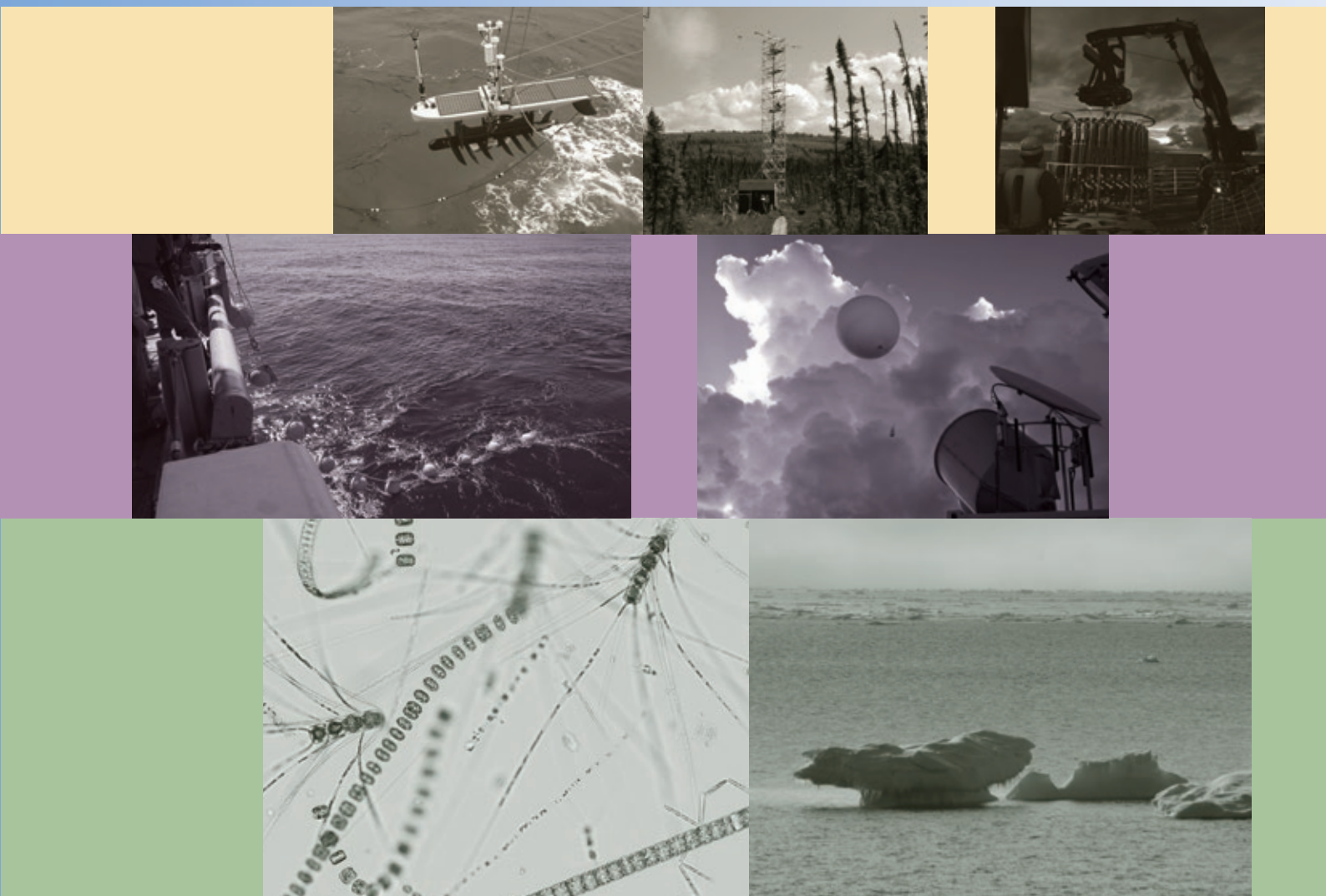




Research and Development on Marine and Global Environmental Change Annual Report FY2018



**Research and Development on Marine and Global
Environmental Change Annual Report FY2018
(April 2018-March 2019)**

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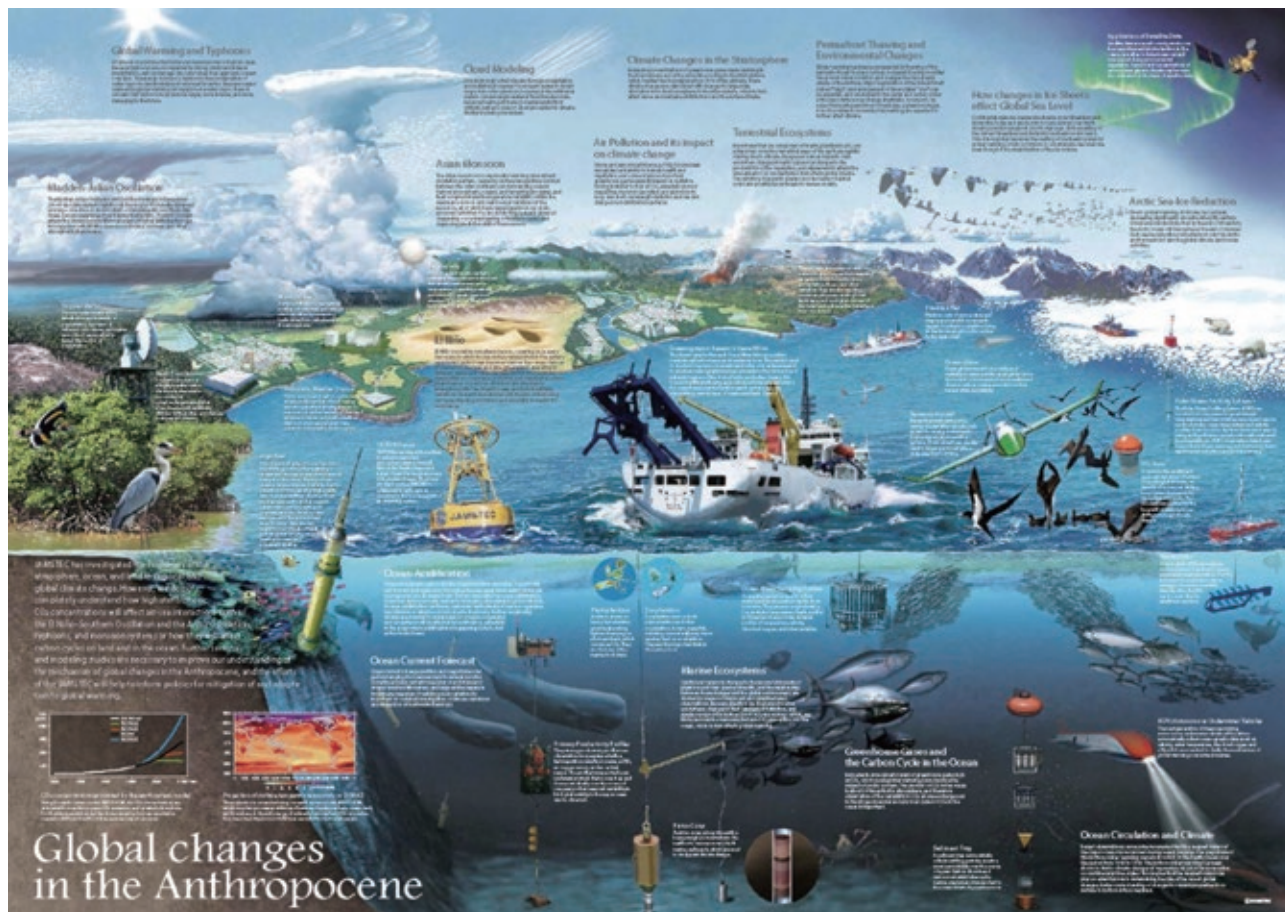
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I. Research Activities and Results

Changing Oceans and Global Environment – Research and Development Center for Global Change –

Research and Development Center for Global Change (RCGC), established in April 2014, aims to explore the oceans and other Earth subsystems to know their state and to detect signal of global environmental changes. Using multidisciplinary approach, including physics, chemistry, biogeochemistry, and ecology, we challenge to the unresolved issues from local to global scales. Several major achievements in this fiscal year are highlighted.



Human footprints in abyss

Marine debris, particularly marine plastics pollution is becoming one of the most serious global environmental issues caused by direct human activities. Its impact on marine environment and ecosystem should be urgently studied and assessed. While it is suggested that deep-sea is likely the major sink of marine plastics, there is little scientific knowledges on its distribution, link to surface data, and impact on valuable biodiversity of the rare deep-sea ecosystems.

The Global Ocean Data Center (GODAC) of JAMSTEC has launched Deep-sea Debris Database in 2017, which summarized marine debris information found on the photos and videos footages which were taken through more than 5000 dives of deep-sea submersibles and remote operating vehicles since the 1980s (<http://www.godac.jamstec.go.jp/catalog/dsdebris/e/>).

We analyzed the data of Deep-sea Debris Database, and quantitatively reported the distribution of marine macro-debris on the deep-sea floor of the world ocean on the international science-policy journal [*Chiba et al.*, 2018]. Collaborating with the World Conservation Monitoring Centre, the relative organization of the UN Environmental Programme which has been leading the fighting against marine plastic pollution, we focused on the information of single-use plastics such as plastic bags, PET bottles and food containers. The published paper is the first report of propagation of macro-plastic debris on the sea floor deeper than 6000 m. As the UNEP newsletter picked up the story, our finding has attracted much attention of the major international media, and been reported worldwide. Highlights of the paper are as follows.

Plastic debris accounted for 33% of all artificial debris, which includes metal, rubber, fabric, glass, and fishing net*, among which, 89% are single-use plastics. The ratio of plastics and single-use plastics increased to 52% and 92% on the sea-floor deeper than 6000 m, suggesting plastics could be more easily transported to offshore and deep-seas compared to other marine debris (Fig.1). The deepest record was the fragment of plastic bags at 10898 m in Mariana Trench. Single-use plastics were often observed to provide sessile animals with substrate to attach on the soft seafloor where they are normally unable to settle (Fig.2). Thus, besides the impact by entanglement and covering on deep-sea organisms, plastics would introduce the novel species to deep-sea ecosystems and risk its biodiversity.

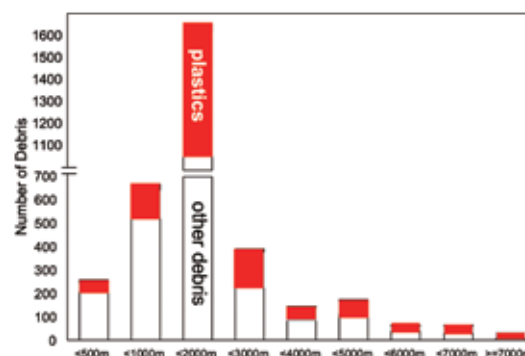


Fig.1 Distribution of marine debris by depth range.



Fig.2 Sea anemone settled on a plastic bag. Depth 501 m, Date: May 11, 2012, Off Otsuchi.
Deep-Sea Debris Database ID: HPD1384OUT0048
<http://www.godac.jamstec.go.jp/jedi/player/e/HPD1384OUT0048>

There is a momentum in international ocean observing community toward the establishment of the global monitoring network to measure marine debris and plastics in a harmonized manner. At the same time, Global Ocean Observing System (GOOS) are considering development of new Essential Ocean Variables (EOVs) for marine debris/plastics. Our paper stresses the urgent need of strengthening the link of ocean observing community and policy, and the framework to promote it.

* Although rubber, fabric and fishing net recorded in the database quite likely are made of synthetic materials, we here separate these materials from plastics. Therefore, our study may underestimate the possible threats of marine plastic pollution.

Reference

Chiba et al. (2018), Human footprint in the abyss: 30year records of deep-sea plastic debris, *Marine Policy*, 96, 204–212, <https://doi.org/10.1016/j.marpol.2018.03.022>.

Annual Rossby Waves Below the Pycnocline in the Indian Ocean

Argo floats periodically move up and down between the sea surface and (nominally) 2,000-m depth and provide valuable in situ measurements of ocean temperature and salinity with unprecedented density. Nagura [2018] collected and processed these observations and examined annual variability in the Indian Ocean, which had been a data-sparse region until the advent of Argo floats. Pressure and horizontal velocity below the pycnocline of the Indian Ocean was estimated using in situ hydrographic observations obtained from Argo floats and conductivity-temperature-depth sensors. Pressure and velocity at 1,000-m depth show significant annual variability in the Arabian Sea and between 10°S and 20°S in the South Indian Ocean (Fig.3). Wavenumbers were estimated by fitting a straight line to annual harmonic phase by amplitude-weighted least squares fit. Results showed that vertical wavenumber tends to decrease poleward in both hemispheres, and vertical wavelength is more than tripled from about 5,000 m at 5°N/S to 16,000 m at 20°N/S. The inverse radius of deformation squared (defined as $f^2 m^2 / N^2$) does not show clear dependence on latitude, because poleward increase in the magnitude of the Coriolis parameter (f) compensates for poleward decrease in vertical wavenumber (m), and Brunt-Väisälä frequency (N) varies little meridionally in the analysis domain. According to the dispersion relation of quasi-geostrophic Rossby waves, these meridional structures in m and deformation radius result in steeper angle of ray trajectory at a higher latitude in the longitude-depth plane. Energy estimated from in situ observations shows a consistent pattern with this expectation. The line of constant phase of annual pressure harmonic is steeper in angle at higher latitudes, which is also expected from the uniform deformation radius and constant N . This result indicates that energy penetrates deeper at higher latitudes at the annual timescale in the Indian Ocean.

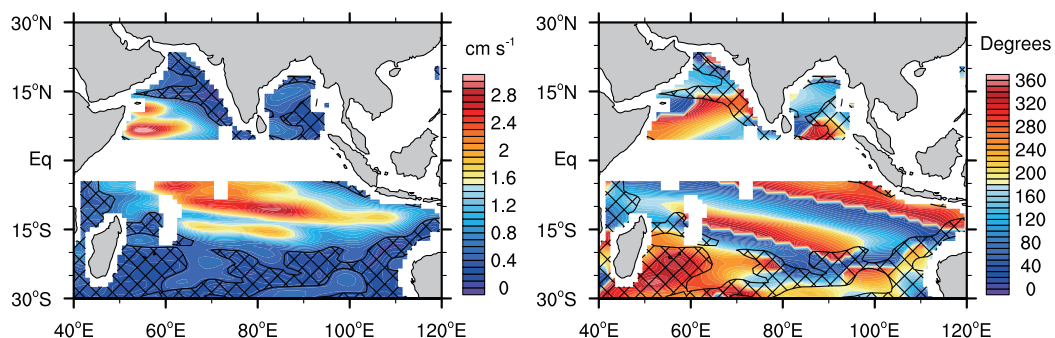


Fig.3 (Left) Amplitude and (right) phase for annual harmonic of zonal velocity at 1,000-m depth. Hatched is the region where annual harmonic amplitude is smaller than analysis error.

Reference

Nagura, M. (2018), Annual Rossby waves below the pycnocline in the Indian Ocean, *Journal of Geophysical Research – Oceans*, 123, 9405–9415, <https://doi.org/10.1029/2018JC014362>.

