A plan for studying the 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. For these studies, one of the largest uncertainties is the effects of GIA, which, on the other hand, includes valuable information about the rheological properties of the solid Earth, because GIA is the rheological response of the solid Earth to the ice mass loading. 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 urgent and 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, in addition to the several precise observations at Syowa station and surounding areas, 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.
Combining these new observations with other in-site data, various satellite data and numerical modeling, we aim to estimating a precise GIA model, constructing a reliable ice melting history after LGM (the Last Glacial Maximum) and obtaining the viscoelastic structure of the Earth's interior.
To achieve the goal, we are planing to conduct the following studies;
(1) conducting glacial topographic surveys, geological surveys, gravity measurements, and GNSS measurements at the in-land areas of the East Antarctica, where very few observations were conducted so far, and reevaluating the glacial topography using the in-situ observations and recent precise DEM (Digital Elevation Model),
(2) improving the accuracies of the retreat ages of the ice sheets using the micro glacier topography from the detailed airborne photographic data obtained by unmanned aerial vehicles, the cosmogenic nuclide exposure ages of the basement bowling samples and the moraine rocks,
(3) monitoring the present day ice sheet movements and sea level changes by combining satellite data and in-situ geodetic and other observations in and around Syowa Station, and
(4) finally aiming at the quantitative reconstruction of the ice melting history over the last millions years, and the improvement of the models for predicting the future global changes.

Keywords: ice sheet, sea level rise, Glacial Isostatic Adjustment, ice sheet metling history, East Antarctica, viscoelastic structure

Food web in the marginal ice zone: material flow from sea ice through to myctophid fish

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The seasonal prevalence of the sea ice zone is a critical element in the Southern Ocean ecosystem structure and dynamics. Sea ice formed in coastal polynyas in autumn and winter is transported northward and covers a vast area of the Southern Ocean. This ice contains a large variety of sea ice biota (SIB), such as ice algae, protozoans, and crustacean larvae. The SIB is released as the sea ice melts from the ice edge in spring and summer. Although a flood of SIB biomass is released into the water column, there is little information on the pathway and dynamics of the SIB released into the Southern Ocean. The sea ice changes that occur with climate change should affect the Southern Ocean ecosystem via this pathway.

We have been investigating the flow of materials derived from SIB through to the Southern Ocean ecosystem after its release into the water column. In a series of studies, we found the nursery grounds of the Antarctic myctophid fish *Electrona antarctica*, which is an important component of the oceanic food web, in the waters influenced by sea ice. This paper introduces a study of 1) the dynamics of SIB inferred from the flora of floating sea ice (ice algae) and the water column at the ice edge and 2) detritus containing diatoms found in the stomachs of *E. antarctica* larvae. The origin of the diatoms is discussed.

A comparison of the numbers of algal cells in sea ice and the water column revealed that more than 90% of the cells of the dominant diatom species were removed from the surface mixed layer. Most of the algal cells were thought to sink into deeper waters or to be grazed by zooplankton close to the sea ice. Detritus served as a food item for early stage larvae of *E. antarctica*, and some of the diatom species in the detritus were usually dominant in the SIB assemblage, suggesting that the *E. antarctica* larvae feed on SIB indirectly, eating the faecal pellets of zooplankton or aggregates.

In January 2017, we conducted drifter observations using a sediment trap in the vicinity of the ice edge; these should provide more direct information on the dynamics of sinking material from the SIB. Regarding the food habits of *E. antarctica* larvae, a metagenome analysis of the diatoms in the stomach and a biomarker analysis will be conducted to determine the detailed pathway of material flow from sea ice.

