Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

MIS21-01 Room:301A Time:May 27 11:00-11:15

Integrated multidisciplinary study on change in the Southern Ocean and the Antarctic ice sheet

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The Antarctic ice sheet holds 90% of ice and is the largest fresh water reservoir on the Earth, which is equivalent to 70 m height of sea level. On the other hand, the Southern Ocean produces densest seawater, called the Antarctic bottom water, which is huge negative heat reservoir occupied 30-40% of whole seawater on the Earth, and is also giant reservoir of carbon dioxide. Consequently, the Antarctic ice sheet and the Southern Ocean are giant reservoirs of heat, water and material on the Earth, and the most significant components that control global climate and sea level changes. The changes in the Antarctic ice sheet and the Southern Ocean most likely indicate the precursor and driving force of the global environmental changes, and these changes are essential for future projection of Earth system. However, the Antarctic ice sheet and the Southern Ocean are the mostly unknown components in the Earth system due to the difficulties of the observation in these areas. Especially, studies on the East Antarctic area are very poor, and are behind in understanding of the ice sheet and the ocean behavior.

The interaction among the atmosphere, ice sheet, solid earth and ocean is vital to understand the Antarctic ice sheet, because the status under ice shelf around the boundary between ice sheet and ocean is essential factor. The physical, biological and chemical processes in the Southern Ocean are extremely important for understanding the carbon cycles which affect the global climate. Moreover, the impact on the ecological system in the Southern Ocean with huge biological production, followed by fluctuations in ocean circulation and sea ice has to be elucidated. Therefore, the primary processes and the mechanism of the interactions should be made clear in the context of the global environmental changes driven by the Antarctic ice sheet and the Southern Ocean throughout the various kinds of the interactions, and the integrated multidisciplinary study is required with the different fields of the observation data from geological to present time scale together with modeling studies. Furthermore, the developments of the observation instruments are important element to obtain the field observation data in the unexplored under and edge of sea ice, that is a key area to understanding the interactions. The program and the framework of the integrated multidisciplinary study focused on the Southern Ocean and the Antarctic ice sheet from the viewpoints of giant reservoirs of heat, water and carbon dioxide, which drive changes in the global climate and ecological system, are introduced, and the future direction and the prospects of this program are discussed.

Keywords: Southern Ocean, Antarctic ice sheet, ocean circulation, ecological system, carbon cycle

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MIS21-02 Room:301A Time:May 27 11:15-11:30

Reconstruction of the East Antarctic ice sheet variability during the last 3 Ma and glacial dynamism in the warm world

SUGANUMA, Yusuke[1*] ; OKUNO, Jun'ichi[1]

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Reconstructing past variability of the Antarctic ice sheets is essential to understand their stability and to anticipate their contribution to sea level change as a result of future climate change in a high-CO2 world. Recent studies have reported a significant decrease in thickness of the East Antarctic Ice Sheet (EAIS) during the last several million years. However, the geographical extent of this decrease and subsequent isostatic rebound remain uncertain and a topic of debate. Recently, we reconstructed magnitude and timing of ice sheet retreat at the central part of the Sor Rondane Mountains in Dronning Maud Land, East Antarctica, based on detailed geomorphological survey, cosmogenic exposure dating, and glacial isostatic adjustment modeling (GIA). Three distinct deglaciation phases are identified in this area during the Quaternary and the ice sheet thinning is estimated to be at least 500 m during the Pleistocene. Although this is the first attempt to estimate the absolute thickness of the EAIS thinning during the Quaternary with GIA modeling, local effects, such as regional ice flow and damming, to the ice sheet thickness reconstruction remain unclear. Here, we propose that a new expedition plan for the Japanese Antarctic Research Expedition (JARE) phase IX program (2015 - 2020 austral summer seasons) for providing a better constraint for the EAIS thickness reconstruction during the last 3 Ma. In this plan, we are going to carry out expeditions in the Belgica and Yamato Mountains. This will contribute further understanding of the glacial dynamism of the EAIS in the warm world and interaction with the reorganization of the Southern Ocean circulation through the moisture transport from the Southern Ocean to the interior.

