Integrated multidisciplinary study in Antarctica and next six-year Japanese Antarctic Research Project phase IX

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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 the Earth system. The six-year Japanese Antarctic Research Project phase IX centered on main scientific theme of “Investigation of changes in the Earth system from Antarctica” will be commenced from 2016/2017 austral summer season with the three subthemes. The three subthemes are followings, “Investigation of the whole global atmospheric system through precise observation of the Antarctic atmosphere”, “Investigation of the interaction of atmosphere, ice sheets, sea ice, and ocean from integrated research in areas bordering ice sheets and sea ice” and “Reconstruction of the Antarctic paleoclimate to elucidate changes in the Earth system.” Integrated multidisciplinary study are required to promote these subthemes under the main scientific theme in order to elucidate changes in the Antarctic subsystem and its effect to the Earth system. Especially, multidisciplinary study is key to understand the interactions around the boundary between ice sheet and ocean, namely ice shelf and sea ice areas, in the context of the Southern Ocean and the Antarctic ice sheet, which correspond to the second subtheme.
We will present the outline of the six-year Japanese Antarctic Research Project phase IX briefly and the necessity of integrated multidisciplinary study in Antarctica is discussed.

Keywords: Antarctica, ice sheet, ocean

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Interaction of the solid Earth and the Antarctic ice sheet

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The Antarctic ice sheet, which relates to the global climate changes through the sea level rise and ocean circulation, is an essential element of the Earth system for predicting the future environment changes. Thus many studies of the ice sheet changes have been conducted by means of geomorphological, geological, geodetic surveys, as well as satellite gravimetry and satellite altimetry. However these studies thus far conducted have been affected by the large uncertainties of GlA (Glacial Isostatic Adjustment), which is the rheological response of the solid Earth to the ice mass loading. Therefore the precise estimation of the GIA effects is an urgent and an important task for these studies. The effects of GIA, on the other hand, include valuable information about the rheological properties of the solid Earth. Thus the observational studies of the GIA effects should greatly contribute to investigate the inner structure of the Earth. GIA, as a keyword to investigate the interaction between the solid Earth and the ice sheet changes, is an important research target not only for a practical requirement of predicting global changes but also for a more pure scientific interest to know the structures of the deep Earth's interior.
In view of these points, we plan to conduct geomorphological, geological and geodetic surveys in the inland mountain areas and the coastal areas in East Antarctica, where the in-situ data for constraining GIA models are very few. In addition, we will conduct precise monitoring of the land movements at Syowa Station using space geodetic observations such as SLR (Satellite Laser Ranging) and VLBI (Very Long Baseline Interferometer) as well as sea bottom geomorphological surveys on continental shelves using new technology of ROV (Remotely operated Vehicle) and AUV (Autonomous Underwater Vehicle). Combining these observations with the analyses of the sea bottom cores obtained by the bowling surveys on the continental shelves, various satellite data analyses and numerical modeling, we will precisely estimate the response of the solid Earth due to the GIA effects and corresponding sea level changes. These procedures lead us to a precise GIA model and constructing a reliable ice melting history after LGM (the Last Glacial Maximum) and the viscoelastic structure of the Earth's interior.
We will present the outline of this research project.

Keywords: GIA, Antarctic ice sheet, Sea level rise

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Summary of marine geological survey in the Indian sector of the Southern Ocean: Preliminary reports of KH-16-1 cruise

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Marin geological survey in the Indian sector of the Southern Ocean have been done during the KH-16-1 expedition by R/V Hakuho-maru. Multichannel seismic (MCS) reflection survey was conducted in the Del Cano Rise and the Conrad Rise to prepare the future IODP proposal. It is interpreted that sediment waves in the Conrad Rise were originally formed by the Antarctic Circumpoar Current (Oiwane et al., 2014). Sediment waves were also observed under the seafloor on the Del Cano Rise, suggesting main axis of the ACC was occasionally fluctuated to north during past glacial stages.