New Deep-ocean Profiling Floats Reveal Rapid Decrease in Antarctic Bottom Water

In the coastal regions near Adélie/George V Land, dense water has been formed as a result of a large amount of sea ice formation at the Mertz Glacier Polynya. The water descends into the deep ocean and forms the AABW by mixing with surrounding waters. Recently however, the mechanism of sea ice formation in the region has changed drastically due to the calving of the Mertz Glacier Tongue in 2010. It is likely that this event changed the properties of the AABW off the Adélie/George V Land coast; however, the details have yet to be clarified due to a lack of available data.

To examine changes in the AABW off the Adélie/George V Land coast, JAMSTEC's research vessel (R/V) *Mirai* deployed the "Deep NINJA" deep-ocean profiling float in December 2012 (Fig.4). The float can allow us to examine the changes in the AABW off the Adélie/George V Land even under the sea ice during the Antarctic winter. We analyzed 20-months of observation data obtained by these floats along with other historical hydrographic data (Fig.5). As a result, we discovered that the thickness of the AABW has been decreasing by 57 m per year since 2011, which is four to five times faster than its average of 12 m per year since the 1990s (Fig.6).

The reduced supply of AABW could affect not only the waters surrounding the region, but also ocean circulation, material cycles, and global climates. Therefore, the long-term monitoring and analysis of changes in the AABW is important to estimate its impacts on the climate. This is the first study to identify changes in water masses and/or ocean circulation using deep-ocean profiling floats [Kobayashi, 2018].



Fig.4 Deep-ocean profiling float "Deep NINJA" is deployed in the Antarctic Ocean from the R/V *Mirai*.

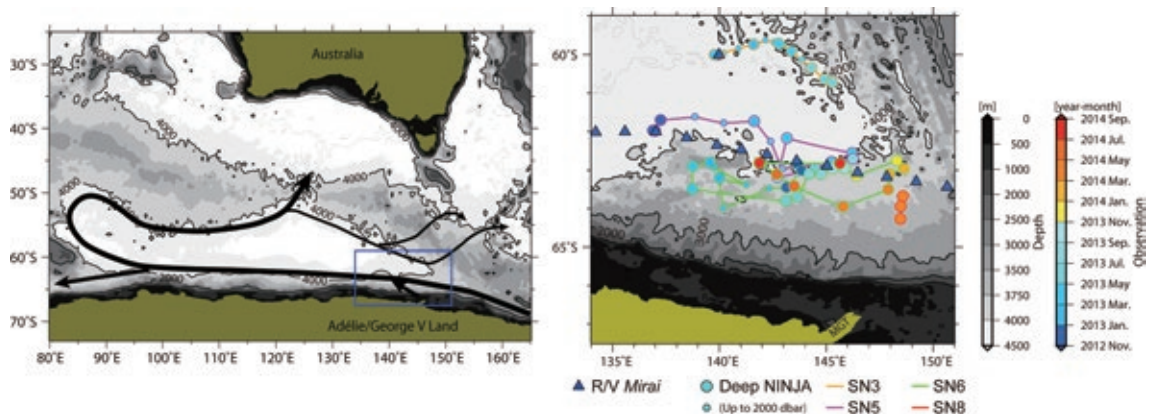


Fig.5 Left) Oceanic region in which this research took place. The black arrow represents the flow of the AABW. Right) Observation points by the "Deep NINJA" deep-ocean profiling floats and the R/V *Mirai*.

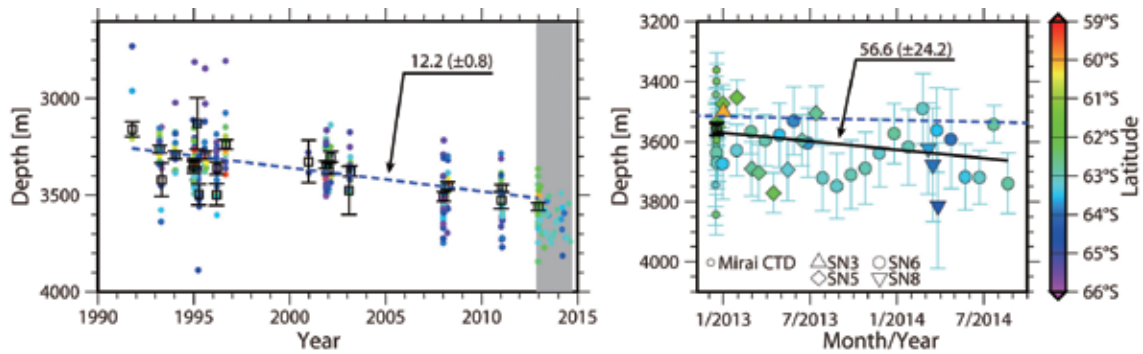


Fig.6 Depth changes at the upper boundary of the AABW at the reference station of 140°E 62°S. The square box with solid error bar represents the average and the standard error of the data collected during each observation cruise. As indicated here, the upper boundary of the AABW is getting deeper, meaning that the overall thickness of the AABW is decreasing. The average thinning rate beginning in the 1990s was 12.2 m/year (shown by the blue dashed lines), while the “Deep NINJA” observations showed a rate of 56.6 m/year (black solid line).

Reference

Kobayashi, T. (2018), Rapid volume reduction in Antarctic Bottom Water off the Adélie/George V Land coast observed by deep floats, *Deep Sea Research Part I*, 140, 95–117, doi:10.1016/j.dsr.2018.07.014.

We found significant increases of anthropogenic CO₂ in Antarctic Bottom Water

The ocean absorbs about 30% of CO₂ emitted into the atmosphere as a result of human activities, which we term “anthropogenic CO₂”. The Southern Ocean undertakes about 40% of anthropogenic CO₂ entering the ocean. Therefore, to investigate Southern Ocean CO₂ uptake is an important task for the prediction of global warming caused by anthropogenic CO₂ increases in the atmosphere.

As part of Japan Agency for Marine-Earth Science and Technology expedition MR12–05 by R/V *Mirai* (cruise dates: 28 November 2012 to 15 February 2013) conducted under the framework of the Global Ship-based Hydrographic Investigations Program (GO-SHIP), we collected data along the WOCE SO4 section, nominally at ~62°S in the Southern Ocean (Fig.7). In this study, we calculated anthropogenic CO₂ by using high quality data for salinity, temperature, dissolved inorganic carbon (C_T), dissolved oxygen (DO), and total alkalinity (A_T) collected during that cruise from 33°E to 160°E. We used data for dichlorodifluoromethane (CFC-12) and sulfur hexafluoride (SF₆) as a proxy for increases of anthropogenic CO₂. Data for salinity, temperature, DO, CFC-12, and SF₆ were obtained at each station, whereas C_T and A_T data were taken every few stations. The analytical methods were nearly the same as those in previous studies [Murata *et al.*, 2007, 2010].

To detect decadal-scale increases of anthropogenic CO₂ in the region, we compared our GO-SHIP data with high-quality data obtained between 1994 and 1996 during the cruises of World Ocean Circulation Experiment (WOCE) program by R/V *Nathaniel B. Palmer* from 3 May to 4 July 1996 [Takahashi *et al.*, 2005] and by R/V *Aurora Australis* from 13 December 1994 to 1 February 1995 [Tilbrook & Rintoul, 1995]. We combined the data from the two cruises so as to nearly match the GO-SHIP observation line.

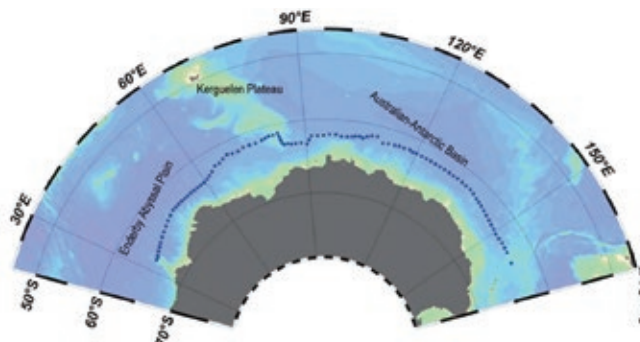


Fig.7 Station map for R/V *Mirai* cruise MR12–05 along the WOCE SO4 section from 28 November 2012 to 15 February 2013.

I. Research Activities and Results

Research and Development Center for Global Change

Decadal-scale increases of anthropogenic CO_2 were calculated according to the method used in our previous studies [Murata *et al.*, 2007, 2010]. Different from our previous studies, in this study, we introduced a term to subtract changes of C_T caused by dissolution or production of calcium carbonate (CaCO_3), because alkalinity changes are not negligible in the Southern Ocean [e.g., Freeman & Lovenduski, 2015]. The decadal change in anthropogenic CO_2 was computed by subtracting anthropogenic CO_2 estimated for WOCE from those for GO-SHIP.

We also utilized CFC-12 concentrations (pmol/kg) to confirm spatial variations of anthropogenic CO_2 in the ocean, a widely used practice [Huhn *et al.*, 2013]. Although the efficacy of CFC-12 as a tracer for estimating water mass ages is waning as atmospheric CFC-12 concentrations decrease from their levels since the mid-1990s (observations from NOAA's Global Monitoring Division at <http://www.cmdl.noaa.gov/hats>), it is still a useful proxy for the uptake and redistribution of atmospheric gases. Unlike CFC-12, SF_6 continues to increase in concentration in the atmosphere; thus, this gas may remain a good proxy. We used SF_6 concentrations (fmol/kg) from the most recent cruise to examine ventilation and circulation conditions in the study area.

We found a clear contrast in distributions of increases of anthropogenic CO_2 (hereafter abbreviated as ΔantCO_2) across the Kerguelen Plateau between the eastern (Australian-Antarctic Basin) and western (Enderby Abyssal Plain) sides, ΔantCO_2 being large and positive ($>5 \mu\text{mol/kg}$) at all depths in the Australian-Antarctic Basin and smaller or even negative ΔantCO_2 in the Enderby Abyssal Plain (Fig.8a). The negative ΔantCO_2 in the upper layers around the Kerguelen Plateau may reflect short-term variations of caused by topographic steering that mask decadal signals.

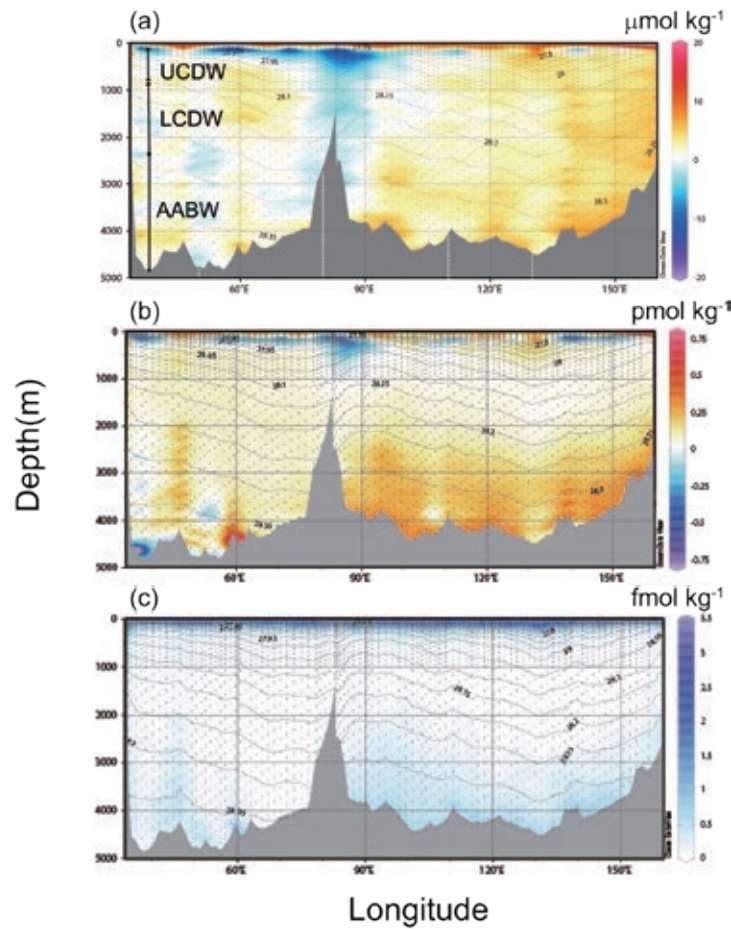


Fig.8 Depth-longitude sections of (a) ΔantCO_2 , (b) $\Delta\text{CFC-12}$, and (c) SF_6 concentrations at 62°S . Bathymetry is shown in gray. The peak around 80°E represents the Kerguelen plateau. Contours show γ_n (contour interval, 0.05 kg/m^3) and dots show sampling depths. White dashed lines in (a) are boundaries of longitudinal sectors. Water masses are also indicated in (a), except for AASW, which overlies UCDW. We adopted the following definitions of water masses from Williams *et al.* [2015]: $\gamma_n \leq 27.75 \text{ kg/m}^3$ for Antarctic Surface Water (AASW), $27.75 \text{ kg/m}^3 < \gamma_n \leq 28.15 \text{ kg/m}^3$ for Upper Circumpolar Deep Water (UCDW), $28.15 \text{ kg/m}^3 < \gamma_n \leq 28.27 \text{ kg/m}^3$ for Lower Circumpolar Deep Water (LCDW), and $\gamma_n > 28.27 \text{ kg/m}^3$ for Antarctic Bottom Water (AABW).

The distribution pattern of $\Delta\text{CFC-12}$ is similar to that of ΔantCO_2 ; in that, $\Delta\text{CFC-12}$ values are large and positive in the deep and bottom layers ($\gamma^n > 28.25 \text{ kg/m}^3$) of the Australian-Antarctic Basin and smaller but still positive in the Enderby Abyssal Plain (Fig.8b). However, large positive values of $\Delta\text{CFC-12}$ around 45°E and 60°E do not appear distinctly in the ΔantCO_2 results. These local signals are probably associated with AABW produced in the Cape Darnley polynya [Ohshima *et al.*, 2013]. They appear in the $\Delta\text{CFC-12}$ data because CFC-12 measurements are more responsive in water mass changes due to shorter air–sea equilibrium time than calculated values of anthropogenic CO_2 . Although we found large positive ΔantCO_2 values throughout the water column east of 120°E , they were not matched in the $\Delta\text{CFC-12}$ results. If upwelling of old deep water increased AOU in an earlier cruise, increases of anthropogenic CO_2 between two cruises are calculated to be high. In addition, enhanced biological production can affect the disequilibrium of CO_2 between atmosphere and sea surface [Arrigo *et al.*, 2008] such that the upper water layers can draw more anthropogenic CO_2 from the atmosphere.

Vertical distributions of SF_6 have their maxima ($>2.0 \text{ fmol/kg}$) in AASW throughout the section (Fig.8c). In the Australian-Antarctic Basin, SF_6 has a broad minimum ($<0.1 \text{ fmol/kg}$) between 500 and 3,000 m, then increases from 3,000 m to the bottom, reaching values greater than 0.2 fmol/kg along the seafloor. In the Enderby Abyssal Plain, concentrations are low ($<0.1 \text{ fmol/kg}$) from 500 m to the bottom east of 70°E . As with $\Delta\text{CFC-12}$, local signals of SF_6 appear around 45°E and 60°E .