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MIS21-03 Room:301A Time:May 27 11:30-11:45

Interannual Variation of Surface Wind over the Southern Ocean -Correlation Feature with DPOI and KDOI-

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1.Introduction

It is well known that most of the surface in the southern hemisphere is covered by ocean and especially its high latitudes are governed by the strongest surface winds of the entire ocean. Previous studies have pointed out that there are some meteorological patterns over the southern ocean such as Southern Annular Mode (SAM; Thompson and Wallace,2000), Antarctic Oscillation (AAO; Gong and Wang, 1999) and Antarctic Circumpolar Wave (ACW; White and Peterson,1996), and then that they are related to the strength of the westerly winds and affect large change of ecological environment in the Antarctic/ Southern Ocean during recent decades (Aoki, 2002; Marshall, 2003; Naganobu et al., 2014, IPCC, 2001, 2007, 2013).

The Antarctic krill (Euphausia super- ba) is a key species in the Antarctic Ocean, so understanding of its relationships with climate and oceanic condition is considered to be a fundamental issue. Naganobu et al.(1999) and Kondo(2008) found significant correlations between the krill recruitment and DPOI (Drake Passage Oscillation Index) which is a climate indice defined by the sea-level pressure differences between Rio Gallegos at the southern edge of the South America and Esperanza at the northern edge of the Antarctic Peninsula. The strength of the westerlies affects krill recruitment, so the strong (weak) westerlies resulted in high (low) krill recruitment. Further, it was also suggested that the westerly wind changes around the Drake Passage have high correlations with those in wide area including south of the Indian Ocean, so the DPOI is a good index as an environmental condition in the Southern Ocean (Yoda, 2011).

In this study, we focus on spatial features in wind variations over the southern ocean that the DPOI has high correlations with, and then derive a similar indice to DPOI in the Prydz Bay area, Kerguelen Davis Oscillation Index (KDOI) which is defined by the sea level pressure difference between Kerguelen Island and Davis. Correlations analyses are made between time series of these indices and surface winds data set.

2.Data

Number of marine meteorological observations over the southern hemisphere decreases as going to the past, so it is difficult to use data sets by numerical model and reanalysis data having long-term time coverage with persistent reliability. Instead, we also use the data set of surface winds which have been constructed by satellite scatterometer data. In this study, time series of monthly data are used.

3.Results

First, we notice time variations of DPOI and KDOI. Their spectra reveal significant peaks at the periods of 6-month and 12-months, and another peak at the periods of 32 months and 24months for DPOI and KDOI, respectively (Fig1.). In addition, the DPOI has also high energy level in the periods longer than 100 months, suggesting dominance of long-term variations.

Second, to investigate the relationship of DPOI and KDOI with surface winds from the NCEP/NCAR reanalysis data set over the southern ocean, we derive spatial correlations of the index with the zonal components. Results reveal that in interannual timescales by 12-month running mean, the DPOI has high correlations in the Drake Passage and south of Australia (Fig.2), and the KDOI in Prydz Bay and north of the Weddell and Ross seas (Fig.3). On the other hand, correlation distributions for long-term time scales by 36-month running mean show negative values in west of the Drake Passage and Ross sea for DPOI, and positive values in the same areas for KDOI. In addition, in areas of the Ross ice shelf and Ronne ice shelf, the DPOI and KDOI have positive and negative, respectively, correlations (Fig4., Fig5.). Further, both in time scales, no correlations are found west of the Drake Passage both for DPOI and KDOI.

These suggest that the surface wind variations over the southern ocean have different spatial features in interannual time scales, and thus these details will be examined.

Keywords: Circumpolar westerlies, DPOI, KDOI, AAOI

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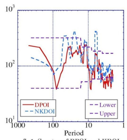

fig1. Spectra of DPOI and KDOI.

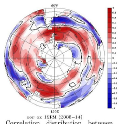

fig2. Correlation distribution between DPOI and the zonal wind (12-month running mean).

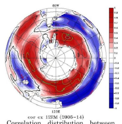

fig3. Correlation distribution between KDOI and the zonal wind (12-month running mean).

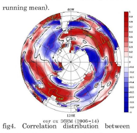

fig4. Correlation distribution between DPOI and the zonal wind (36-month running mean).

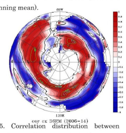

fig5. Correlation distribution between KDOI and the zonal wind (36-month running mean).