Keywords: sea ice biota, ice algae, food web, marginal ice zone, marine snow, detritus

Paleo-environmental changes at coastal lakes along the Soya Coast, East Antarctica during the Holocene

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The East Antarctic Ice Sheet (EAIS) is the largest glacial system on Earth, and documenting its changes is important to understand and estimate its future behavior. Antarctic coastal lakes are invaluable archives of paleo-climate and paleo-environment changes caused by the retreat of Antarctic Ice Sheet. In Soya Kaigan (Coast) of Lutzow-Holm Bay region, many coastal lakes are located in ice-free areas. This study discussed the environmental change inferred from microscopic observation of fossil diatom assemblages in a sediment cores from coastal freshwater lakes, Lake Oyako-ike, Lake Maruwanminami-ike and Lake Maruwan-Oike, in Soya Coast along with biomarkers and microscopic observation of microalgae and cyanobacteria, sedimentary facies and AMS 14C dating.
Three lakes are considered as marine relict lakes resulted from the recession of glaciers and subsequent isostatic uplift. The Ok4C-01 core (length 135 cm) from Lake Oyako-ike was divided in 4 zones according to the diatom assemblage changes. This lake has changed from costal marine to freshwater lake at ca. 1100 cal yr BP (core depth 60 cm). The MwS4C-01 core (length 147 cm) from Lake Maruwanminami-ike was also divided in 4 zones. The transition timing from marine to freshwater lake was ca. 2400 cal yr BP (core depth 65 cm). The Mw4C-01 core (length 226 cm) from Lake Maruwan-Oike was divided in 4 zones as well. This lake has changed at ca. 2800 cal yr BP (core depth 22 cm). Diatom assemblage changes in these sediment cores show similar pattern with other analyses results such as sediment facies and elemental analyses (TC, TS, TN contents).
Diatom assemblages in these sediment samples implied that more specific environmental changes not only transition from marine to freshwater but also an existence of sea-ice (*Fragilariopsis curta*, *F. cylindrus*), a desalination process (*Psammothidium papilio*) and an oligotrophication of lake water.

Keywords: Antarctica, Paleoenvironment, Lake sediment, Diatom assemblage

Pliocene seasonal sea-ice history around the Kerguelen Plateau in the Southern Ocean based on diatom analysis

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Fossil diatoms have been regarded as a useful proxy for paleoceanographic reconstruction such as past sea-ice distribution in the Southern Ocean (Armand et al., 2005). Several studies have attempted to reveal sea-ice history based on fluctuation of the sea-ice related diatoms, however there is few paleoceanographic studies focusing on changes of summer and winter sea-ice distribution. We categorized the sea-ice related diatoms reported in Armand et al. (2005) into two groups, summer sea-ice diatom species and winter sea-ice diatom species. The former group is abundantly observed within summer sea-ice zone and the latter group is widely found within winter sea-ice zone. In this study, late Pliocene summer and winter sea-ice distributions in the Indian sector of the Southern Ocean are estimated based on temporal changes in abundance of the summer and winter sea-ice diatom species. Analyzed samples are ODP Leg 188 Hole 1165B and Leg 119 Hole 745B, which are located near recent summer and winter sea-ice edge respectively.

Keywords: Southern Ocean, paleoenvironment, sea ice, ODP, diatom

The middle Miocene paleoceanography based on diatoms and chrysophyte cysts in the Atlantic sector of the Southern Ocean

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The Southern Ocean, which is composed of the Antarctic Circumpolar Current (ACC) and several water masses, is an important element as having great influence on global climate change. Therefore, it is significant to reconstruct the paleoceanographic history in the Southern Ocean including the ACC, and many researchers have been approaching this issue using various methods. For example, changes in sediment structures derived from seismic profiling of deep-sea sediments have been widely accepted as an evidence for the past ACC fluctuations. However, there are almost no previous studies that show long-term and detailed ACC changes, while many of paleo-ACC studies have been made with order of “epoch” or have been focused on much shorter time-range.
In the Southern Ocean, abundant and continuous occurrences of siliceous microfossils such as diatoms and chrysophyte cysts are often found from the Neogene sediments. Generally, diatoms thrive in high-latitude or upwelling regions and they show clear segregation of their habitat corresponding to the distribution of the water masses. Therefore, it is likely that the changes in abundance of subtropical diatom taxa, which inhabit north of the ACC, reveal the long-term migration history of the ACC from north to south vice versa. In addition, as most chrysophytes inhabit freshwater environment, the occurrences of fossil chrysophyte cysts in the Southern Ocean are mainly originated from Antarctic terrestrial freshwater (i.e., melt-water of the ice sheet). Therefore, fossil chrysophyte cyst can be treated as a useful tool to reconstruct the changes of the Antarctic ice sheet in the geological past. In this presentation, we would like to present and discuss on several paleoenvironmental events in the Southern Ocean during the late Miocene–Pliocene (ca. 9–3 Ma) based on fossil diatom and chrysophyte cyst analysis preserved in sediment core samples from the Atlantic sector of the Southern Ocean (ODP Leg 113 Site 689 and DSDP Leg 71 Site 513), which include repetitive north-south migrations of the ACC in a 100–200 kyr cycle observed in 7–4.8 Ma.