Previous studies have noted that sea ice inhibits the air–sea exchange of CO_2 and hence the storage of anthropogenic CO_2 [e.g., Poisson & Chen, 1987]. However, Arrigo *et al.* [2008] argued in the case of the Ross Sea that the continental shelf and its associated coastal polynyas, where AABW forms, are a strong anthropogenic CO_2 sink due to factors including high biological productivity, intense winds, high ventilation rates, and extensive winter sea ice cover. Because the Ross Sea produces part of the AABW in the Australian-Antarctic Basin, we believe that the mechanism of Arrigo *et al.* [2008] applies to the basin. In any case, large increases of anthropogenic CO_2 approaching the CO_2 equilibrium are reported elsewhere in the Southern Ocean [McNeil *et al.*, 2001]. Therefore, we conclude that AABW serves as an efficient storage of anthropogenic CO_2 .

Our result highlights the importance of anthropogenic CO_2 stored in AABW in estimates of the global carbon budget, because AABW infiltrates and affects almost the entire world ocean.

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I. Research Activities and Results

Research and Development Center for Global Change

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Tilbrook, B., and S. Rintoul (1995), Hydrographic, chemical and total CO₂ data obtained during the RSV *aurora australis* in the Southern Pacific Ocean during WOCE Section P12 (SR03/S04, EXPOCODE 09AR9404_1), (13 December, 1994–01 February, 1995), <http://cdiac.ornl.gov/ftp/oceans/p12woce/>. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Department of Energy, Oak Ridge, Tennessee, https://doi.org/10.3334/CDIAC/otg.09AR9404_1.

Atmospheric PM_{2.5} Nitrogen Components Increase Phytoplankton Levels

Nutrients such as nitrogen compounds, which control the amount of phytoplankton near the ocean's surface, are mostly supplied by deep ocean circulation. Figure 9 shows schematic diagram of processes supplying nutrients to the ocean's surface. However, in the western North Pacific subtropical area, the amount of nutrients supplied to the ocean's surface in this manner is extremely small, indicating the importance of nutrients sourced from the atmosphere instead. Until now, the effects of the nutrient supply process from the atmosphere have only been estimated based on the amount of nutrients deposited into the ocean; quantitative evaluations considering process-level response of marine ecosystems as well have not been previously undertaken.

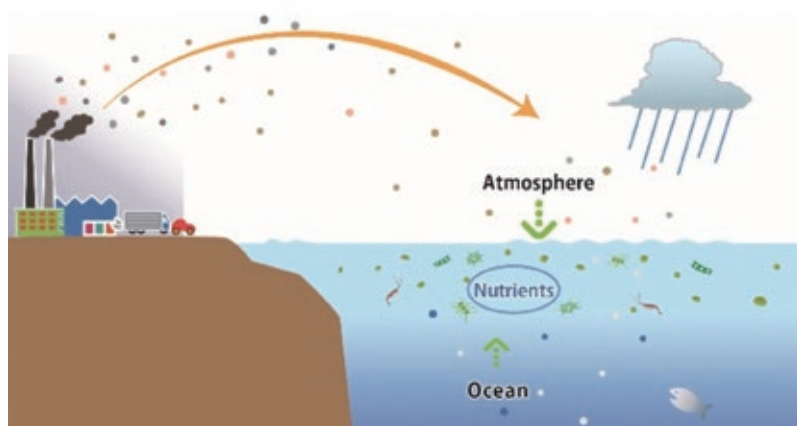


Fig.9 Schematic diagram of processes supplying nutrients to the ocean's surface, including atmospheric deposition and ocean circulation.

To better understand this process across the atmosphere and ocean, we developed improved numerical models by combining an atmospheric regional chemical transport model (WRF-CMAQ) and a 3-D lower trophic-marine ecosystem model (NEMURO). Then, these models were coupled on JAMSTEC's Earth Simulator supercomputer to accurately estimate the response of phytoplankton in the western North Pacific to deposition of nitrogen compounds emitted in East Asia. The monthly mean values for the wet and dry deposition of nitrogen compounds, including gases (HNO₃ and NH₃) and aerosol particles (NO₃⁻ and NH₄⁺), were determined using the WRF-CMAQ for the western North Pacific subtropical area from 2009–2016. These values were input into the NEMURO for the sea surface layer as an additional nitrogen source.

Figure 10 shows the annual mean spatial distribution of phytoplankton (chlorophyll a) mass concentration in the surface calculated by the NEMURO with and without nitrogen deposition from the atmosphere into the ocean [Taketani *et al.*, 2018]. Phytoplankton concentration increases noticeably in low- to mid-latitude regions (subtropical areas) when atmospheric nitrogen deposition was considered. Figure 11 shows the comparison of calculated and satellite-derived phytoplankton quantities in the subtropical area defined in Fig.10. When the

deposition of nitrogen compounds from the atmosphere is not considered, the model underestimated in reference to the satellite-derived results. However, the results show that the amount of phytoplankton near the surface of the western North Pacific subtropical area becomes 2.3 times larger when the supply of nitrogen compounds from the atmosphere is taken into consideration, consistent with the satellite analysis. This indicates that the nitrogen compounds in $PM_{2.5}$ emitted from East Asia are likely to play an important role in increasing the amount of phytoplankton in the western North Pacific subtropical area. These findings are the first to clarify this direct relationship between atmospheric matter and marine ecosystems.

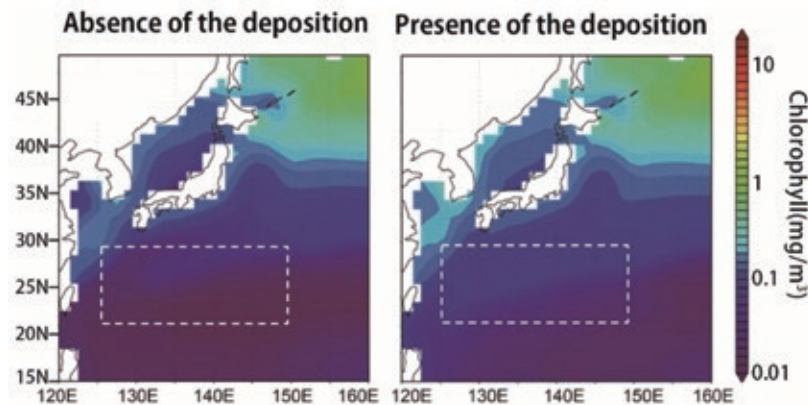


Fig.10 Annual mean spatial distribution of phytoplankton (chlorophyll a) mass concentration in the surface of the western North Pacific calculated with and without nitrogen deposition from the atmosphere into the ocean. White dotted rectangle is the subtropical focus area of this study (20–30°N, 125–150°E).

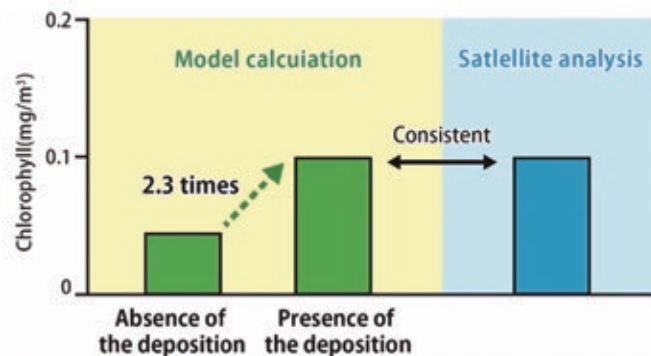


Fig.11 Comparison of calculated and satellite-derived phytoplankton quantities in the subtropical area defined in Fig.10.

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Microbiological process in pelagic ecosystems

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Microbes play important roles in major marine biogeochemical processes, such as nutrient cycles and inorganic/organic matter fluxes. However, the dynamics of microbes has not been used for a parameter 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, prokaryotic community composition, and prokaryotic activity along with water columns and across regions to clarify prokaryote-mediated carbon and nitrogen flux mechanisms in the pelagic systems.

In FY2018, we conducted prokaryotic community analysis in the water columns of Izu-Ogasawara trench area in three cruises conducted by R/V *Kaimei*, in order to reveal geochemical and geophysical impacts of this pelagic realm on microbial ecosystems as follows.

- 1) To determine the microbial community composition and diversity throughout the water columns.
- 2) To estimate the impacts of biogeochemical cycles in the epipelagic to hadalpelagic layers.

Microbiological processes throughout water column of the Izu-Ogasawara Trench

Prokaryotes play a major role in marine biogeochemical fluxes. Microbially mediated biogeochemical transformation rate is one of the major research topics in marine microbial ecology. However, the linkages between prokaryotes activity and biogeochemistry in the epi-, meso-, bathy-, abysso- and hadal pelagic layers are not systematically investigated despite of the efforts that highlighted the role of microbes in the cycling of inorganic/organic matter. In FY2018, we determined prokaryotic compositions in water samples taken along with the water columns in the Izu-Ogasawara Trench during KM16-02, KM16-08 and KM17-01 cruises (Fig.1). We here highlight a part of results from FY2018 research projects that revealed distribution pattern of prokaryotic composition throughout water column of the Izu-Ogasawara Trench area.

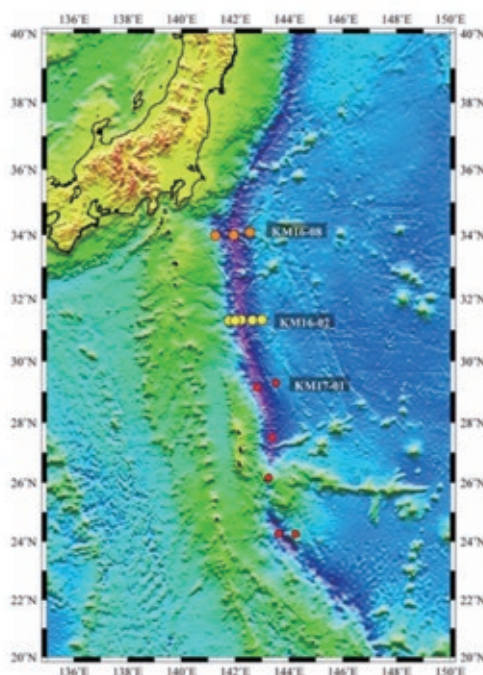


Fig.1 Sampling stations during KM16-02, KM16-08 and KM17-01 cruise.

Distribution patterns of prokaryotic diversity and community composition in the surface, meso-, bathy- abysso- and hadalpelagic layers of the Izu-Ogasawara Trench.

The results showed that depth profiles of prokaryotic (bacteria and archaea) abundance and contribution of bacteria to the total prokaryotes in the Izu-Ogasawara Trench were similar with the pelagic ocean systems reported before (Fig.2). The abundance of prokaryotes exponentially decreased with increasing water depth, from the epipelagic layer to the hadalpelagic layer (Fig.2a). Bacteria dominated in the epipelagic layer and slightly decreased in mesopelagic layer. Contributions of bacteria were constant below the bathypelagic layer even in the abysso and hadal pelagic layers (Fig.2d).

The predominant prokaryotic SSU rRNA gene phylotypes (197 OTUs out of 19651 OTUs) were identified by SSU rRNA gene amplicon sequencing. A clustering analysis of the predominant phylotypes showed depth-dependent distribution pattern (Fig.3). Prokaryotic communities in the epi- and mesopelagic layer were distinct from the other layers, and the other communities also showed the depth dependent clustering pattern.

The data set suggested that prokaryotic community composition in each water layers harbor unique microbial ecosystem along with the water columns in the Izu-Ogasawara Trench.

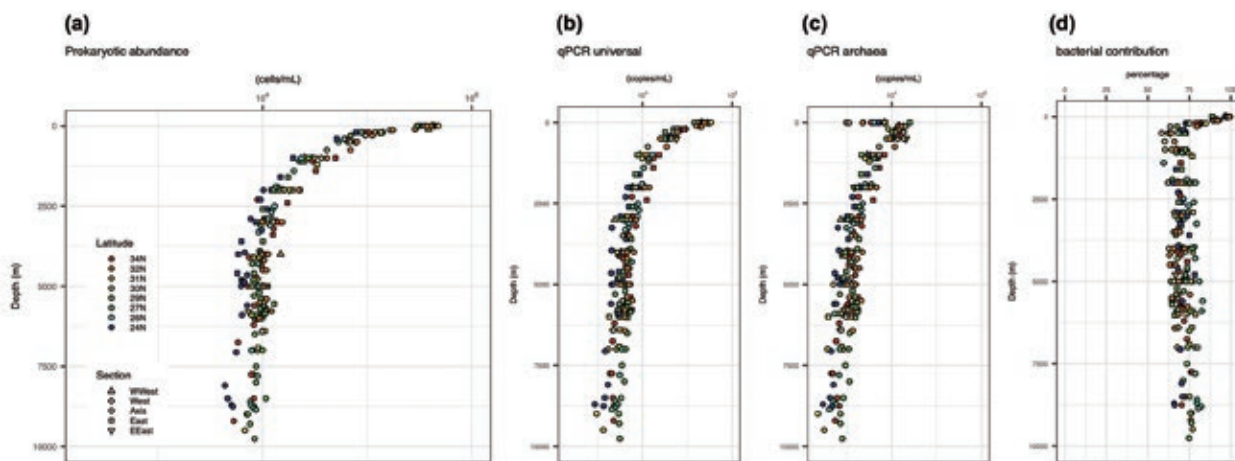


Fig.2 Depth profiles of prokaryotic abundance (a), Number of prokaryotes (b) and archaea (c) (the both were determined by a qPCR method), and percentage contribution of bacteria (d, calculated from the number of prokaryotes and archaea) in the Izu-Ogasawara trench through the water columns.

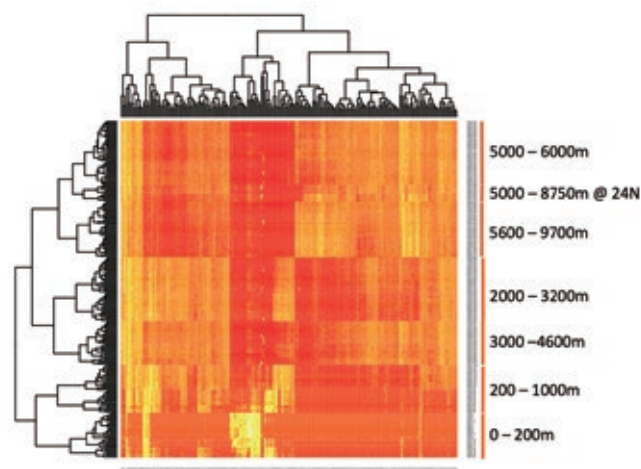


Fig.3 Heatmap representing the abundance (number of reads) of the dominant phylotypes (columns) among the sampling stations (rows). Clustering pattern among the sampling stations showed that distinct difference among the pelagic layers and inter-trench difference between the Izu-Ogasawara Trench and the Mariana trench. Samples, which indicated “5000-8750@24N”, were taken from the northern part of the Mariana Trench. Sampling points of the Mariana Trench and the Izu-Ogasawara Trench were adjacent to each other across the Hahajima Seamount.

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Improved prediction of interannual extreme events through the use of a seasonal climate forecast system with an unprecedented ensemble size of 108

– Application Laboratory –

Climate information obtained from seasonal predictions has a wide range of practical applications, such as predicting crop failures or the incidence of heat strokes. The key to seasonal predictions mainly lies in the ocean, and there particularly in the tropics, where phenomena like El Niño-Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) are known to have profound influences on the global climate.

Due to the chaotic nature of the coupled ocean-atmosphere system, small differences in initial conditions can lead to widely diverging predictions. Therefore, multi-member forecasts are used to determine the most likely outcome (which can be estimated as the ensemble average) and to estimate the frequency distribution of events. Additionally, if the size of the ensemble is sufficiently large, it is expected that information about the probability of extreme events (which are rare by definition) can be obtained. Here we test the merit of this approach by using the SINTEX-F seasonal prediction system to conduct a 108-member reforecast for the period 1983-2015. This is the largest ensemble in a single-model reforecast conducted by any modeling center to date (press release 2019/01/24). Our focus is on ENSO and the IOD.