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MIS21-04 Room:301A Time:May 27 11:45-12:15

Variability of the Southern Ocean in annual to decadal time scales

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I review physical oceanographic changes observed in the Southern Ocean since ca. 1980 i.e. modern instrumental records started.

The Southern Ocean is surrounded by the atmosphere, solid Earth, sea ice, and ice sheets. Eastward momentum flux from the atmosphere shows a significant increasing trend with southward shift. Heat and fresh water flux from the atmosphere are not well constrained. Freshwater flux from the ice sheet is generally increasing with regional contrasts.

Despite increasing wind stress, the Antarctic Circumpolar Current transport has not shown a trend. Geostrophic surface currents estimated from satellite altimeters suggest that the increased wind enhanced mesoscale eddies generated via baroclinic instability. The eddy enhancement is spatially localised. The role of these ”standing eddies” is a recent hot topic.

In some numerical simulations, the meridional overturning circulation shows a strengthening trend in the upper cell (Circumpolar Deep Water upwelling and surface northward transport) and a weakening trend in the lower cell (CDW upwelling and Antarctic Bottom Water sinking). Estimated transport from a box inverse model does not contradict these results.

The most conspicuous hydrographic change is the decreasing AABW, which has a strong link with recent warming and freshening of the water mass. In the Indian-to-Pacific sector, dissolved oxygen decreased (appears as an increase in the density coordinate), which might have resulted from an ice calving event in the Ross Sea in the 1990s.

I emphasise that these changes, which have been discussed as though they are independent, interact with each other. Feed back mechanisms likely exist. Comprehensive understanding of the ”Antarctic climate system” requires a comprehensive observing system that covers atmosphere, solid Earth and ice components of the system as well as the ocean.

Keywords: SAM intensification, eddy saturation hypothesis, Antarctic Bottom Water decrease, freshening

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MIS21-05 Room:301A Time:May 27 12:15-12:45

Prospects of Antarctic climate and ice sheet studies based on ice cores

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Ice cores from Antarctica have provided valuable information on past climate changes and interactions over various spacial and temporal scales. In particular, the Japanese ice core and climate modeling communities have made efforts to collect and analyze deep ice cores from Antarctic inland site, Dome Fuji. The orbital tuning of O2/N2 ratio with the local summer insolation based on physical link enables us to construct an accurate age model for this ice core and hence for histories of atmospheric CO2 concentrations and various Antarctic environmental parameters such as temperature, accumulation rate and aerosol fluxes and forcings (e.g. Kawamura et al., 2007 Nature; Iizuka et al., 2012 Nature; Uemura et al., 2012 Clim. Past)). The accurate age scale also enabled the IPCC-class climate and ice sheet models to run with realistic history of greenhouse-gas radiative forcing, and it was a key to the successful simulation of the glacial-interglacial cycles with realistic timing and amplitude (Abe-Ouchi et al., 2013 Nature).

An important next challenge for the Antarctic paleoclimate community is to understand the Antarctic ice sheet changes and feedbacks in response to external forcing such as changes in greenhouse effect and ocean temperature. For example, paleo-sea-level studies have suggested that sea level was higher than present by more than 4m during the last interglacial (Marine Isotope Stage 5e), and by up to ˜20 m (with high uncertainty) during the interglacial some 420,000 years ago (MIS 11). Together with Greenland ice mass and ice-core evidences, Antarctic ice sheet is suggested to have contributed to the both sea-level high stands. However, the CO2 level in those periods were not particularly high compared to the Holocene preindustrial level, and the orbital forcing (northern summer insolation) is weak during MIS 11. To solve the enigma, it is not enough to study the interglacials in relation to the instantaneous forcings such as insolation and CO2, but it is also necessary to study the histories of climatic components such as temperature, ice volume and bedrock, from the preceding glacial periods to the interglacials.

Other aspects of Antarctic ice-core paleoclimate will also be covered in the presentation. For example, ice cores from inland and coastal regions should be measured with process studies for better reconstructions and understanding of aerosol radiative forcing and sea ice extent around Antarctica.