Keywords: Diatom, Chrysophyte cyst, Southern Ocean, Antarctic Circumpolar Current, DSDP, ODP

Climate model experiments using state-of-the art boundary conditions for the Mid to Late Pliocene

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The Mid to Late Pliocene (3.3-3.0 million years ago) represented a period during which atmospheric CO_2 concentrations were similar to that of present day. Globally, the climate was warmer by about 2-3^{o}C, and warmer for prolonged periods. The idea of an analogue to future global climate change, albeit with caveats, has created much interest in this period, with focus on both climate proxy data and model simulations. At a time when there was reduced glaciation in Antarctica, there is evidence from benthic foraminifera to suggest that North Pacific deep waters were much colder than North Atlantic Deep Water and that subsequent glaciation of Antarctica had global ramifications by altering the deep ocean circulation and contributing to the intensification of glaciation in the opposite hemisphere.

The Pliocene Model Intercomparison Project (PlioMIP) was established by bringing together the paleodata analysis group, PRISM, and various climate modelling groups to further our knowledge of this period. Specific protocols have been set up for climate model experimental design, utilizing the latest paleoenvironmental reconstruction datasets which include Pliocene vegetation, soils, ice distribution and ocean bathymetry. In particular, Pliocene ice sheet reconstructions depict a West Antarctic seaway, no ice over West Antarctica, small increases in the elevation in the interior of Antarctica and retreat of ice sheet in the low-lying Wilkes and Aurora subglacial basins, in accordance to proxy evidence. In the present study, we ran experiments using the atmosphere-ocean coupled model, MIROC4m, to investigate their effects on the climate by incorporating all these latest boundary conditions from PlioMIP2. Related sensitivity experiments help to quantify the relative contribution to Pliocene warmth from individual boundary conditions and to investigate the climate and Earth system sensitivity.

Keywords: Pliocene, Climate modelling, Climate change, Antarctic ice sheet

Sensitivity studies of ice divide position using a numerical ice-sheet/shelf model

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Ice divides are important locations for drilling on ice-sheets. Since the ice flow pattern, which affects dating, is significantly different between an ice divide and the other areas, sensitivity of the ice-divide position to changes in various boundary conditions should be investigated. In this study, numerical experiments under synthetic configurations are systematically conducted using a numerical ice-sheet/shelf model IcIES, to evaluate how local bedrock topography and/or ice-sheet extent affects the ice-divide position.

