

Research Institute for Global Change (RIGC) Annual Report FY2024



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Research Institute for Global Change (RIGC)
Annual Report FY2024
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Organization



Research Institute for Global Change (RIGC)

Annual Report FY2024

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I. Research Activities and Results

– Global Ocean Observation Research Center (GOORC) – Basin-scale salinity variation in the upper ocean over the North Pacific

Salinity is an essential factor that determines the ocean state and is also used to determine the footprint of changes in the hydrological cycle. The development of the Argo observation system has enabled us to reveal a clearer picture of spatiotemporal variations in salinity. While salinity variations near the surface have been investigated in the last decade, those in the subsurface have yet to be studied enough. We examined interannual variations in upper ocean salinity in the North Pacific Ocean (NP) comprehensively over a period of 18 years (2004–2021) with gridded datasets produced from in situ observations (Hosoda, 2007; Ishii et al., 2017) considering vertical profiles of salinity. The standard deviations of salinity anomalies from monthly climatology just before the Argo era were quite small compared to those after it, underlining the significance of the Argo observation system in capturing interannual variations in water properties.

Salinity above 400 dbar increased in the eastern and western mid-latitude regions and decreased in the central subarctic and subtropics from the first half to the latter half of the 2010s (Fig. 1a). This spatial pattern resembled that of the temperature (Kawai et al., 2023). While the freshening in the subtropics was remarkable above 100 dbar, salinity changes in the subarctic were large even in the subsurface (Fig. 1b). The first mode of the complex empirical orthogonal function analysis indicated the eastward (westward) propagation of salinity anomalies in the subarctic (subtropics), that is, a clockwise shift (Fig. 2). Salinity budget analysis revealed that the changes in the 2010s were mainly caused by geostrophic advection in zonal regions around 40°N and 20°N, and the eastern NP. Precipitation also contributed to freshening in the subtropics, but not in the central subarctic. The meridional migration of salinity fronts in the subarctic and subtropics contributed to freshening in the central NP. The dynamic height at the sea surface decreased around the subarctic front and the subtropics south of 20°N and west of 170°W, and increased in the Kuroshio recirculation region, indicating that the subtropical gyre contracted meridionally (Fig. 3a). The change in Sverdrup transport calculated from wind stress in an atmospheric reanalysis qualitatively corresponds to Fig. 3a, except around the Aleutian Islands (Fig. 3b). The change in dynamic height can be mainly attributed to wind stress. It is unclear whether salinification in the eastern and western regions inevitably synchronizes and should be further examined.

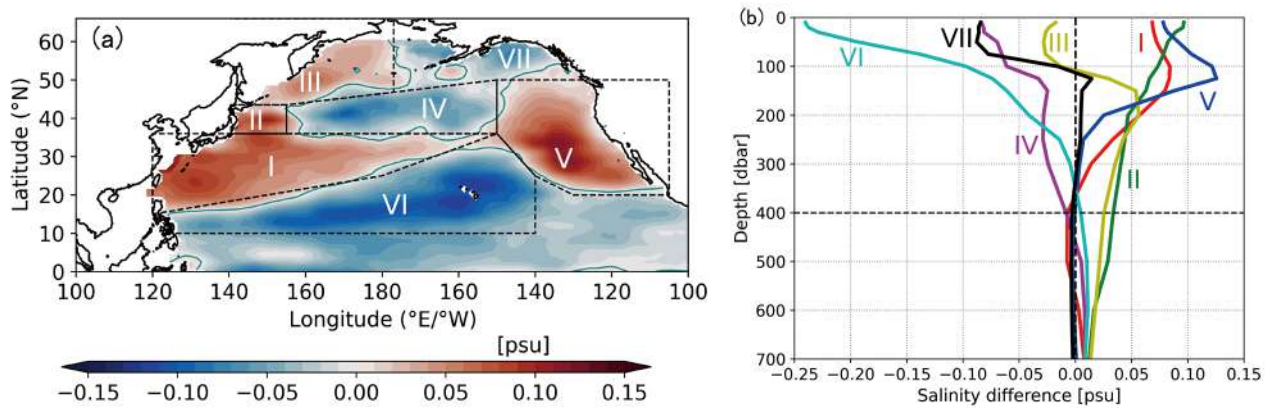


Fig. 1 (a) Differences of five-year mean salinity above 400 dbar from 2009–2013 to 2015–2019. Thin green contour denotes zero. **(b)** Vertical profiles of the salinity differences in the boxes shown in panel (a).

I. Research Activities and Results

Global Ocean Observation Research Center (GOORC)

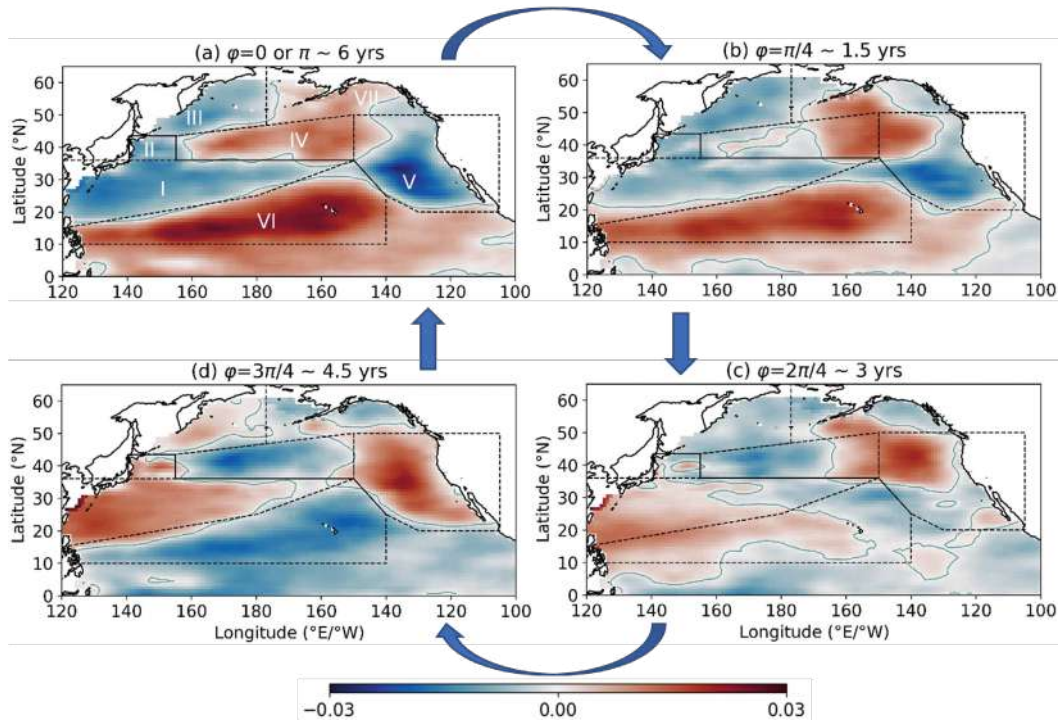


Fig. 2 First mode of the complex empirical orthogonal function (CEOF) for monthly salinity anomaly averaged above 400 dbar. (a) The CEOF when its real part in Region VI peaks ($\phi = 0$ or π). (b) The CEOF one-eighth period after (a) ($\phi = \pi/4$). (c) One-quarter after (a) ($\phi = \pi/2$). (d) Three-eighths period after (a) ($\phi = 3\pi/4$). Thin green contour denotes zero.

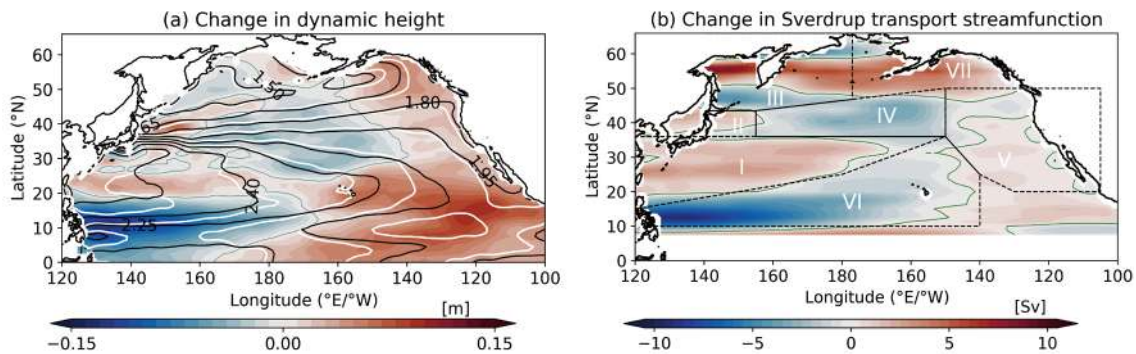


Fig. 3 Differences of five-year mean (a) dynamic height and (b) Sverdrup transport streamfunction from 2009-2013 to 2015-2019. The dynamic height is calculated from the MOAA GPV data (Hosoda, 2007) to the reference pressure of 2000 dbar. Sverdrup transport is obtained from the wind stress of JRA-55 (Kobayashi et al., 2015). White and black contours show the dynamic height in 2009-2013 and 2015-2019, respectively. Thin green contour denotes zero.

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The Biological Carbon Pump Revealed by Dissolved Oxygen

The ocean plays a fundamental role in regulating Earth's climate by absorbing atmospheric carbon dioxide (CO₂) and storing it over long timescales. A major pathway for this storage is the biological carbon pump, in which phytoplankton convert dissolved CO₂ into organic matter through photosynthesis, and a portion of this material sinks as particulate detritus, transferring carbon from the surface to the ocean interior. Although the biological carbon pump has long been considered a critical component of the global carbon cycle, its quantitative contribution to global carbon sequestration remains highly uncertain due to the difficulty of directly measuring the complex pathways of carbon transport.

To overcome this limitation, we estimate the global biological export production using dissolved oxygen (DO) as a proxy for biological carbon fixation. Photosynthesis produces oxygen at nearly the same stoichiometric ratio as CO₂ consumption; therefore, the net biological oxygen production can be used to infer corresponding organic carbon production. However, DO in the upper ocean is also strongly influenced by physical processes, including air–sea oxygen exchange, horizontal and vertical advection, and turbulent mixing. Using more than 400,000 in situ DO profiles, along with state-of-the-art datasets describing physical ocean processes, we evaluate a full dissolved-oxygen budget and quantify net DO removal driven by physical processes (Fig. 4). The biological oxygen production required to balance this physical loss is then converted into carbon units using the photosynthetic ratio.

Our results provide the first observationally constrained, globally integrated estimate of annual biological carbon export of $7.36 \pm 2.12 \text{ Pg C yr}^{-1}$, substantially lower than the widely cited estimate of $\sim 13 \text{ Pg C yr}^{-1}$ (Boyd et al., 2019). The spatial distribution further reveals that high-latitude and tropical regions are dominant contributors to global export. This new constraint fundamentally advances our understanding of the ocean carbon cycle and provides a framework for integrating future biogeochemical observations (Yamaguchi et al., 2024).

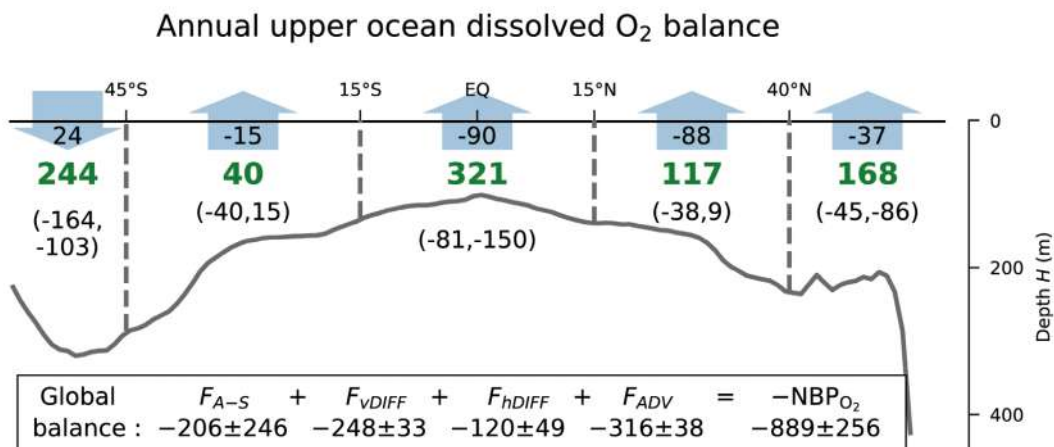


Fig. 4 Estimated upper ocean dissolved oxygen balance, including physical oxygen transfers by air–sea exchange (F_{A-S} , the top numbers with arrows), diffusion ($F_{VDIFF} + F_{HDIFF}$, the first numbers in paratheses), and advection (F_{ADV} , the second numbers in paratheses), and net biological production of oxygen (F_{NBP} , green bold numbers). Global balance is reported as the sums with their uncertainties in the bottom box. The unit of all budget terms are $\text{Tmol O}_2 \text{ yr}^{-1}$. Assuming a photosynthetic stoichiometric ratio of $\Delta\text{O}_2/\Delta\text{C} = 1.45$, the estimated net biological oxygen production of $889 \pm 256 \text{ Tmol O}_2 \text{ yr}^{-1}$ corresponds to $7.36 \pm 2.12 \text{ Pg C yr}^{-1}$ of carbon fixation.

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Global Ocean Observation Research Center (GOORC)

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– Institute of Arctic Climate and Environment Research (IACE) – Enhancement of floor heating under the Arctic sea ice revealed by analysis of 20-years’ cruise dataset

Whereas sea ice decline in the Arctic Ocean is recognized as a serious issue of global environmental changes, the record minimum of the Arctic sea ice extent has not been updated since 2012. Previous studies reported continuous ocean warming under the sea ice cover in the Canadian side of the Arctic Ocean and indicated the enhanced inflow of the Pacific-origin warm water as a primary factor (Watanabe et al., 2017; Timmermans et al., 2018). Since this ocean heat has a potential to cause the drastic decline of overlying sea ice, it is highly important to understand spatial and temporal variability in the ocean heat distribution associated with the Pacific-origin water transport.

Here we found the unrecognized remarkable accumulation of ocean heat around the Chukchi Borderland, located northwest of Alaska, by the synthetic analysis of hydrographic (temperature and salinity) data obtained by the Research Vessel (R/V) *Mirai* cruise over the early 21st century (Fig. 1; Muramatsu et al., 2025). A statistically significant decadal trend of $16.6 \pm 10.6 \text{ MJ m}^{-2} \text{ year}^{-1}$ in the subsurface ocean heat content during 1999–2020 was captured by shipboard hydrographic data, and associated with the transport of Pacific Summer Water (PSW) from Barrow Canyon northwest of the Alaskan coast, where similar warming appeared (Fig. 2). Satellite-derived geostrophic ocean velocity indicated that the northwestward ocean current flowing from Barrow Canyon to the Chukchi Borderland became faster in the late 2010s, in association with southeastward shift of the Beaufort Gyre, circulating clockwise around the Canada Basin. Therefore, we suggest that the warming of PSW passing over the Chukchi shelf and intensification of the northwestward ocean current along the shelf–basin boundary both acted to enhance the heat transport and contributed to the positive trend in downstream subsurface ocean heat content. Our findings fill important gaps in the understanding of ocean heat distribution/transport, which is a key factor for sea ice freezing/melting, in the central Arctic.

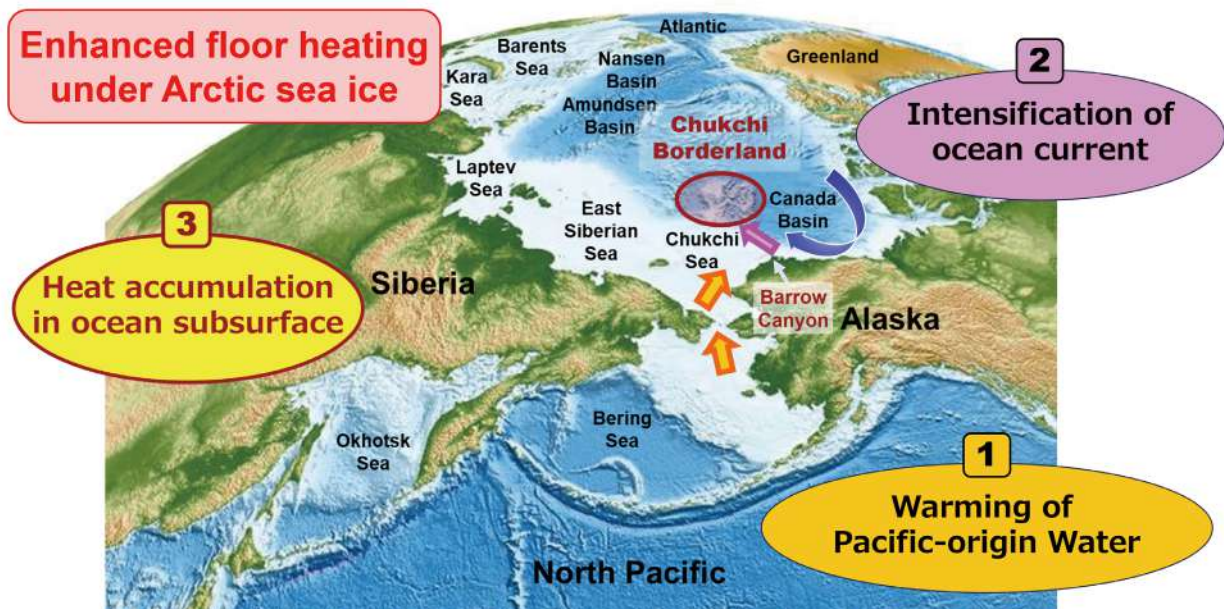


Fig. 1 Schematic image of a role of the Pacific-origin water in floor heating under the Arctic sea ice.