Keywords: Southern Ocean of the Indian sector, ACC, Multichannel seismic reflection survey, KH-16-1 cruise, Del Cano Rise, Conrad Rise

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Transitions of redox state and nutrient status in the Southern Ocean since the last glacial: Evidence from speciation analyses of C, Fe, and P in sediments at the Conrad Rise

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The Southern Ocean, a high-nutrient, low-chlorophyll region, has played an important role in regulating global climate system. The Southern Ocean became suboxic during the last glacial period (~40 to 19 kyr ago) and changed to oxic toward Holocene. In order to elucidate changes in the redox state and nutrient status of the seawater caused by sea ice, we performed C, Fe and P speciation analyses of the marine sediments (COR-1bPC) recovered in 2010 at the Conrad Rise in the Southern Ocean (KH10-7 cruise).
Thirty-seven samples were quantified for five P-bearing species (P_{abs}, P_{Fe}, P_{auth}, P_{det} & P_{org}) by modified SEDEX method of Ruttenberg (1992) and four Fe-bearing species (Fe_{HCl}, Fe_{carb}, Fe_{ox} & Fe_{mag}) by the method of Poulton et al. (2005). The abundance and the stable isotope compositions of organic carbon were measured using EA-irMS at Center for Advanced Marine Core Research, Kochi University. Average content of P_{det}, which represent the continent flux, in the dark colored (last glacial) sediments was 0.004 wt.%. Conversely, that in the light colored (interglacial) sediment was 0.002 wt.%. The $\delta^{13}C_{org}$ values in last glacial period (avg. = −23.63 ‰) was isotopically lighter than those in the interglacial period (avg. = −21.73 ‰
). These results suggest that the Conrad Rise (54.2 °S) was covered by sea ice during the last glacial period. Suppression by sea ice of atmosphere-ocean interactions would have decreased dissolved oxygen concentration and gradually created suboxic condition. Fluctuating contents of P_{Fe} and Fe_{ox} indicate occurrence of short-term oxidation events during the last glacial period. In the deglacial period, abundance of C_{org} decreased but that of all P-bearing phases, Fe_{HCl}, and Fe_{ox} abruptly increased to the maximum value. This suggests that melting of the sea ice would have increased P and Fe nutrient supply to the surface ocean and dissolved oxygen supply to the deep ocean, leading to enhanced decomposition of organic matter and drastic changes into oxic conditions. Such environmental changes would have been due to southward migration of Antarctic Circumpolar Current (ACC). Speciation analysis of C, Fe and P in sediments is a powerful tool toward reconstruction of redox and nutrient states in the ocean.

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The impact of Drake and Tasmanian Passages on Antarctic regions and deep ocean temperature

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Through the Cenozoic, the climate has long term cooling trend. At Eocene/Oligocene boundary, the opening of the Drake and Tasmanian Passages caused the development of Antarctic Circumpolar Current and led to the thermal isolation of Antarctica (Kennett, 1977), and previous modeling studies investigated the effect of the opening those passages (Sijp and England, 2004, 2011, Zhang et al., 2010). In addition to the passages, the effect of the land-sea configuration change was investigated (Sijp et al., 2014, Lunt et al., 2015). And CO2 is considered as the important forcing of the Cenozoic cooling (Hansen et al., 2013). In long-term climate change, the relative importance of various forcings wasn't understood well. It is suggested that the different conditions about land-sea configuration, CO2 concentration, and the existence of Antarctic ice sheet in these previous studies affect the amplitude of the Antarctic regions at the closing the passages.
Here we investigate the Antarctic regions and deep ocean temperature change between the opening and closing Drake and Tasmanian Passage under with Antarctic ice sheet and without that. Our result says that the closing passages cause the temperature increase at Antarctic regions through the strong deep water formation at Southern Ocean and strong southward heat transport. The deep ocean temperature is mainly affected by the absence of the Antarctic ice sheet. Our results suggest that the absence of Antarctic ice sheet largely affect the temperature change of the deep ocean and at the Antarctic regions by closing Drake and Tasmanian Passages.