Figure 1 shows predictions of the 1988/89 La Niña event, the strongest in the reforecast period, initialized from June 1, 1988. Some of the 108 members are able to reproduce the extreme La Niña event (orange lines), while the 12 members of the conventional forecast (light blue lines) fail. Thus, where the conventional 12-member forecast indicated a 0% probability for an extreme La Niña event, the 108-member forecast correctly predicts a finite probability. We further evaluate the prediction skill of strong ENSO and IOD events, which roughly occur every 7 years. The results show that increasing the ensemble size from 12 to 108 leads to more accurate probabilistic predictions of strong ENSO and IOD events. This increased skill of the new 108-member prediction system should lead to significant improvements in the usefulness of forecast information, particularly for the mitigation of crop failures and the control of infectious diseases such as malaria.

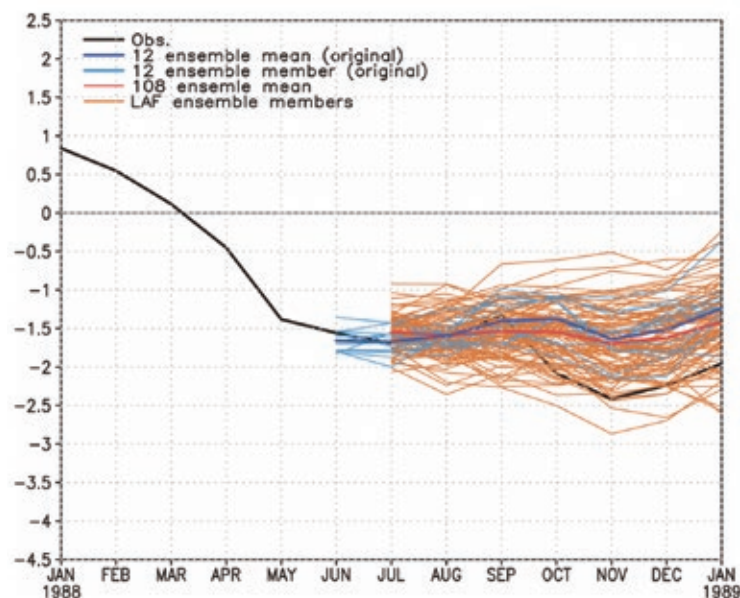


Fig.1 Evolution of the Niño 3.4 index (sea-surface temperature anomalies averaged over the area 190-240°E, 5°S-5°N in the tropical Pacific; °C). The individual lines show the observations (thick black line), the conventional SINTEX-F 12-member ensemble (light blue lines), the mean of the 12-member ensemble (thick blue line), the mean of the 108-member ensemble (thick red line), and the additional 96 ensemble members that, together with the conventional 12-member ensemble, form the 108-member ensemble (orange lines). All forecasts are initiated on June 1, 1988.

Wind patterns off the Philippines and Taiwan influence tropical cyclone formation

In this study we analyze a combination of observed and reanalyzed atmospheric and oceanic data to demonstrate that the distribution of tropical cyclone formation is influenced by the Philippines–Taiwan Oscillation (PTO). The PTO involves a north-south oscillation on interannual time scales of the wind patterns off the Philippines and Taiwan, which happens to be in the tropical cyclone formation region in the Western Pacific Ocean. A relation was found between the differences in horizontal wind vorticity (PTO index) and the occurrence of tropical cyclone formation in the same area between years 1979 and 2014. The results showed that when the PTO index is positive (i.e. when the trade wind weakens, the wind off the Philippines strengthens in an anticlockwise direction and the wind off Taiwan strengthens in a clockwise direction; Fig.2b), tropical cyclones form more frequently south of 18°N. Conversely, when the PTO index is negative (i.e. when the anticlockwise wind off the Philippines and the clockwise wind off Taiwan both weaken; Fig.2c), tropical cyclones form more frequently north of 18°N. Furthermore, when the PTO index is positive, the number of tropical cyclones that approach Japan increases.

Annual variations in the formation of tropical cyclones in the Western Pacific Ocean have often been linked to large-scale climatic fluctuations, such as El Niño. This study shows that local climatic processes (i.e. wind patterns off the Philippines–Taiwan) might be a better predictor of the occurrence of tropical cyclones in that region. Overall, these findings suggest a new direction in climate variability research: large-scale climatic fluctuations affecting the entire Pacific Ocean (e.g. El Niño, El Niño Modoki) and discrete phenomena (e.g. tropical cyclones in the western North Pacific Ocean) are connected via local climatic fluctuations, such as the PTO. Consequently, if ocean-atmosphere coupled seasonal forecast models operated by research units such as JAMSTEC's Application Laboratory can reliably predict El Niño Modoki, it will also be possible to forecast the PTO. The possibilities of seasonal forecast applications will hence expand. We will continue further research toward comprehensive prediction of seasonal climatic fluctuations by utilizing ocean-atmosphere coupled models.

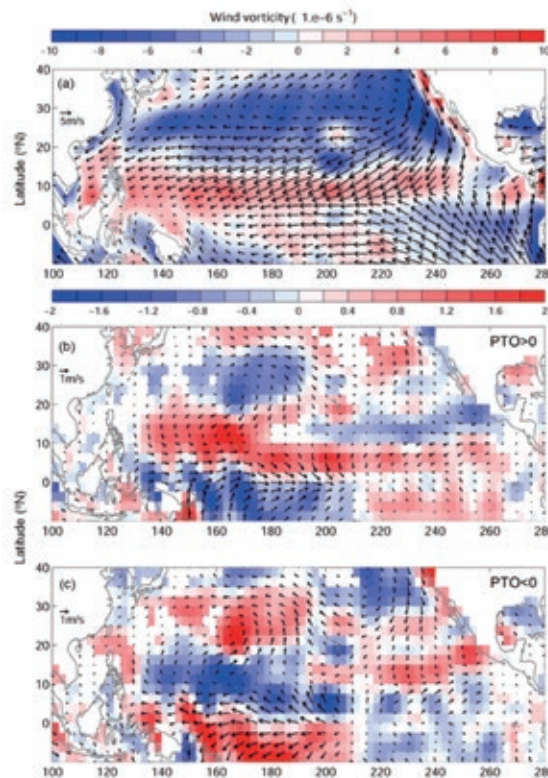


Fig.2 Oceanic wind patterns at 1000 hPa. Arrows indicate wind direction and strength, color shading indicates horizontal wind vorticity, and blank areas represent statistically non-significant values. (a) Mean values between years 1979 and 2014, (b) anomalies (deviations from the mean) when the PTO was positive, (c) anomalies when the PTO was negative.

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I. Research Activities and Results

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Changing Arctic

– Institute of Arctic Climate and Environment Research –

The Arctic is one of the most significant region where we can find the impact of global warming, which is closely corelated with rapid decrease of the Arctic sea ice. 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, Arctic warming and sea-ice decrease have strong 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 influence 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 the Arctic countries; 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.



Interannual variation in solar heating in the Chukchi Sea, Arctic Ocean

Summer Arctic sea-ice cover has rapidly declined due to global warming over the past few decades. The albedo of sea ice is much higher than that of open water; a decrease in sea-ice cover is associated with an increase in solar heating and thus surface warming in the Arctic Ocean. The reduction in sea-ice cover also plays a significant role in the polar amplification of climate change and in marine and terrestrial ecological dynamics in the Arctic region. This sea-ice reduction accompanied by sea surface warming has been particularly pronounced in the Pacific side of the Arctic Ocean. Heat transport of Pacific water through the Bering Strait, which has increased in recent years, plays an important role in decreasing winter sea-ice formation and in sea-ice melt during summer in the Canada Basin. In 2007, which was marked by an extreme retreat of Arctic sea ice, the heat transport was sufficient to cause one third of the seasonal Arctic sea-ice loss.

The Chukchi Sea (Fig.1) is located between the Bering Sea and the Arctic basin and is a pathway for Pacific water from the Bering Strait. We anticipate that solar heating significantly modifies Pacific water in the Chukchi Sea. However, there have been no quantitative analyses of solar heating in the Chukchi Sea. In this study, we estimated interannual variation in summer solar heating in the Chukchi Sea by analyzing satellite-derived sea-ice concentration data and reanalysis shortwave radiation data, and compared its impact on the heat budget in the Chukchi Sea with that of heat transport through the Bering Strait after validating the reanalysis data using in-situ shortwave radiation data obtained by the R/V *Mirai*.

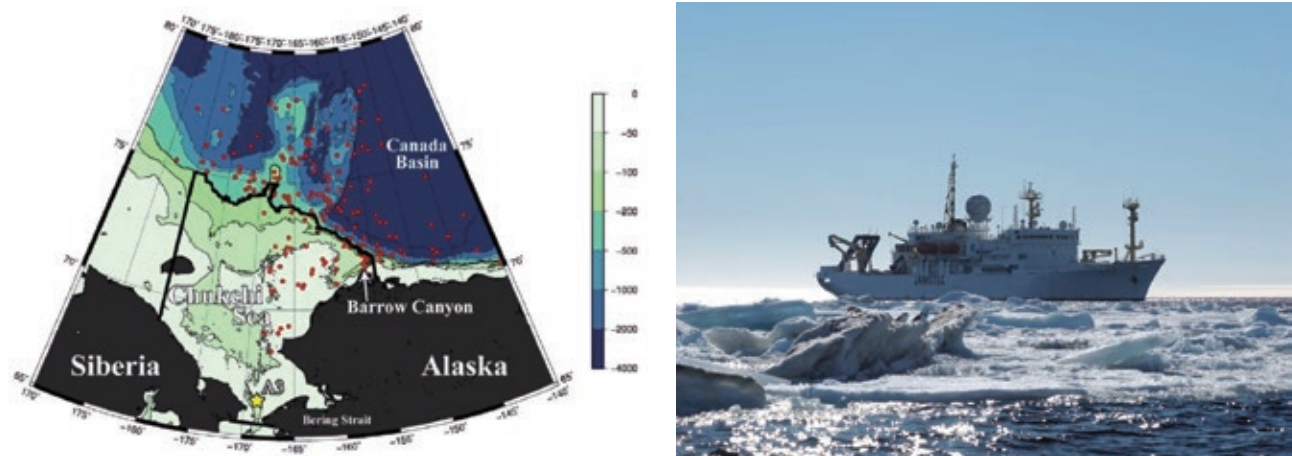


Fig.1 (left) Bottom topography (m) in the Chukchi Sea. Red dots indicate the locations of in-situ downward shortwave radiation observations by R/V *Mirai*. (right) R/V *Mirai* in the Chukchi Sea in September 2016.

First, the downward shortwave radiation from the reanalysis products was compared with in-situ data obtained by the R/V *Mirai*. We concluded that NCEP–CFSR data reproduced in-situ data most accurately compared with NCEP/NCAR Reanalysis 1 and ERA-Interim., and used NCEP–CFSR downward shortwave radiation data in our analyses. We here made times series of solar heating using satellite-derived sea-ice concentration data and NCEP–CFSR shortwave radiation data during 1999–2015.

Figure 2 shows the horizontal distribution of cumulative solar heating from May to September in the Chukchi Sea, averaged over 1999–2015. Solar heating generally decreased with latitude because of early sea-ice retreat and late freezing in the southern region. Strong solar heating was also observed along the Alaskan coast probably due to warm Alaskan coastal current. Summertime solar heating integrated over the Chukchi Sea varied interannually from 3.6×10^{20} J in 2000 to 6.7×10^{20} J in 2015 (Fig.3). The summertime solar heating was negatively correlated with summertime sea-ice concentration averaged over the Chukchi Sea and was considerably (1.3- to 1.9-fold) larger than the northward heat flux through the Bering Strait. The summer time total heating in the Chukchi Sea, calculated as the sum of solar heating, northward heat flux through the Bering Strait, sea-ice melting heat, and latent heat, sensible heat and longwave radiation fluxes, was positive throughout the analysis period, ranging from 2.9×10^{20} J in 2000 to 8.4×10^{20} J in 2007. The interannual variation in total heating was

significantly correlated with the interannual variation in solar heating, as well as with the northward heat flux through the Bering Strait. In addition, the interannual variability in the total heating in the Chukchi Sea was roughly twice that of the northward heat flux through the Bering Strait and the solar heating. These results imply that the heat in the Chukchi Sea provided by the northward heat flux through the Bering Strait is amplified by solar heating in the Chukchi Sea.

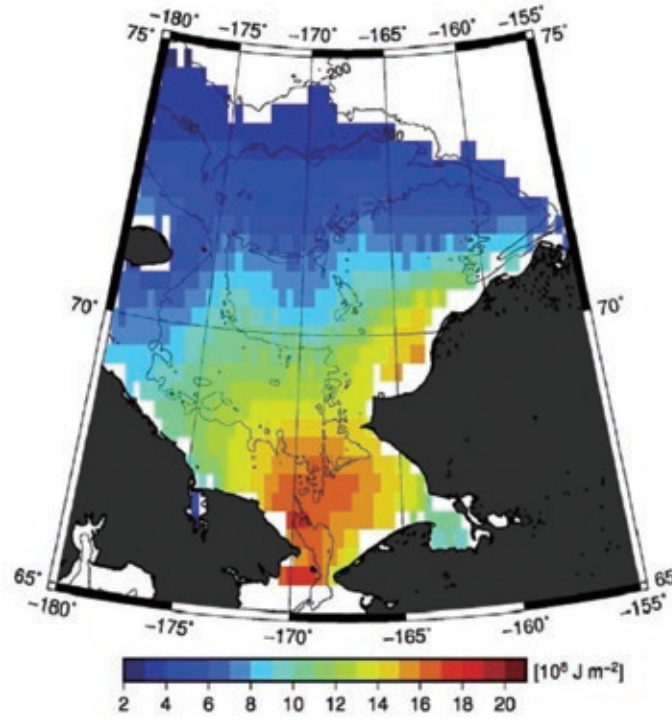


Fig.2 Horizontal distribution of cumulative solar heating from May to September in the Chukchi Sea averaged over 1999–2015 (10^8 J m^{-2}) estimated using NCEP–CFSR downward shortwave radiation data.

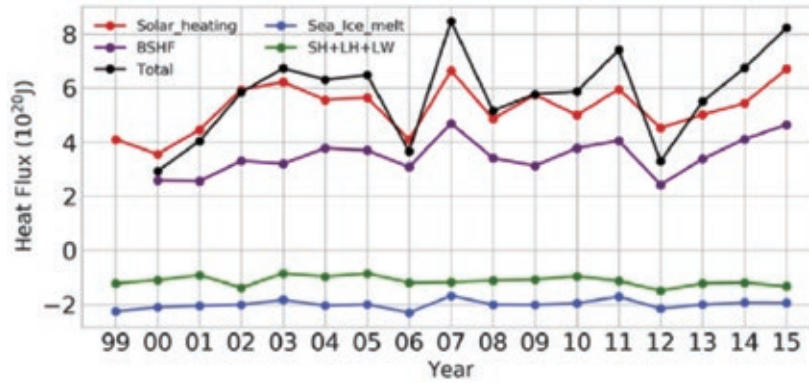


Fig.3 Interannual variation in solar heating (red), total heating (black), sea-ice melting heat (blue), and the sum of the sensible heat (SH), latent heat (LH) and longwave radiation (LW) fluxes (green) integrated in the Chukchi Sea from May to September (10^{20} J). Purple line indicates northward heat flux through the Bering Strait (BSHF) integrated from May to September.