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Institute of Arctic Climate and Environment Research (IACE)

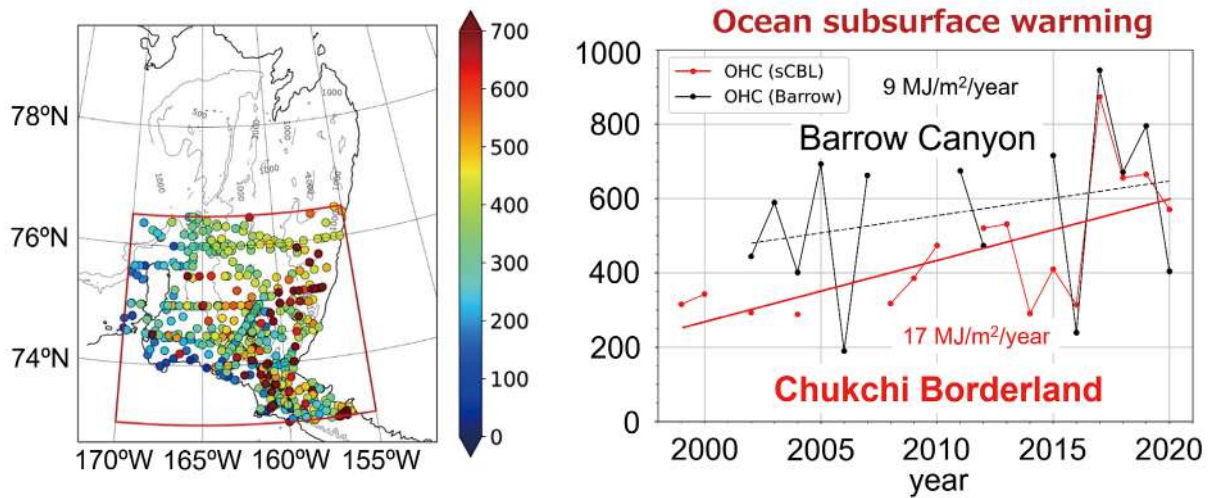


Fig. 2 Subsurface ocean heat content in the southern Chukchi Borderland region [MJ/m²]. (Left) Spatial distribution at all stations analyzed in our study. (Right) Interannual time series for 1999–2020. Black dots show the subsurface ocean heat content calculated using the mooring-based dataset in Barrow Canyon.

On a broader scale, the stepwise reduction of the Arctic sea ice was explained by the shortened residence time according to acceleration of the Transpolar Drift Stream toward the Fram Strait (Sumata et al., 2023). Moreover, the enhanced role of ocean heat transport through the major Arctic gateways (i.e., the Barents Sea Opening, Fram Strait, and Bering Strait) and a poleward shift of its greater impact on sea ice variability were simulated by ensemble historical and future experiments using climate models. It was also reported that the anomalously warm PSW delayed the southward advance of the sea ice area on the Pacific side. Our findings further elucidate the ocean heat transport from the Chukchi shelf to the western Arctic basin, especially from Barrow Canyon to the Chukchi Borderland, which is one of the key processes influencing change in sea ice on a regional scale. However, the PSW transport to regions further downstream in the central Arctic is still unknown. Therefore, more in-depth investigations on the detailed pathways and heat transport of PSW to the deeper basins should be conducted. Heat budget analyses, including vertical mixing with the surface layer, are also necessary for more quantitative evaluation of the impact of PSW on the freezing/melting of overlying sea ice. Numerical model experiments would be important in achieving this objective. The target region in the present study is regarded as a potential fishable area where “the agreement to prevent unregulated high seas fisheries in the central Arctic Ocean” was acknowledged in 2018 and entered into force in 2021 (<https://www.fao.org/faolex/results/details/en/c/LEX-FAOC199323/>). The detected subsurface warming would influence the habitat shift and biomass of fishery resources.

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Long-term observations of black carbon and carbon monoxide in the Poker Flat Research Range, central Alaska, with a focus on forest wildfire emissions

Climate change in the Arctic region has been strongly accelerated compared to the global average (Box et al., 2019). Black Carbon (BC) aerosols strongly contribute to climate warming by absorbing solar radiation and decreasing ice and snow surface albedo (Bond et al., 2013). Forest wildfires in the northern American region are one of the important BC emission sources in the Arctic and subarctic troposphere. The occurrences of forest wildfires in interior Alaska have increased since the 1980s (Sierra-Hernández et al., 2022). Consequently, the impact of BC from forest wildfires on the Arctic climate will be more important in the future.

In this study (Kinase et al., 2025), we observed concentrations of BC and carbon monoxide (CO) at the Poker Flat Research Range (PFRR; 65.12° N, 147.43° W, 500 m a.s.l.), estimated BC sources, and evaluated impacts of forest wildfires on BC concentrations in Alaska. This site is located in the centre of interior Alaska and is surrounded by forests that frequently experience wildfires. The BC mass concentration did not show a clear seasonal variation. However, abrupt peaks were occasionally observed during summer (Fig. 3(a)). Corresponding peaks in the CO mixing ratio were also observed in summer, indicating that both BC and CO were emitted from the same source (Fig. 3(a)).

To estimate BC source sectors and regions, the FLEXPART (FLEXible PARTicle dispersion model)-WRF (Weather Research & Forecast) model was used in backward mode. FLEXPART-WRF could capture observational results (Fig. 3(a)) in which the median simulated/observed ratio was 1.0. In the warm season, the possible BC source regions were Russia (3.6–74 % in the 10–90 percentile) and Alaska (12–85 % in the 10–90 percentile) and sometimes Canada (1.0–21 % in the 10–90 percentile) (Fig. 3(b) and (c)), and the possible source sector was estimated to be biomass burning (8.1–88 % in the 10–90 percentile) (Fig. 3(b) and (c)). Focusing on cases of high BC mass concentrations, FLEXPART-WRF confirmed that the observed cases of high BC mass concentrations were primarily affected by local forest wildfires in Alaska (Fig. 4(a)).

Finally, we investigated the relationship between forest fire intensity and the concentration ratio of BC and CO (BC/ Δ CO ratio), as previous studies (Pan et al., 2017) suggested that the different combustion condition can alter BC/ Δ CO ratio. Airmasses containing high BC concentration were tracked using the HYSPLIT model, and forest fire intensity possibly affected the BC concentration was estimated along with the trajectory using the fire radiative power (FRP) observed by the satellite. As a result, a positive correlation was found between these parameters (Fig. 4(b)). For the first time, the properties of the BC/ Δ CO ratio from forest wildfires in Alaska were systematically characterized in terms of FRP, suggesting the potential to improve emission inventories and/or emission factors by using FRP.

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Institute of Arctic Climate and Environment Research (IACE)

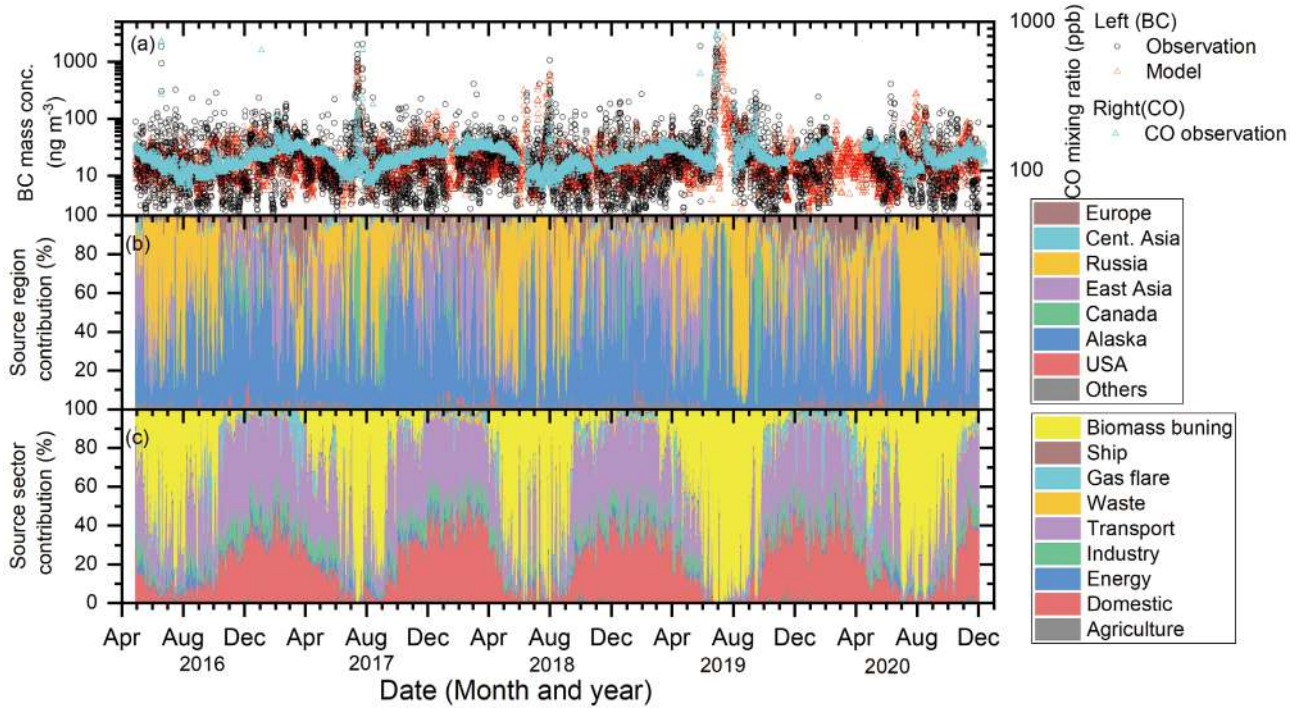


Fig. 3 Time series of (a) BC mass concentrations and CO mixing ratio, (b) attribution of BC at the PFRR to source regions, and (c) to source sectors. Black open circles, light blue open triangles, and red open triangles in (a) show the 6-hour average BC and CO observations and 6-hourly BC simulations, respectively. Individual colour bars in (b) and (c) depict the estimated contributions from the source regions and sectors, respectively.

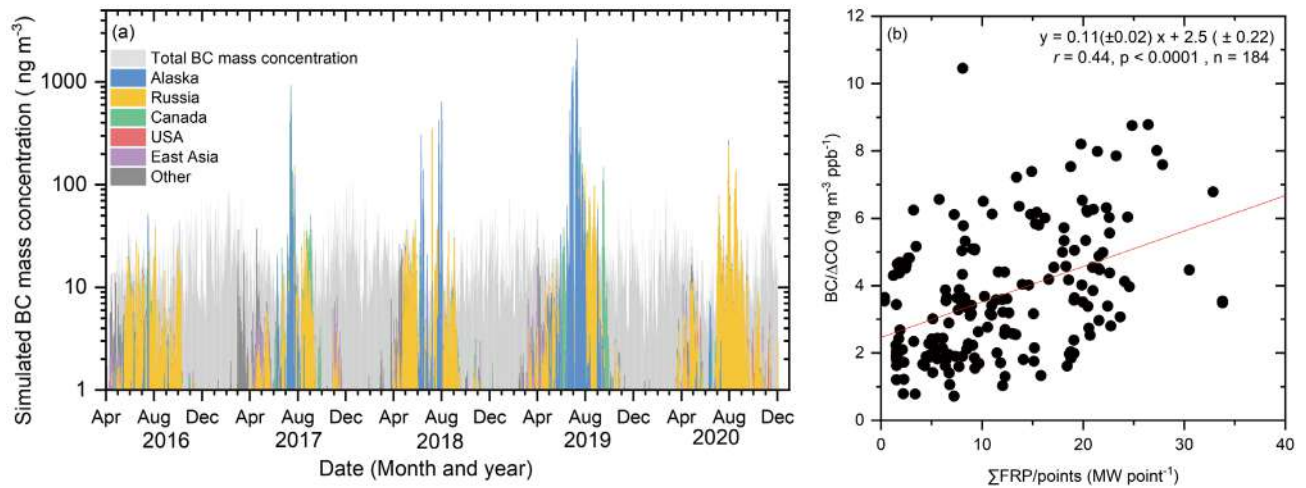


Fig. 4 (a) A time series of the 6-hourly BC mass concentrations at the PFRR simulated by the FLEXPART-WRF model. Light grey bars show the total BC mass concentrations. Other individual colour bars (overlaid on the light grey bars) show the BC mass concentrations for biomass burning from each source region. (b) The scatter plot (black filled circles) between the hourly BC/ΔCO ratio observed at the PFRR and the ΣFRP/point values in cases of high BC concentrations (>98 percentile). Data from June to September were analyzed. The ΣFRP/point values are the average FRP of the hot spots (points) present along the backward trajectories from the PFRR. A red line indicates the result of a linear regression fit.

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How Sea Ice Edges Drive Global-Scale Atmosphere and Ocean Circulation

Enormous amounts of heat and moisture are released from the ocean to the atmosphere near the sea ice edge during cold-air outbreaks. Furthermore, it has been pointed out that the intense horizontal temperature gradient at sea ice edges modulates surface baroclinicity, thereby affecting the activity of synoptic-scale cyclones in the Arctic. The sea ice extent has been diminishing rapidly due to global warming, and therefore a deeper understanding of the sea ice edge position and the three-dimensional atmospheric structure near sea ice edges is of great importance for elucidating the changes in atmosphere and ocean circulation in recent years. Our group investigated long-term changes in sea ice edge positions and atmospheric structures, including temperature and vertical velocity, in the vicinity of sea ice edge in the Barents and Greenland Seas over the last 45 years based on satellite observations and atmospheric reanalysis data.

Using satellite observations, we demonstrated that sea ice edge positions have been shifting rapidly in recent decades both in the Barents Sea and Greenland Sea (Masunaga et al., 2024). In the central Barents Sea, the sea ice edge fluctuated between the narrow warm currents at 76°N and 74°N in winter until the mid-2000s, resulting in two prominent peaks in the horizontal distribution of sea ice edge occurrence (Fig. 5a). The fluctuation is regulated by the mean surface wind direction. However, typical sea ice edge positions have been fixed along the narrow ocean current at 76°N (Fig. 5b), rather than fluctuating, since the rapid warming in the Barents Sea occurred around 2005. In addition, sea ice edges have frequently been observed near the northern continental slope since the 2010s, suggesting the imprint of the recent warming of the Spitsbergen Current.

In the Greenland Sea, sea ice edges were typically located along the East Greenland Current all seasons, including the warm season, before 2010s (Fig. 5c). However, in recent decades, the sea ice edges in the warm season tend to be positioned further west or even missing as manifested by the reduced occurrence of sea ice edge along the East Greenland Current (Fig. 5d). It was found that the decrease in sea ice thickness, as well as the warming in the Greenland Sea, play an important role. Thus, typical sea ice edge positions have been changing rapidly in recent decade in the Barents Sea and Greenland Sea.

Our group further investigated local atmospheric features near the sea ice edge (Masunaga, 2024). We revealed that near-surface winds exhibit intense convergence along the sea ice edge in the cold-season climatology (Fig. 6a). It was confirmed that the intense near-surface wind convergence induces upward motion that extends into the free-atmosphere beyond the atmospheric boundary layer (Fig. 6b). Thus, the near-surface wind convergence and associated upward motion can be a key pathway through which the sea ice edge modulates large-scale atmospheric circulation.

To clarify what synoptic-scale situations give rise to the intense near-surface wind convergence anchored along the sea ice edge in the long-term climatology, we analyzed daily synoptic-scale atmospheric fields in greater detail. It was suggested that the mean wind convergence reflects the confluence of northerly winds formed near the east coast of Greenland, known as the barrier jet (Moore & Renfrew, 2005), and easterly winds induced

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by synoptic-scale cyclones over the Greenland Sea. The frequent generation of small cyclones and associated surface wind convergence over the Greenland Sea is also considered to be a contributing factor. This surface wind structure is very similar to that formed near western boundary currents such as the Gulf Stream, although the underlying shaping processes differ.