Keywords: ice-sheet

Responses of marine ice sheet to basal melting of ice shelves

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Integrated study of combining climate models and ice sheet models are required to understand the response of Antarctic ice sheet to climate changes, and basal melting beneath ice shelves is a key player (Mengel et al. 2015; Deconto and Pollard 2016; Kusahara 2016). Simulations by high-resolution ocean models that resolves ice shelf cavity circulations show that basal melt rate of ice shelves increase drastically in a warm climates (Timmermann et al. 2013; Obase et al. in press), and could cause collapse of marine ice sheet.
Previous studies investigated the model dependency on the response of marine ice sheet to changing ice accumulation, ice temperature, and basal sliding, but not for changing basal mass balance (Vieli and Payne 2005; Pattyn et al. 2012; Pattyn et al. 2013). Recent study with explicit treatment of basal melt rate suggests that careful treatment of basal melt rate near grounding line and higher horizontal resolution are required for simulating grounding line retreat because of abrupt change in basal mass balance near grounding lines (Gladstone et al. 2017).
In this study, we investigate the responses of marine ice sheet to basal melt rate beneath ice shelves under an idealized flow-line system. We use a numerical ice sheet-shelf model IcIES for flow-line calculation. Ice flow is approximated by Shallow Ice Approximation for grounded ice and Shallow Shelf Approximation for floating ice, and sub-grid scale grounding line migration is parameterized with ice flux at the grounding line (Schoof 2007). In the flow-line calculation, ice flux that is orthogonal to ice flow and lateral resistive stress are set to zero. The ice sheet and ice shelf are assumed to be isothermal, therefore thermodynamics is not included. Bedrock topography is taken from several ice sheet drainages from Antarctic ice sheet. We systematically simulate steady-states of ice sheet shape under a given basal melt rate and bedrock topography. We discuss the determining factors of changing basal melt rate, changing sea level, and bedrock topography on the stability of marine ice sheet.

West Antarctic ice shelf melting causes Ross Sea freshening and Circumpolar Deep Water warming.

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Ross Sea (RS) freshening and Circumpolar Deep Water (CDW) warming have been unveiled from oceanographic observations, yet responsible mechanisms remain uncertain. Using a sea-ice/ice-shelf/ocean model, we show that enhanced ice shelf melting in West Antarctica explains the observed changes. The RS continental shelf freshening is caused by an increase in ice shelf meltwater from the Amundsen/Bellingshausen Sea. This weakens the Antarctic Bottom Water formation in the RS, which reduces the density of mid-depth and deep water, allowing CDW to shift further south and causing open ocean warming. The warming signal is transmitted onto the Amundsen/Bellingshausen Sea continental shelves including the ice shelf cavities, implying a positive feedback. Good agreement between simulations and observations suggests that the proposed mechanism is able to explain the ongoing RS freshening and CDW warming. Warmer water on the shelf likely enhances ice shelf melting and may amplify the rate of sea level rise.

Keywords: Ice shelf-ocean interaction, Amundsen-Bellingshausen Sea, Ross Sea , Circumpolar Deep Water

Possibility of AABW source originating from meddle size of Polynya along the coast of Australian-Antarctic Basin

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Antarctic Bottom Water (AABW) originating from Vincennes Polynya (VP) was discovered recently (Kitade et al. 2014). The fact that middle size of Polynya also produces AABW suggests the possibility that the unknown formation area still exists along the coast of Australian-Antarctic Basin (AA basin). From the viewpoint of sea ice production, the amount of sea ice production of Sackleton Polynya (SP) in the west of VP is about 1.4 times that of VP (Tamura et al. 2016), implying that SP is a possible candidate for AABW formation area.
A deep float, called “Deep NINJA” which is able to observe temperature and salinity at depths up to 4,000 m, was developed by Japan Agency for Marine-Earth Science and Technology and Tsurumi-Seiki Co. (Kobayashi et al., 2015). Five deep floats were deployed along 110°E in Jan. 2014. One of them drifted westward almost along the continental rise and had been observing 40 profiles within two years. However, no signal of newly formed AABW was observed except off VP, and such property is consistent with The Baseline Research on Oceanography, Krill and the Environment (BROKE) survey. Therefore, as a result of investigating the salinity of Dense Shelf Water (DSW) on the shelf in the elephant seal bio-logging data, it was found that the salinity of DSW’s core in offshore SP is 0.1 or lower than that in offshore VP. Although this cannot be explained by sea ice production difference, it can be explained by considering AVISO absolute dynamic topography data, ocean climatology data and sea ice melting amount. Moreover, it was thought that AABW was not formed offshore of the SP’s shelf because the salt content of DSW was insufficient for AABW formation. Although these facts do not completely negate the additional formation of AABW originating form middle size of polynya located at west of VP, their formation volume of AABW is suggested to be much smaller than that off VP. As a result of investigating the possibility of AABW formation in other medium size polynya using the same algorithm, Dibble Polynya was considered as the most influential unconfirmed candidate in the polynya facing the AA basin.