We used the summertime northward heat flux through Barrow Canyon, one of the major heat fluxes from the Chukchi Sea to the Arctic basin, to investigate the influence of solar heating in more detail. The interannual variation in the northward heat flux through Barrow Canyon was not correlated with that though the Bering Strait. In contrast, the northward heat flux through Barrow Canyon was significantly correlated with solar heating in the Chukchi Sea, especially along the flow paths from the Bering Strait to Barrow Canyon. This implies that modification of Pacific water in the Chukchi Sea by solar heating plays an important role in heat transport from the Chukchi Sea to the Arctic basin.

Development of the under-the-ice drone system

AUV (Autonomous Underwater Vehicle) is the best platform for under-the-ice survey in Arctic. The project included development of a middle weight under-the-ice drone, navigation systems, and sensors started in 2017. The drone has a camera and a multi beam sonar to observe bottom of the ice. In 2018, we worked on the system design and components design of the drone.

It is a serious problem of under-the-ice drones how to get their position under the ice. In 2016 we proposed an electromagnetic (EM) under-the-ice positioning method and then started basic research of low frequency EM propagation between air-ice-seawater interface. We carried out a measurement test of EM propagation using an underwater antenna newly developed in Saroma Lake in February 2018. Attenuation measured at distance of 100 m from the transmission point horizontally in 10 kHz is about 140 dB when the antenna depth is 4 m. We estimated the effective service area which is about 30 m when transmission power is 10 W.

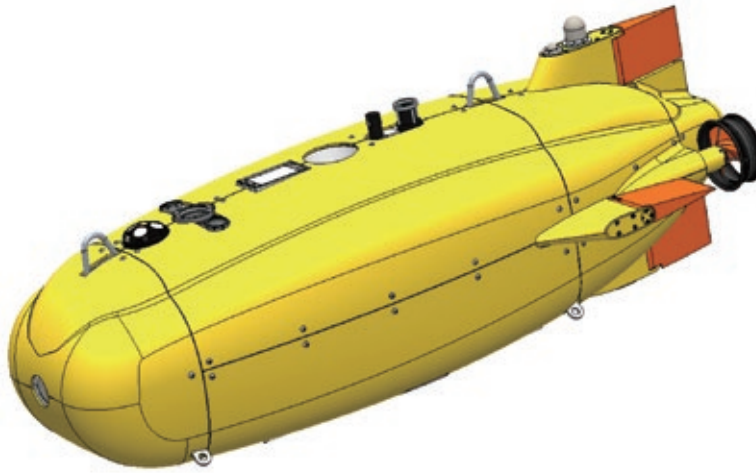


Fig.4 An outline view of the under-the-ice drone

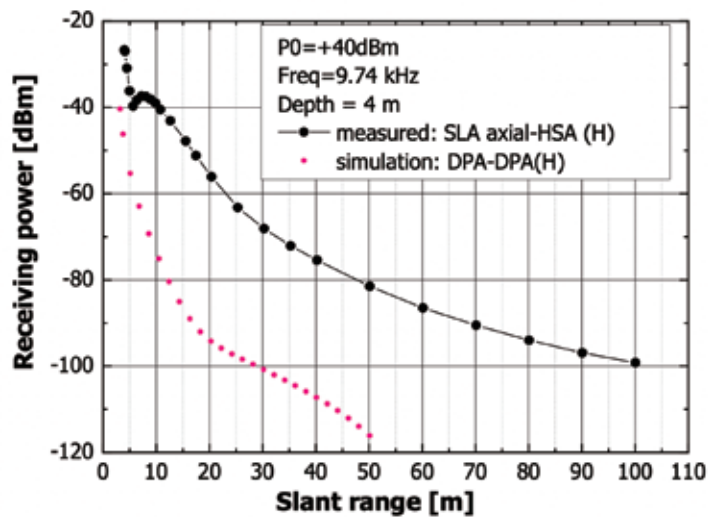


Fig.5 Receiving power vs. distance measured at frequency of 10 kHz using the small loop antenna (TX on ice surface) and the half sheath antenna (RX underwater). At the time, the calculation data (red dots) which used a simple model was not fitted to measured one.

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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 active 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. While we deploy our observation network for long-term monitoring at various sites in the MC region based on the collaboration with local agencies including the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) of the Republic of the Philippines and Aero-Meteorological Observatory of National Hydro-Meteorological Service (AMO/NHMS) of the Socialist Republic of Viet Nam, we have organized an international field campaign, Years of the Maritime Continent (YMC), as one of core institutes. YMC is a multi-national effort, which aims to expedite the progress of improving understanding of local multi-scale variabilities of the MC weather-climate system and its global impact. Its observation phase has started since July 2017 and is scheduled to continue until February 2020 as Phase-1, and beyond that as Phase-2. During this campaign period, we at JAMSTEC have conducted several intensive observations with Indonesian Agency for the Assessment and Application of Technology (BPPT) and Indonesian Agency of Meteorology Climatology and Geophysics (BMKG) in addition to PAGASA and AMO/NHMS in their respective countries in 2017 and 2018. More detailed information about the YMC can be found in YMC JAMSTEC site at <http://www.jamstec.go.jp/ymc/>. Figure 1 summarizes our major land-based observation sites.

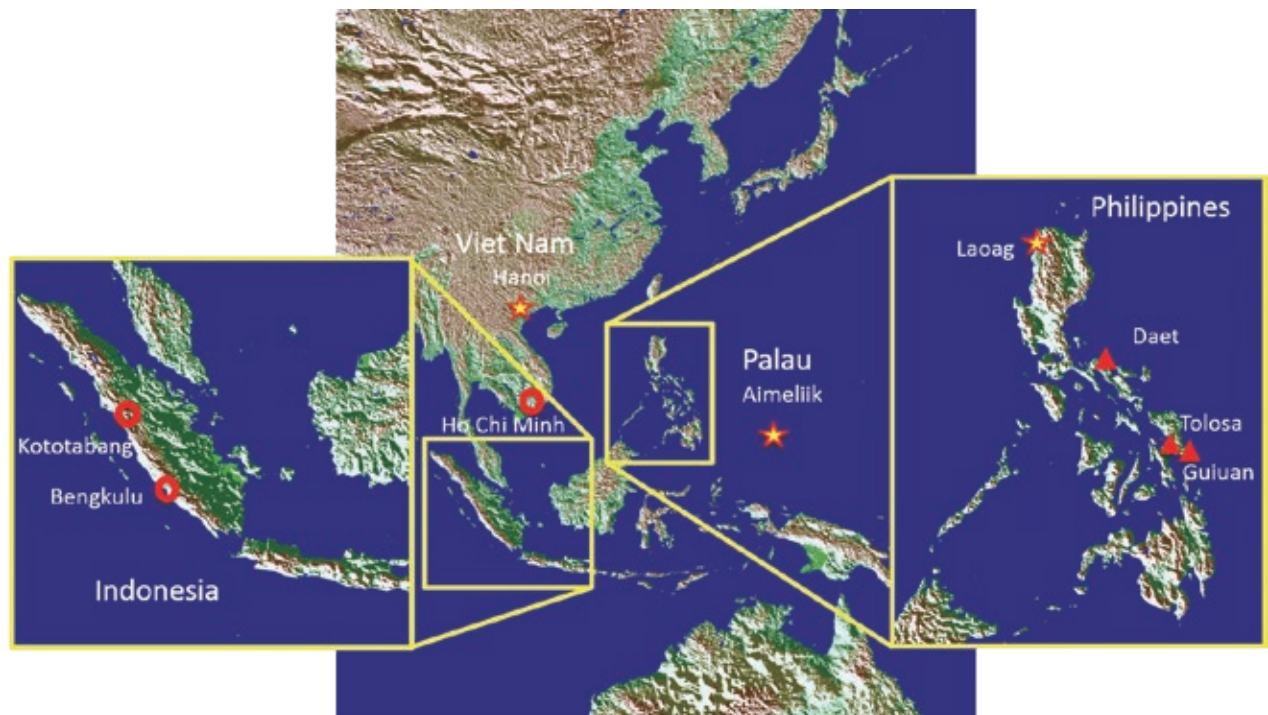


Fig.1 Major observation sites, where DCOP deploys their own instruments for long-term monitoring and/or conducts intensive observations under the YMC project. Red circle/triangle indicate YMC-IOP/long-term monitoring sites, while star indicates both have been carried out.

Drastic thickening of the barrier layer due to the MJO

As a part of YMC, its pilot study was conducted prior to the campaign period on and off the west coast of Sumatra Island in November - December 2015. Since its main scientific targets were to study the mechanism of offshore migration of rainfall region, which is diurnally developed over the coast in the evening, and to study a relationship between diurnal cycle of rain and the Madden-Julian Oscillation (MJO), the research vessel (R/V) *Mirai* was deployed about 50 km off the coast for about one month (Fig.2), while meteorological measurements at Bengkulu land-based site were conducted for two months. During the stationary observation onboard the *Mirai*, various atmospheric and oceanic measurements including 3-hourly radiosonde sounding and conductivity-temperature-depth (CTD) measurement were carried out. This intensive observation successfully captured the passage of the atmospheric convection associated with the MJO in mid-December (Fig.3). Since ocean condition may affect migration processes of diurnally-developed rainfall region, detailed ocean structure is also a key to understand atmospheric phenomena.

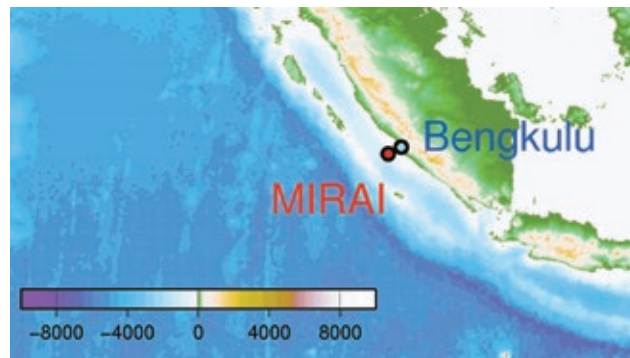


Fig.2 Observation sites during the YMC pilot study in 2015. Red / light blue dots indicate the location of R/V *Mirai* / Bengkulu, respectively.

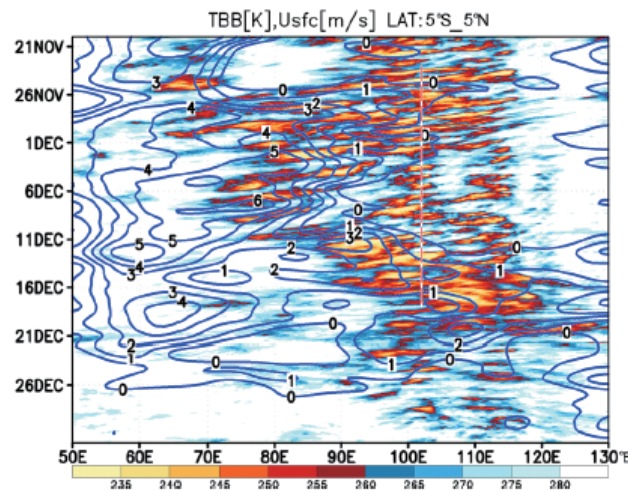


Fig.3 Time-longitude cross-section of infrared radiation brightness temperature (shading) and surface westerly wind speed (contour) averaged over 5-deg. from the equator. [Moteki et al., 2018]

Figure 4 shows time series of the 24-hour running mean of the mixed layer depth (MLD), isothermal depth (ILD), and barrier layer thickness (BLT), and the sea surface winds. Barrier layer (BL) is defined as a layer between the top of pycnocline and the top of the thermocline, and BLT is calculated as a difference between ILD and MLD. BL forms a barrier to the entrainment and turbulent mixing of cold thermocline water into the warm mixed layer and inhibits the momentum of downward mixing. Thus, to know BL's existence and/or their behavior provides useful information about air-sea interaction. Prior to arrival of the convective center of the MJO, the halocline above a depth of 20 m was very strong, and the BLT was 5-10 m. During the peak of the MJO forcing

in 13-16 December, the isothermal layer drastically deepened from 20 to 100 m. Meanwhile, the mixed layer deepening lagged behind the isothermal layer deepening by 1 day, and the BL underwent drastic thickening to 60 m within 24 hours. Using CTD data as well as oceanic analysis product, *Moteki et al.* [2018] further studied its behavior and mechanism, and found that vertical oceanic mixing due to the MJO forcing and the vertical stretching by the oceanic downwelling coastal Kelvin wave were responsible for this drastic thickening of BLT (not shown). Since BL affects sea surface temperature (SST) by interfering vertical mixing, this might cause a difference of surface temperature difference between over ocean and over land. Recently, *Dipankar et al.* [2019] showed that a low-SST bias (in-situ SST is higher than that in analysis product) in initial conditions caused a delay of simulated diurnal cycle of rain over land. Thus, if such surface temperature difference is crucial for diurnal cycle rain and/or their offshore migration, ocean surface structure near the coast as shown by *Moteki et al.* [2018] has a strong impact onto their behavior. It should be further studied using those in-situ measurement and numerical models.

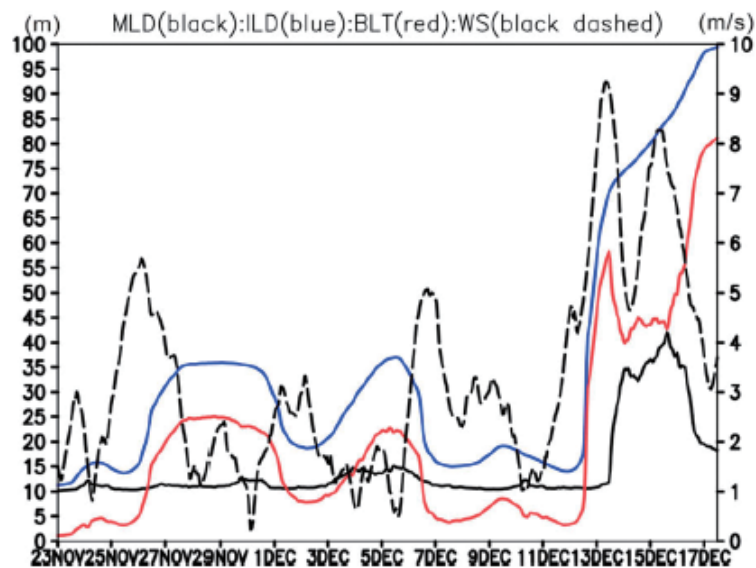


Fig.4 Time-series of 24-hour running mean MLD (black solid), ILT (blue), BLT (red), and surface wind speed (black dashed) obtained at the R/V *Mirai*. [*Moteki et al.*, 2018]

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Toward Comprehensive Projection of Global Change

– Department of Integrated Climate Change Projection Research & Project Team for Advanced Climate Modeling –

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.

From FY2017, JAMSTEC started undertaking "Integrated Research Program for Advancing Climate Models", or TOUGOU (abbreviation taken from its Japanese name) funded by Ministry of Education, Culture, Sports, Science and Technology (MEXT) by establishing a dedicated project team. Under this program and based on the protocol for global change projection experiments being discussed by scientists from across the world (CMIP6 protocol), we perform experiments using the models developed at JAMSTEC. This annual report includes results obtained under this program.