Keywords: Ice core, Antarctic ice sheet, Climate change

MIS21-06 Room:301A Time:May 27 14:15-14:30

Sea ice production and bottom water formation in the Southern Ocean from a global view

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Global overturning circulation is driven by density differences: water sinks in dense water formation areas and then gradually upwells in other areas. Densest water is produced in the Southern Ocean and named as Antarctic Bottom Water (AABW). AABW extends to the abyssal layer of the global ocean, accounting for 30-40% of the global ocean mass. AABW production is a major contributor to the global overturning circulation and represents an important sink for heat and possibly CO_2. AABW originates as dense shelf water, which forms on the continental shelf by regionally varying combinations of brine rejection from sea ice growth and ocean/ice-shelf interactions. By contrast, such dense/bottom water cannot be produced in the Arctic Ocean. Densest water in the North Pacific is produced in the Okhotsk Sea, which causes the North Pacific overturning extending to the intermediate layer. Saline water rejected during sea ice formation is the main source of such dense water, and thus sea ice production is a key factor in the overturning circulation. We have developed an algorithm to estimate sea ice production globally from satellite data with heat flux calculation. Global mapping of sea ice production demonstrates that the production rate is particularly high in the Antarctic coastal polynyas, in contrast to the Arctic ones. This is consistent with the formation of Antarctic Bottom Water (AABW). High sea ice production around the Antarctica is caused by two factors. One is divergent ice field there, resulting in active polynya formation, which is in contrast to the Arctic Ocean. The other factor is the presence of fast ice (landfast ice and glacier tongue). Most of the Antarctic polynyas are formed on the western side of fast ice. Winds diverging from a boundary comprising both coastline and fast ice are the primary determinant of polynya formation. The blocking effect of fast ice on westward sea ice advection by the coastal current would be another key factor. The Cape Darnley polynya (65-69E) is found to be the second highest ice production area in the Southern Ocean, suggesting a source of AABW. Recent Japanese IPY observations revealed that this is the missing (fourth) source of AABW. In the region off the Mertz Glacier Tongue (MGT), the third source of AABW, sea ice production decreased by as much as 40%, due to the MGT calving in early 2010. Recent observations suggested a significant reduction in AABW there, likely caused by the decrease in sea ice production. These demonstrate the strong linkage between variabilities of sea ice production and bottom water.

Keywords: Antarctic Bottom Water, sea ice production, coastal polynya, overturning, landfast ice

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MIS21-07 Room:301A Time:May 27 14:30-14:45

Sea ice production variability in the Antarctic coastal polynyas

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The sinking of dense water in the polar oceans plays a key role in global thermohaline circulation, leading to heat and material exchange between the atmosphere and deep ocean. High ice production in Antarctic coastal polynyas is responsible for the dense water formation, leading to Antarctic Bottom Water (AABW) formation. Our past studies gave the mapping of sea ice production in the Southern Ocean, based on heat-flux calculation with ice thickness data derived from satellite data. This study presents the interannual and seasonal variability of sea ice production in the 13 major coastal polynyas from 1992 to 2013. In general, the interannual variability of sea ice production shows a good correlation with polynya extent rather than surface air temperature. The Ross Ice Shelf polynya experienced large ice production reduction events in 2000 and 2002 due to the effects of the giant icebergs B-15 and C-19, which calved from the Ross Ice Shelf, and the ice production later recovered to the same level as that in the 1990s. The Mertz Glacier polynya also experienced a large ice production reduction event in 2010 due to the calving of the Mertz Glacier Tongue, and new minimum ice production records have been set every year since.

Keywords: sea ice production, coastal polynya, interannual variability, Antarctica, remote sensing

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MIS21-08 Room:301A Time:May 27 14:45-15:00

A new method to detect landfast sea ice in the Antarctic Ocean using AMSR-E data

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Landfast ice (fast ice) is stationary sea ice attached to coastal features such as the shoreline and grounded icebergs. Antarctic fast ice extent is estimated to be only about 5% (0.8×10^6 km^2) of the entire sea-ice extent, although the spatial distribution and variability of fast ice are not yet well understood. Fast ice exerts a significant influence on the climate system, biogeochemical cycles, biological activity, and ship navigation, despite its relatively small extent. For example, most Antarctic coastal polynyas form on the western side of fast ice, indicating the important role of fast ice in polynya formation. Further, fast ice forms an important interface between the ice sheet/shelves and the moving pack ice zone, and has been shown to influence floating ice tongue/ice shelf stability.

