

InitMIP-Antarctica experiments with the ice sheet model SICOPOLIS

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The Ice Sheet Model Intercomparison Project for CMIP6 (ISMIP6) brings together a consortium of international ice sheet and climate models to explore the contribution from the Greenland and Antarctic ice sheets to future sea level rise. For such projections, initialisations are required that provide initial states of the respective ice sheet. InitMIP-Antarctica is an early initiative within ISMIP6 in order to explore this issue for the Antarctic ice sheet across a variety of models and initialisation techniques. We contribute to InitMIP-Antarctica with the ice sheet model SICOPOLIS and a spin-up-type initialisation, that is, a paleoclimatic simulation over 135 ka until the present. A major new component of the model is a physically-based parameterisation of ice shelf basal melting. In this parameterisation, basal melting of ice shelves is computed as a function of both the depth of ice below mean sea level and far-field ocean temperatures. The parameterisation is tuned differently for eight Antarctic sectors in order to achieve reasonable agreement with the modern spatial distribution of ice shelf basal melting. InitMIP-Antarctica also comprises three future climate scenarios, all to be run over 100 a: ctrl (present-day climate), asmb (prescribed schematic surface mass balance anomaly) and abmb (prescribed schematic basal melting anomaly under ice shelves). We present and discuss the performance of the spin-up in terms of agreement between simulated and observed present-day geometry and flow. Further, we investigate the response of the Antarctic ice sheet to the three future climate scenarios.

Keywords: Antarctica, Ice sheet, Ice shelf, Basal melting, Climate change, Modelling

過去21.6万年間の、東南極における気候に依存した表面質量収支のコントラスト

Climate dependent contrast in surface mass balance in East Antarctica over the past 216 ka

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南極大陸やグリーンランドは、数十万年もの間、雪が降り積もってできた氷床で覆われている。氷床を掘削して得られるアイスコアは、過去の地球環境を知る大きな手がかりである。アイスコアの研究において、積雪の堆積率（年間の堆積量（cm/年））を把握することが不可欠であり、従来、堆積率は、アイスコア中の水の酸素や水素の同位体比から推定されてきたが、この推定の不確定性を検証する手段はこれまでなかった。

本国際研究グループは、南極大陸の上で約2,000km離れたドームふじ地域とドームC地域（図1）のそれぞれで掘削された深層アイスコアを対象に、過去21.6万年間の氷に含まれる1,401対の火山噴火に起因するシグナルを比較し、2地点間に生じた積雪の堆積率の比を、同位体比を用いる方法よりも精密に割り出すことに成功した。

火山噴火シグナルから導いた堆積率比は、水の水素同位体比を用いて推定した堆積率比と大まかな傾向としては一致するものの、海洋同位体ステージ5dと呼ばれる約10.6～11.5万年前の時期には、約20%異なることが判明した。この結果は、水素同位体比を用いた従来推定法には、最大で約20%の不確定性があることを意味する。また、最終氷期の始まりの時期である海洋同位体ステージ5dには、南極の広域の積雪堆積パターンや氷床の厚さがダイナミックに変動していたことを示唆している。

さらに、現在の間氷期（約1万年前から現在）の間、火山噴火の信号から導いた堆積率比は±1%の範囲で安定していたことが明らかになった。これは、南極の広域の積雪堆積パターンが、時間的にも空間的にもほとんど変化がなかったことを意味している。そして、南極の内陸部では氷床の厚さが過去約1万5千年にわたり増大を続けていることが明らかになった。

アイスコアを用いた種々の研究において、年間堆積率の推定値は分析の基礎となる重要な情報である。本研究により、アイスコアの年代決定計算など、さまざまな研究の信頼度が向上することが期待できる。また、雪

の堆積率の変動が解明されることにより、氷期・間氷期サイクルのなかでの南極氷床上の降水の分布と氷床変動の関係の解明、ひいては地球全体の気候システムの理解につながると期待できる。

キーワード：南極、堆積、アイスコア

Keywords: Antarctica, precipitation, ice core

南極ドームふじ氷床コアの O_2/N_2 による年代決定の高精度化（8～16.5万年前）

Improvement in dating of the Dome Fuji ice core using O_2/N_2 (80-165 ka)

