Processes Research
- (11) **A.M. Obukhov Institute of Atmospheric Physics (IAP), Russian Academy of Sciences, Russia**
Theme: Research Cooperation of Atmospheric Composition Change related to Environmental and Climate Change
Program: Department of Environmental Geochemical Cycle Research
- (12) **Departement Oceanographie et Dynamique des Ecosystemes, L'Institut Français de Recherche pour l'Exploitation de la Mer (ODF/IFREMER), France**
Theme: Scale Interactions and Material Transport using Output from High-resolution Ocean Simulations
Program: Application Laboratory
- (13) **The Agency for Meteorology, Climatology and Geophysics of the Republic of Indonesia (BMKG), Indonesia**
Theme: Weather and Climate over the Indonesian Maritime Continent
Program: Department of Coupled Ocean-Atmosphere-Land Processes Research

Funded research projects

(1) Development of a New Ecosystem Model to Represent the Adaptive Capacity of Plankton Communities in the North Pacific (FY2012-2017)

Fund: Core Research for Evolutional Science and Technology (CREST)

Funding institution: Japan Science and Technology Agency (JST)

Program: Research and Development Center for Global Change

(2) Research on use and improvement of ocean database (FY2015-2017)

Fund: Environment Research and Technology Development Fund (ERTDF)

Funding institution: Meteorological Research Institute (MRI), Japan Meteorological Agency (JMA)

Program: Research and Development Center for Global Chang

(3) Commissioned business of measurement of certified reference material of nutrients (FY2016)

Institution: The General Environmental Technos Co., Ltd.

Program: Research and Development Center for Global Change

(4) Validation of GPM/DPR on the oceanic precipitating clouds by utilizing the data from R/V Mirai onboard instruments (FY2016-2018)

Fund: Precipitation Measuring Mission (PMM)

Funding institution: Japan Aerospace Exploration Agency (JAXA)

Program: Research and Development Center for Global Change

(5) Detection of temporal variation in marine primary production (FY2016-2018)

Fund: Environment Research and Technology Development Fund (ERTDF)

Funding institution: National Institute for Environmental Studies (NIES)

Program: Research and Development Center for Global Change

(6) Ocean Deployment of drifting buoys with pCO₂ Sensor – Toward Resolving Data Gap Area – (FY2016-2020)

Fund: Global Environment Research Account for National Institutes

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

Program: Research and Development Center for Global Change

(7) Prediction of newly found climate phenomena and its societal application (FY2014-2016)

Fund: Environment Research and Technology Development Fund (ERTDF)

Funding institution: Ministry of the Environment

Program: Application Laboratory

(8) Establishment of an Early-warning System for Infectious Diseases in Southern Africa Incorporating Climate Predictions (FY2014-2018)

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

Funding institution: Japan Agency for Medical Research and Development (AMED)

Program: Application Laboratory

- (9) **Assimilation of high-resolution satellite sea surface temperature data, including Himawari-8, into numerical ocean models and validation of the products (FY2015-2018)**
Fund: A contract research funded by Japan Aerospace Exploration Agency
Funding institution: Japan Aerospace Exploration Agency (JAXA)
Program: Application Laboratory
- (10) **Collection/arrangement/analysis of the scientific data and development of the nowcast systems for the information infrastructure (FY2016-2019)**
Institution: The Ocean Policy Research Institute, The Sasakawa Peace Foundation
Program: Application Laboratory
- (11) **Arctic Challenge for Sustainability (ArCS) (FY2015-2019)**
Fund: National flagship project funded by the Ministry of Education, Culture, Sports, Science and Technology
Funding institution: Ministry of Education, Culture, Sports, Science and Technology (MEXT)
Program: Institute of Arctic Climate and Environment Research
- (12) **Studies on effects of large-scale tropical disturbances upon climate in East Asia (FY2015-2017)**
Fund: Environment Research and Technology Development Fund (ERTDF)
Funding institution: Atmosphere and Ocean Research Institute (AORI), The University of Tokyo
Program: Department of Coupled Ocean-Atmosphere-Land Processes Research
- (13) **Science and Technology Experience Course (Course A) (FY2016)**
Fund: “Japan-Asia Youth Exchange Program in Science” (SAKURA Exchange Program in Science)
Funding institution: Japan Science and Technology Agency (JST)
Program: Department of Coupled Ocean-Atmosphere-Land Processes Research
- (14) **Integrated carbon observation and analysis system for early detection of carbon cycle change in global and Asia-Pacific region**
Developing an optimal combination of an atmospheric transport model and CO₂ inversion/assimilation method towards an integrated analysis system (FY2014-2016)
Fund: Environment Research and Technology Development Fund (ERTDF)
Funding institution: National Institute for Environmental Studies (NIES)
Program: Department of Environmental Geochemical Cycle Research
- (15) **Evaluation of spatio-temporal patterns in terrestrial carbon budget based on integrated land observation data (FY2014-2016)**
Fund: Environment Research and Technology Development Fund (ERTDF)
Funding institution: National Institute for Environmental Studies (NIES)
Program: Department of Environmental Geochemical Cycle Research
- (16) **Regional-scale aerosol observations and model evaluations (FY2014-2016)**
Fund: Environment Research and Technology Development Fund (ERTDF)
Funding institution: Graduate School of Science, The University of Tokyo
Program: Department of Environmental Geochemical Cycle Research

II. Related Activities

Funded research projects

(17) Estimation of Asian CH₄ emission and evaluation of emission reduction by inverse modeling (FY2015-2017)

Fund: Environment Research and Technology Development Fund (ERTDF)