In FY 2018, a paleoclimate experiment targeting realization of the last glacial maximum has been performed with an updated dust emission scheme, leading to higher aerosol concentration in the Antarctic region than with older experiments without the additional dust emission. The result shows that temperature around the periphery of Antarctic continent is elevated. Analysis revealed that downward longwave radiation was enhanced due to aerosol – cloud interactions.

Experiment to investigate the role of stratosphere in forming tropospheric climate has been also conducted. It turned out that climate fields such as location of zonal jet and sea level pressure are better reproduced with a higher model top and a finer vertical resolution of stratosphere, indicating the importance of stratosphere for the tropospheric dynamics.

The effects of a well-resolved stratosphere on the simulated circulation in a climate model

Troposphere-stratosphere-mesosphere coupling processes play an important role in meteorological phenomena on time scales from days to years. Numerical prediction global models in the world tend to include stratosphere, even up to mesopause (~85km), including Japan Meteorological Agency. In order to investigate the roles of the middle atmosphere (stratosphere and mesosphere) on the troposphere, several studies separated CMIP models into high and low top models and investigated differences among them. However, there are clear limitations to such an approach as the effects of the different physical parameterizations used in each model cannot be removed.

In this study, the impact of stratospheric representation is investigated using the Model for Interdisciplinary Research On Climate Atmospheric General Circulation Model (MIROC-AGCM) run with different model-lid heights and stratospheric vertical resolutions, but unchanged horizontal resolutions (~1.125°) and subgrid parameterizations. One hundred year integrations of the model were conducted using configurations with 34, 42, 72 and 168 vertical layers and model-lid heights of ~27 km (L34), 47 km (L42), 47 km (L72) and 100 km (L168). Compared with the L42 model, the L34 model produces a poorer simulation of the stratospheric Brewer-Dobson circulation (BDC) in the lower stratosphere, with weaker polar downwelling and accompanying cold pole and westerly jet biases. The westerly bias extends into the troposphere and even to the surface. The tropospheric westerlies and zone of baroclinic wave activity shift northward; surface pressure has negative (positive) biases in the high (mid) latitudes, with concomitant precipitation shifts (see Fig.1). The L72/L168 models generate a Quasi-Biennial Oscillation (QBO) while the L34/42 models do not. The L168 model includes

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the mesosphere, and thus resolves the upper branch of the BDC. The L72 model simulates stronger polar downwelling associated with the BDC than does the L42 model. However, experiments with prescribed nudging of the tropical stratospheric winds suggest differences in the QBO representation cannot account for L72-L42 differences in the climatological polar night jet structure. The results show that the stratospheric vertical resolution and inclusion of the full middle atmosphere significantly affect tropospheric circulations.

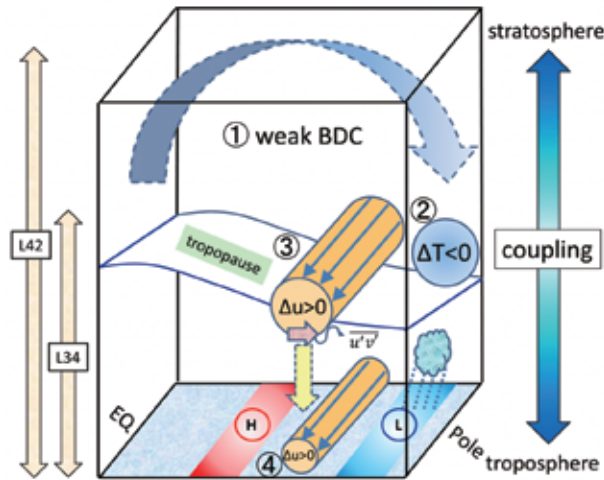


Fig.1 Schematic illustration of some differences in the simulated circulation between the model without the stratosphere (L34) and that with the stratosphere (L42); i.e., L34–L42. 1) The L34 model simulates a weaker BDC than does the L42 model. 2) The mean polar temperature is closer to the radiative equilibrium in L34 than in L42 due to the suppression of the BDC and the weaker adiabatic heating associated with the reduced polar downwelling in the L34 model. 3) The stratospheric jet is stronger, consistent with thermal wind balance. 4) The westerly mean wind differences seen prominently in the stratosphere extend, to some extent, down to the surface. The transport of angular momentum by the waves in the upper troposphere is shifted poleward in L34 relative to L42. 5) The distributions of surface pressure and precipitation in the model simulations are also affected by the inclusion of the stratosphere.

Evaluation of the effect of mineral dust aerosol on glacial climate

Aerosol is one of the most uncertain agents for future projection [IPCC, 2013]. Mineral dust aerosol is the most abundant aerosol among all kinds of aerosols including anthropogenic aerosols. Because mineral dust is natural aerosol, we are able to learn from the past. Dust has been one of key interests for paleoclimate researches because ice core data suggests clear coherency of dust flux with glacial-interglacial cycles (Dome Fuji Ice Core Project Members 2017). Here we analyzed the role of enhanced mineral dust emission and deposition on mean climate state during the last glacial maximum (LGM).

The dust deposition flux was underestimated in a few orders of magnitude over the high latitudes in the LGM experiment for Paleoclimate Modelling Intercomparison Project phase 3 using MIROC-ESM (LGM. a) compared to paleo-proxy data. In order to improve the underestimation, we forced to emit glaciogenic dust estimated by Mahowald *et al.* [2006] (LGMglac.a) and obtained well matched dust deposition flux with deposition data archives [Kohfeld *et al.*, 2013, Albani *et al.*, 2014]. The analyses suggested that the glaciogenic dust weaken the cooling over periphery of the Antarctica. This is caused by enhanced downward radiation over the area. Because of the strong glaciogenic dust emission from the South America, negative radiative anomaly by aerosol-radiation interaction dominates over the direct downstream area, but the effect of this radiative anomaly is minor on the surface temperature, probably because the downstream area is over ocean. When the dust reached the vicinity of the Antarctica, the effect of dust on the surface temperature becomes positive. By analyses it is found that this is caused by enhanced high level cloud by aerosol-cloud interaction. And it leads the enhanced longwave radiation and surface temperature rise in contrast to unchanged radiative balance at the top of atmosphere [Ohgaito *et al.*, 2018].

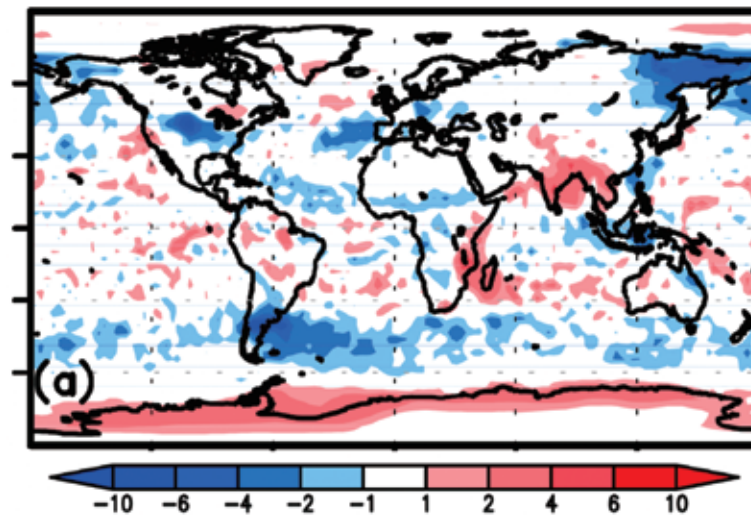


Fig.2 Anomaly of surface radiation budget between LGMglac.a and LGM.a (positive, downward) (W m^{-2}).

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Toward comprehensive understanding of the local weather to global scale atmospheric variability

– Department of Seamless Environmental Prediction Research –

Better prediction of the severe weather events that may induce meteorological disaster is a socially demanding problem. Understanding of the interaction between the large-scale environment and the local weather events is essential to this problem. To achieve this goal, we have been developing a global high-resolution atmospheric model that is capable of simulating the local to global scale convective phenomena in a seamless framework. We made progress in understanding and prediction of severe weather events and their environment during the third mid-term plan under tight collaboration with dedicated research projects using the state-of-the-art supercomputers.

Among our research targets, tropical intraseasonal oscillation (ISO) is of special focus, which receive worldwide attention of the operational weather centers, as well as research communities. Our global cloud-system-resolving simulation approach enables novel in-depth investigation of the multi-scale interactions within the ISO. Close collaboration between the field observation and modeling study is another strength of JAMSTEC. In FY2018, we extend our approach to the comprehensive analysis of the ISO events during the field campaigns led by JAMSTEC (cf. DCOP) during the third mid-term plan.

Diversity of multi-scale interactions in the tropical Intraseasonal Oscillation

Tropical intraseasonal oscillation (ISO) has broad impacts on world weather and climate, such as tropical cyclogenesis [e.g., *Nakano et al.*, 2015; *Nasuno et al.*, 2016] and severe weather events [e.g., *Wu et al.*, 2013], and therefore the ISO has been regarded as a promising source of predictability in extended-range (longer than a week) forecasts [*Vitart et al.*, 2017]. International organizations (e.g., World Meteorological Organization, WMO) promote better understanding and prediction of the ISO, where JAMSTEC play a unique role by leading international field campaigns [e.g., *Yoneyama et al.*, 2008, 2013] and by modeling study using Nonhydrostatic ICosahedral Atmospheric Model (NICAM; [*Satoh et al.*, 2014]) [e.g., *Miura et al.*, 2007; *Miyakawa et al.*, 2014; *Nasuno et al.*, 2017]. The Years of the Maritime Continent (YMC) is the latest multi-national project, where JAMSTEC serve as a major institute (<http://www.jamstec.go.jp/ymc/index.html>; DCOP). The Maritime Continent (MC; Indonesia, Philippines and surrounding oceans) is a key region for the ISO prediction, where complicated multi-scale interactions significantly modulate the ISO behavior. DSEP has been in charge of the global cloud-system-resolving (7-km/14-km mesh) near real-time forecasts using NICAM during the field campaigns, Pre-YMC 2015, YMC-Sumatra 2017, and YMC-BSM 2018, under close collaboration with DCOP. Here we report the research results on the multi-scale processes in the boreal winter ISO over the MC based on the comparisons between the 2015 and 2017 simulations [*Nasuno*, 2019].

In order to understand the roles of the high-frequency local variability (e.g., diurnal variations) in the ISO life cycle, we made moisture budget analysis, by taking an advantage of the high resolution of the simulation data. We focus on the moisture variability because its importance on the ISO dynamics are well known by previous studies [*Yokoi and Sobel*, 2015; *Nasuno et al.*, 2017]. We calculated advection terms of the moisture tendency equations by separating each variable into low-frequency (7-day average) and high-frequency (deviations from the 7-day averages) components in the same manner as *Nasuno et al.* [2017]. A merit of this analysis is a direct estimation of the moisture advection by high-frequency variability (especially vertical component), which is only indirectly diagnosed from observable data.

Figure 1 shows vertical profiles of the simulated vertical moisture advection in the western MC (90-120E, 12S-8N) including the observation sites in 2015 and 2017 over land (red) and over ocean (blue). It is expected that the relationship between the high-frequency (local) and low-frequency (e.g., ISO and large-scale) variability is different over land and over ocean. In 2015, vertical advection of moisture was pronounced over land than over ocean. In particular, lower tropospheric moistening associated with the low-frequency components was pronounced (Fig.1a). In 2017, by contrast, advection over ocean prevailed that over land, with deep moistening

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by the low-frequency components (Fig.1b). Such difference in the land-ocean contrast between the two years is attributable to the environmental conditions; under a peak El Niño condition with large-scale subsidence anomalies over the western MC in 2015, and under a moderate La Niña condition with enhanced large-scale upward motion over the western MC in 2017. In addition, the fact that local circulation over the land region in the MC tends to be enhanced in the El Niño years despite the mean subsidence anomalies [Jiang and Li, 2018] can be responsible for the enhanced lower tropospheric moistening over land in 2015.

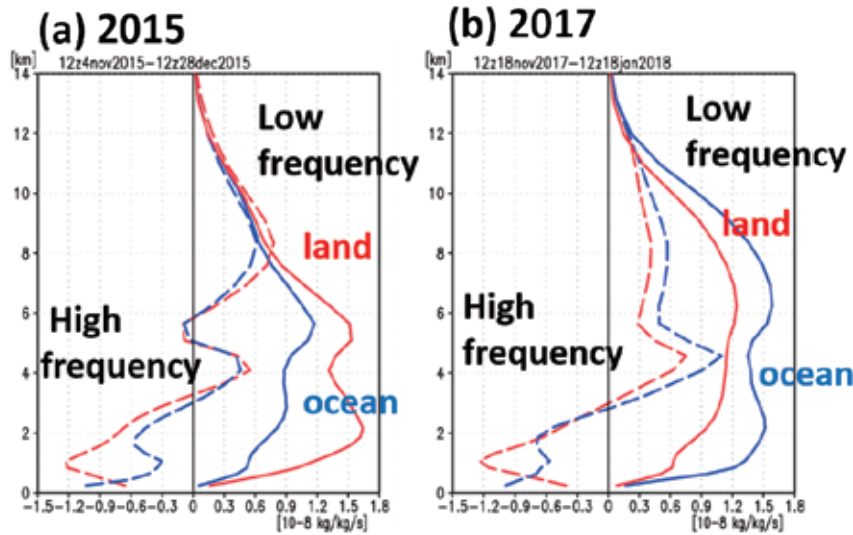


Fig.1 Vertical profiles of period-mean vertical advection of moisture over the western Maritime Continent (90°-120°E, 12°S-8°N) during (a) the Pre-YMC 2015 and (b) the YMC-Sumatra 2017 campaigns. Advection by the low-frequency (7-day mean) variability (solid lines) and that by the high-frequency (<7 day) variability (dashed lines) averaged over the land (red) and ocean (blue) regions are plotted.

In order to understand the scale interactions within the ISO, we examined time series of the relationship between the low-frequency and high-frequency advection. Over ocean, upper tropospheric moistening (lower tropospheric drying) by the high-frequency variability was enhanced during active period of ISO in both years, whereas the relationship over land diverged between the two years. Figure 2 shows the time-height section of the moisture advection over land. In 2015, the moistening associated with the high-frequency variability was synchronized with the low-frequency counterparts, implying that the local convection helps the evolution of the ISO. In 2017, by contrast, the relationship between the low-frequency and the high-frequency advection was not clear. These results suggest that the interaction between the local convection and the ISO are more complicated over land than that over ocean. Further investigation of the major constituents of the high-frequency variability will provide a clue to understand such diversity. The time series of the surface precipitation during the 2015 and 2017 period (Fig.2, bottom panels) indicates that the diurnal variation has greater amplitude than the low-frequency variation, especially in 2015. It is useful to examine the role of diurnal variation in the ISO in the forthcoming studies.

In this way, we made progress in understating the interaction between the local convection in the western MC and the large-scale fields (e.g., ISO), and its dependence on the environmental conditions (e.g., El Niño Southern Oscillation phase) in the YMC campaigns. As a next step, we plan to promote more comprehensive understanding of the scale interactions and its diversity by integrating the products from other countries/institutes in the YMC project.