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The Dome Fuji ice core preserves valuable information on the climatic changes over the last 720 kyr, which enables to investigate forcings and mechanisms in the Earth's system. Precise ice core chronology is essential to determine sequences and durations of climate events, and to examine the phasing with forcings and other paleoclimatic records. Orbital scale variations in O_2/N_2 ratio of occluded air in the Vostok ice core are similar to those in local summer solstice insolation¹⁾. By using this similarity, Kawamura et al. (2007) synchronized the O_2/N_2 variations in the Dome Fuji and Vostok ice cores with local summer insolation, and established chronology for the ice cores with accuracy generally better than ± 2000 years (DFO-2006). However, it was recently pointed out by using detailed age matching between Dome Fuji, EDC and Chinese speleothem records that the DFO-2006 chronology around 90 kyr BP is too old by ~ 3 kyr³⁾. Possible cause of this error is dislocation of O_2/N_2 peaks because of large noise in the O_2/N_2 record. Recently, O_2/N_2 variations between 300 and 800 kyr has been reconstructed from EPICA Dome C ice core^{4),5)}, however, their records do not always show similar variation with local summer insolation. Thus, their O_2/N_2 record was not used for orbital tuning. These recent studies motivate us to examine the reliability of age markers based on the O_2/N_2 ratio of Dome Fuji ice core. In this study, we reanalyzed O_2/N_2 ratio in the first Dome Fuji ice core for 1200 – 1974 m, which covers 80 – 165 kyr BP.

Fractionation of O_2/N_2 ratio occurs from ice surface during storage⁶⁾. Because the first Dome Fuji core has been stored for about 20 years, we expect fractionated O_2/N_2 near the surface of ice. We thus tested different thickness of surface shaving, and found that shaving-off of about 1 cm of surface (and only using the inner part of the ice) is required for precise measurements for the ice samples below 1200 m depth. Because of this careful examination and improvement in methodology, our new O_2/N_2 data set on average do not indicate preferential loss of O_2 . Reproducibility of O_2/N_2 ratio are $\pm 0.425\%$ for 1200 – 1440 m, $\pm 0.263\%$ for 1440 – 1640 m and $\pm 0.088\%$ for 1640 – 1974 m, respectively.

We find large scatter in the new O_2/N_2 data between 1200 and 1440m (typical amplitude: $\sim 6 - 10\%$). This depth range is just below bubble-clathrate transition zone where both air bubbles and clathrate hydrates were observed by microscopes. To investigate the cause of this scatter, we conducted a high-resolution continuous analysis at 2.5-cm resolution for 1399.030 – 1399.484 m. The O_2/N_2 shows unexpected wave-like variation from -17 to -9 % with a wavelength of ~ 18 cm. The amplitude is comparable to the typical scatter in the O_2/N_2 data set from the discrete 11-cm samples. If we take 11 cm average of the high-resolution data, the average ratio only varies by $\pm 1\%$, which is insufficient to explain the scatter in the discrete data. Our current speculation is that the wavelength and/or amplitude of the O_2/N_2 variations in other depths may be larger than those in the investigated section, and that O_2/N_2 of 11 cm samples can also vary by up to 10 %.

Our new Dome Fuji O_2/N_2 record confirms strong correlation with local summer insolation. Assuming no phasing between O_2/N_2 and insolation variations, O_2/N_2 data was smoothed by a low-pass filter with the cut-off period of 16.7 – 10.0 kyr, and then tuned with local summer solstice insolation by peak-to-peak matching²⁾. Because the scatter in 1200 – 1440 m does not reflect insolation signal, we rejected data points as outliers if they deviate from fitting curve by more than 3.3%.

Compared with the DFO-2006 chronology, the new age scale (DF-2016) is younger around 90 and 130 kyr BP, while it is older around 150 kyr BP. There were sharp steps in annual layer thickness (calculated from depth – age relationship) at 94.2 and 150.3 kyr BP from DFO-2006³⁾, but these unnatural steps disappeared in that from DF-2016. The DF-2016 and speleothem (U-Th) age scales agree within 1000 yrs. These results indicate that the revised chronology greatly improved from the DFO-2006 chronology.

To summarize, even though large O_2/N_2 fractionation occurs near the surface of the ice core over two decades of storage, the original O_2/N_2 ratio is preserved in the inner part of ice if it is stored at -50°C, and it can be precisely measured by sufficiently removing the ice surface. Accurate chronology can be constructed by orbital tuning of the high quality O_2/N_2 ratio from the Dome Fuji ice core with local summer insolation.