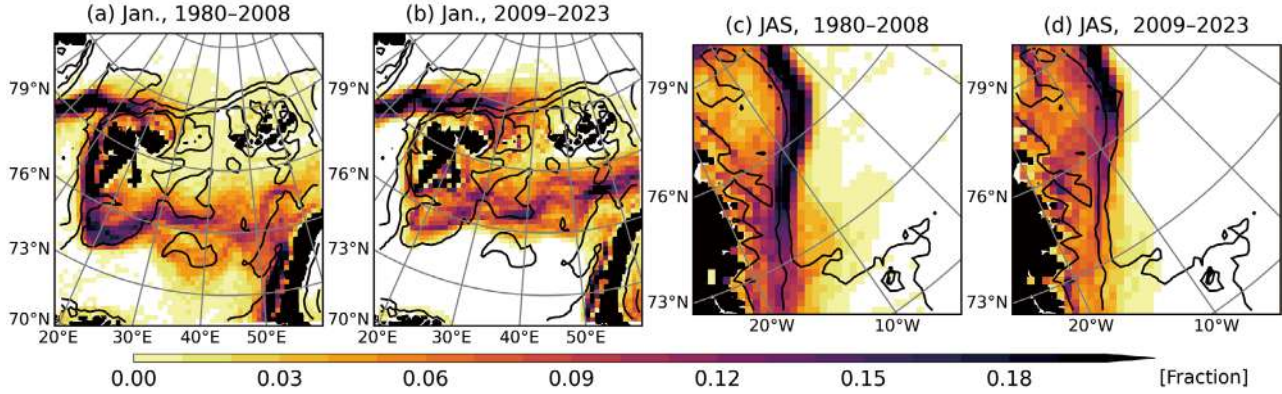


Fig. 5 Distributions of sea ice edge occurrence frequency based on satellite observations in Barents Sea for (a) January 1980–2008, (b) January 2009–2023, and in the Greenland Sea in (c) July–September for 1980–2008, (d) July–September for 2009–2023. Black lines indicate bathymetry contours of 200, 500, and 2000 m.

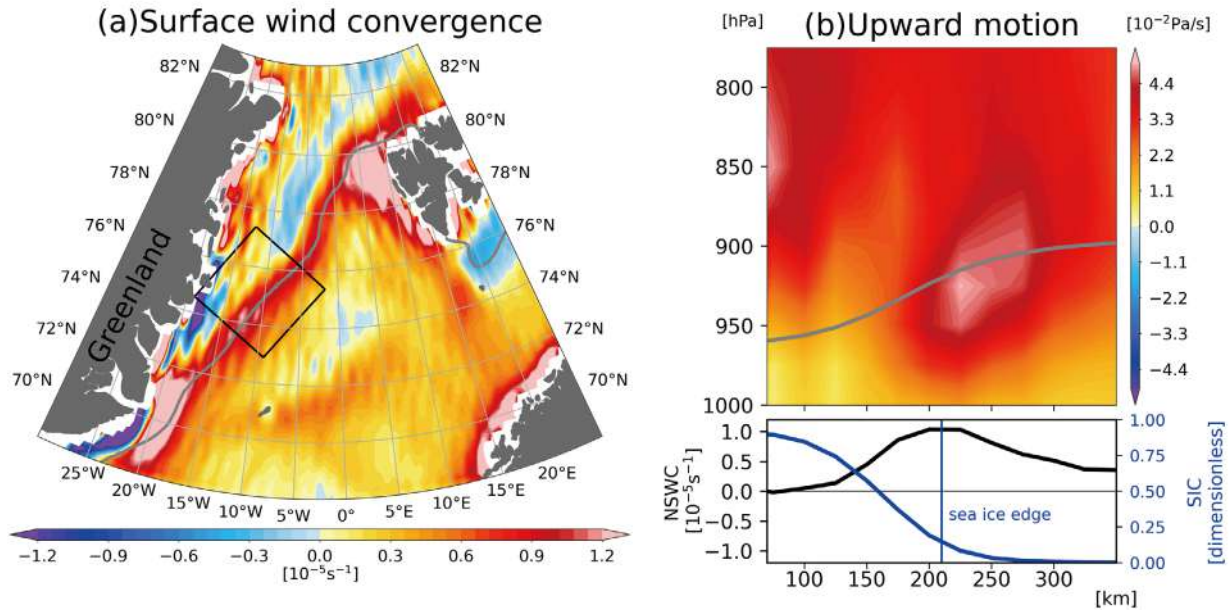


Fig. 6 (a) Climatological-mean near-surface wind convergence (color) and sea ice concentration (contours; 15% only) in January. (b) The corresponding pressure vertical velocity (color; positive for upward) averaged along the sea ice edge for the grey box in (a). The grey line in (b) indicates the top of atmospheric boundary layer. The lower panel in (b) shows the corresponding near-surface wind convergence (black; left axis) and sea ice concentration (blue; right axis). The abscissa indicates the distance from the northwestern rims of the rectangular boxes in (a) (km). These plots are based on the ERA5 reanalysis.

These findings suggest that recent sea ice edge shifts may have been affecting larger-scale atmospheric circulation by modulating near-surface wind convergence and associated upward motion. In addition, the recent sea ice edge shifts may be affecting global ocean circulation through changes in the distribution of heat and moisture release. To further elucidate these effects, long-term simulations with a high-horizontal resolution numerical model are required. Our efforts to conduct long-term simulations with global cloud-resolving and eddy-resolving models are already underway. In the future, the impacts of the sea ice edge shifts on global atmospheric and oceanic circulation are expected to be clarified using these high-resolution model outputs.

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– Earth Surface System Research Center (ESS) – Siberian wildfires enhance aerosol particle concentrations nucleating ice over high-latitude oceans

Ice-nucleating particles (INPs) significantly influence aerosol-cloud-precipitation interactions at regional and global scales. However, information regarding the concentrations and origins of INPs over the open ocean, particularly at high latitudes, remains insufficient due to access difficulties. In this study, we investigated the concentrations and origins of INPs over the western North Pacific to the Arctic Ocean through shipborne observations conducted in the early autumn of 2016 (MR16-06 cruise of R/V *Mirai*).

The temperature dependence of number concentrations of INP (N_{INPs}) measured in the four latitudinal bands (40–50 °N, 50–60 °N, 60–70 °N, and $\geq 70^\circ\text{N}$) during the cruise are shown in the lower panels of Fig. 1. The N_{INPs} active at -25°C ($N_{\text{INPs}}(-25^\circ\text{C})$) and -15°C ($N_{\text{INPs}}(-15^\circ\text{C})$) varied from 0.034 to 41.2 L^{-1} and < 0.0005 to 0.11 L^{-1} , respectively, and those over the Arctic Ocean ($\geq 70^\circ\text{N}$) were lowest. Temperature dependence of N_{INPs} for latitudes $\geq 70^\circ\text{N}$ in this study were almost within the range of variability reported over the marine boundary layer. On the other hand, N_{INPs} at 60–70°N on August 29–31, 2016, and $< 70^\circ\text{N}$ on September 19–30, 2016, tended to be higher than those reported previously.

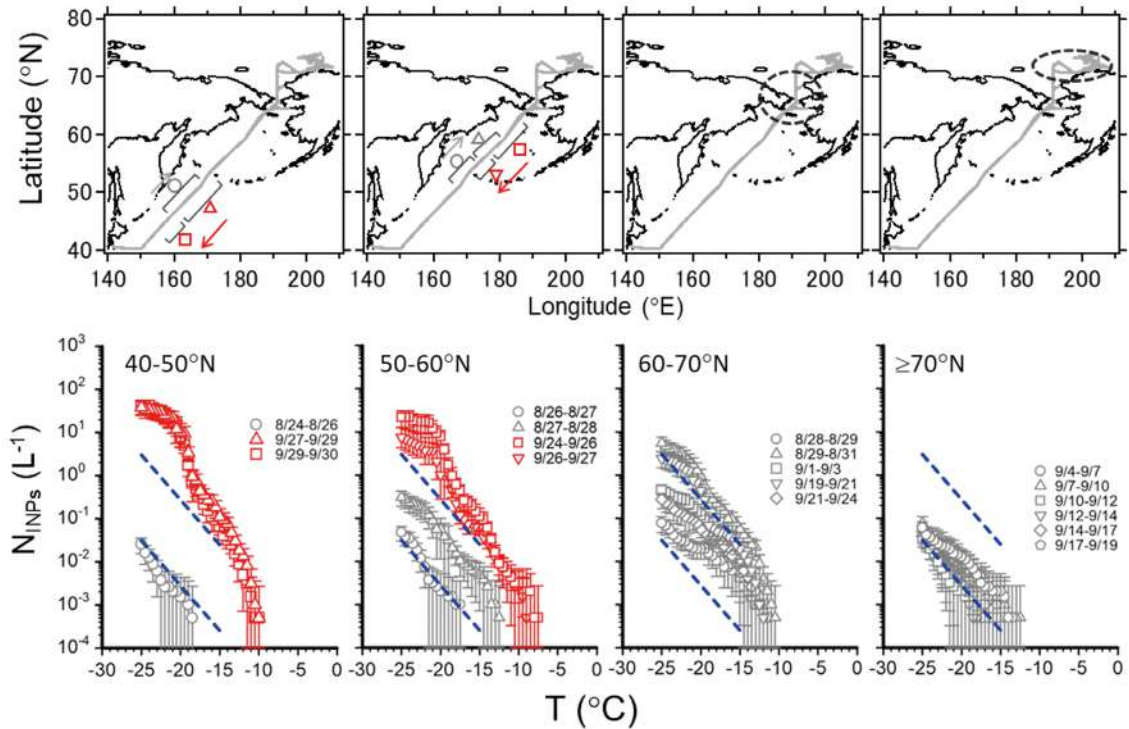


Fig. 1 Number concentrations of INPs (N_{INPs}) as a function of temperature (lower panels) and the corresponding sampling areas on the track (symbols and gray broken circles area in upper panels) during the cruise. The solid gray line in the upper panels indicates the cruise track. Symbols in the lower panels depicting N_{INPs} indicate the sampling period (Month/Day in 2016) results. The red symbols for 40–60°N indicate data for the return (southward) cruise. Error bars in the N_{INPs} plots indicate 95% confidence intervals. The broken blue lines represent the upper and lower levels of N_{INPs} measured in the marine boundary layer at various locations.

The variation factors for N_{INPs} were estimated by comparison with the chemical composition and auto-fluorescent properties of ambient aerosol particles (Fig. 2). During the periods of high ice-nucleating particle concentrations, we found extremely high concentrations of black carbon generated from combustion (Fig. 2(b), bottom left), levoglucosan (Fig. 2(c)) indicating biomass burning emissions, iron and manganese (Fig. 2(d)) related to mineral dust, and auto-fluorescent particles (Fig. 2(e)) likely from biogenic emissions. Furthermore, analysis of backward trajectories using meteorological data indicated that the air mass over the Bering Sea and

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western North Pacific, where ice-nucleating particle concentrations were significantly elevated, originated from central Siberia (Fig. 2(f), red dashed lines) with intensive wildfires. Combining these findings, it was concluded that the high concentration of ice-nucleating particles observed was attributable to the aerosol particles originating from Siberian wildfires (particularly those containing a high biogenic and mineral aerosols). This suggests that aerosols released from Siberian wildfires can be transported over distances of several thousand kilometers, significantly contributing to the increase in ice-nucleating particle concentrations in the high-latitude oceans. This study indicated a substantial role of boreal wildfires in supplying INPs onto the oceans, including high latitudes, depending on the transportation and emission conditions.

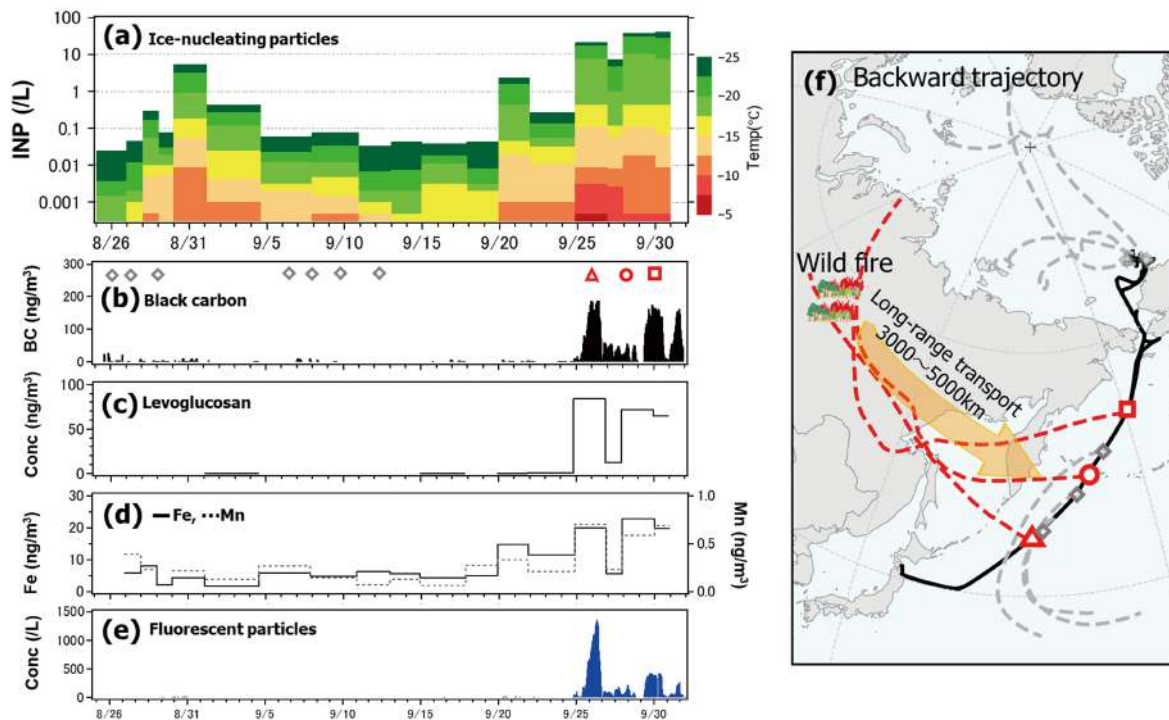


Fig. 2 Temporal variation of the number concentration of ice-nucleating particles (a), mass concentrations of black carbon (b), levoglucosan (c), Fe and Mn (d) and number concentration of fluorescent particles (e) along the cruise track over the western North Pacific to the Arctic Ocean. Backward trajectories from locations of aerosol particle samplings (f): red broken lines indicate cases of high INP concentrations and gray broken lines indicate other cases. Colors in panel (a) indicate temperatures of INP activation. The time indicated by the symbols on panel (b) corresponds to the position of the symbols on panel (f).

Reference

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Impacts of Subglacial Meltwater Discharge on Biological Production in the fjord

Subglacial meltwater discharge into fjords plays a crucial role in maintaining rich marine ecosystems, largely by enhancing phytoplankton proliferation (Meire et al., 2017) which supports fisheries and other biological communities. However, the progressive retreat and disappearance of glaciers due to global warming raise significant concerns about their impact on these ecosystems.

To quantify this impact, a newly developed lower-trophic level marine ecosystem model was applied to a Greenlandic fjord. The modeling approach employed in Hoshiba et al. (2024) successfully quantified the

nutrient supply processes for primary production initiated by subglacial discharge during the summer months. The results demonstrated that the density difference between low-salinity subglacial discharged water and high-salinity offshore seawater predominantly contribute to the surface layer by means of the vertical circulation (mixing and stirring the entire fjord water system), thereby playing a pivotal role in primary production, rather than subglacial discharge itself transporting nutrients (Fig. 3).