Detection of fast ice has been carried out along the East Antarctic coast based on cloud-free visible and infrared satellite images. However, this method, while providing extremely high resolution, is less suitable for making a circumpolar dataset. By using passive microwave satellite (SSM/I and AMSR-E) data, fast ice is detected based on the characteristic that the brightness temperature fast ice tends to be lower than that of thin ice and are similar to that of ice sheet. However, the only the climatology of fast ice extent can be shown by this method, because the temporal resolution is coarse (three months) and there is some false detection.

In this study, fast ice area is detected based on spatial and temporal matching of brightness temperature of AMSR-E: pixels whose spatial distribution of brightness temperature is similar for a certain period, that is motionless sea-ice pixels, are detected as fast ice. The preliminary results show that this method can detect fast ice area with relatively finer temporal resolution (from a few weeks to one month). Further, false detections caused by the previous method are reduced significantly. This technique will complement the existing high-resolution MODIS fast ice dataset. Further, by applying this technique to AMSR2 and SSMI data, change in the fast ice extent for the longer period of about 30-years could be examined.

Keywords: Landfast sea ice, Coastal polynya, Ice shelf, Ice tongue, Ice sheet, Antarctica

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MIS21-09 Room:301A Time:May 27 15:00-15:15

Biogeochemical study in the sea ice area of the Southern Ocean

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Sea ice has rarely been considered in estimates of global biogeochemical cycles, especially gas exchanges, because of the assumption that, in ice-covered seas, sea-ice acts as a barrier for atmosphere?ocean exchange. However, recent work has shown that sea ice and its snow cover play an active role in the exchange of gases between the ocean and atmosphere. Our results provide a useful reference for future studies as the ongoing drastic changes in polar climate and sea ice extent are likely to alter the biogeochemical cycles in polar ocean-sea ice-atmosphere system. In this presentation, we will show the preliminary results obtained at the international sea ice research by Aurora Australis off East Antarctica (SIPEX-II) in 2012 and a mid-winter sea ice cruise by Polarstern in the Weddell Sea, Antarctica (AWECS) in 2013. In addition, we will also show the ongoing research for the effect of Antarctic bottom water formation on the biogeochemical cycles in the Southern Ocean.

Keywords: Sea ice, Polar ocean, Southern Ocean, Biogeochemical cycles

MIS21-10 Room:301A Time:May 27 15:15-15:30

Antarctic ice shelves' basal melting and its mechanisms under the LGM and a CO2 doubling climate

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Basal melting of Antarctic ice shelves is considered to be an important factor to the retreat of Antarctic ice sheet in the past or future, but little consensus exists on how the rate of basal melting changes against climatic forcing.

We investigate Antarctic Ocean and basal melting of Antarctic ice shelves under the Last Glacial Maximum (LGM) and an equilibrium CO_2 doubling climate as well as present-day, using a circumpolar ocean model with ice shelf cavity component (Kusahara and Hasumi 2013). As the circumpolar ocean model requires atmospheric forcing at sea surface and oceanic forcing at lateral boundary of the model domain, we use outputs of a climate model (MIROC) simulations. To test the sensitivity to climate, we use present-day Antarctic ice sheet/shelf configuration in all experiments.

Although global radiative forcing of LGM and CO_2 doubling climate are similar, change in basal melting amount under the CO_2 doubling climate is more pronounced than the LGM. Change in background climate modifies basal melt rate of ice shelves through changes in water mass properties on continental shelves. Active sea ice production in the Antarctic Coast forms cold and dense water on continental shelves under a colder climate. Under a warmer climate, decreased sea ice production and dense water on continental shelves enable warm deep water in the Southern Ocean to intrude onto continental shelves and increase basal melting. This behavior of the water mass properties on continental shelves is not well represented in the climate model with a coarse resolution.

A series of sensitivity experiment shows that atmospheric heat-derived forcing is the most important to sea ice production and basal melt rate. These results suggest that basal melt rate of ice shelves is not simply parameterized from deep ocean temperature in the Southern Ocean, and that it is required to consider water mass formation process in the Antarctic Coast.