1) Bender, M. L., EPSL, 2002. 2) Kawamura et al., Nature, 2007. 3) Fujita et al., CP, 2015. 4) Landais et al., CP, 2012. 5) Bazin et al., CP, 2016. 6) Ikeda-Fukazawa et al., EPSL, 2005.

キーワード：アイスコア、ドームふじ、年代決定、 O_2/N_2

Keywords: ice core, Dome Fuji, chronology, O_2/N_2

東南極大陸縁辺の海底地形調査

Seafloor topography surveys around the East Antarctic continental margin

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Seafloor topography is fundamental information for marine research. However, the detailed topography in the Southern Ocean has not generally been understood yet. Especially, seafloor topography around the Antarctica margin covered by sea ices has been unknown. The Antarctic continental margin is the boundary area between ice sheet and ocean and the bathymetry around this region is essential element to understand the interaction between ice sheet and ocean as well as the tectonic evolutions. Single beam echo soundings have been conducted by old icebreaker Shirase, and multi beam echo-sounder has been installed on new icebreaker Shirase and the swath bathymetry data have been obtained since the 51st Japanese Antarctic Research Expedition (2009-2010). Moreover, sub-bottom profiler has also been equipped on the new icebreaker. Unknown seafloor topography and sub-bottom profiles under sea ices around the Antarctic margin such as continental shelf and slope are becoming clear, and those data are used as basic data for the Antarctic bottom water channels as well as paleoenvironment studies. Those data combined with magnetic and gravity anomalies have also contributed to the study related to the continental breakup. But there is a limit to observations by the icebreaker. The surveys under sea ices using ROV and/or AUV should be considered. We introduce the present status of multi beam echo-sounder and sub-bottom profiler obtained around the East Antarctic continental margin by icebreaker Shirase and future development of research using ROV and/or AUV are discussed.

キーワード：海底地形、東南極、大陸縁辺

Keywords: seafloor topography, East Antarctica, continental margin

氷期の南極温暖イベントに対応した南大洋における海氷拡大

Sea ice expansion in Antarctic warming events in the glacial Southern Ocean

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The Southern Ocean has played an important role in the evolution of the global climate system. Area of sea ice shows a large seasonal variation in the Southern Ocean. Sea ice coverage on sea surface strongly affects the climate of the Southern Hemisphere through its impacts on the energy and gas budget, on the atmospheric circulation, on the hydrological cycle, and on the biological productivity. However, millennial-scale sea ice coverage and its impacts are not well understood. Here we show high-resolution records of sea ice-rafted debris (SIRD) and diatom assemblage to reveal a rapid change of sea ice distribution in the glacial Southern Ocean. The depositions of rock-fragment SIRD excluding volcanic glass and pumice were associated with increasing of sea-ice diatoms, suggesting that the millennial-scale events of cooling and sea-ice expansion were occurred in the glacial South Indian Ocean. The extent of sea ice in the Southern Ocean is occurred during the Antarctic isotope maximum (AIM) events, which is partly linked with the Heinrich Events in the Northern Hemisphere.

キーワード：南大洋、海氷、南極温暖イベント、ハインリッヒイベント

Keywords: Southern Ocean, sea-ice, Antarctic warming events, Heinrich Event

コンラッドライズにおける最終氷期以降の放散虫群集変化と海洋環境との関係

Radiolarian changes since the last glacial period in the Conrad Rise and their relation to the oceanic environments

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It is well known that the oceanic circulation in the Southern Ocean plays an important role in the global climate changes. For reconstruction of the past ocean circulation in the Southern Ocean, siliceous microfossils such as diatoms and radiolarians preserved abundantly in deep-sea sediments are widely used as paleoceanographic proxies. Fossil assemblages of diatoms (phytoplankton) indicate usually surface water environments, while radiolarians (zooplankton) can be used as indicator for not only surface but also intermediate and deep water conditions because of their discrete habitat depths for each species. In this study, quantitative analysis of radiolarians was conducted for core COR-1bPC (54°S) from Conrad Rise in the Indian Ocean sector of the Southern Ocean.