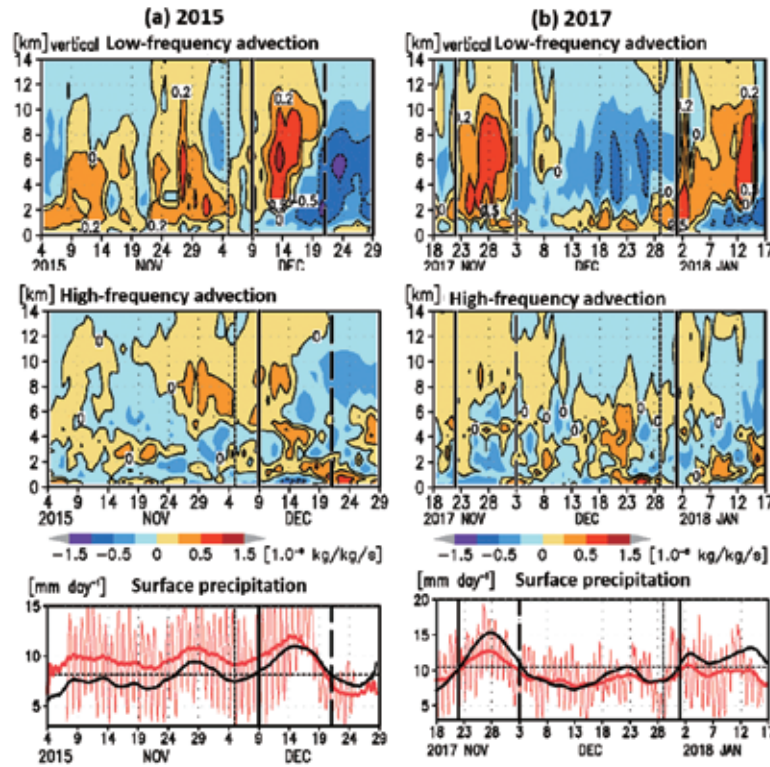


Fig.2 Time-height section of the simulated anomalous moisture advection in the land area of the western Maritime Continent (90° - 120° E, 12° S- 8° N) during (a) the Pre-YMC 2015 and (b) the YMC-Sumatra 2017 campaigns. (top) Vertical advection by the low-frequency (7-day mean) variability and (middle) advection by the high-frequency (<7 -day) variability. The deviations from period-mean profiles are plotted. Surface precipitation are also drawn in the bottom panels. The dotted, solid, and dashed vertical lines indicate the beginning of the preconditioning, active, and inactive periods of the ISO, respectively. (Reproduced from Figs.4 and 5 of [Nasuno, 2019]).

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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 and nitrous oxide, 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. Based on these marine ecosystem isotope models, we had developed a one-dimensional marine ecosystem isotopomer model in 2015, which can predict sea-to-air N_2O emissions directly (Green part in Fig.1). In 2016, we had added ammonia compartment into the marine ecosystem isotopomer model and had predicted the impact of ocean acidification on sea-to-air N_2O emission. In this year, we examined the response of N_2O production from nitrification to acidification in a series of incubation experiments in the western North Pacific. We found, contrary to previous findings, that the effect of ocean acidification on N_2O production during nitrification and nitrification rates are probably uncoupled. In the future, we are planning to improve the marine ecosystem isotopomer model using these results.

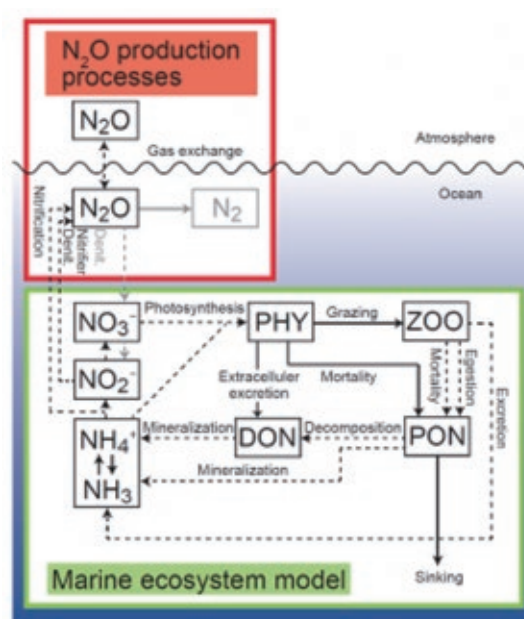


Fig.1 A schematic representation of the marine ecosystem isotopomer model, which consists of a marine ecosystem model based on *Yoshikawa et al.* [2005] and the N_2O production processes with nitrogen isotopomers based on *Yoshikawa et al.* [2016]. The symbols NO_3^- , NO_2^- , NH_4^+ , NH_3 , PHY, ZOO,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

Response of N₂O production rate to ocean acidification in the western North Pacific

Ocean acidification, induced by the increase in anthropogenic CO₂ emissions, has a profound impact on marine organisms and biogeochemical processes. The response of marine microbial activities to ocean acidification might play a crucial role in the future evolution of air–sea fluxes of biogenic gases such as nitrous oxide (N₂O), a strong greenhouse gas and the dominant stratospheric ozone-depleting substance. Using measurements of nitrification rates, *Beman et al.* [2011] estimated that the decrease in nitrification induced by ocean acidification could lead to a reduction in N₂O production ranging from ~0.06 to 0.83 TgN yr⁻¹, which is comparable to all current N₂O production from industrial processes and fossil fuel consumption.

To directly assess the response of rates and relations between N₂O production and nitrification to acidification, a series of seawater manipulation experiments were conducted in the subtropical and subarctic western North Pacific (WNP) (Fig.2).

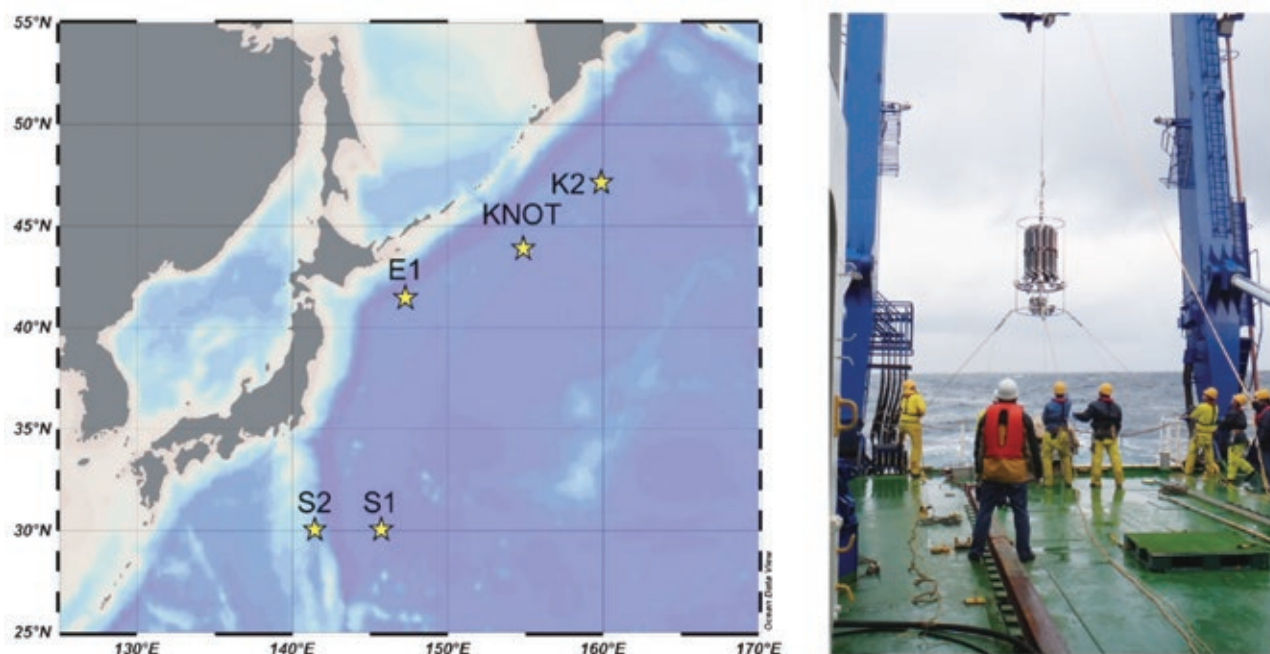


Fig.2 Map of study sites (stars) and picture of seawater sampling at subarctic station KNOT during YK16-16. Water sampler was casted in the sea from the research ship and seawater of active at 100-200 m depth, where microbial nitrification is active, was collected.

The experiments revealed that, with the exceptions of stations S1 and S2 (where the N₂O production rates are low, and near the limit of quantification (LOQ)), 6 among 10 (60%) N₂O production rates show a significant increase (P value ≤ 0.05) with the decline in pH (Fig.3b). Moreover, none of the 14 N₂O production rates show a statistically significant decrease with the decline in pH. The N₂O production rates measured in the subarctic sites increased by 19–82% in experiments K2, E1, and KNOT in response to a 0.1 unit decrease in ocean pH. On the other hand, nitrification rates remained constant or decreased in response to decreasing pH (Fig.3a). The variation in nitrification rates as function of the decline in seawater pH was significant (P value ≤ 0.05) in experiments K2, E1, KNOT whereas the other experiments did not show any significant response of the nitrification rate to the reduction in pH. The nitrification rates measured in the subarctic sites declined by 3–15% in response to a 0.1 unit decrease in pH. These results are in the same range as the reduction in nitrification rates measured by *Beman et al.* [2011] in response to a 0.1 unit decrease in pH (3–44%, mean 21%); 60% of the incubation experiments conducted in the subarctic WNP show statistically significant increases in the N₂O production rates with the decline in pH (Fig.3b). These findings suggest, contrary to the hypothesis of *Beman et al.* [2011], that the effect of ocean acidification on nitrification and associated N₂O production rates is probably uncoupled in some parts of the ocean.

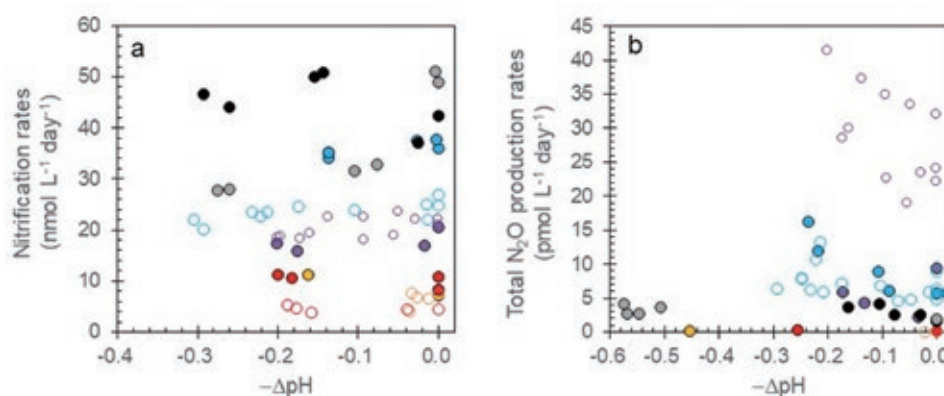


Fig.3 Results of acidification experiments. Horizontal axis shows decrease of pH whereas vertical axis shows rate of nitrification or N₂O production. Symbols with warm and cold colors respectively denote results for subtropical and subarctic sites. Decrease in pH is accompanied by decrease in nitrification rate and increase in N₂O production rate. [Breider *et al.*, 2019].

The study revealed that N₂O emission from the western North Pacific Ocean would not decrease but increase by ocean acidification. However, there are production and consumption processes of N₂O other than nitrification tested in this study, and dominant process would be different among oceanic regions. Increase in atmospheric N₂O concentration accelerates global warming and delays the recovery of ozone layer that was damaged by chlorofluorocarbons. Additional research is needed to see the response of other N₂O producing/consuming processes to ocean acidification as well as to study on other oceanic regions.

Publication List

Publication with Peer Review (Published)

- Kawagucci, S., A. Makabe, T. Kodama, Y. Matsui, C. Yoshikawa, E. Ono, M. Wakita, T. Nunoura, H. Uchida, and T. Yokokawa (2018), Hadal water biogeochemistry over the Izu-Ogasawara Trench observed with a full-depth CTD-CMS, *Ocean Science*, 14(4), 575–588, doi:10.5194/os-2018-37.
- Yasunaka, S., Y. Nojiri, T. Hashioka, C. Yoshikawa, T. Kodama, S. Nakaoka, S. Chiba, F. Hashihama, M. Wakita, K. Furuya, D. Sasano, A. Murata, H. Uchida, and M. Aoyama (2018), Basin-scale distribution of NH₄⁺ and NO₂⁻ in the Pacific Ocean, *Journal of Oceanography*, 74(1), 1–11, doi:10.1007/s10872-017-0433-1.
- Yoshikawa, C., A. Makabe, Y. Matsui, T. Nunoura, and N. Ohkouchi (2018), Nitrate isotope distribution in the subarctic and subtropical North Pacific, *Geochemistry, Geophysics, Geosystems*, 19(7), 2212–2224, doi:10.1029/2018GC007528.

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 the port of Sekinehama which was requested from the Aomori Prefectural Fisheries Experiment Station has been measured from 2002 to distribute for fishermen. The high frequent observation on the pier of Sekinehama Port was also added to detect seasonal and annual environmental changes after we observed the cold Oyashio Water in 2014. The in-situ observation using the continuous measuring pH device was enhanced in 2017 for understanding acidification effect on the coastal organisms in the Tsugaru Strait area.

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, MORSETS (MIO Ocean Radar data Site for Easter Tsugaru Strait, <http://www.godac.jamstec.go.jp/morsets/e/top/>) on September 2015. This web site is accessed mostly from Aomori area early morning. Probably a lot of fishermen check this site before fishing. We have been updated this web site year by year to improve convenience. The radar data has also been used for preliminary analyses of the relationship between the catch by the setnets and the marine environment.

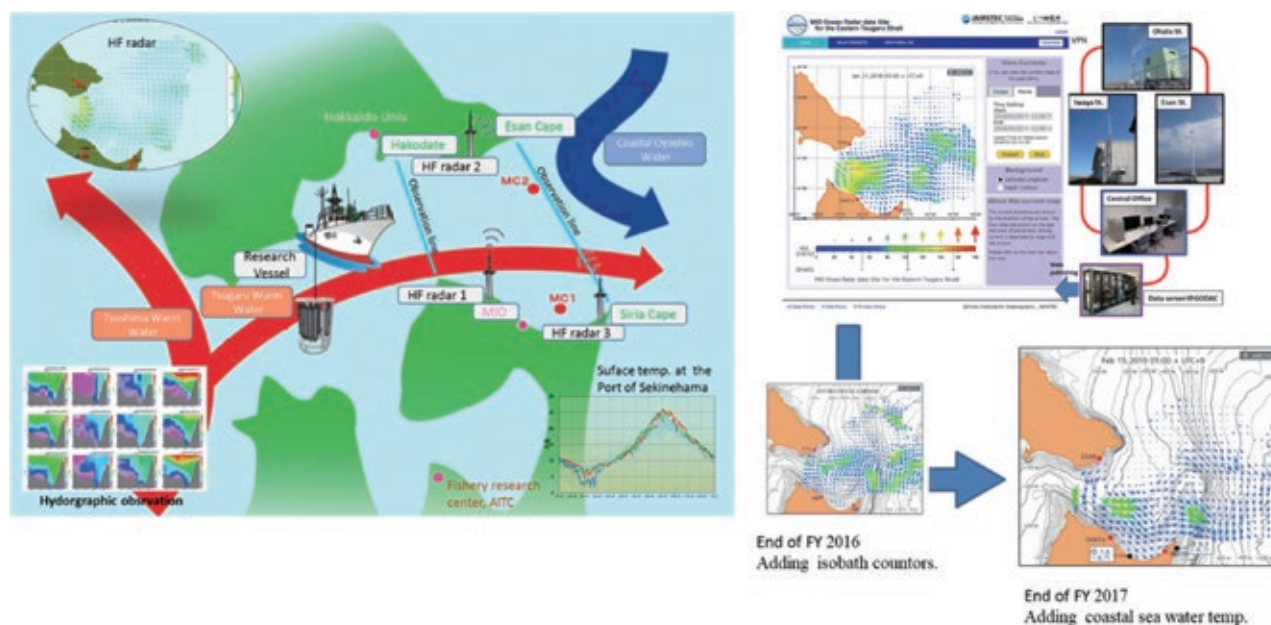


Fig.1 Schematic of MIO research program and web site of MORSETS.