Keywords: Antarctica, Ice Shelves, Basal Melting, Sea Ice, Sea Ice Production, Southern Ocean, Continental Shelf, Ocean model, Climate model

MIS21-11 Room:301A Time:May 28 09:00-09:15

Glacial-interglacial variations in nutrient cycle and biological productivity in the Southern Ocean

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The Southern Ocean has played a significant role in the global climate system during the geologic past, even in the present-day. The Southern Ocean also became an important investigated region of paleoceanographic focus because of its unique role in global deep-water circulation and its potential significance for the global carbon. For example, it has been proposed that primary production was higher and nutrient utilization in surface waters was more efficient in the glacial Subantarctic Southern Ocean than today, effectively lowering the glacial atmospheric CO2 concentration. However, it was reported that biological production was much lowered during the glacials in the Antarctic zone, which is south of the Antarctic polar front.

We evaluated nutrient supply and biological production in the Antarctic zone of the Southern Ocean using a piston core PS2603-3 from the Enderby Abyssal Plain. Biogenic opal concentrations were significantly increased for the last two peak interglacials Holocene and Marine Isotope Stage (MIS) 5e. δ15N of bulk sediments were lowered during the interglacials (Holocene and MIS 5), whereas they were increased during the glacials (LGM and MIS 6). Lower primary production and nutrient utilization for the full glacials was mainly caused by weak upwelling of Circumpolar Deep Water (CDW) in the polar region due to surface water stratification by sea-ice coverage and its melting water input. Low values of δ15N at MIS 5e suggest that the nutrient utilization was much higher than Holocene due to warmer surface condition in the Indian sector of the Southern Ocean. These results indicate that the surface water stratification was significantly broken at the last interglacial owing to an extreme retreat of sea ice distribution and southward shift of polar front with warmer Southern Ocean.

Keywords: Southern Ocean, productivity, nutrient, stratification

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MIS21-12 Room:301A Time:May 28 09:15-09:30

Miocene-Pliocene paleoenvironmental reconstruction using siliceous microfossils in the Weddell Sea sediments

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The latest Oligocene-Pliocene (ca. 25-3 Ma) microfossil assemblages of diatoms as well as *Chaetoceros* resting spores and chrysophyte cysts from the sediments drilled by the Ocean Drilling Program (ODP) Leg 113 Hole 689B are investigated to reveal the paleoceanographic changes around the Weddell Sea, Antarctic Ocean. As a result of the biochronological analysis, forty-one diatom bioevents including twenty-five biohorizons are recognized.

In the paleoceanographic analysis, a distinct peak of *Thalassionema nitzschioides* var. *parva* are observed at 18 Ma (million years ago before present), which may indicate a migration of the Antarctic Circumpolar Current. The increases in the abundance of sea-ice related diatom taxa from 13 Ma and at 9.5-5 Ma are also observed, which seem to be related to the growth of seasonal and multi-year sea-ice distributions around the late Miocene period. High abundances of subantarctic species and chrysophyte cysts from ca. 4.8-3 Ma are may appear to be associated with the Pliocene warmth event. In addition, the diversification of diatoms at 9.5 Ma might be caused by strengthening of seasonal variations in sea-ice distribution. Moreover, the diversification of diatoms and abrupt increase in *Chaetoceros* resting spores and chrysophyte cysts at ca. 4.8 Ma may be associated with eutrophication by strong nutrient supply.

Furthermore, this study has a potential to contribute the prediction of the global climate change in the future because the studied ages of this study include the Miocene and Pliocene known as high pCO_2 periods, as well as the reconstructions of the past Antarctic sea-ice and ice-sheet distributions.

Keywords: the Weddell Sea, diatom, chrysophyte cyst, resting spore, sea-ice

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MIS21-13 Room:301A Time:May 28 09:30-09:45

Evidence from phosphorus speciation for changing nutrient status in the Southern Ocean since the last glacial period