キーワード：古海洋学、生物生産性、中層水

Keywords: paleoceanography, biogenic productivity, intermediate water

最終間氷期の突然かつ急激な南極氷床崩壊イベントの検証とメカニズムの解明に向けて

Toward understanding the cause and mechanism of catastrophic collapse of Antarctic ice sheets during the last interglacial

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現在進行中の地球温暖化は我々の生活に様々な影響をもたらすが、中でも“海面上昇”は最も深刻な脅威の一つと考えられている。最新の観測から予想を超える急速なペースでの極域氷床の融解が進行中であることが明らかになり、温暖化の進行によって海面が大きく上昇する懸念が高まっている。こうした将来の海水準変動を予測する上で過去の温暖期の海水準変動がどうであったかを調べるのは有益である。これまでの古環境の研究において、現在よりも僅かに温暖な最終間氷期（13-11.5万年前）の末期には、6mもの突然かつ急激な海面上昇があったと報告されている。これが事実であれば、現在のような間氷期の気候状態で、氷床の大規模な崩壊とそれに伴う海水準上昇を誘発する臨界点が極域の氷床に存在することになる。この最終間氷期における劇的な海面上昇に対するグリーンランド氷床融解の寄与は最大の見積もりでも2m程度とされるので、当時の海水準上昇の主因は南極氷床の大規模な融解によるものと考えることができる。近年の温暖化によって現在の気候状態（全球平均の表層海水温度）はすでに最終間氷期のレベルに達しており、南極氷床の大規模な崩壊が将来に起こり得る可能性を検証することは喫緊の課題と言える。この問題に取り組むためには、最終間氷期に実際に急激な南極氷床の大規模崩壊があったかを精査することが重要である。しかし、最終間氷期の南極氷床縁辺海域における気候・海洋情報は、ほとんど蓄積されておらず、最終間氷期に南極氷床が大規模崩壊した直接的な証拠はいまだに得られていない。本講演では不可逆的な氷床融解への臨界点である「ティッピング・ポイント」の理解において過去の温暖期に起こった突然かつ急激な南極氷床崩壊イベントの検証とそのメカニズムを解明することの重要性について解説する予定である。

キーワード：南極氷床、最終間氷期、海水準上昇

Keywords: Antarctic ice sheet, last interglacial, sea level rise

Amundsen Sea simulation with optimized ocean, sea ice, and thermodynamic ice shelf model parameters

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The ice shelves and glaciers of the West Antarctic Ice Sheet (WAIS) are melting and thinning rapidly in the Amundsen Sea (AS) and Bellingshausen Sea (BS), with consequences for global sea level rise and ocean circulation. First, approximately 10% of the observed sea level rise has been attributed to the thinning of WAIS between 2005 and 2010. Second, the melting of ice shelves in the AS and BS will freshen the shelf water locally as well as downstream in the Ross Sea (RS), which may lead to a change in the characteristics of Antarctic Bottom Water formed in the RS and thus influence the global thermohaline circulation.

Agreement between model results and observations are crucial for understanding and projecting these impacts on the current and future climate. Thus, we aim to conduct model optimization for a regional Amundsen and Bellingshausen Seas configuration of the MITgcm. Currently, we have adjusted a small number of model parameters to better fit the available observations during the 2007-2010 period using trial-and-error adjustment and a Green's function approach. As a result of adjustments, our model shows significantly better match with observations than previous modeling studies, especially for Winter Water (WW). Since density of sea water depends largely on salinity at low temperature, this is important for assessing the impact of WW on Pine Island Glacier melt rate. We also conduct several sensitivity studies, showing the impact of surface heat loss on the thickness and properties of WW.

Our work is a first step toward improved representation of ice-shelf ocean interactions in the ECCO (Estimating the Circulation and Climate of the Ocean) global ocean retrospective analysis. In this presentation, we briefly explain our overall project and present some preliminary results pertaining to sensitivity simulations using high resolution (2 km) configuration and adjoint sensitivity simulations.

キーワード : Amundsen/Bellingshausen Sea, Ice shelf-ocean interaction, Circumpolar Deep Water
Keywords: Amundsen/Bellingshausen Sea, Ice shelf-ocean interaction, Circumpolar Deep Water

白瀬氷河における氷舌－海洋相互作用の現場観測

Observations of ice tongue-ocean interaction at Shirase Glacier

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Shirase Glacier Tongue (SGT) is a thick floating slab of ice that forms where the glacier flows down onto the ocean surface at the southern closed-section of Lutzow-Holm Bay (LHB) off Enderby Land, East Antarctica. Compared with other major ice shelves/tongues around Antarctica, SGT is smaller in area but its basal melt rate was estimated to be relatively high at a rate of ~7 m per year (Rignot et al., 2013) based on presence of warm deep water. Although comprehensive hydrographic observations in LHB is indispensable for understanding the SGT-ocean interaction, they are extremely limited, with exception of those conducted by wintering party of the 31st Japanese Antarctic Research Expedition (JARE) in 1990/92. Detailed analysis of the JARE-31 winter hydrographic observations suggests a 3-dimensional circulation, associated with the SGT-ocean interaction, that comprises: (1) warm modified CDW (Circumpolar Deep Water) flows southward at the deep layer of submarine canyon that leads into the region beneath SGT, (2) mCDW meets to melt the base of SGT, and (3) mixture of mCDW and basal melt water exports northward at subsurface layer.