Keywords: Antarctic Bottom Water, Dense Shelf Water, Australian-Antarctic Basin, Formation process of shelf water , Vincennes Polynya, Sackleton Polynya

Recent quick changes of Antarctic Bottom Water off the Adélie Coast, Antarctica

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In the study, changes of Antarctic Bottom Water (AABW) off the Adélie Coast, Antarctica, were examined mainly with observations of deep floats for December 2012 to August 2014. AABW was observed to have disappeared rapidly in the order of the densest part and its thickness had decreased quickly by around 45 m yr^{-1}, several times of the rate for the recent decades. Temperature and salinity on isopycnals showed seasonal changes, but there were no clear trends. The results of the repeat hydrographies clarified that the rapid deepening would have begun around 2010/11, at the latest and that AABW were largely freshened by around 0.005 in 2011. The changes of AABW ought to have raised the sea level by around 4.7 (3.1-6.5) mm yr^{-1} for 1900-4000 dbar, which agreed well with the independent observations within errors; 5.8 mm yr^{-1} of Aviso, 0.5 mm yr^{-1} of Argo for 0-1900 dbar, and 1.8 mm yr^{-1} of the mass component at averages for 2011-2014. The collapse of Mertz Glacier Tongue in February 2010 was expected to lead the larger changes of AABW. Its rapid disappearance would be caused by the smaller supply of ALBW due to the smaller sea ice production there and it would continue for a longer time because the revolutionary change of the ocean conditions would hinder the supply of a locally formed coastal dense water from recovering to the similar level before the collapse. However, the “long-term” freshening might be changed less by the collapse; the “large” freshening in 2011 would correspond to the freshening due to the global warming for about 5-6 years, and then very small changes would follow for several years.

Keywords: deep and bottom water, float obseravation

Increasing fresh water impact on Sea Level Rise in Australian-Antarctic Basin

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Significant warming and freshening of Antarctic Bottom Water (AABW) in the Australian-Antarctic Basin are reported in previous studies. The reported changes are, however, based on repeated hydrographic data with 5-10-year interval, and hence, may be subject to temporal aliasing due to shorter time scale variability. In this study, we have assessed temperature and salinity using repeated hydrographic data with 1-2-year interval. The Conductivity-Temperature-Depth (CTD) data are obtained by the training and research vessel Umitaka-maru along 110˚E, where locates slightly west of WOCE section I09s.
In the region south of 60˚S, both warming and freshening trends in deep layers (e.g., below 2000 m) are clear since 1990s and they are consistent with previous studies. However, it is found that temperature and salinity changes are not strongly correlated. Linear freshening trend is clearly intensified to bottom (~ -0.01 PSS-78/decade). However, warming trend includes shorter vertical scale variations; taking maximum at 3000-3500 m (~0.025 ℃/decade), but weakened toward bottom. In deep layers below 2000 m, as for freshening, linear trend component explains over 90% of standard deviation. As for warming, however, it explains only about 50 % on average, meaning that shorter time scale variability effects only for temperature variations. Finally, impact of linear warming and freshening trends on Sea Level Rise (SLR) are estimated. Reflecting the dominant linear trend component, impact of freshening in deep layers explains 60% of overall SLR trend. This implies that deep freshening can be main component that induces SLR in near future.