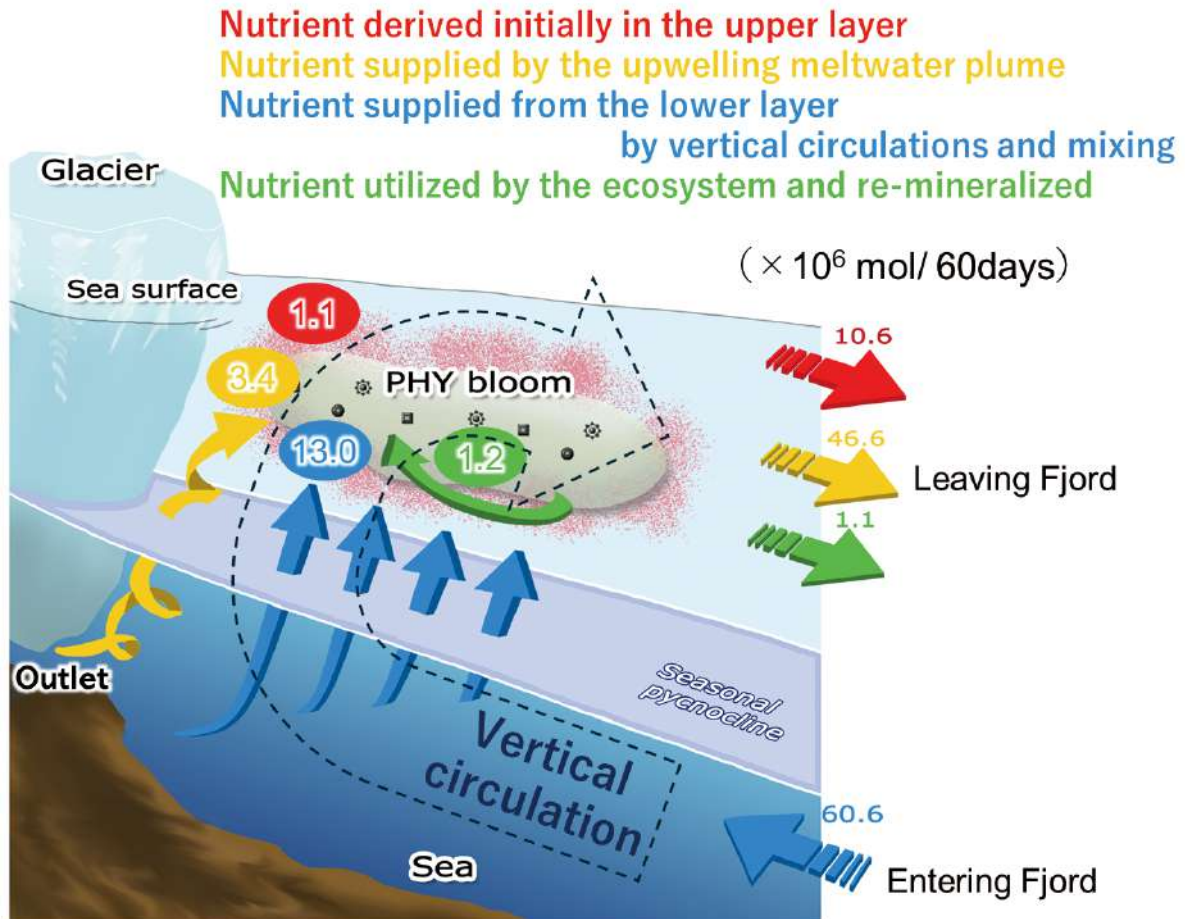


Fig. 3 Schematic representation of the nutrient budget in the fjord during the summer. All the numbers represent the difference between with and without subglacial meltwater discharge for 60-day model runs, and the numbers enclosed in the circles around “PHY bloom” indicate the primary productions of each nutrient source.

Sensitivity experiments were conducted to estimate the effects of variability in subglacial discharge and glacier recession resulting from global warming (Fig. 4). These experiments demonstrated that while conditions of increasing subglacial discharge generally led to increased primary production, conditions involving significant glacial retreat coupled with large discharges of suspended sediment resulted in dramatically lower biological production. This suggests that extreme global warming could ultimately lead to a dramatic decrease in biological production in fjord areas, despite initial increases in meltwater.

In light of the ongoing shrinkage of numerous glaciers worldwide (e.g., Bhatia et al., 2021; Wang et al., 2021) and the anticipated further changes in the coming decades, the findings of this study must serve as a foundation for the development of integrated research. The model developed here, and its application to other fjords, should allow us to predict changes in biological production in polar regions, providing an assessment of global warming's impact on marine ecosystems. In order to enhance our comprehension of the biogeochemical cycle between terrestrial and marine environments, it is imperative to engage in continuous field observations and utilize numerical modeling.

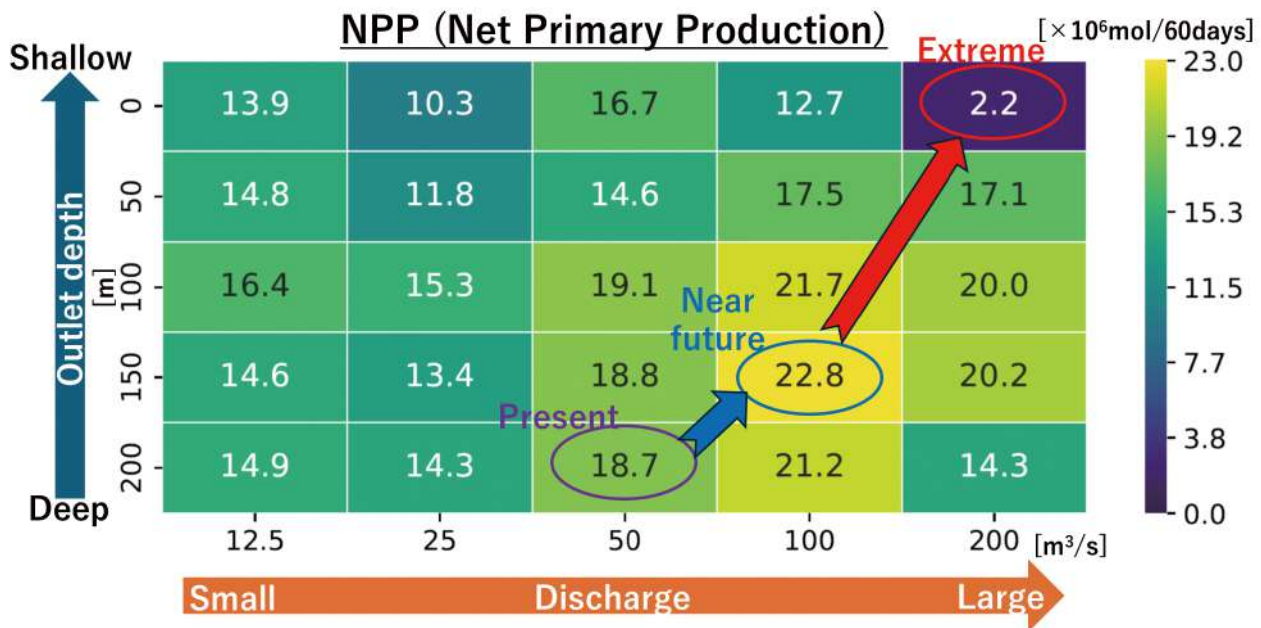


Fig. 4 Sensitivity experiment results with respect to changes in discharge (x-axis) and outlet depth (y-axis). The presented NPPs (Net Primay Productions) are valued relative to those obtained in the case without meltwater discharge, integrated over the entire model domain, and accumulated for the 60-day model runs.

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– Research Center for Environmental Modeling and Application (CEMA) –

Identifying Warming Slowdown Due to Reductions in Non-CO₂ Greenhouse Gas Emissions — An Analysis of the Warming Slowdown from 1998 to 2012 —

Accumulated research, including the IPCC's Sixth Assessment Report (AR6), has concluded that “it is unequivocal that human influence has warmed the atmosphere, ocean and land.” Observational data shows that global warming slowed between 1998 and 2012 (Eyring et al., 2021). However, the AR6 only qualitatively attributed this slowdown to the internal variability of the climate system, solar radiation, and volcanic activity, without quantitatively assessing the exact contributions of each factor. To comprehensively understand the reasons behind the slowdown in global warming, a quantitative analysis of the contribution of these components was necessary.

In this study, the Simple Climate Model for Optimization version 3.3 (SCM4OPT v3.3) (Su et al., 2022) was used to evaluate the contributions of various anthropogenic and natural forcing factors to global warming (Fig. 1) (Su et al., 2024). The analysis showed that during the 1998–2012 warming slowdown, compared to 1951–2012, CO₂, aerosols, and volcanic activity contributed to accelerating the global mean temperature rise, while La Niña and decreased solar activity slowed it. The key finding of this study is that the reduction of methane and ozone-depleting substances (ODS) significantly contributed to the observed slowdown in temperature increase during this period, accounting for about 24% of the overall slowdown. Methane emissions increased sharply in the 1980s but were suppressed in the 1990s due to improvements in agricultural practices and reductions in energy sector emissions. This stabilization caused by methane contributed to a slower warming trend compared to earlier periods (Fig. 2).

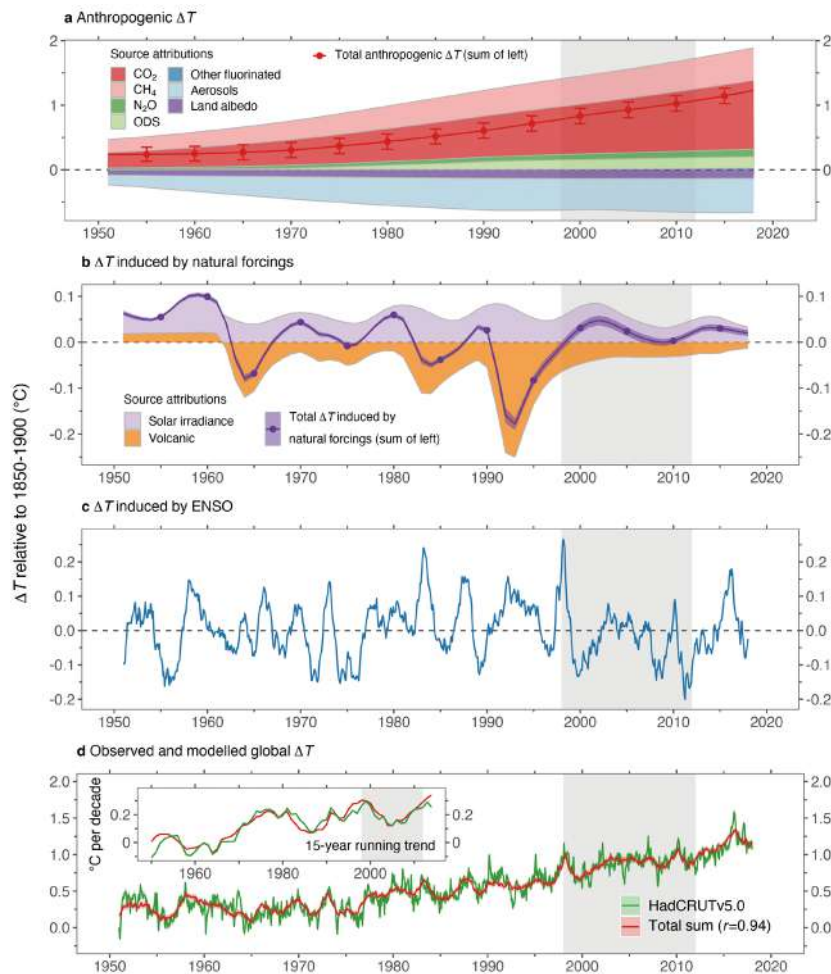


Fig. 1 Anthropogenic and natural ΔT . a Anthropogenic ΔT . The thick red solid line and error bars indicate total anthropogenic ΔT . b ΔT caused by natural forcings. The thick purple solid line and range represent the total ΔT induced by natural forcings. Colour ribbons in a & b show ΔT caused by individual factors. c ΔT caused by ENSO. d HadCRUT5 and the total summed ΔT . Pearson's correlation between the total sum and HadCRUT5 is shown in d. The inset in d depicts 15-year running trends.

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Many ODS, such as chlorofluorocarbons (CFCs), also have a greenhouse effect. However, their contribution to warming decreased after they were internationally regulated under the Montreal Protocol. This study showed that the radiative forcing (warming effect) of ODS stabilized during the slowdown period and contributed to suppressing the rise in temperatures (Fig. 2). The study also examined natural factors such as the El Niño–Southern Oscillation (ENSO) and variations in solar activity. La Niña, the cooler phase of ENSO, played a major role in cooling the Earth from the late 1990s to the early 2000s. The descending solar cycle, resulting in less solar radiation reaching the Earth, also contributed to the slowdown. These natural factors accounted for approximately 75% of the total slowdown, as this study revealed (Fig. 2). The results of this study demonstrate that methane and ODS played an important role in the global warming slowdown between 1998 and 2012, in addition to natural variability. By analyzing and interpreting past climate change events in this way, the study suggests that reducing all greenhouse gases, not just CO₂, is crucial for addressing future climate crises.

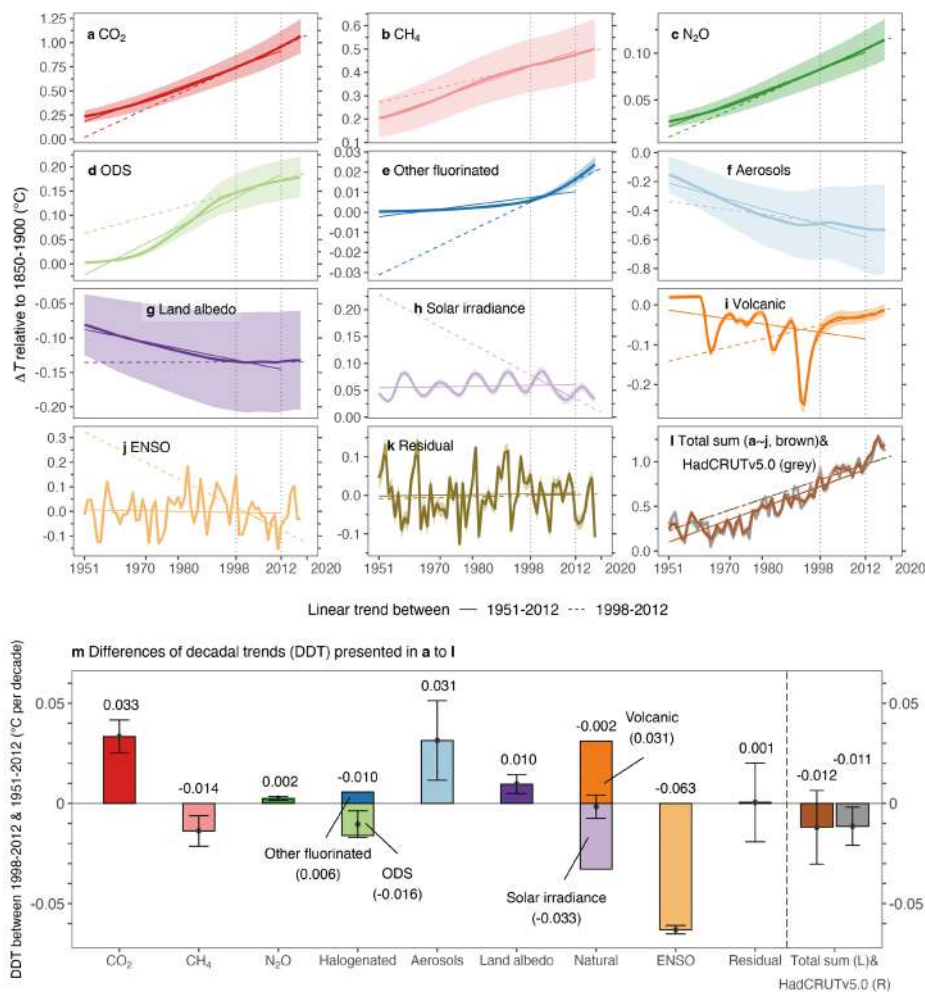


Fig. 2 Anthropogenic and natural ΔT by source and their DDT between 1998–2012 and 1951–2012. a to j represent ΔT and uncertainty ranges caused by individual anthropogenic and natural factors. k indicates the residual term of the statistical model. The total sum and HadCRUT5 and their uncertainty ranges are depicted in l. Thin solid and solid with extended dashed lines denote linear trends from 1951 to 2012 and 1998 to 2012, respectively. m illustrates DDT derived from a to l. The mean is displayed on top of the bar, and the error bar is the one-sigma produced by the ensemble of statistical regressions.

References

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Future changes in synoptic-scale conditions associated with widespread heavy precipitation

Widespread and simultaneous heavy precipitation events in Japan are often caused by synoptic-scale precipitation systems, such as approaching tropical cyclones and stationary fronts. Such events generate new records of multi-day accumulated precipitation across many regions in Japan, triggering severe and concurrent disasters across the country. Synoptic-scale systems that cause widespread heavy precipitation are classified using 5-km large-ensemble simulations, and their future changes are evaluated (Sugimoto et al. 2024).

We use large ensemble regional-scale climate simulations (NHRCM05) with 5 km horizontal resolution (Kawase et al., 2023), which dynamically downscales the historical and +4 K warming global experiments from d4PDF (Mizuta et al., 2017; Fujita et al., 2020). For the NHRCM05, both historical and +4K warming climate conditions provide 12 members over 60 years, yielding 720 model years each. Widespread heavy precipitation events are identified from annual maxima of area-averaged daily and 5-day accumulated precipitation over land in Japan (Amax1d and Amax5d). Standardized sea level pressure (SLP) patterns are classified into six clusters using K-means to understand synoptic-scale disturbances associated with Amax1d and Amax5d.