To explore in detail the SGT-ocean interaction, summer comprehensive hydrographic observations in LHB are now in progress during JARE-58 in 2016/17 under the project called ROBOTICA. In this talk, preliminary results from the JARE-58 hydrographic observations are also presented.

キーワード：白瀬氷河氷舌、底面融解、周極深層水

Keywords: Shirase Glacier Tongue, basal melt, Circumpolar Deep Water

Breakup of land-fast sea ice in Lutzow-Holm Bay, East Antarctica and its teleconnection to tropical Pacific

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A large land-fast sea ice breakup occurred in 2016 in Lutzow-Holm Bay, East Antarctica. The breakup caused calving from the Shirase Glacier Tongue (SGT), which is otherwise held back by the ice. Although similar breakups and calving have been observed in the past, the timing and magnitudes are not well-constrained. We analyzed the ice's breakup latitude during 1997-2016 to investigate the variables controlling breakup and examine correlation with local calving for a longer period. The breakup latitude had a persistently high correlation with sea-surface temperature (SST) in the tropical Pacific, which exceeds correlations with local atmospheric variables. The multi-decadal variability of the tropical SST can explain the multi-decadal variation of the calving front of SGT from the 1950s through the breakup of fast ice. The SST-regressed breakup latitude can potentially explain 5 out of 6 SGT calving events from the mid-20th century, including its frontal retreat in the 1980s. Our proposed teleconnection between tropical SST and Antarctic sea ice could lead to better predictions of breakup and might impact the glacier flux for a wider region.

アルゴフロートにより観測された南極環海流の定常蛇行

Standing meanders of the Antarctic Circumpolar Current as observed by Argo floats

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1. 海洋研究開発機構

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南大洋の渦は、たとえば渦運動エネルギーや渦運動量鉛直輸送などで定量化されてきたが、近年「流線の長さ」に着目する研究が現れた。南大洋には世界最大流量を誇る南極環海流がある。この海流の流量は西風の数年規模の変動に対してほとんど変動しない事が知られてきた。これが定常蛇行の近辺で風の変動に対する調整がおこっているせいではないか、という仮説がある。その調整にともなう現象として流線が長くなる事象が渦分解数値モデルで見られた。

アルゴフロートを用いて類似した現象が観測されうるか調べた。南極環海流に沿って7つの定常蛇行が観測された。この定常蛇行近辺の上層1000mの渦輸送を計算すると、渦に伴って流線の曲率半径が増加すなわち流線が長くなっている事が示唆された。この効果は海底地形東側（環海流の下流側）で特に大きい。下流側は多くの場合極向きの渦輸送を持ち、子午面循環や運動量収支でも重要な役割を果たすが、流線の長さの決定にも重要な事が分かった。

キーワード：南極環海流、年々変動、渦輸送、曲率

Keywords: Antarctic Circumpolar Current, Interdecadal variability, Eddy transport, Curvature

南極氷床と気候の変動及び相互作用に関する研究展望

Research prospects on variations and interactions of Antarctic ice sheet and climate

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南極気候変動研究の一環として、以下を提案する。

アイスコアの分析や氷床の直接観測により、南極氷床と全球気候の現在や過去の状態を明らかにし、それらの変動メカニズムと相互作用を解明する。特に、過去数十万年の気温や降雪量、海氷、炭素循環に関する分析や、氷床質量収支や海洋との相互作用にかかる観測を軸とする。

【研究内容】

1) ドームふじ等で採取されたアイスコアを解析し、南極及び全球の環境変動を復元する。氷床・気候モデルの入力となる二酸化炭素や、気温や海水温復元のための水同位体や希ガス、放射強制力や物質循環に関わるエアロゾル、海氷由来物質、気候不安定性復元のためのメタン濃度、標高変化に関連する空気含有量、年代精度向上のための成分などを分析する。特に、南極氷床が縮小した「スーパー温暖期」に着目し、数値モデルや海底コアデータを用いた比較研究を行う（古海洋・モデル研究と連携）。古環境シグナル形成プロセスの研究も実施する。