I. Research Activities and Results

Mutsu Institute for Oceanography

Publication List

Publication with Peer Review (Published)

- Kawagucci, S., A. Makabe, T. Kodama, Y. Matsui, C. Yshikawa, E. Ono, M. Wakita, T. Nunonura, H. Ushida, and T. Yokokawa, Hadal water biogeochemistry over the Izu–Ogasawara Trench observed with a full-depth CTD-CMS, *Ocean Science*, 14, 575–588, doi:10.5194/os-14-575-2018.
- Sugie, K., T. Yoshimura, and M. Wakita (2018), Impact of CO₂ on the elemental composition of the particulate and dissolved organic matter of marine diatoms emerged after nitrate depletion, *Limnology and Oceanography*, 63(5), 1924–1943, doi:10.1002/lno.10816.
- Sukigara, C., Y. Mino, H. Kawakami, M. C. Honda, T. Fujiki, K. Matsumoto, M. Wakita, and T. Saino (2019), Sinking dynamics of particulate matter in the subarctic and subtropical regions of the western North Pacific, *Deep Sea Research Part I: Oceanographic Research*, 114, 17–27, doi:10.1016/j.dsr.2018.11.004.
- Uchimiya, M., H. Fukuda, M. Wakita, M. Kitamura, H. Kawakami, M. C. Honda, H. Ogawa, and T. Nagata (2018), Balancing organic carbon supply and consumption in the ocean's interior: Evidence from repeated biogeochemical observations conducted in the subarctic and subtropical western North Pacific, *Limnology and Oceanography*, 63(5), 2015–2027, doi:10.1002/lno.10821.
- Watanabe, Y. W., B. F. Li, and M. Wakita (2018), Long-Term Trends of Direct and Indirect Anthropogenic Effects on Changes in Ocean pH, *Geophysical Research Letters*, 45(17), 9106–9113, doi:10.1029/2018GL078084.

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) 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

(4) 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

(5) Graduate School of Maritime Sciences, Kobe University

Theme: Integration of observational and modeling studies of atmospheric ozone, precursors, and aerosols (SLCPs) over oceans around Japan

Program: Research and Development Center for Global Change

(6) The Center for Academic Resources and Archives, Tohoku University

Theme: Development of ultra-microscale skeletal density quantification of marine calcifiers by the Microfocus X-ray Computed Tomography

Program: Research and Development Center for Global Change

(7) Tohoku National Fisheries Research Institute, Japan Fisheries Research and Education Agency

Theme: Study on genetic diversity of phytoplankton and zooplankton

Program: Research and Development Center for Global Change

(8) National Institute of Maritime, Port and Aviation Technology

Theme: Observation of air quality and sea conditions in the coastal area of Kanagawa Prefecture and Tokyo Bay using regular routes

Program: Research and Development Center for Global Change

(9) 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

II. Related Activities
Research collaboration

(10) Center for Frontier Medical Engineering, Chiba University / School of Engineering, Tohoku University / Faculty of Engineering, Niigata University / Information Technology R&D Center, Mitsubishi Electric Corporation

Theme: Technology development for under-ice measurement in the Arctic Ocean

Program: Institute of Arctic Climate and Environment Change Research

(11) Hokkaido University /Japan Science and Technology Agency

Theme: Development of the learning tool for education and outreach activities on the Arctic

Program: Institute of Arctic Climate and Environment Change Research

(12) Iwate University

Theme: Design of a new platform with the EM lighthouse traveling on the sea-ice

Program: Institute of Arctic Climate and Environment Change Research

(13) Meisei Electric Co., Ltd.

Theme: The observational research for atmospheric water vapor with the use of newly developed sonde

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

(14) 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

(15) 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

(16) Japan Fisheries Research and Education Agency

Theme: Clarifications of ocean acidification and water-mass modification in the Tsugaru Strait and off Tohoku region

Program: Mutsu Institute for Oceanography

(17) Aomori Prefectural Industrial Technology Research Center

Theme: Collaborative research on coastal environment change around the Tsugaru Strait and Aomori Prefecture

Program: Mutsu Institute for Oceanography

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: Research and Development Center for Global Change

(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: Research and Development Center for Global Change

- Arctic Ocean Observation Research

Program: Institute of Arctic Climate and Environment Research

- Northern Fresh Water Cycle and Changing Atmospheric Pattern

Program: Research and Development Center for Global Change

(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 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

(9) 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

(10) 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

(11) 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

(12) 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

(13) Royal Netherlands Institute for Sea Research (NIOZ), Netherlands

Theme: Proxy development Paleooceanography

Program: Biogeochemistry Department

(14) 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

(15) 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

(16) 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

(17) 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

(18) University of Bergen (UiB), Norway

Theme: climate, weather, and air-sea interaction

Program: Application Laboratory

II. Related Activities
Research collaboration

(19) L’Institut Français de Recherche pour l’Exploitation de la Mer (IFREMER), France

Theme:

- Ocean Monitoring

Program: Research and Development Center for Global Change

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

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

- Observational Research of Black Carbon in Alaska relevant to Climate and Environmental Changes in the Arctic

Program: Institute of Arctic Climate and Environment Research

(2) University of Hawaii (UH), USA

Theme:

- Sub-seasonal Predictability of Tropical and Extratropical Climate Modes

Programs: Department of Coupled Ocean-Atmosphere-Land Processes Research, and
Application Laboratory

- Mid-Latitude Ocean-Atmosphere Variability

Program: Application Laboratory

- 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

Programs: Research and Development Center for Global Change, and
Department of Coupled Ocean-Atmosphere-Land Processes Research

(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: Research and Development Center for Global Change

- (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: Research and Development Center for Global Change
- (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: Research and Development Center for Global Change
- (8) **Universidad de Concepción (UDEC), Chile**
Theme: Basic Research on Paleooceanography, 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: Research and Development Center for Global Change
- (12) **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
- (13) **The National Institute of Water and Atmospheric Research (NIWA), New Zealand**
Theme: Investigation of Climate Predictability and Applicability over New Zealand using Statistical Downscaling Method
Program: Application Laboratory
- (14) **Korean Polar Research Institute (KOPRI), Korea**
Theme: Marine Research in the western Arctic Ocean
Program: Institute of Arctic Climate and Environment Research

II. Related Activities
Research collaboration

- (15) The University of Oxford, United Kingdom / Le Centre National de la Recherche Scientifique, France / Indian Institute of Tropical Meteorology, India / Potsdam Institut für Klimafolgenforschung, Germany / Institute of Atmospheric Physics, China**
Theme: Globally Observed Teleconnections in Hierarchies of Atmospheric Models
Program: Department of Seamless Environmental Prediction Research
- (16) Institute for Biological Problems of Cryolithozone (IBPC), Siberian Branch of Russian Academy of Sciences, Russia**
Theme: Cooperative Research on Black Carbon in the Eastern Siberia
Program: Institute of Arctic Climate and Environment Research
- (17) The National Institute of Aeronautics and Space of the Republic of Indonesia (LAPAN), Indonesia**
Theme: Cooperative Atmospheric Research over the Indonesian Maritime Continent
Program: Department of Coupled Ocean-Atmosphere-Land Processes Research
- (18) Nanjing University of Information Science and Technology (NUIST), China**
Theme: Cooperative Research on Climate Variability Prediction and its Application
Program: Application Laboratory

Funded research projects

- (1) 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: Research and Development Center for Global Change
- (2) 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
- (3) 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
- (4) 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: Research and Development Center for Global Change
- (5) 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
- (6) Top-down model development for estimation of total carbon (CO₂, CH₄, CO) sources and sinks (FY2017-2019)**
Fund: Environment Research and Technology Development Fund (ERTDF)
Funding institution: National Institute for Environmental Studies (NIES)
Program: Research and Development Center for Global Change
- (7) Top-down evaluation of BC and CH₄ emission estimates from Asia using field and satellite observations (FY2018-2020)**
Fund: Environment Research and Technology Development Fund (ERTDF)
Funding institution: National Institute for Environmental Studies (NIES)
Program: Research and Development Center for Global Change
- (8) Estimations of methane emissions using GOSAT/GOSAT-2 and surface observation data (FY2018-2020)**
Fund: Environment Research and Technology Development Fund (ERTDF)
Funding institution: Chiba University
Program: Research and Development Center for Global Change

II. Related Activities

Funded research projects

(9) Development, Analysis, and Implementation of Computationally Efficient Models for Resolving Cellular and COMMunity Composition of Plankton (CECOMP) (FY2018-2021)

Fund: JSPS International Joint Research Program (JRPs-LEAD with DFG)

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

Program: Research and Development Center for Global Change

(10) Development of feasibility report for the Collaborative Study of Kuroshio and its adjacent seas in the IOC/UNESCO Sub-Commission WESTPAC (FY2018-2018)

Fund: Aid for the UNESCO activities by the government support for development Exchanges and cooperation for the outreaches and developments of the UNESCO activities to contribute to the achievements of Sustainable Development Goals (SDGs)

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

Program: Research and Development Center for Global Change

(11) Disentangling the role of chemolithotrophs in the Pacific and Southern Oceans (FY2018-2019)

Fund: JSPS Joint Research Projects and Joint Seminars under the Bilateral Programs

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

Program: Research and Development Center for Marine Biosciences

(12) 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

(13) 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

(14) A novel modelling technique to understand the impact of the Gulf Stream and Kuroshio on climate (FY2018-2019)

Fund: JSPS Joint Research Projects and Joint Seminars under the Bilateral Programs

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

Program: Application Laboratory

(15) Improvement of prediction skills of two-month lead Kanto area mean surface air temperature (FY2018-2019)

Fund: Research grants from TEPCO Fuel & Power, Inc.

Funding institution: TEPCO Fuel & Power, Inc.

Program: Application Laboratory

(16) 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

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

Fund: Environment Research and Technology Development Fund (ERTDF)
Funding institution: Hokkaido University
Program: Institute of Arctic Climate and Environment Research

(18) 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: Institute of Arctic Climate and Environment Research

(19) Quantifying Human Influence on Ocean Melting of the West Antarctic Ice Sheet (FY2018-2021)

Fund: JSPS International Joint Research Program (JRPs-LEAD with UKRI)
Funding institution: Japan Society for the Promotion of Science (JSPS)
Program: Institute of Arctic Climate and Environment Research

(20) 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

(21) 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

(22) Research on methane-climate feedback (FY2017-2019)

Fund: Environment Research and Technology Development Fund (ERTDF)
Funding institution: National Institute for Environmental Studies (NIES)
Program: Project Team for Advanced Climate Modeling

(23) Sophisticated Earth system model for evaluating emission reductions needed (FY2017-2021)

Fund: Integrated Research Program for Advancing Climate Models (TOUGOU)
Funding institution: Ministry of Education, Culture, Sports, Science and Technology (MEXT)
Program: Project Team for Advanced Climate Modeling

(24) Prediction and Projection of Large-Scale Climate Changes Based on Advanced Model Development (FY2017-2021)

Fund: Integrated Research Program for Advancing Climate Models (TOUGOU)
Funding institution: Atmosphere and Ocean Research Institute (AORI), The University of Tokyo
Program: Project Team for Advanced Climate Modeling

(25) 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 Environmental Geochemical Cycle Research

II. Related Activities

Funded research projects

(26) 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

(27) Globally Observed Teleconnections and their Role and Representation in the Hierarchies of Atmospheric Models (FY2016-2019)

Fund: Strategic International Research Cooperative Program “Belmont Forum”

Funding institution: Japan Science and Technology Agency (JST)

Program: Department of Seamless Environmental Prediction Research

(28) Study of atmospheric hierarchical structure by fusion of observation data from a global radar network and high-resolution general circulation models (FY2018-2018)

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

Funding institution: Japan Science and Technology Agency (JST)

Program: Department of Seamless Environmental Prediction Research

(29) 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

- **The Most Cited Paper Award 2018, Progress in Earth and Planetary Science**

Dr. Naohiko Ohkouchi, Dr. Nanako O. Ogawa (Department of Biogeochemistry)

Biochemical and physiological bases for the use of carbon and nitrogen isotopes in environmental and ecological studies
(April, 2018)

- **Young Researchers' Award 2018, Japan Association of Aerosol Science and Technology**

Dr. Fumikazu Taketani (Research and Development Center for Global Change)

Studies of heterogeneous reaction and chemical property of the aerosol particles using laser spectroscopy
(August, 2018)

- **Best Oral Presentation Award, PICES 2018 Annual Meeting**

Dr. Yu-Lin Chang (Application Laboratory)

Potential impact of ocean circulation on Japanese eel larvae migration
(November, 2018)

- **Invention Encouragement Award, 2018 Kanto Regional Commendation for Invention**

Dr. Saburo Sakai (Department of Biogeochemistry)

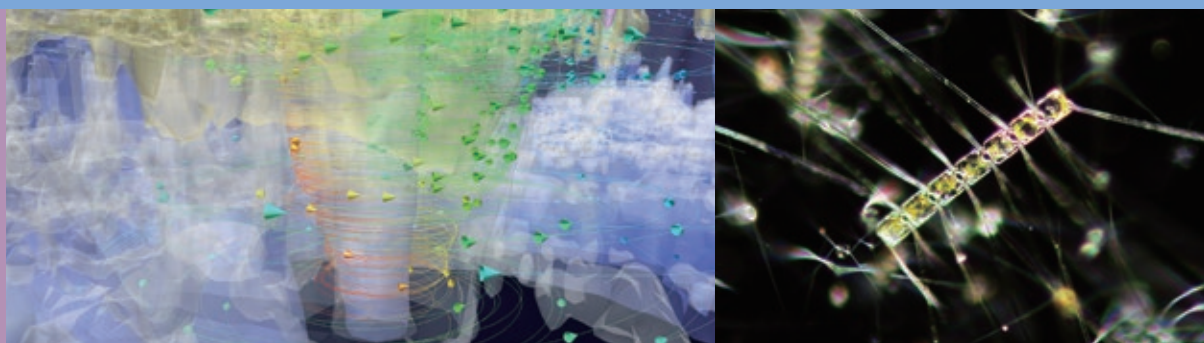
A device for efficiently collecting the powder created when using a high-precision micromill system
(November, 2018)

* Papers in this Annual Report may be overlap across groups or fiscal years.

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Research and Development on Marine and Global Environmental Change

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