NHRCM05 reasonably captures spatial precipitation patterns during Amax1d and Amax5d events, as well as their temporal standard deviations. For Amax1d, four clusters are characterized by a disturbance structure over southwestern or central Japan and northeastward precipitation extension from the center of the disturbance, mainly occurring during July–October (Fig. 3). These are interpreted as tropical cyclone (TC)-associated events, consistent with seasonal TC activity. Of the remaining two clusters, one is related to migratory extratropical cyclones, while the other represents Baiu-frontal systems. In +4K climate, spatial patterns remain similar to the historical events, but TC-associated frequencies relatively decrease while non-TC-associated frequencies increase: –18% for TC-associated events and +38%/+71% for non-TC-associated events (Fig. 4). For Amax5d, similar results are obtained; that is, TC-associated events dominate five clusters, while the remaining Baiu-front-related cluster is concentrated in late June–July. TC-associated Amax5d events decrease by 16% in +4K, while Baiu-front events increase by +91%. These results are consistent with a projected decline in TC occurrence frequency over the western North Pacific in future climates of d4PDF datasets.

For Baiu-front events, both Amax1d and Amax5d intensify in the +4K experiment compared to the historical simulation, primarily due to enhanced lower-tropospheric moisture transport associated with increased precipitable water under a warming climate, despite weakened atmospheric instability. Similar mechanisms emerge for migratory extratropical cyclone cases of Amax1d, with increased water vapor transport and enhanced precipitations. We suggest that heavy precipitation comparable to TC may occur more often during spring to early summer but driven by different synoptic systems.

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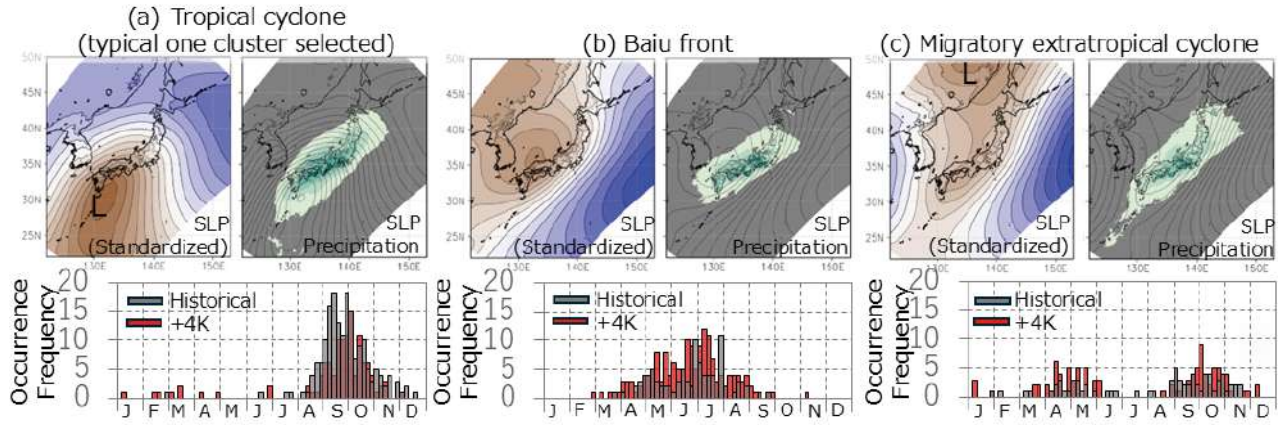


Fig. 3 Composites of spatial patterns for standardized SLP (upper left) and row SLP and precipitation (upper right) for each cluster of Amax1d events, (a) TC-associated, (b) Baiu front, and (c) migratory extratropical cyclone. For upper right figures in each, the contour interval of SLP is 1 hPa, and the area with precipitation of $<15 \text{ mm day}^{-1}$ is colored gray. Occurrence frequency of Amax1d events (unit: times) are also shown at the bottom of each (a)–(c). Capital letters in the x-axis indicate the month from January (J) to December (D). Gray and red colors indicate the historical and +4K experiments. (reproduced from Figs. 3 and 4 of Sugimoto et al. 2024)

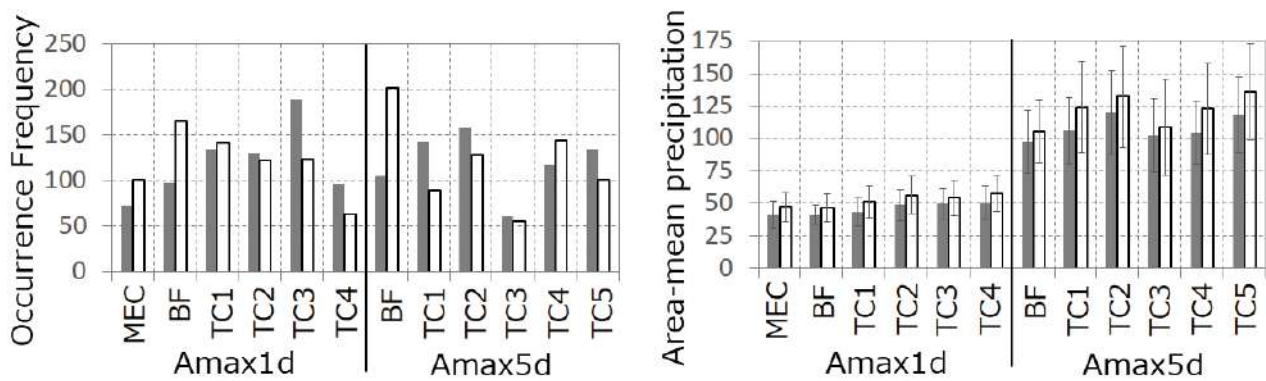


Fig. 4 Composites of occurrence frequency (left, unit: times) and area-mean precipitation (right, unit: mm day^{-1} or mm 5-day^{-1}) of Amax1d and Amax5d events for each cluster. Gray bars indicate the historical experiment, and open black bars indicate the +4K experiment. MEC, BF, and TC1–TC5 refer to clusters for migratory extratropical cyclones, Baiu front, and TC-associated, respectively. Error bars in right figure indicate ranges of $+1 \sigma$ and -1σ values. (reproduced from Fig. 5 of Sugimoto et al., 2024)

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– Marine Biodiversity and Environmental Assessment Research Center (BioEnv) –

Ascetosporean protists mitigate negative mutations

We reported novel RNA editing phenomena in ascetosporean protists, a group that has remained largely understudied in marine environments for many years. This finding substantially expanded our understanding of the complexity of cellular functions and molecular evolution. It also highlighted that studies of poorly understood organisms, such as deep-sea protists, are essential not only for more accurate assessments of marine biodiversity but also for elucidating evolutionary processes.

The diversity and ecological functions of marine microbial eukaryotes (protists) remain only partially understood. Ascetosporeans are among the most poorly understood protist groups and had remained uncultivable for many years. In Yabuki et al. (2025), axenic cultures were successfully established using Hemi medium, which was newly developed in our previous study (Tahyreva et al., 2018), from samples collected in Japanese waters, enabling subsequent molecular analyses.

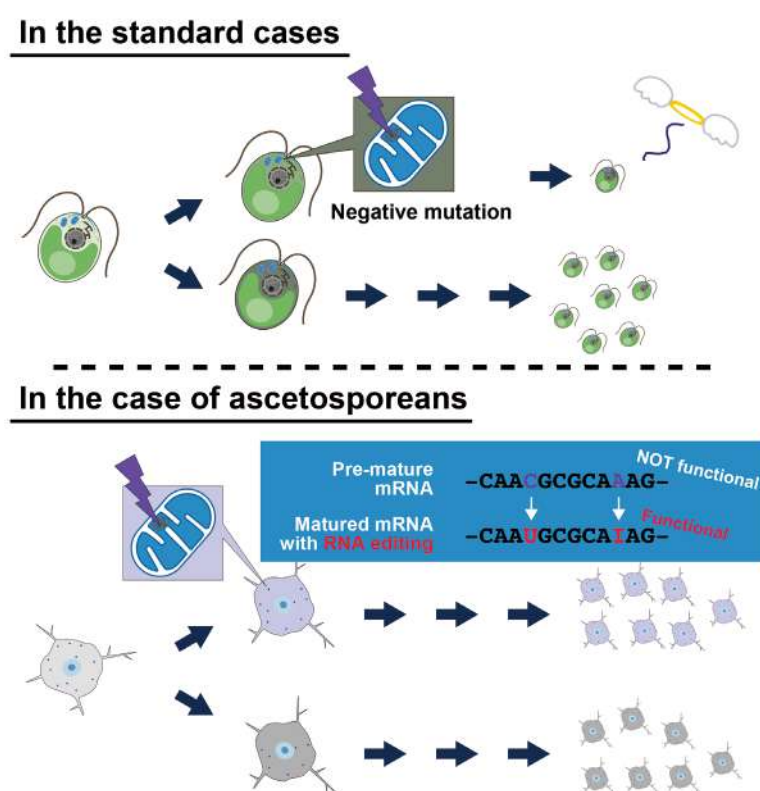


Fig. 1 Schematic summary of the function of ascetosporean RNA editing in the mitochondria. When negative mutation is inserted into the genome, the individual with it cannot survive no longer for standard organisms. However, ascetosporeans can fix such mutations by RNA editing and keep functional RNA sequences.

It is generally accepted that DNA continuously changes through the generations. While some mutations have positive effects on individuals, others exert negative or neutral effects. When the negative effect is so serious, the individual with such a mutation cannot survive and the other individuals occupy that niche (Fig. 1). However, it was revealed that ascetosporeans can survive even if the massive and negative mutations are heavily stocked in their mitochondrial genomes. The key function to mitigate the negative mutation in the mitochondrial genome of ascetosporeans is RNA editing: some adenosine and cytidine nucleosides are substituted to inosine and uridine nucleosides, respectively, after the transcription. These substitutions update the information encoded in mRNA molecules, thereby restoring appropriate amino acid sequences. Prior to RNA editing, the immature mRNA sequences contained multiple internal stop codons, and proper amino acid residues required for functional polypeptides were not specified at several positions. Such mutations would typically be eliminated

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from populations through natural selection and therefore not become fixed in other organisms. In contrast, ascetosporeans have overcome these mutations and survived through mechanisms that mitigate their negative effects. Although the functional significance of their RNA editing can be inferred, their molecular mechanism was just partially elucidated. Based on RNA-seq data, potential key enzymes for C-to-U and A-to-I substitutions were suggested: the homologues of pentatricopeptide repeat proteins with DYW motif (PPR-DYW protein) and Adenosine deaminase acting on RNA (ADAR) were suggested for C-to-U and A-to-I substitutions, respectively (Fig. 2). However, further studies to confirm that those proteins are involved in their RNA editing are needed and it is entirely unclear how each editing site is specifically recognized. Since novel RNA editing in the organelles are being expected in the field of genetic engineering and medical biology, their molecular mechanism attracted attention and the studies to unveil the mechanisms are ongoing. The diversity of ascetosporeans was not fully understood and the recent eDNA analyses suggested that many ascetosporeans remain to be found and described in natural environments. The possibility that other ascetosporeans possess different types of RNA editing cannot be ruled out. It remains unclear how RNA editing contributes to their ecological adaptation, and elucidating this role represents an important topic for future research. Studies on ascetosporeans have only just begun and are expected to expand in a multidisciplinary manner.

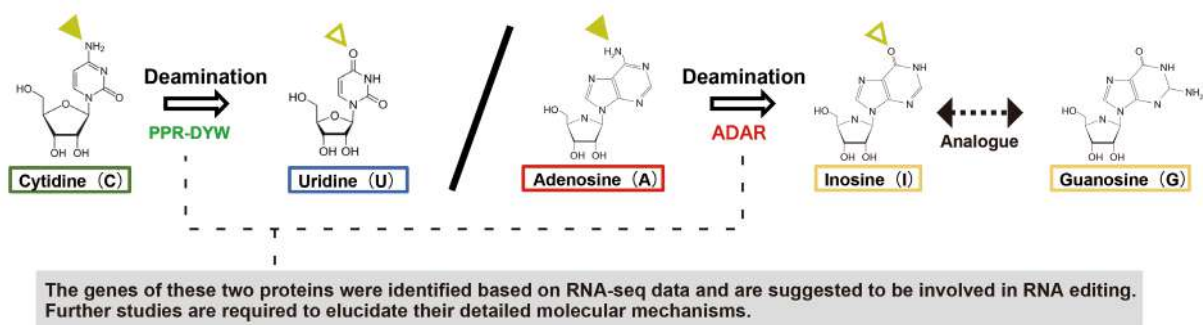


Fig. 2 Summary of two types of RNA editing found from ascetosporeans. PPR-DYW protein and Adenosine deaminase acting on RNA (ADAR) may be utilized for C-to-U and A-to-I substitution, respectively.

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An observational study of microplastics sinking into the deep sea within Kuroshio Extension Recirculation Gyre of the western North Pacific Ocean

We estimated the amount of sinking microplastics (hereafter referred to as "MPs") from the surface to the deep sea through actual observation. Specifically, we analyzed marine sinking particles within the Kuroshio Extension recirculation gyre (hereafter referred to as "KE recirculation gyre") in the subtropical western North Pacific Ocean (Fig. 3). Previous observations have suggested the accumulation of large amounts of MPs and macroplastic debris on the deep-sea floor of the KE recirculation gyre off the Boso Peninsula. However, few studies have quantitatively determined exactly how much MPs have sunk into the deep sea.

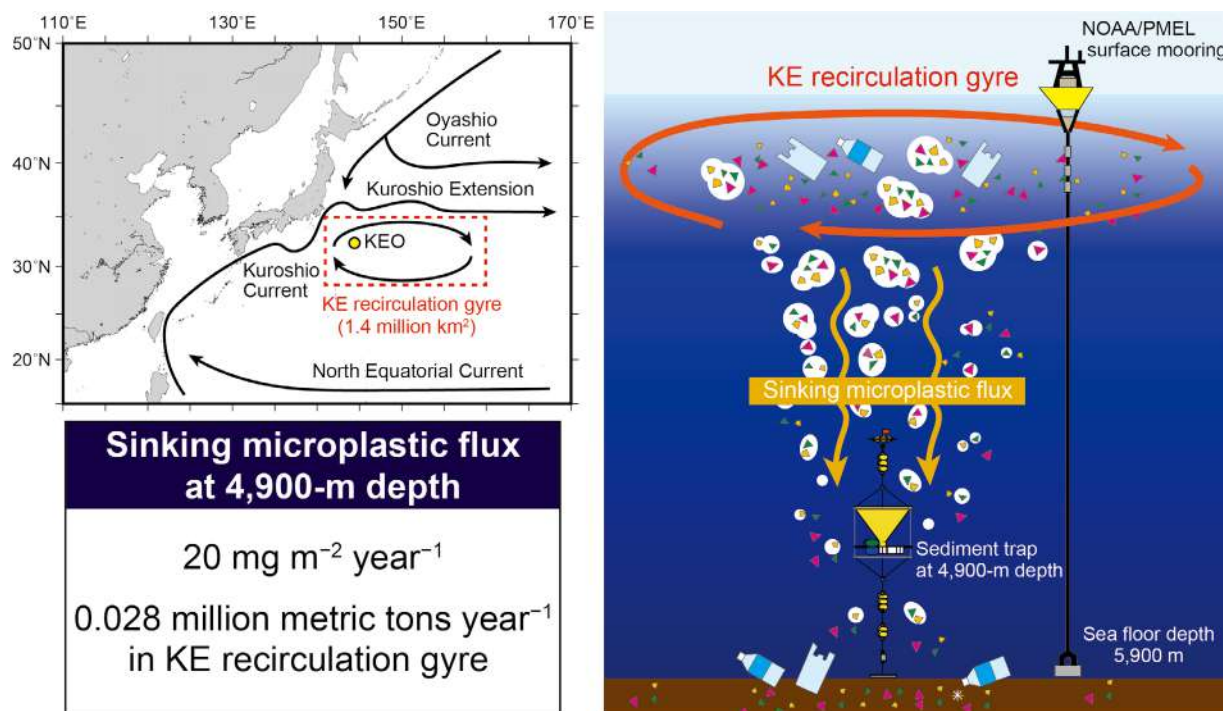


Fig. 3 Schematic diagram of the study.