2) 氷河と氷床の現地観測とリモートセンシングにより氷床流動と質量変化を測定する。氷床沿岸部や氷河流域全体での質量収支・氷損失を定量化し、氷河加速や棚氷底面融解、接地線移動などの状態とメカニズムを理解する（海洋観測・固体地球観測と連携）。観測成果を用いて氷床モデルの精緻化に寄与し、氷床量と海水準の将来予測精度向上に貢献する（気候等のモデル研究と連携）。

キーワード：南極氷床、気候変動、アイスコア、氷床融解

Keywords: Antarctic ice sheet, Climate change, Ice cores, Ice sheet melting

大気海洋結合モデルや氷床モデルを組み合わせた過去から将来の南極南大洋の統合的モデリングの現状

Current climate-ice sheet studies related to Antarctica and Southern ocean using Earth system models

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Climate-Antarctica ice sheet and Southern ocean interaction not only affects the local climate but also affect the global climate and ocean. We present some of our current modelling studies and plan using coupled atmosphere and ocean model and ice sheet model. In one of our studies, Eocene experiments were carried out to test the model's ability to reproduce proxy data and to investigate the climate system under high CO₂ concentration. Furthermore, in order to investigate to what extent topographical changes are responsible for the difference between the Eocene and present day climates, we created Eocene-like geometries from the present day topography. We present the individual effects of the Drake Passage, Tasman Gateway, Antarctica Ice Sheet on the climate.

キーワード：古気候、気候モデリング、南極氷床

Keywords: paleoclimate, Climate modeling, Antarctica ice sheet

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 surrounding 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.

キーワード：氷床、海水準変動、GIA、氷床融解史、東南極、粘弾性構造

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

季節海氷融解期の生態系：海氷中生物–ハダカイワシ間のエネルギー転送過程

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

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南大洋における海氷の季節的消長は、南大洋生態系の動態をつかさどる重要な要素である。沿岸ポリニアなどで生成された海氷は、その中に微小な藻類や原生動物、甲殻類幼生などのSea ice biota (SIB) を包含し、秋から冬にかけて北側へ移送され広大な面積を覆っていく。このSIBは、春から夏の間海氷融解期に北から順次水柱中に放出される。この放出されるSIBの生物量は膨大なものと考えられるが、放出後の海洋生態系における経路・動態はよく分かっていない。今後気候変動とともに予想される海氷量の変動は、この経路を通して、生態系変動として南大洋に広く波及すると考えられる。

我々は、このSIBが放出されたあとどのように南大洋生態系に流れていくのかを調べており、これまで、鳥類をはじめとする高次捕食者の餌として重要なハダカイワシ科魚類*Electrona antarctica*が、初期生活史において海氷の影響下にある海域を利用していることを明らかにしている。本講演では、1) 海氷中やその周辺海域の微細藻類群集の情報から、水柱中に放出された後の微細藻類群集の動態について調べた結果を紹介する。さらに、2) *E. antarctica* 仔魚の胃内容物中に見出されるデトリタスを分析したところ珪藻類が多量に含まれることが分かった。これらのデトリタスの由来についても考察する。

融解期に海氷から放出された総細胞数と観測時における表層水柱に現存した細胞数を比較したところ、海氷中に優占したほとんどの種において、90%以上が表層混合層から除去されていることが分かった。このことから微細藻類の多くが放出後、沈降や動物プランクトンによる摂食圧を受けて、水柱から除去されていたと推定される。*E. antarctica* 仔魚は、胃内容物にデトリタスが含まれることや、デトリタスを摂食することが知られている*Oncaea*属のカイアシ類が含まれることから、とくに仔魚の初期においてはデトリタスが一定の役割をもつことは明らかである。そのデトリタスに含まれる珪藻の中には主として海氷中に見出される種も含まれることから、沈降する動物プランクトンの糞粒やマリンスノーを介して、間接的にSIBを摂食していると推定される。

2017年には氷縁近傍でのセジメントトラップを装備した漂流系の観測を行っており、サンプルの解析が進めばSIBの沈降過程について直接的な情報が得られるであろう。また、*E. antarctica* 仔魚については、デトリタスのゲノム解析やバイオマーカーの分析を行い、より詳細にSIBからの物質の流れを解明していく計画である。