Funding institution: Nara Women's University

Program: Department of Environmental Geochemical Cycle Research

(18) Impacts of Short-Lived Climate Pollutants from Asia on the Arctic Climate and Environment (FY2015-2017)

Fund: Environment Research and Technology Development Fund (ERTDF)

Funding institution: National Institute for Environmental Studies (NIES)

Program: Department of Environmental Geochemical Cycle Research

(19) Effective utilization of new satellite observations on air pollution at km-class spatial resolution for frontier science and policy on ozone and PM_{2.5} issues (FY2015-2017)

Fund: Coordination Funds for Promoting AeroSpace Utilization

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

Program: Department of Environmental Geochemical Cycle Research

(20) C budget of ecosystems and cities and villages on permafrost in eastern Russian Arctic (COPERA) (FY2015-2019)

Fund: Strategic International Research Cooperative Program “Belmont Forum”

Funding institution: Japan Science and Technology Agency (JST)

Program: Department of Environmental Geochemical Cycle Research

(21) Improvement of forest radiative transfer model (FY2016-2018)

Fund: Environment Research and Technology Development Fund (ERTDF)

Funding institution: Hokkaido University

Program: Department of Environmental Geochemical Cycle Research

(22) Acquisition of ground truth data for mapping of biophysical parameters of forest (FY2016-2018)

Fund: Global Change Observation Mission (GCOM)

Funding institution: Japan Aerospace Exploration Agency (JAXA)

Program: Department of Environmental Geochemical Cycle Research

(23) Research algorithm development of GCOM-C1 LAI/FAPAR, and NPP (FY2016-2018)

Fund: Global Change Observation Mission (GCOM)

Funding institution: Japan Aerospace Exploration Agency (JAXA)

Program: Department of Environmental Geochemical Cycle Research

(24) Elucidating variability of stratospheric circulations associated with a global warming (FY2015-2017)

Fund: Environment Research and Technology Development Fund (ERTDF)

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

Program: Department of Integrated Climate Change Projection Research

(25) Assessing dynamic permafrost degradation mechanism and vulnerability (FY2016-2018)

Fund: Environment Research and Technology Development Fund (ERTDF)
Funding institution: Ministry of the Environment
Program: Department of Integrated Climate Change Projection Research

(26) Investigation of the possibility to improve an Earth system model utilizing GCOM-C data (FY2016-2018)

Fund: Global Change Observation Mission (GCOM)
Funding institution: Japan Aerospace Exploration Agency (JAXA)
Program: Department of Integrated Climate Change Projection Research

(27) Climate change projection contributing to stabilization target setting promotion for climate change research and linkage coordination (FY2012-2016)

Fund: Program for Risk Information on Climate Change
Funding institution: Ministry of Education, Culture, Sports, Science and Technology (MEXT)
Program: Project Team for Risk Information on Climate Change

(28) Prediction and Diagnosis of Imminent Global Climate Change (FY2012-2016)

Fund: Program for Risk Information on Climate Change
Funding institution: Atmosphere and Ocean Research Institute (AORI), The University of Tokyo
Program: Project Team for Risk Information on Climate Change

(29) Impact of Short Lived Climate Pollutants on Global Water Cycle (FY2014-2018)

Fund: Environment Research and Technology Development Fund (ERTDF)
Funding institution: Kyushu University
Program: Department of Seamless Environmental Prediction Research

(30) Meteorological and Agricultural Information System (FY2014-2018)

Fund: Cross-ministerial Strategic Innovation Promotion Program
Funding institution: Central Region Agricultural Research Center (CARC), National Agriculture and Food Research Organization (NARO)
Program: Department of Seamless Environmental Prediction Research

(31) Globally Observed Teleconnections and their Role and Representation in the Hierarchies of Atmospheric Models (FY2016-2018)

Fund: Strategic International Research Cooperative Program “Belmont Forum”
Funding institution: Japan Science and Technology Agency (JST)
Program: Department of Seamless Environmental Prediction Research

(32) Development and improvement of the method for isolation and purification of various organic compounds to evaluate the dynamics of marine ecosystems and material cycling (FY2013-2018)

Fund: Core Research for Evolutional Science and Technology (CREST)
Funding institution: Japan Science and Technology Agency (JST)
Program: Department of Biogeochemistry

Awards

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

Dr. Kunio Yoneyama (Department of Coupled Ocean-Atmosphere-Land Processes Research)

The MJO study using research vessels and promotion of international field projects

(October, 2016)

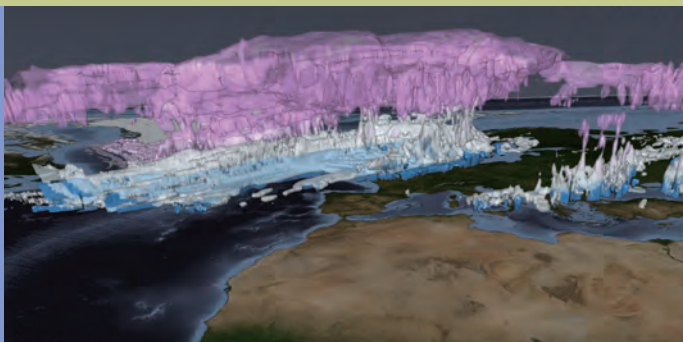
- **“Horiuchi Award” of the Meteorological Society of Japan**

Dr. Prabir K. Patra (Department of Environmental Geochemical Cycle Research)

Study on global circulation of greenhouse gases based on model analysis

(October, 2016)

Published by: Japan Agency for Marine-Earth Science and Technology (JAMSTEC)
Publication Date: February 2018
ISBN: 978-4-901833-36-3
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