In this study, archived samples of marine sinking particles from station KEO, within the KE recirculation gyre, were used to calculate the amount of sinking MPs. The samples used were collected in a time series every 18–21 days from July 1, 2014, to October 2, 2016, using a sediment trap moored at a water depth of 4,900 m at station KEO. There were concerns about the contamination of the archived samples due to the release of MPs from the polyethylene bottles in which the samples were stored and the MPs in the formalin seawater used as a preservative. However, analysis of the formalin seawater stored in polyethylene bottles for approximately two and a half years demonstrated that it contained only 0.25 MPs per volume used for MPs analysis, which was negligible compared to the amount of MPs detected in the marine sinking particles.

Marine sinking particle samples were analyzed and MPs were detected in all samples, with 17 different types of plastics were identified. Ninety percent of the MPs detected were less than 100 μm in size (Fig. 4). The amount of sinking MPs per square meter ranged from 111 to 889 pieces per day (Fig. 4). On average there were 352 pieces, similar to the sinking MPs in the northeast Atlantic subtropical gyre. On mass basis, they varied from 4.5×10^{-3} to 3.8×10^{-1} mg per day during the observation period, with a mean value of 5.4×10^{-2} mg. MP carbon accounted for an average of 1.5% and a maximum of 9.6% of the total organic carbon content in sinking particles. Seasonal variations in sinking MPs indicated that it was driven primarily by an increase in marine sinking particles, owing to increased primary production in the surface layer. The amount of sinking MPs per square meter per year at station KEO was 20 mg. By extrapolating this value to the entire area of the KE recirculation gyre, it was estimated that 0.028 million metric tons of MPs were transported annually to a water depth of 4,900 m (Fig. 3). These results suggest that a large amount of MPs are transported by the Kuroshio Current and Kuroshio Extension to this area and accumulate in the deep sea.

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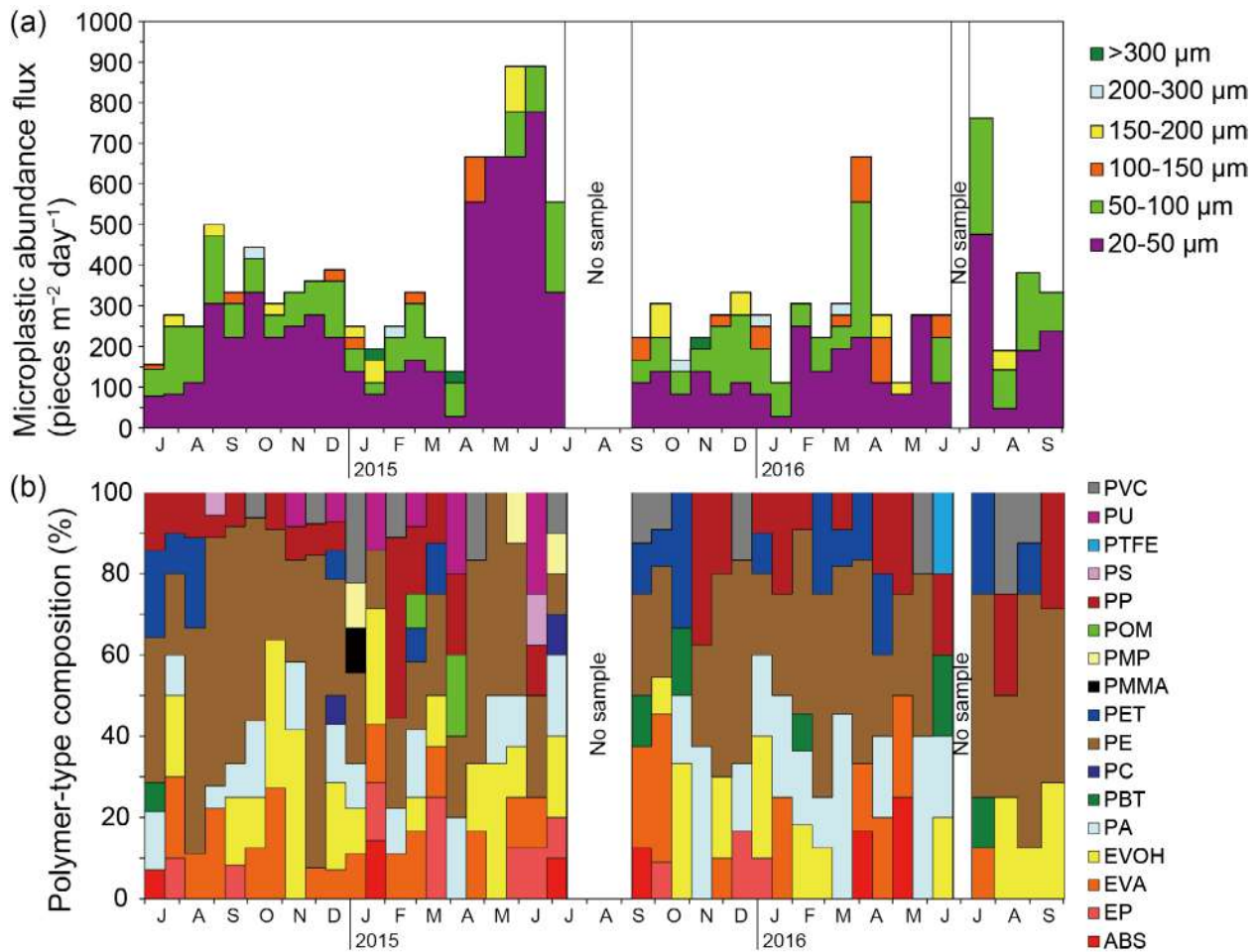


Fig. 4 Time-series of microplastic abundance fluxes at Stn. KEO. (a) Microplastic abundance fluxes. (b) Polymer-type composition by number of particles.

Reference

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– Center for Coupled Ocean-Atmosphere Research (CCOAR) – Vertical Structure of Cross-Equatorial Northerly Surge and its Relationship with MJO Phases Observed during YMC-CSO2021

In 2021, JAMSTEC, in collaboration with the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG), conducted high-frequency radiosonde observations of the "Cross-Equatorial Northerly Surge (CENS)," a key phenomenon driving heavy rainfall in the Maritime Continent. We captured six CENS events and revealed that their vertical structures vary significantly depending on the phase of the Madden-Julian Oscillation (MJO). Using radiosonde data, we successfully captured the vertical structures of six distinct CENS events. While previous studies defined CENS by surface wind speed and examined its frequency and relationship with rainfall, this study is significant for clarifying the differences in vertical structure for each specific event.

Highlights

Observation of Six Events: 2021 saw six CENS events, the third highest in the past 48 years. We successfully captured the distinct vertical structure of each (Fig. 1). Analysis also revealed that CENS occurred significantly more frequently during La Niña years than El Niño years.

Influence of MJO: We found that CENS frequency was high not only when the MJO was over the Maritime Continent (Phases 4-5, 35%) but also when it was over the Western Pacific (Phases 6-7, 52%).

Impact on Rainfall: We confirmed that these surges generated strong updrafts, creating conditions favorable for heavy rainfall across the Maritime Continent.

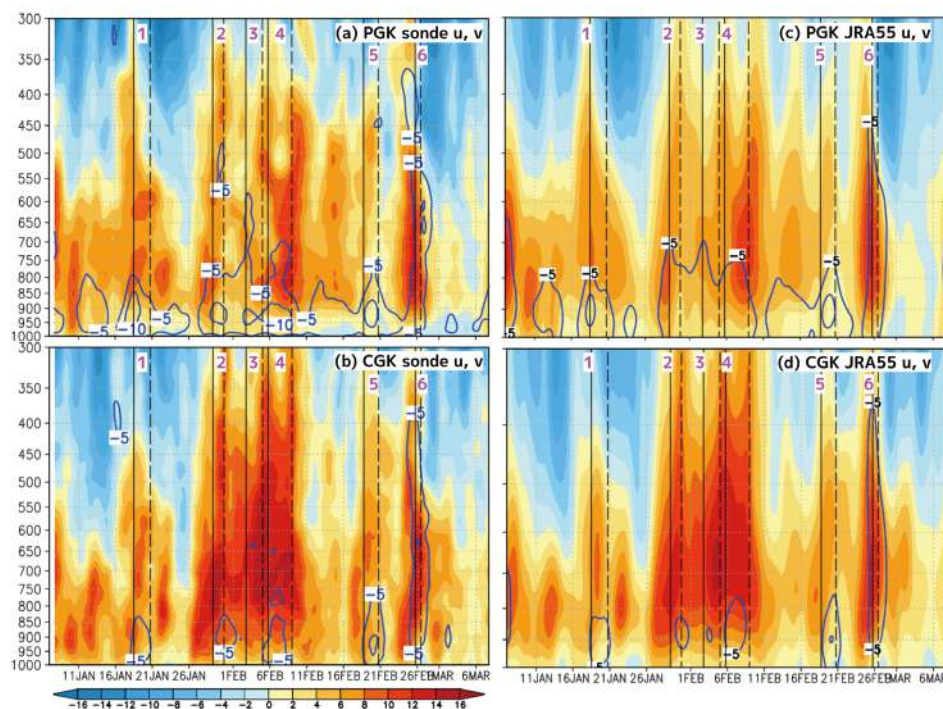


Fig. 1 Time-height cross-section from January 8 to March 8, 2021, during the YMC-CSO2021 campaign. The plot shows zonal wind (westerlies in warm colors), northerly wind (contours every 5 m/s), and the start (solid lines) and end (dashed lines) dates of the six detected CENS events. Data compares radiosonde observations (left panels) with JRA55 reanalysis (right panels) at Pangkal Pinang (top panels) and Jakarta (bottom panels). Taken from Moteki (2024).

Reference

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The eastern edge of Pacific warm pool study

Air-sea interactions in the tropical ocean are significantly influenced by atmospheric variability and depend significantly on the structure of the upper ocean, such as the mixed layer isothermal layer, and thermocline, which are closely related to sea surface temperature variability. Particularly in the western tropical Pacific, the presence of Pacific warm pool greatly affects air-sea interactions and the associated atmospheric convective activity. However, observations of the detailed vertical structure of the upper ocean remain limited, and this makes it difficult to understand the various processes involved in the associated air-sea interactions. Considering basin-scale phenomena such as El Niño and Southern Oscillation (ENSO), understanding the mechanisms that determine the location and extent of the warm pool is thought to lead to a further understanding of the phenomenon. Addressing this scientific need, the TPOS2020 project has conducted process studies on air-sea interactions at the warm pool edge. We conducted an observation cruise MR20-01 by R/V *Mirai* in January-February 2020 (Nagano et al. 2022).

During this cruise, we conducted stationary observations for about four days at the eastern edge of the warm pool, although the period was very short. Observations of air-sea interactions revealed how enhanced easterly winds driven by atmospheric inertial gravity waves increased latent heat fluxes at the sea surface, consequently intensifying cumulus convection. Conversely, changes in the background atmospheric conditions — specifically strengthened atmospheric stratification and weakened winds — were also observed. These changes weakened the coupling between the ocean and atmosphere, preventing atmospheric disturbances from becoming locally confined and thereby inhibiting the intensification of convective activity. Although insights into short-term atmospheric variability were gained, the role of longer-timescale oceanic variability remained unclear due to the limited observation period. With this background, another *Mirai* cruise (MR25-01), targeting the eastern edge of the Warm Pool, was conducted from January 12 to February 25, 2025. The MR25-01 cruise conducted stationary observation, including moored observations, related to air-ocean interactions over 14 days at the eastern edge of the Warm Pool. Concurrently, three Wave Gliders and one surface moored buoy were deployed to the north, south, west, and east of the R/V *Mirai* to observe sea surface conditions and surface-level atmospheric conditions (Fig. 2). The stationary observations included CTDO/LADCP and sounding observations every 3 hours, TurboMAP observations every 6 hours, and other measurements of the upper ocean and lower atmosphere. Continuous observations were also conducted using Doppler radar, lidar, various meteorological instruments, and a shipboard ADCP.

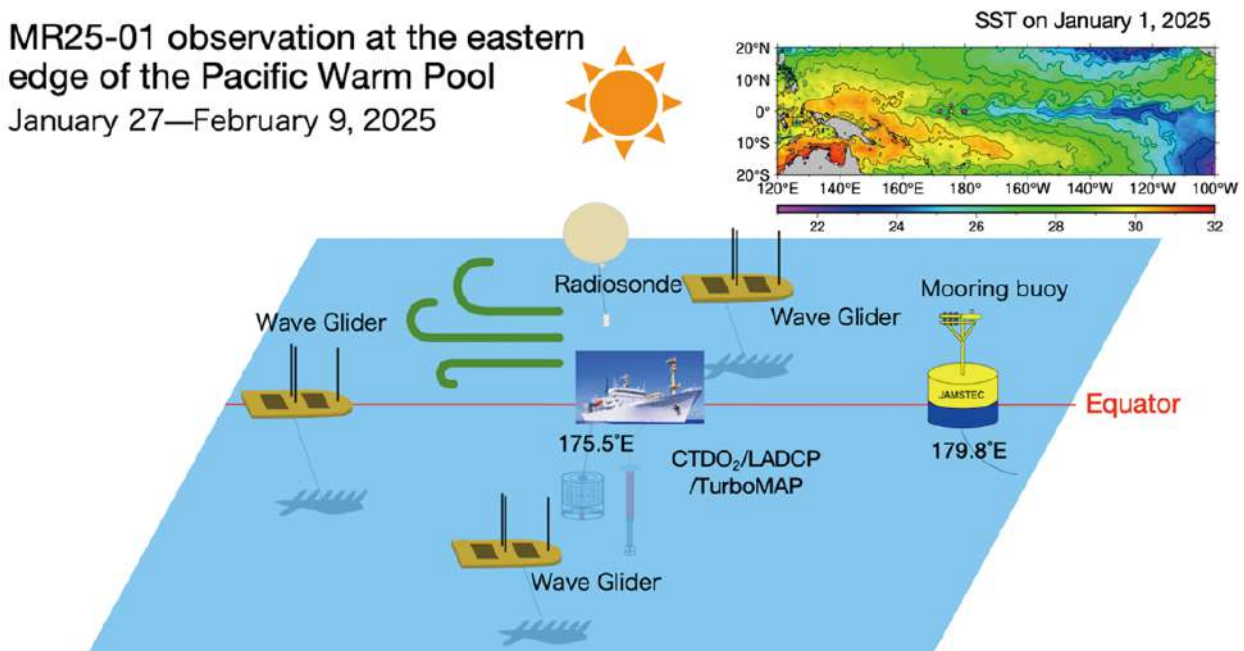


Fig. 2 Configuration of the stationary observation during MR25-01 cruise.

The observation period was under the influence of La Niña, with easterly winds dominating near the equator from the sea surface to approximately 750 hPa level (Fig. 3, upper). Below the sea surface, a westward-flowing South Equatorial Current was observed down to around 100 m. An eastward-flowing Equatorial Undercurrent was confirmed between approximately 100 m and 300 m below that. The average isotherm depth was around 80 m, while the mixed layer depth was approximately 50 m, both exhibiting significant diurnal variations (Fig. 3, bottom). Changes in the isotherm depth correlated with the strength of the easterly winds. A barrier layer persisted throughout the observation period. This barrier layer tended to thin when the isotherm depth became shallower and thickened during the first few days of February and the final days of the observation period when the isotherm depth was relatively deep. Vertical diffusivity, estimated from TurboMAP observations, begins to increase near the bottom of the mixed layer and becomes more dominant at the bottom of the thermocline (Fig. 3, bottom). Focusing on the bottom of the mixed layer, vertical diffusivity tends to be larger when the mixed layer is shallow and smaller when it is deep. In summary, the mixed layer exhibits diurnal variations influenced by solar radiation. Although vertical diffusivity increases at its bottom, the presence of the barrier layer prevents a decrease in mixed layer water temperature even when the mixed layer becomes shallow at night. Consequently, mixed layer or sea surface temperatures rise. However, when easterly winds strengthen and the isothermal layer becomes shallower, the barrier layer also thins, leading to a decrease in mixed layer temperature due to vertical diffusion. This relationship between changes in winds and the vertical structure of the upper ocean is thought to have caused the mixed layer temperature variations observed at the eastern edge of the warm pool.

During MR20-01, the atmospheric vertical structure transitioned from unstable to stable, capturing both the development of convective activity due to ocean-atmosphere coupling and the weakening of this coupling caused by atmospheric waves. In contrast, during MR25-01, the atmosphere remained stable throughout the observation period, potentially allowing us to capture the process by which ocean variability or air-sea interactions can destabilize the atmosphere. By observing the relationship between the atmosphere and ocean in detail across these distinct phases, we believe our understanding of the ocean-atmosphere coupling at the warm pool edge and the mechanisms governing the expansion and degradation of the warm pool will be improved.