キーワード：海氷生物群集、海氷微細藻類、食物網、海氷縁辺域、マリンスノー、デトリタス

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

南極宗谷海岸の沿岸湖沼における古環境復元

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

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南極氷床は地球上で最も大きい氷床であり、世界の氷河の90 %を南極氷床が占めている。このように莫大な氷に覆われている南極大陸は地球全体の気候に重要な働きをしているとともに、地球全体の変化が顕著に反映される場所でもある。東南極の宗谷海岸には南極氷床の後退により形成された数多い湖沼が分布している。本研究では東南極宗谷海岸の沿岸湖沼から採集した湖底堆積物から産出する珪藻化石の群集変化を時系列で復元することを通して、湖沼の水環境の変動を復元することを目指している。

堆積相の特徴、クロロフィル化合物やカロチノイドの分析結果、藻類やシアノバクテリアの観察結果ならびに珪藻分析の結果から、親子池（コア名：Ok4C-01）のコアの年代は304 - 2,187 cal yr BPであり、沿岸海的环境から湖沼と変遷した時期は約1100 cal yr BP (core depth 60 cm)であった。丸湾大池（コア名：Mw4C-01）・丸湾南池（コア名：MwS4C-01）のコアの年代は、それぞれ2,220 - 5,630 cal yr BP と 1,260 - 4,840 cal yr BPであり、沿岸海的环境から湖沼と変遷した時期は丸湾大池で2800 cal yr BP (core depth 22 cm)、丸湾南池で2400 cal yr BP (core depth 65 cm)であった。珪藻の群集変化に基づいた結果は他の分析結果とも整合性のある結果であった。

珪藻の群集変化によって海洋から淡水への変遷だけではなく、海氷 (*Fragilariopsis curta*, *F. cylindrus*)や湖沼の低塩化(*Psammothidium papilio*)と貧栄養化のような詳しい環境復元ができた。

キーワード：南極、古環境、湖沼堆積物、珪藻群集

Keywords: Antarctica, Paleoenvironment, Lake sediment, Diatom assemblage

南大洋Kerguelen海台近海から産出した珪藻化石を用いた鮮新世の季節性海水分布の復元

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

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南大洋の古環境推定には、海底堆積物から産出する珪藻化石が重要な指標として用いられてきた。例えば、海水分布域の復元は、生物地理学的研究（e.g., Armand et al., 2005）により明らかになった海水関連珪藻の産出量変動にもとづいている。しかし、これまでに海水分布の季節性に注目した復元例、すなわち、夏季および冬季の海水縁を復元した研究例はほとんどない。Armand et al. (2005) に報告されている海水指標種群には、分布域が夏季海水域に概ね限られる種（夏季海水種）と冬季海水域まで広域に多産する種（冬季海水種）が見られる。そこで本研究では、海水指標種群を夏季・冬季海水種に細分化し、その産出量変動から長期にわたる夏季・冬季海水分布域の推定を試みた。分析に用いた試料は、南大洋インド洋区の堆積物試料ODP Leg 188 Hole 1165B（夏季海水縁近傍）およびODP Leg 119 Hole 745B（冬季海水縁近傍）である。本発表では、鮮新世温暖期およびその後の寒冷化に対して、南大洋インド洋区で夏季・冬季海水縁がどのように分布・変動していたのかを報告する。

キーワード：南大洋、古環境、海水、ODP、珪藻

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

南大洋大西洋区における珪藻・黄金色藻シスト化石に基づく後期中新世の古海洋環境復元

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

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南大洋を構成する南極周極流や各種の水塊は、地球規模の気候変動にも寄与する重要な要素である。そのため、それらの変動史を地質時代に遡って復元することは必須の課題であり、これまでに様々な手法による古環境復元の試みがなされてきた。例えば、南極周極流の復元に関しては、深海堆積物の地震波探査から得られた堆積構造の変化などに基づく復元が行われてきた。しかし、年代決定の困難さなどの要因から、これらの研究例は、世 (epoch) オーダーでの復元あるいはごく一部の期間のみを対象とした復元にとどまっている。