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The Southern Ocean, a high-nutrient, low-chlorophyll region, plays an important role in regulating global climate system. The Southern Ocean became anoxic during the last glacial period (~70 to 10 kyr ago), with its maximum at the Last Glacial Maximum (LGM). In order to elucidate changes in the redox state and nutrient status of the seawater caused by sea ice and/or shelf ice, we performed phosphorus speciation analysis of the marine sediments (COR-1bPC) recovered at the Conrad Rise in the Southern Ocean by 2010 KH10-07 cruise. Selected, freeze-dried and powdered 37 samples were used for sequential extraction of phosphorus-bearing phases (loosely sorbed P (P_{abs}), iron-bound P (P_{Fe}), authigenic apatite P + biogenic apatite + $CaCO_3$-associated P (P_{auth}), detrital apatite P (P_{det}), organic P (P_{org})) by modified SEDEX method of Ruttenberg (1992). Phosphorus concentrations of each sample solution were measured by molybdenum blue method. Average contents of P_{auth}, P_{det}, P_{org}, and P_{tot} in the dark colored sediments (corresponding to the last glacial period) was 0.020 wt.%, 0.004 wt.%, 0.008 wt.%, and 0.059 wt.%, respectively. Conversely, those in the light colored sediment (the interglacial period) were 0.005 wt.%, 0.002 wt.%, 0.004 wt.%, and 0.022 wt.%, respectively. During the last glacial period, where the Southern Ocean was covered by sea ice, suppressed interactions between atmosphere and ocean would have decreased dissolved oxygen concentration and gradually created anoxic condition. Such anoxic condition would have occasionally but repeatedly expanded to include the Conrad Rise and affected P_{Fe} abundance in sediment. In the LGM, abundance of P_{auth}, P_{det}, P_{org}, P_{Fe}, and P_{tot} suddenly increased to the maximum value. Sources of phosphorus to the ocean are either or combination of wind-driven dust, glacier-scored debris, or regeneration from sediments upon reductive dissolution of P-absorbed Fe (oxy)hydroxide. Wind-driven dust is unlikely because the surface of Antarctic Continent was covered by ice sheet. Therefore, the latter two processes would have increased P and Fe nutrient supply to the ocean, enhanced primary production, induced anoxic condition by consumption of dissolved oxygen upon degradation of organic matter, and decreased pCO_2. Analysis of phosphorus speciation is useful in reconstructing redox and nutrient states in the ocean.

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MIS21-14 Room:301A Time:May 28 09:45-10:00

Role of Southern Ocean stratification in glacial atmospheric CO2 reduction evaluated by a three-dimensional OGCM

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Atmospheric carbon dioxide (CO_2) concentration during glacial periods is known to be considerably lower than during interglacial periods. However, previous studies using an ocean general circulation model (OGCM) fail to reproduce this. Paleoclimate proxy data of the Last Glacial Maximum indicate high salinity (>37.0 psu) and long water mass residence time (>3,000 years) in the Southern Ocean, suggesting that salinity stratification was enhanced and more carbon was stored there. The reproducibility of salinity and water mass age is considered insufficient in previous OGCMs simulations, which might affect the reproducibility of atmospheric CO_2 concentration. This study investigated the role of enhanced stratification in the Southern Ocean in the variation of atmospheric CO_2concentration using an OGCM. We found that deep water formation in East Antarctica is required to explain high salinity in the South Atlantic. Contrary to previous estimates, saltier deep Southern Ocean resulted in increased atmospheric CO_2 concentration. This is because Antarctic Bottom Water flow increased and residence time of carbon decreased in the deep Pacific Ocean. On the other hand, weakening of vertical mixing contributed to the increase of the vertical gradient of dissolved inorganic carbon and decrease of atmospheric CO_2concentration by up to 18 ppmv. However, we show that it is unable to explain the full magnitude of recorded reduction of glacial atmospheric CO_2 concentration by the contribution of the Southern Ocean. Our findings indicate that detailed understanding of the impact of enhanced stratification in the Southern Ocean on the Pacific Ocean might be crucial to understanding the mechanisms behind the variations of the glacial-interglacial ocean carbon cycle.

Keywords: carbon cycle, glacial/interglacial, Southern Ocean, meridional overturning circulation

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Global oxygenation by enhanced deep convection in the Southern Ocean under millennial-scale global warming

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Global warming is expected to reduce oceanic oxygen content as reduction in oxygen solubility, enhanced stratification and slower ocean circulation tend to decrease the supply of oxygen into the ocean interior and to enhance biological oxygen utilization (Keeling et al., 2010). The resulting expansion of oxygen minimum zone may have adverse impacts on marine life such as widespread mortality and/or reduced available habitat. Previous modeling studies using Earth System Models of Intermediate Complexity show that oxygen reduction would persist for a thousand years or more, and that the decreases in the total oxygen concentration is as large as 20-50% (Schmittner et al., 2008; Shaffer et al., 2009). However, millennial-scale change in ocean oxygen concentration has not yet been investigated with a fully coupled atmosphere-ocean general circulation model (AOGCM).