Finally, it is worth noting the upcoming project. A new observational research project in the equatorial Pacific, TEPEX (TPOS Equatorial Pacific Experiment), primarily led by the United States, is scheduled to begin in 2026 for a two-year period. Detailed observations related to air-sea interactions, similar to those conducted in this study, are planned for the eastern edge of the warm pool during the second quarter of 2026. This research is currently being conducted in collaboration with such studies.

I. Research Activities and Results

Center for Coupled Ocean-Atmosphere Research (CCOAR)

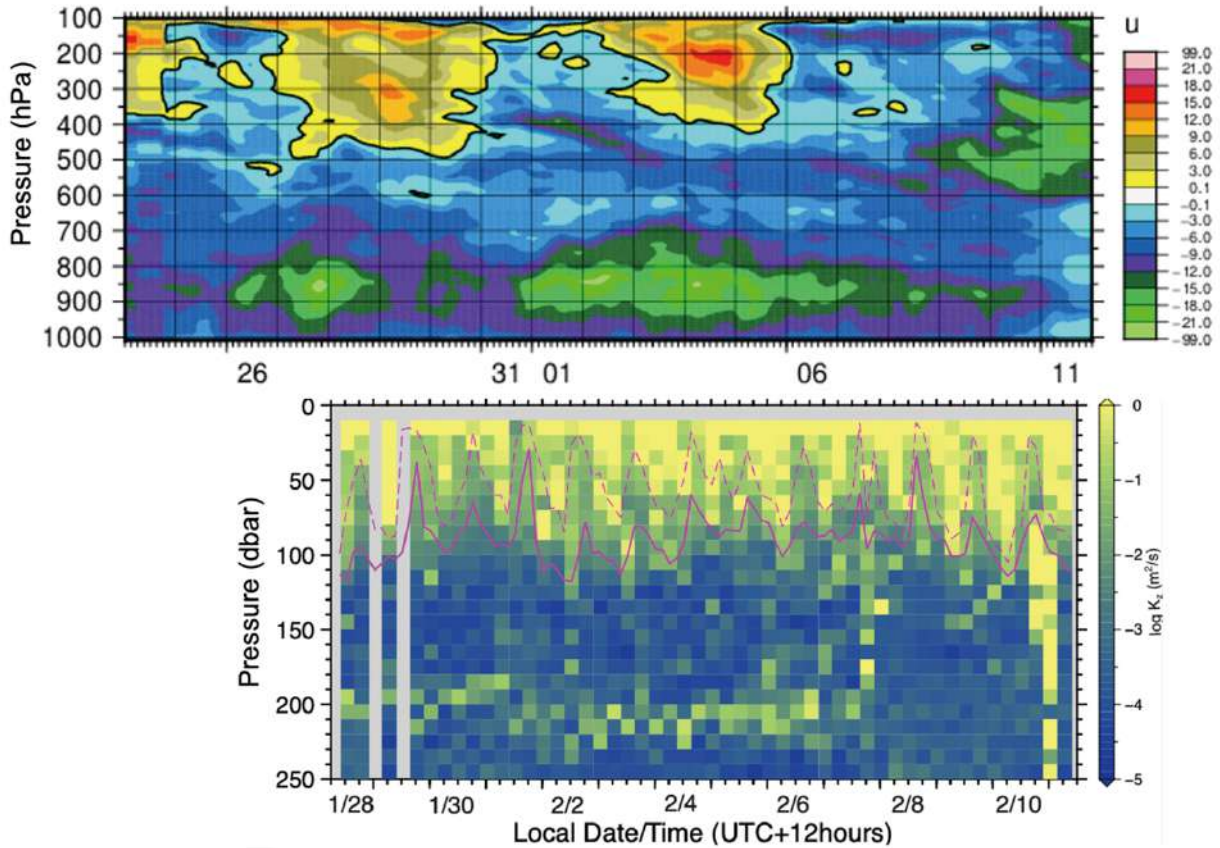


Fig. 3 Time-height diagram of the zonal wind observed by radiosonde (upper) and time-depth diagram of vertical diffusivity derived from TurboMAP observation (lower) during the stationary observation in MR25-06 cruise. The magenda dashed and solid line indicate mixed and isothermal layer depth, respectively.

Reference

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– Mutsu Institute for Oceanography (MIO) – Ocean acidification and changes in biological production in the western subarctic North Pacific over the quarter century, 1999–2023

Changes in the physical and biogeochemical conditions of the ocean over time (e.g., ocean warming, salinification/freshening, deoxygenation, ocean acidification, eutrophication, and changes in ocean circulation) can affect marine ecosystems. Ocean acidification in the surface layer has been comprehensively documented over the past several decades through time-series data collected from CO₂ monitoring sites in the open ocean. The continuing acidification trend suggests that the western subarctic region of the North Pacific could become the first area to experience wintertime aragonite undersaturation (Orr et al., 2005). A CO₂ monitoring site at 47°N, 160°E (station K2) in the western subarctic region of the North Pacific Ocean (Fig. 1; e.g., Wakita et al., 2017) is located in a high-nutrient, low-chlorophyll (HNLC) region where macronutrient concentrations remain largely undepleted throughout the year (e.g., Martin and Fitzwater, 1988). Further time-series observations at station K2 are essential to assess interannual variations in biological production and their responses to atmospheric forcing and oceanic conditions.

In this study, we use biogeochemical observational data for the past 25 years (1999–2023) to investigate ocean acidification and changes in biological production at station K2. During this period, satellite-derived sea surface temperatures increased at a rate of 0.056°C yr⁻¹, while the surface mixed-layer salinity decreased by 0.004 yr⁻¹. As a result of the oceanic uptake of anthropogenic CO₂ from the atmosphere, the deseasonalized annual mean surface mixed-layer pH and saturation states of calcium carbonate minerals of calcite and aragonite decreased at rates of 0.0013 ± 0.0004, 0.007 ± 0.003, and 0.004 ± 0.002 yr⁻¹, respectively (Fig. 2a–b). These rates are consistent with those calculated for winter (Fig. 2a–b).

Under these acidification conditions, no significant trends were observed in either the annual mean or winter concentrations of nutrients (phosphate, nitrate, and silicate), or in total alkalinity in the surface mixed layer (Fig. 2c). However, the decadal trends in nutrient concentrations show a significant increase in May and decrease in July. Net community production (NCP), which is an index of biological production, was estimated from differences in nutrient concentrations between winter and May or July (Fig. 2d). This analysis revealed significant decreasing trends in NCP from winter to May, followed by increasing trends from winter to July. The stoichiometric molar ratio of Si associated with the July NCP increase (P:N:Si = 1:15:55) is higher than the previously reported ratio (1:16:40). A significant decreasing trend in satellite-derived photosynthetically active radiation (PAR) was observed in May (0.20 ± 0.08 yr⁻¹), which may be linked to reduced biological production during that month. This decrease may be offset by increased production in summer that is likely due to a shift in the timing of the diatom bloom. These findings highlight the effects of long-term changes of potential drivers of both atmospheric and deep oceanic origin on oceanic biological production.

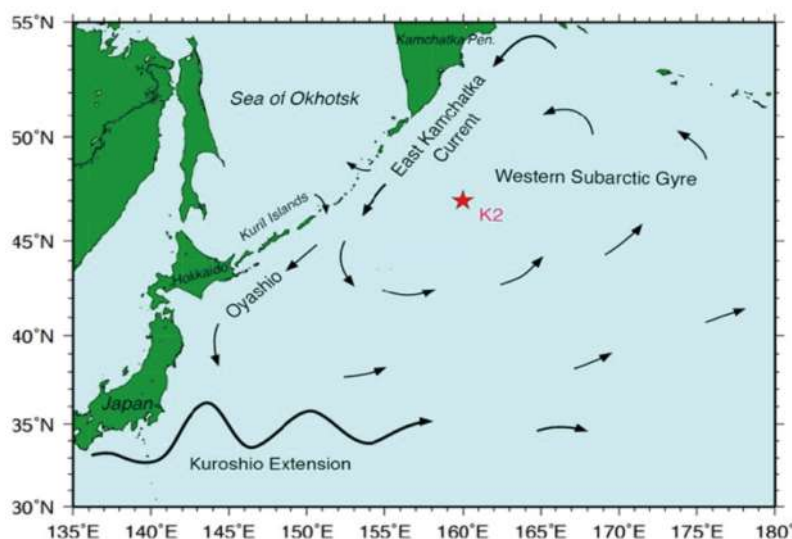


Fig. 1 Location of the time-series station K2 and the main currents in the western subarctic region of the North Pacific Ocean.

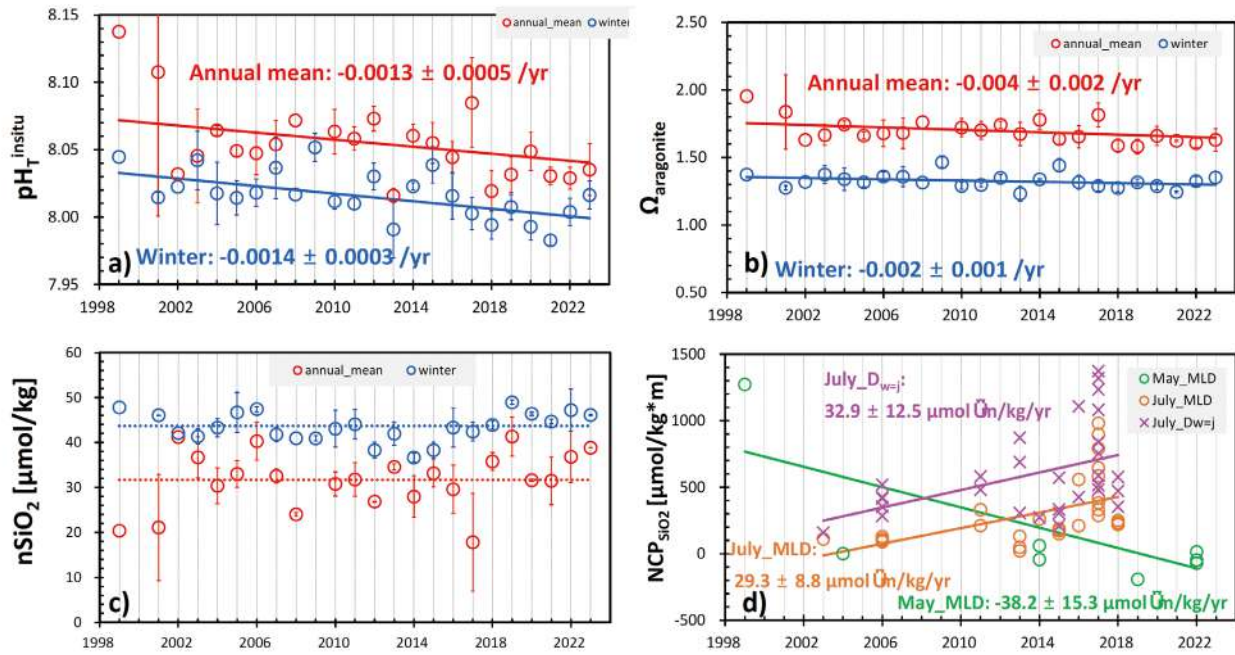


Fig. 2 Time-series of the (a) $\text{pH}_T^{\text{in situ}}$, (b) CaCO_3 saturation state with respect to aragonite ($\Omega_{\text{aragonite}}$), (c) nSiO_2 , and (d) $\text{NCP}_{\text{SiO}_2}$ within the MLD from winter to May (green circles) and July (orange circles), and $\text{NCP}_{\text{SiO}_2}^{\text{w-j}}$ from surface to $D_{\text{w-j}}$ (water depth at which the SiO_2 contents in the winter mixed layer matched that in the upper water sampling layer in July) (pink crosses) at station K2. The circles and vertical lines are the annual means and standard deviations in the surface mixed layer (red circles) and winter mixed layer (blue circles). The regression lines (solid lines) indicate significant trends ($p < 0.05$), whereas the dotted lines indicate insignificant temporal trends. The error values are the standard errors of the slopes of the linear regressions.

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I. Research Activities and Results

Publication List

- Christensen, T. R., Commene, R., Dolman, H., Edgar, C. W., Elberling, B., Emmerton, C. A., Euskirchen, E. S., Feng, L., Göckede, M., Grelle, A., Helbig, M., Holl, D., Järveoja, J., Karsanaev, S. V., Kobayashi, H., Kutzbach, L., Liu, J., Luijkx, I. T., López-Blanco, E., Lunneberg, K., Mammarella, I., Marushchak, M. E., Mastepanov, M., Matsuura, Y., Maximov, T. C., Merbold, L., Meyer, G., Nilsson, M. B., Niwa, Y., Oechel, W., Palmer, P. I., Park, S.-J., Parmentier, F.-J. W., Peichl, M., Peters, W., Petrov, R., Quinton, W., Rödenbeck, C., Sachs, T., Schulze, C., Sonntag, O., St. Louis, V. L., Tuittila, E.-S., Ueyama, M., Varlagin, A., Zona, D., & Natali, S. M. (2025). Wildfires offset the increasing but spatially heterogeneous Arctic–boreal CO₂ uptake. *Nature Climate Change*, **15**, 188–195. <https://doi.org/10.1038/s41558-024-02234-5>
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II. Related Activities

Research Collaboration

1. Domestic Research Collaboration

(1) JFE Advantech Co., Ltd.

Theme: Evaluation of the pressure characteristics of the deep ocean fluorometer/turbidity meter

Program: Global Ocean Observation Research Center

(2) Japan Aerospace Exploration Agency (JAXA)

Theme: Verification for the GCOM-W & AMSR3-based snowfall, snowpack and soil moisture retrievals in the Arctic and elucidation of water and material balance in large northern river basins using an ecohydrological model and satellite data assimilation method

Program: Institute of Arctic Climate and Environment Research

(3) Japan Aerospace Exploration Agency (JAXA)

Theme: Development of the voxel-based plant canopy radiative transfer and estimation and validation of large-scale ecosystem parameters from SGLI

Program: Institute of Arctic Climate and Environment Research

(4) National Maritime Research Institute (NMRI), National Institute of Maritime, Port and Aviation Technology (MPAT) / Graduate School of Frontier Sciences, The University of Tokyo / KITAMI Institute of Technology / Japan Radio Co., Ltd.

Theme: Research on the application of observation methods for sea ice characteristics and waves around ships

Program: Institute of Arctic Climate and Environment Research

(5) Chuo University

Theme: Basic Research on Sea Ice Drilling Robot

Program: Institute of Arctic Climate and Environment Research

(6) National Institute for Environmental Studies (NIES) / National Institute of Information and Communications Technology (NICT)

Theme: Nitrogen dioxide concentration observations by the Global Observing Satellite for Greenhouse gases and Water cycle: Development of derivation algorithms, data processing schemes, product validation systems and data utilization methodologies

Program: Earth Surface System Research Center

(7) Japan Aerospace Exploration Agency (JAXA)

Theme: GCOM-C SGLI-based near-real-time observing system for monitoring ocean color in Asian waters

Program: Earth Surface System Research Center

(8) City of Mombetsu

Theme: Cooperative research for development of real-time monitoring station on the oceanic carbonate systems, Assessing the Flexible Phytoplankton Functional Type (FlexPFT) model using two different Ocean General Circulation Models

Program: Earth Surface System Research Center

II. Related Activities
Research Collaboration

(9) Tokai University Research & Information Center (TRIC)

Theme: Research and Development of Asian Coastal Ocean Color Monitoring Based on GCOM-C SGLI Observations
Program: Earth Surface System Research Center

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

Theme: Assessing the Flexible Phytoplankton Functional Type (FlexPFT) model using two different Ocean General Circulation Models
Program: Earth Surface System Research Center

(11) Kobe University

Theme: Combined study of observation and modeling for atmosphere-ocean material circulation over the Asian region
Program: Earth Surface System Research Center

(12) National Institute of Maritime, Port and Aviation Technology (MPAT)

Theme: Observations of air pollutants and greenhouse gases over Tokyo Bay: Research use of Tokyo Wan Ferry
Program: Earth Surface System Research Center

(13) 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: Research Center for Environmental Modeling and Application

(14) Japan Aerospace Exploration Agency (JAXA)

Theme: Contribution to satellite products development by sharing needs and results of a climate change research project
Program: Research Center for Environmental Modeling and Application

(15) Japan Aerospace Exploration Agency (JAXA)

Theme: Application of the observed strong dependence of snow growth on atmospheric temperature to the emergent constraint of climate projection and intense rain prediction
Program: Research Center for Environmental Modeling and Application

(16) National Institute of Information and Communications Technology (NICT)

Theme: Reducing Uncertainty in Global Warming Projections Through Optimization of Snow Aggregation Modeling Informed by Ground-Based Cloud Radar Observations
Program: Research Center for Environmental Modeling and Application

(17) SoftBank Corp.