Keywords: Antarctic Bottom Water, warming, freshening, sea level rise

Temporal and spatial variability of atmosphere and ocean in the Southern Ocean

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The variability of atmospheric circulation in the Southern Ocean (SO) is dominated by a zonally symmetric pattern, that is the Southern Annular Mode (SAM) (Thompson and Wallace, 2000), which is characterized by a dipole in the westerly winds with opposing centers between mid- and high-latitudes. Especially, the westerly winds prevail in the Drake Passage, suggesting key area of oceanic and atmospheric variations. Our previous study focusing on structures in surface oceanic layer near the Drake Passage clarified that their year-to-year variations have relationships with the DPOI which is a good indication of surface winds across the Passage and related to the Krill recruitments (Naganobu et al., 1999, 2008). In addition, we examine year-to-year variations in the surface wind field over the SO characterized by the DPOI, and detected another variation associated with the meridional shift of the westerly wind area over the Southern Ocean (Indian-Pacific-Atlantic sector) and having high correlation with the DPOI (Yagi et al., 2017). However, the influence of DPOI-related variation in the surface winds on the oceanic field still remains unclear. In this study, we investigate relationships between the sea-surface-temperature (SST) and surface wind variations over the SO.

The leading mode, derived from the empirical orthogonal function (EOF) analysis for the monthly-mean zonal wind field, has a contribution of 55.5% with maxima on the Drake Passage. The score of this mode has a high correlation with the DPOI (0.94), so is related to the DPOI. Its spectrum has significant peaks at the periods of 6-month and 12-months, and another peak at the periods of 30-months. We focus on variabilities with time scales of about 3 years. To examine relationship between the DPOI-related surface wind and SST over the SO, we derive time series of the score of the 1st EOF mode for the zonal wind which are band-pass filtered for periods around 3 years, and examine its spatial correlations with the SST field. Results reveal that high correlations are found over the entire SO region. Spatial correlations indicate that there are negative areas to the west of the Drake Passage and positive ones to the east of it, and maxima in the Ross and Weddell seas. Relationships will be examined between surface wind and SST fields in these regions in detail.

Keywords: Westerly Wind, DPOI, Air-Sea interaction

Variability of Antarctic coastal polynyas and their linkage with fast ice revealed from AMSR-E and AMSR2 data

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A coastal polynya is newly-forming thin sea-ice areas formed by divergent ice motion driven by prevailing winds and/or ocean currents. In coastal polynyas, huge amounts of heat flux from the ocean to the atmosphere occur because the heat insulation effect of sea-ice is greatly reduced in the case of thin ice, and accordingly sea ice is formed actively. Dense water formed in Antarctic coastal polynyas with the intense sea-ice production is a major source of Antarctic Bottom Water (AABW), which is a key player in the global climate system.

In Antarctic coastal polynya areas, algorithms that detect the polynya areas and estimate the thin ice thickness from passive microwave satellite data (SSM/I-SSMIS: 1992—present or AMSR-E: 2003—2011) had been developed to estimate the ice and dense water production. Fast ice areas were also detected using the passive microwave data. The spatial (grid) resolution of AMSR-E (about 6 km at 89 GHz) is four times higher than that of SSM/I-SSMIS in the pixel density. This advantage of AMSR-E is critical for the monitoring of the coastal polynyas and fast ice because of their small areal extent (i.e., from 10 to 100 km at most).

The coincident circumpolar mapping of Antarctic coastal polynyas and fast ice from AMSR-E had revealed that most of the polynyas are formed on the western side of fast ice or glacier tongue, indicating an important role of fast ice and glacier tongue in the polynya formation. Because the fast ice and glacier tongue are particularly vulnerable to oceanic and atmospheric conditions, their extent can be changed drastically and suddenly. The change in the fast ice or glacier tongue can cause dramatic changes in sea-ice production in the adjacent polynya and possibly AABW formation, as in the case of the Mertz Glacier Tongue (MGT) calving in 2010. This can potentially contribute to further climate change. Although AMSR-E failed in October 2011, AMSR2, the successor to AMSR-E, was launched in May 2012. The spatial resolution of AMSR2 is improved about 17% from AMSR-E.