Here we use a coupled AOGCM and offline biogeochemical model to simulate multi-millennial oxygen change under atmospheric carbon dioxide doubling and quadrupling. At the first 500 model years in the warming simulation, dissolved oxygen is decreased globally, which is consistent with the previous studies. Thereafter, however, O_2 concentration in the Southern Ocean between subsurface and deep ocean increases and overshoot rapidly, and that in the other deep ocean except the North Atlantic recovery gradually. Consequently, global mean O2 concentration recovers and overshoots by the end of warming experiment, in spite of surface oxygen reduction due to lower oxygen saturation and weaker Atlantic meridional overturning circulation. Recovery of deep ocean convection in the Weddell Sea after initial cessation enhances ventilation and supplies the oxygen into each of the three major basins through strengthened Antarctic Bottom Water, resulting in the oxygen overshoot in the deep ocean. Our results suggest that enhanced deep convection and ventilation in the Southern Ocean have global impact on millennial-scale oxygen change. The mechanisms of cessation and recovery of deep convection in the Weddell Sea will be discussed.

Keywords: dissolved oxygen, global warming, open ocean convection, thermohaline circulation

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Modelling the importance of Southern ocean and Antarctic ice sheet in Plio-Pleistocene climates

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In order to understand the factors influencing the Antarctic climate and Ice sheet and evaluating its influence upon global climate, many paleoclimate modelling under LGM condition and Pliocene are performed and two examples are shown here. Southern Ocean is important as the source of Antarctic Bottom water formation which influences the atlantic meridional overturning circulation (AMOC) and carbon storage. Here we analyse the latest multi models of CMIP5 and PMIP experiments as well as MIROC model (Japanese GCM) and show that the deepening of AMOC simulated in most of the models come from the insufficient model performance in Southern ocean. We further show that the models which don't have shallower glacial AMOC have even stronger AMOC because of the existence of ice sheets, through the feedback between the AMOC, sea ice and wind stress in the north Atlantic. The second topic is on the modeling the Antarctica ice sheet, on which we discuss the influence of global climate change under glacial condition and Pliocene in models to aid interpretation of paleodata showing the increase in altitude in some area and retreat of margin, decrease of sea level in Pliocene. By combining ice sheet model and GCM, we show that the mid Pliocene ice sheet shows an increase in altitude in East Antarctica especially in the Queen Maud Land region because of accumulation increase, while a thinning or retreat in the Wilkes land and Aurora basin where relatively the bedrock is low. Furthur studies need an update in ice sheet modeling treating properly the ocean-ice interaction, basal processes and rebound of bedrock, as well as climate experiments taking into account the different orbital conditions.

Keywords: Climate, ice sheet, paleoclimate, ocean, climate model

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Study of surface mass balance of Shirase Glacier using 2002 to 2014 GRACE satellite gravity data

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Recent studies of the Antarctic ice sheet mass balance using satellite gravity mission GRACE data reported that the Antarctic is decreasing in the last decade, and the decrease is accelerating in recent years. The decrease is mainly due to the large-scale ice sheet melting or run-off in West Antarctica, while the ice sheet mass is slightly increasing at the same time period in East Antarctica. Shirase Glacier, which is located in Enderby Land is the most significant surface mass increase region in East Antarctica. Thus, in this study, we purposed to investigate ice flow mechanism of Shirase Glacier using GRACE and other auxiliary satellite and meteorological data sets. We firstly estimated regional average of inter-annual mass variations of Shirase Glacier using GRACE satellite gravity data from March 2002 to March 2014. The result showed that the mass increase of this region is +23.7 Gt/yr. We considered that the observed positive mass trend was mainly caused by surface ice sheet mass change, because it is known that the GIA mass trend in this region is small. The peak of the positive trend was located at the mouth of the Shirase Glacier (38.6 deg E and-70.5 deg N). One of our interests is whether the observed surface mass increase can just be explained by snow accumulation or should be also considered the effects of horizontal outflow and inflow of basal ice sheet. To clarify this, we compared the GRACE-derived surface mass change with the one calculated from atmospheric objective analysis data of this region. On the basis of the result, we will discuss ice sheet flow mechanism of Shirase Glacier in detail.

Keywords: Antarctic ice sheet change, GRACE, satellite gravity mission, surface mass balance, Shirase Glacier