Theme: Analysis of Stratospheric Turbulence for HAPS Commercial Flight
Program: Research Center for Environmental Modeling and Application

(18) BioJet Co., LTD

Theme: Detailed phylogenetic classification of marine-derived *Aspergillus* by comprehensive genome sequencing and utilization of their useful genome information
Program: Marine Biodiversity and Environmental Assessment Research Center

(19) Kitasato University

Theme: Characterization of secondary metabolites from deep-sea-derived fungi

Program: Marine Biodiversity and Environmental Assessment Research Center

(20) AOI JAPAN CO., LTD.

Theme: Development of LED Lights for equipment deployed at deep-sea bottom

Program: Marine Biodiversity and Environmental Assessment Research Center

(21) Kindai University

Theme: Observational study on improvement of the global air-sea flux measurements

Program: Center for Coupled Ocean-Atmosphere Research

(22) National Institute of Maritime, Port and Aviation Technology (MPAT)

Theme: Collaborative study on air traffic control ADS-B data acquisition and its application as meteorological information

Program: Center for Coupled Ocean-Atmosphere Research

(23) Mitsubishi Electric Corporation

Theme: Applied research on atmospheric observations using the Centimeter Level Augmentation Service (CLAS) of the Quasi-Zenith Satellite System (QZSS)

Program: Center for Coupled Ocean-Atmosphere Research

(24) University of the Ryukyus

Theme: A study on material transport from surface to upper stratosphere by high-altitude radiosonde observations

Program: Center for Coupled Ocean-Atmosphere Research

(25) 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

(26) Japan Marine Science Foundation

Theme: Joint research on changes in the Tsugaru Warm Current

Program: Mutsu Institute for Oceanography

(27) Tokai University / The University of Tokyo / Kagoshima University

Theme: Actual usage of marine environmental data on MORSETS by the local fishermen in Eastern Tsugaru-strait

Program: Mutsu Institute for Oceanography

(28) Kumamoto University

Theme: Studies on technology development and value-added information generation through the expansion of the high-frequency radar observation system around the Tsugaru Strait

Program: Mutsu Institute for Oceanography

2. International Research Collaboration

A. Interagency agreement (*extracted based on the areas of cooperation related to Research Institute for Global Change)

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

Theme:

- Study of Ocean General Circulation and Climate
Program: Global Ocean Observation Research Center
Center for Coupled Ocean-Atmosphere Research
- Research into Marine Biogeochemical Cycles
Program: Global Ocean Observation Research Center

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

Theme:

- Indo-Pacific Ocean and Climate Research and IndoOS (Scientific and Technology Development Cooperation)
Program: Center for Coupled Ocean-Atmosphere Research
- Arctic Observation and Research
Program: Institute of Arctic Climate and Environment Research
- Ocean, Climate and Biogeochemical Research in the North Pacific; Cooperation in Developing and Maintaining JAMSTEC and PMEL Contributions to the North Pacific Surface Mooring Network
Program: Earth Surface System Research Center
- Computer Modeling for Global Environment Research
Program: Research Center for Environmental Modeling and Application

(3) University of Hawai'i (UH), USA

Theme:

- Studies on biogeochemical cycles in the Pacific
Program: Earth Surface System Research Center
- Developing automated nutrient and trace metal sampling and methodology using programmable flow Injection
Program: Institute of Arctic Climate and Environment Research

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

Theme:

- Greenhouse Gas Dynamics of Boreal Forest and Tundra Ecosystems Vulnerability to Arctic Warming
- Arctic Ocean Observation Research
- Northern Fresh Water Cycle and Changing Atmospheric Pattern
Program: Institute of Arctic Climate and Environment Research

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

Theme: Physical Oceanography (The Argo Programme)

Program: Global Ocean Observation Research Center

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

Theme: Marine Plastics

Program: Marine Biodiversity and Environmental Assessment Research Center

Theme: Glacial Hydrology

Program: Institute of Arctic Climate and Environment Research

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

Theme: Ocean Biogeochemistry in the Indian Ocean and Impact on Ocean Climate

Program: Global Ocean Observation Research Center

(8) 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: Center for Coupled Ocean-Atmosphere Research

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

Theme:

- Heat, Carbon and other Material Transports through Ocean Circulation and their Variability
 - 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: Global Ocean Observation Research Center
- Planktonic Community Comparisons, including those of the Continuous Plankton Recorder, in Australasian and Japanese regions
- Program: Marine Biodiversity and Environmental Assessment Research Center

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

Theme:

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

(11) 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
- Abrupt climate change, Modeling Intercomparison Projects, Earth system modeling incl, ice sheets
- Program: Research Center for Environmental Modeling and Application
- Paleoceanography and paleoclimate
- Program: Earth Surface System Research Center

(12) University of Tromsø – The Arctic University of Norway (UiT), Norway

Theme: Marine biology, biogeochemistry, and ice-covered sea observation with ice-breakers

Program: Institute of Arctic Climate and Environment / Research Earth Surface System Research Center

II. Related Activities
Research Collaboration

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

Theme:

- Ocean Monitoring

Program: Global Ocean Observation Research Center

- Marine Debris

Program: Marine Biodiversity and Environmental Assessment Research Center

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

(1) 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: Center for Coupled Ocean-Atmosphere Research

(2) The PM2.5 Research Center (PM2.5 Research Center), The Gwangju Institute of Science and Technology (GIST), Korea

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

Program: Earth Surface System Research Center

(3) 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: Center for Coupled Ocean-Atmosphere Research

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

Theme: Cooperative Research for Weather and Climate over the Indonesian Maritime Continent

Program: Center for Coupled Ocean-Atmosphere Research

(5) Viet Nam Meteorological and Hydrological Administration (VNMHA), Viet Nam

Theme: Research Collaboration on Asian Monsoon Observation over Viet Nam

Program: Center for Coupled Ocean-Atmosphere Research

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

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

Program: Earth Surface System Research Center

(7) The Université de Lorraine (UL), France / The Centre National de la Recherche Scientifique (CNRS), France / Universität Greifswald (UG), Germany

Theme: Enhanced Data stream Analysis

Program: Global Ocean Observation Research Center

(8) Federal Research Centre "The Yakut Scientific Centre (YaSC) of the Siberian Branch of the Russian Academy of Sciences", Russia

Theme: Cooperative Research on Black Carbon in the Eastern Siberia

Program: Earth Surface System Research Center

Funded Research Projects

(1) Elucidation of CO₂ absorption and storage mechanism of subtropical mode water by Argo (FY2023-2026)

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

Funding institution: Japan Science and Technology Agency (JST)

Program: Global Ocean Observation Research Center

(2) Arctic Challenge for Sustainability II (ArCS II) (FY2020-2024)

Fund: National flagship project funded by the Ministry of Education, Culture, Sports, Science and Technology (MEXT)

Funding institution: National Institute of Polar Research (NIPR)

Program: Institute of Arctic Climate and Environment Research

(3) Observation and research collaboration to strengthen Arctic sea ice-ocean environment research capabilities (FY2022-2024)

Fund: National flagship project funded by the Ministry of Education, Culture, Sports, Science and Technology (MEXT)

Arctic Challenge for Sustainability II (ArCS II), International Research Exchange Program

Funding institution: National Institute of Polar Research (NIPR)

Program: Institute of Arctic Climate and Environment Research

(4) Research study on the perturbation of the meteorology and soil radioactivity levels associated with the explosion of the "Little Boy" (FY2022-2025)

Fund: Collaborative Research Fund

Funding institution: Ministry of Health, Labour and Welfare (MHLW)

Program: Institute of Arctic Climate and Environment Research

(5) Initial Phase Study for Engineering-Based Marine CDR Development (FY2024)

Fund: Collaborative Research Fund

Funding institution: Kobelco Eco-Solutions Co.,Ltd.

Program: Institute of Arctic Climate and Environment Research

(6) Development of an observation-based early estimation system for surface fluxes of GHG and other related species (1) (FY2024-2026)

Fund: Environment Research and Technology Development Fund (ERTDF): S-22-1

Program: Institute of Arctic Climate and Environment Research

(7) Nitrogen dioxide concentration observations by the Global Observing Satellite for Greenhouse gases and Water cycle: Development of derivation algorithms, data processing schemes, product validation systems and data utilization methodologies (FY2020-2030)

Fund: Collaborative Research Fund

Funding institution: National Institute for Environmental Studies (NIES)

Program: Earth Surface System Research Center

- (8) **Prompt estimation of country-based emissions using field/satellite observations and data assimilation models (FY2022-2024)**
Fund: Environment Research and Technology Development Fund (ERTDF): 2-2201
Funding institution: Environmental Restoration and Conservation Agency (ERCA)
Program: Earth Surface System Research Center
- (9) **Carbon cycle and Lower trophic level oceanic organisms Investigation for Future Environments (FY2024-2029)**
Fund: Core Research for Evolutional Science and Technology (CREST)
Funding institution: Japan Science and Technology Agency (JST)
Program: Earth Surface System Research Center
- (10) **Integrative quantitative analysis of biological responses using morphometric and genomic approaches (FY2024-2029)**
Fund: Core Research for Evolutional Science and Technology (CREST)
Funding institution: Japan Science and Technology Agency (JST)
Program: Earth Surface System Research Center
- (11) **Observational assessment of climate change impacts on the marine biological pump (FY2024-2029)**
Fund: Core Research for Evolutional Science and Technology (CREST)
Funding institution: Japan Science and Technology Agency (JST)
Program: Earth Surface System Research Center
- (12) **Quantification of global sources and sinks of GHGs using top-down approaches and elucidation of driving mechanisms (FY2024-2026)**
Fund: Environment Research and Technology Development Fund (ERTDF): S-22-2
Funding institution: Environmental Restoration and Conservation Agency (ERCA)
Program: Earth Surface System Research Center
- (13) **Development of an observation-based early estimation system for surface fluxes of GHG and other related species (2) (FY2024-2026)**
Fund: Environment Research and Technology Development Fund (ERTDF): S-22-1
Funding institution: Environmental Restoration and Conservation Agency (ERCA)
Program: Earth Surface System Research Center
- (14) **Quantitative Assessment of Atmospheric Water Cycle Change by Short-Lived Climate Forcers (FY2021-2025)**
Fund: Environment Research and Technology Development Fund (ERTDF): S-20-1
Funding institution: Environmental Restoration and Conservation Agency (ERCA)
Program: Research Center for Environmental Modeling and Application
- (15) **System Research Team (26 Weather/Climate Science Application Area) (FY2022-2024)**
Fund: Feasibility Studies on Next-Generation Supercomputing Infrastructures
Funding institution: Ministry of Education, Culture, Sports, Science and Technology (MEXT)
Program: Research Center for Environmental Modeling and Application

II. Related Activities
Funded Research Projects

(16) Biogeochemical modeling and climate simulations for carbon budget assessment (FY2022-2026)

Fund: Advanced Studies of Climate Change Projection (SENTAN)
Funding institution: Ministry of Education, Culture, Sports, Science and Technology (MEXT)
Program: Research Center for Environmental Modeling and Application

(17) Predictive understanding of Earth system changes based on physical evidence (FY2022-2026)

Fund: Advanced Studies of Climate Change Projection (SENTAN)
Funding institution: Ministry of Education, Culture, Sports, Science and Technology (MEXT)
Program: Research Center for Environmental Modeling and Application

(18) Diagnosis of the impacts of typhoons on large-scale environment using numerical simulation data (FY2022-2026)

Fund: Moonshot Research and Development Program
Funding institution: Japan Science and Technology Agency (JST)
Program: Research Center for Environmental Modeling and Application

(19) Elucidation of driving mechanisms of global sources and sinks of (three major) GHGs using Earth system models and the model evaluation (FY2024-2026)

Fund: Environment Research and Technology Development Fund (ERTDF): S-22-2
Funding institution: Environmental Restoration and Conservation Agency (ERCA)
Program: Research Center for Environmental Modeling and Application

(20) Deep-sea Archaic Refugia in Karst (D-ARK) (FY2023-2026)

Fund: Ocean Shot Research Grant Program
Funding institution: Sasakawa Peace Foundation
Program: Marine Biodiversity and Environmental Assessment Research Center

(21) Development of a novel technology for monitoring benthic plastic debris using imagery (FY2023-2025)

Fund: Environment Research and Technology Development Fund (ERTDF): SII-10-1
Funding institution: Environmental Restoration and Conservation Agency (ERCA)
Program: Marine Biodiversity and Environmental Assessment Research Center

**(22) Data integration and indicator development to capture changes in biodiversity over time—
Demonstrating the effect of conservation and management (FY2023-2025)**

Fund: Environment Research and Technology Development Fund (ERTDF): 4-2302
Funding institution: Environmental Restoration and Conservation Agency (ERCA)
Program: Marine Biodiversity and Environmental Assessment Research Center

(23) Development of a model for assessing biodiversity and ecosystem services in marine areas (FY2023-2027)

Fund: Environment Research and Technology Development Fund (ERTDF): S-21-1
Funding institution: Environmental Restoration and Conservation Agency (ERCA)
Program: Marine Biodiversity and Environmental Assessment Research Center

(24) Habitat creation function of seagrass and macro algal beds (FY2024-2028)

Fund: Environment Research and Technology Development Fund (ERTDF): S-23-2
Funding institution: Environmental Restoration and Conservation Agency (ERCA)
Program: Marine Biodiversity and Environmental Assessment Research Center

(25) Research and Development of JAMSTEC on the Nature Positive Sustainable Development HUB (FY2024-2034)

Fund: Program on Open Innovation Platforms for Industry-academia Co-creation (COI-NEXT)
Funding institution: Japan Science and Technology Agency (JST)
Program: Marine Biodiversity and Environmental Assessment Research Center

(26) Development of Novel Particulate Sensing Technology Towards Global Marine Environmental Prediction (FY2024-2026)

Fund: Fusion Oriented REsearch for disruptive Science and Technology (FOREST)
Funding institution: Japan Science and Technology Agency (JST)
Program: Marine Biodiversity and Environmental Assessment Research Center

(27) Development of innovative atmospheric observation network for future extreme weather (FY2021-2026)

Fund: Fusion Oriented REsearch for disruptive Science and Technology (FOREST)
Funding institution: Japan Science and Technology Agency (JST)
Program: Coupling of Ocean-Atmosphere-Land Research Program

(28) Development of Virtual Mooring (VM) Technology for Stormy Environments (FY2022-2024)

Fund: Moonshot Research and Development Program
Funding institution: Japan Science and Technology Agency (JST)
Program: Center for Coupled Ocean-Atmosphere Research

(29) Test operation under stormy environment in the tropical northwestern Pacific Ocean (FY2022-2024)

Fund: Moonshot Research and Development Program
Funding institution: Japan Science and Technology Agency (JST)
Program: Center for Coupled Ocean-Atmosphere Research

(30) Development of Atmosphere-Ocean Sensors for Stormy Environments (FY2022-2024)

Fund: Moonshot Research and Development Program
Funding institution: Japan Science and Technology Agency (JST)
Program: Center for Coupled Ocean-Atmosphere Research

Awards

- **The Japanese-French Oceanographic Society Award**

Dr. Hiroshi Uchida (Global Ocean Observation Research Center)

Efforts to increase accuracy of ocean observation data

(June, 2024)

- **2023 Editor's Citation for Excellence in Refereeing – *Journal of Geophysical Research: Oceans***

Dr. Ryohei Yamaguchi (Global Ocean Observation Research Center)

(June, 2024)

- **2023 Editor's Citation for Excellence in Refereeing – *Geophysical Research Letters***

Dr. Tatsuya Seiki (Research Center for Environmental Modeling and Application)

(June, 2024)

- **2024 Honorable Mention – 2024 Masao Horiba Awards**

Dr. Tomoko Takahashi (Marine Biodiversity and Environmental Assessment Research Center)

Development of in situ continuous in-flow microplastic monitoring techniques using optical and spectroscopic techniques

(August, 2024)

- **Marine Tech Grand Prix 2024 – Earth Future Award**

Dr. Hideki Kobayashi (Institute of Arctic Climate and Environment Research) / Dr. Roxanne Lai (Institute of Arctic Climate and Environment Research) / Dr. Eko Siswanto (Earth Surface System Research Center)

(September, 2024)

- **The 6th Award for Brilliant Female Researchers (The JST President Award)**

Dr. Naoko Nagatsuka

(October, 2024)

- **Early-Career Research Award – 17th Deep-Sea Biology Symposium**

Dr. Natsumi Hookabe (Marine Biodiversity and Environmental Assessment Research Center) /

Dr. Leah Ann Bergman (Marine Biodiversity and Environmental Assessment Research Center)

(January, 2025)

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JAMSTEC

Japan Agency for Marine-Earth Science and Technology

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