This study developed an algorithm which can detect the polynya area and can estimate the thin ice thickness from AMSR2 data, based on a similar method to the AMSR-E algorithm development. Fast ice areas were also detected using AMSR2 data. Ice production in the polynyas was estimated from heat flux calculation using the sea-ice data from AMSR2. In the major polynyas, the AMSR2 ice production was compared with the AMSR-E ice production though a comparison with the SSM/I-SSMIS ice production. The comparison confirmed that the AMSR2 and AMSR-E data with higher spatial resolution can be used for time series analysis of the relationship between coastal polynyas and fast ice for >10 years. For example, maps of annual ice production and fast ice from AMSR2 and AMSR-E can reveal the details of the Mertz Polynya change before and after the MGT calving. Continuous monitoring of the coastal polynyas by the AMSR series is essential for climate-change-related analyses in the Antarctic Ocean.

Keywords: AMSR2, coastal polynyas, fast ice

Circumpolar mapping of the Antarctic coastal polynyas with discrimination of ice type

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In Antarctic coastal polynyas, high production of sea ice occurs due to huge heat loss to atmosphere, resulting in the formation of dense water, precursor of Antarctic Bottom Water. Sea-ice production within polynyas is directly related to polynya extent and thin-ice thickness within the polynya. Thus, it is important for the calculation of sea-ice production to estimate thin ice thickness accurately. Several studies have developed algorithms for estimation of the thin ice thickness from brightness temperature (TB) of satellite passive microwave sensor [e.g., Martin et al., 2004; Nihashi and Ohshima, 2015]. In these algorithms, ice thickness of less than 20 cm is empirically estimated by utilizing negative correlation between the ice thickness and a ratio of the horizontally to vertically polarized TBs (PR). Several studies have also extended these algorithms to mapping of sea-ice production for Antarctic coastal polynyas. However, ice type, which has an influence on microwave characteristic of thin-ice, has not been considered in these algorithms.

Thin ice (polynya) areas are classified roughly into two ice types. One is active frazil type: a mixture of open water and frazil/grease ice areas. The other is thin solid ice type: nearly uniform thin ice covered area. Nakata et al. [in prep.] indicated that PR-thickness relationships are different clearly between these two ice types: active frazil type has much smaller thickness than solid ice for the same PR value. Based on the result, Nakata et al. [in prep.] also developed a thin ice algorithm in which ice thickness for each ice type is estimated from the corresponding empirical equation after discrimination of ice type. This improved algorithm provides more accurate estimation of sea-ice production. In addition, the algorithm can specify a predominant ice type for each Antarctic coastal polynya, which is useful for examination of the polynya dynamics. In this study, we apply the new algorithm to the entire Southern Ocean and carry out mapping of the Antarctic coastal polynya and its ice production.

We used AMSR-E/Aqua Level 2A (L2A) global swath spatially resampled TBs at 36 and 89GHz. We first mapped all AMSR-E L2A data obtained within a day onto the NSIDC polar stereographic grid (the spatial resolution of 6.25 km), with the land and fast ice mask by Nihashi and Ohshima [2015]. Then, we use the algorithm to obtain ice-type and thin ice thickness. Sea-ice production is calculated from heat flux calculation using the obtained thin ice thickness and ERA-Interim atmospheric data. From the above procedure, we create a data set of ice type, thin ice thickness and ice production for the entire Southern Ocean on a daily basis, during winter (April-October) for the period 2003-2010.

The climatological mapping shows that the active frazil type is more predominant in polynyas in the East Antarctica, where the strong offshore wind is prevailing. Thin solid ice type is predominant in polynyas with relative weak wind, such as in the Ross Ice Shelf polynya. These suggest that the difference in predominant ice type is mainly caused by the difference in strength of offshore wind.

In the previous algorithms, ice thickness was overestimated because the PR-thickness relationship is similar to that of the thin solid ice type. In the new algorithm, sea-ice production in the polynyas along the East Antarctica is corrected. Especially, sea ice production in the Cape Darnley polynya with the highest occurrence frequency of active frazil type is calculated to be about 1.5 times as that of the previous studies.

Keywords: coastal polynya, ice type, sea-ice production, AMSR-E