Keywords: Passage, Cenozoic, Paleoclimate

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Numerical experiments using ice sheet models on the ice-ocean inteaction and stability of Antarctic Ice Sheet

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Ice-ocean interaction in the Antarctica is of importance for the stability of Antarctic Ice Sheet. Sea level rise and its rate due to deglaciation northern hemispheric ice sheets (Ritz et al., 2001, Goelzer et al., 2016), increased basal melting of ice shelves due to warming in seawater temperature around Antarctica has proposed as important mechanism to retreat Antarctic Ice Sheet, and glacial meltwater release from Antarctic ice sheet as a possible amplifying mechanism by enhanced stratification in the Southern Ocean and warmed subsurface ocean (Golledge et al., 2014). The rate of basal melting beneath ice shelf is determined by seawater temperature below ice shelves, but this seawater temperature is often different from that in the subsurface Southern Ocean because of sea ice production in the Antarctic Coast and associated cold and dense shelf water formation (Obase et al., submitted). Previous ice sheet modeling studies, however, lack representation in this physical process because they use subsurface seawater temperature in the Southern Ocean directly to parameterize the rate of basal melting of ice shelves. In this study, we make a parameterization of basal melting which is able to apply ice sheet models, based on model experiments using a regional ocean model and an atmosphere-ocean coupled GCM. We perform 2-d ice sheet model experiments to investigate fundamental behavior of ice sheet-ice shelf system to forcings of ocean-induced basal melting and sea level rise and to quantify the relative importance of external conditions on the threshold of Antarctic ice sheet retreats.

Keywords: Antarctic Ice Sheet, Southern Ocean, Antarctic ice-ocean interaction, Ice shelf

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Mooring measurement of sea ice and ocean in the Cape Darnley Polynya, Antarctica

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Recent remote-sensing, hydrographic and mooring studies have shown that the Cape Darnley Polynya located northwest of the Amery Ice Shelf is an active formation region of Antarctic Bottom Water (Ohshima, Fukamachi and Williams et al., 2013). To reveal production of sea ice and high salinity shelf water, total of five moorings were deployed between 2010 to 2015 by the Japanese Antarctic Research Expedition over the continental shelf within the Cape Darnley Polynya. The experiment yielded sea-ice thickness data for the first time in the Antarctic coastal polynyas as well as velocity and water property data. The water property data revealed high salinity shelf water associated with sea-ice production in the polynya.

Keywords: polynya, sea ice, mooring

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The role of turbulent mixing in the modified Shelf Water overflows that produce Cape Darnley Bottom Water

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The mixing process associated with modified Shelf Water (mSW) overflows that eventually mix to form Cape Darnley Bottom Water (CDBW) was investigated by hydrographic and microstructure observations off the Cape Darnley Polynya (CDP), East Antarctica, in January 2009. Closely spaced microstructure observations revealed that mSW properties varied considerably within a distance of ~4 km across the shelf edge. Near the bottom, the rate of turbulent kinetic energy dissipation was enhanced to values greater than 10^{-7} W kg^{-1}, and the vertical scale of the bottom boundary layer (BBL) was on the order of 10 m. The observed BBL around the shelf edge was characterized by strong vertical mixing with turbulent eddy diffusivities of ~$O(10^{-3}$–$10^{-2})$ m^2 s^{-1}. A geostrophically balanced density current, which resulted from the presence of mSW over the continental shelf, is considered the primary energy source for the turbulent mixing in the BBL. This turbulent mixing transforms the overflowing mSW through mixing with ambient water masses, specifically with the overlying modified Circumpolar Deep Water. The BBL is also thought to partly contribute to the gradual descent of mSW down the continental slope through bottom Ekman transport. We conclude that turbulent mixing, primarily caused by a density current, plays an important role in CDBW formation, by modifying the mSW overflowing from the CDP.

Keywords: turbulent mixing, modified Shelf Water, Cape Darnley Bottom Water

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Relative importance of bottom water originating from the Vincennes Bay Polynya on AABW in the Australia-Antarctic Basin

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Antarctic Bottom Water (AABW) is the densest water in the ocean and globally significant. Historically there have been three well-known source regions in the Weddell and Ross Seas, and off Adélie Land. One-year moorings in 2013-14 at 3200m and 3400m depths on the eastern slope of ridge at the north of Vincennes Bay reveal the property of the AABW originating from the Vincennes Bay Polynya (hereinafter VBBW). The VBBW had a thickness of 300m at least and reached at the bottom of 3400m depth. Observational result obtained from 2011 to 2016 have shown that the water property of AABW off Vincennes Bay was mainly influenced by Australian-Antarctic Basin AABW (AA-AABW), which is the mixed water of Ross Sea Bottom Water (RSBW) and Adélie Land Bottom Water (ADLBW), and the VBBW were distributed over them. Long-term water mass changes during 1994-2015 have been examined and significant freshening trends of AA-AABW were detected along 110E. This change of water property was considered to increase relative impact of the VBBW on the AABW in the Australian-Antarctic Basin.