南大洋の新第三系海底堆積物には、珪藻や黄金色藻シストなど保存の良い珪質微化石が豊富かつ連続的に産出する。珪藻は、高緯度海域や湧昇流帯で特に繁栄している分類群であり、各水塊に応じた棲み分けをしている場合が多い。ゆえに、亜熱帯域 (南極周極流よりも北側の水塊) に特有な種群の消長を調べることで、南極周極流の南北移動を長期間にわたり連続的に復元できる可能性がある。また、黄金色藻は主に淡水棲であり、海洋コア中の黄金色藻シスト化石は南極大陸を起源とする融氷水の流れ込み、すなわち大陸氷床の融解を指標していると考えられる。そのため、南大洋における黄金色藻シスト化石の産出量変動は、地質時代に遡って南極大陸氷床の変遷史を解明するうえで有用なツールとなる。本発表では、南大洋大西洋区で掘削されたボーリングコア試料ODP Leg 113 Site 689およびDSDP Leg 71 Site 513のうち、後期中新世から鮮新世 (約9–3 Ma) の堆積物中に保存された珪藻・黄金色藻シスト化石の分析から示唆される古環境変動イベント、特に約7–4.8 Maにおける南極周極流の10–20万年オーダーの周期での南北移動などについて報告する。

キーワード：珪藻、黄金色藻シスト、南大洋、南極周極流、DSDP、ODP

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

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 CO₂ concentrations were similar to that of present day. Globally, the climate was warmer by about 2-3°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.

キーワード : Pliocene、 Climate modelling、 Climate change、 Antarctic ice sheet

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.

キーワード：氷床

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.

キーワード : Ice shelf-ocean interaction, Amundsen-Bellingshausen Sea, Ross Sea , Circumpolar Deep Water

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

オーストラリア南極海盆に面した中規模ポリニヤを起源とする南極底層水生成源の可能性

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 from 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.

キーワード：南極底層水、高密度陸棚水、オーストラリア南極海盆、陸棚水形成過程、ビンセネスポリニヤ、シャックルトンポリニヤ

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

南極アデリー海岸沖で観測された南極底層水の急速な変化

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.

キーワード：深・底層水、フロート観測

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 109s.

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 °C/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.

キーワード：南極底層水、高温化、低塩分化、海面上昇

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

南大洋上における大気・海洋変動の時空間特性

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

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南半球における大気循環場の変動特性として代表的な南半球環状モード(Southern Annular Mode : SAM) (Thompson and Wallace, 2000)では、中緯度域と高緯度域の気圧偏差の変化に伴う偏西風の強弱で特徴付けられる。特にドレーク海峡付近では間断なく吹いており、そこでの変動は南大洋域における大気-海洋変動を知る上でのキー海域と言える。先行研究では、ドレーク海峡付近における生態系変動と同海峡を横切る偏西風強弱の指数であるDPOI (Drake Passage Oscillation Index) に密接な関係があることが示された(Naganobu et al., 1999,2008)。また、DPOIに関連する海上風の経年変動として南大洋上で緯度方向に構造を有する第二の変動場が検出された (Yagi et al., 2017)。しかしながら、DPOIに関連する海上風変動が海洋に及ぼす影響は未解明である。本研究では、南大洋上における海面水温変動と海上風変動が如何なる関係を有するのかを調査する。

月平均の東西風のEOF解析から導出した第1モードは、寄与率が55.5%で海上風変動の半分以上に寄与し、ドレーク海峡で振幅が最大である。この時係数は、AAOIと0.47、DPOIと0.94の相関をもち、DPOIに関連する変動が最も支配的であることが明らかになった。この時係数のスペクトルには、12ヶ月および24ヶ月に加えて、30ヶ月の周期帯でエネルギーが高いので、3年付近の周期帯における変動に注目する。DPOIに関連する海上風変動と南大洋上における海面水温変動との関係を明らかにするために、約3年の周期帯を抽出するバンドパスフィルターを施した東西風EOF第1モードの時係数と海面水温偏差との同時相関分布図を作成した。その結果、南大洋全域で正と負の高い相関がみられ、ドレーク海峡西方(南太平洋側)で負の相関、東方(南大西洋側)で正の相関を示すとともに、ロス海北部とウェッデル海に極大がみられることから、両海域における海上風速および海面水温の関係性をより詳細に調査していく必要がある。

キーワード：偏西風、DPOI、大気海洋相互作用

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.

キーワード : AMSR2、沿岸ポリニヤ、定着氷

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.

キーワード：沿岸ポリニヤ、海氷タイプ、海氷生産量、AMSR-E

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