Keywords: Antarctic Bottom Water, freshening, Australian-Antarctic Basin

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Rapid and persistent freshening of Antarctic Bottom Water in the Australian-Antarctic Basin

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Summer hydrographic data obtained along 110°E meridional transect are used to document multi-decadal change in abyssal hydrographic condition south of 60°S. Data are obtained every year after 2011and it is clarified that freshening observed at beginning of 2000s (e.g., Aoki et al., 2005) is still persistent in the recent years. The observed freshening is clearly intensified to the bottom, and thus, likely induced by increased fresh water discharge near the formation regions of Antarctic Bottom Water. Also, observed freshening implies rise in sea level. Haline component of sea level rise (against 1995) in the recent years (~13.5 mm) is quadrupled after 2005 and is comparable to that of thermal component (~11.0 mm). Thus it is concerned that haline component can be the main contributor to sea level rise in the Southern Ocean in near future.

Keywords: Antarctic Bottom Water, freshening, sea level rise

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Southern Ocean eddies observed by Argo floats

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There is no landmass that blocks zonally flowing Antarctic Circumpolar Current (ACC) in the Southern Ocean. This means all meridional transport in the upper layer is driven by non-geostrophic dynamics; the Ekman transport by the westerly jet and by mesoscale eddies. Synoptic observation of these Southern Ocean eddies were limited to the surface where satellite altemetry data are available, but recent increase in number of Argo floats, thanks to the vibrant effort of the community, deployed in the Southern Ocean now enables us to describe the eddies in the mid-depth (1000 m). The eddies are highly localised to several locations where the ACC negotiates the bottom topography. In these "eddy hot spots", such important physics were observed as efficient downward transport of eastward momentum imposed by the wind at the surface and upgradient eddy transport.

Keywords: Southern Ocean, Eddy

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Interannual Variation of Surface Wind Field over the Southern Ocean and DPOI

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The Southern Ocean (SO) is a single oceanic domain encircling the globe, and covered by the strong eastward flowing Antarctic Circumpolar Current (ACC). Especially, westerly winds principally drive the ACC, and the easterlies are critical for the westward flow along the Antarctic continental margin. Previous studies pointed out that there are some dominant atmospheric variabilities over the SO such as the Southern Annular Mode (SAM), the Antarctic Oscillation (AAO) and the Pacific South America (PSA), and they are related to the strength of westerly winds and affect large change of ecological environment in the Antarctic/Southern Ocean during recent decades (Boyd and Roberts, 1993). Naganobu et al.(1999, 2008) found significant correlations between the krill recruitment and DPOI (Drake Passage Oscillation Index) which is a climate index 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. DPOI can be taken as an index of the climate-ocean-environmental ecosystem variability in the Antarctic Peninsula.

In this study, we examine dominant variations in the atmospheric field over the SO by comparing with dominant modes revealed by previous studies. To clarify spatial features for interannual variation in the surface wind field over the SO, we investigate relationships among DPOI, AAOI and dominant modes in surface wind field.

In order to investigate the spatial structures of zonal wind variations, we perform empirical orthogonal function (EOF) analysis. The spatial feature of the 1st EOF mode for the zonal wind, having contribution ratio of 27.6%, is similar to that of the AAOI pattern derived from the 1st mode of the 700-hPa height in the NCEP reanalysis. The score of this mode has a high correlation with the AAOI (0.74). Thus, the leading EOF mode of the zonal wind is related to the Atmospheric SAM pattern. The spatial distribution of the 2nd EOF mode, having contribution ratio of 15.4% reveals a dominant pattern in the Atlantic and Indian sectors with maxima, poleward of that for the 1st EOF mode. The score of this mode has high correlation with DPOI (0.62).These suggest that the DPOI-related variations are characterized by spatial features in the 2nd EOF mode of the zonal wind, and their mechanisms will be examined in further studies.

Keywords: Westerly Wind, DPOI, AAOI, Interannual Variation, Air-Sea interaction

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