A plan for studying the interaction of the solid Earth and the Antarctic ice sheet

*福田 洋一[1]、西島 潤[2]、風間 卓仁[1]、中村 和樹[3]、土井 浩一郎[4]、菅沼 悠介[4]、奥野 淳一[4]、新谷 昌人[5]、金田 平太郎[6]、青山 雄一[4]、三浦 英樹[4]
*Yoichi Fukuda[1], Jun Nishijima[2], Takahito Kazama[1], Kazuki Nakamura[3], Koichiro Doi[4], Yusuke Suganuma[4], Jun'ichi Okuno[4], Akito Araya[5], Heitaro Kaneda[6], Yuichi Aoyama[4], Hideki Miura[4]

1. 京都大学大学院理学研究科、2. 九州大学工学研究院、3. 日本大学工学部、4. 国立極地研究所、5. 東京大学地震研究所、6. 千葉大学理学研究科
1. Graduate School of Science, Kyoto University, 2. Graduate School of Engineering, Kyushu University, 3. Faculty of Engineering, Nihon University, 4. National Institute of Polar Research, 5. ERI, University of Tokyo, 6. Graduate School of Science, Chiba University

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.

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 metling 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

*茂木 正人[1,2]、真壁 竜介[2,3]、溝端 浩平[1]、高尾 信太郎[2,3]、嶋田 啓志[1]、宮崎 奈穂[1]、高橋 邦夫[2,3]、小達 恒夫[2,3]
*Masato Moteki[1,2], Ryosuke Makabe[2,3], Kohei Mizobata[1], Shintaro Takao[2,3], Keishi Shimada[1], Naho Miyazaki[1], Kunio Takahashi[2,3], Tsuneo Odate[2,3]

1. 東京海洋大学、2. 国立極地研究所、3. 総合研究大学院大学
1. Tokyo University of Marine Science and Technology, 2. National Institute of Polar Research, 3. The Graduate University for Advanced Studies

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、水柱中に放出されあと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

*姜 怡辰[1]、鹿島 薫[2]、瀬戸 浩二[3]、谷 幸則[4]、渡邊 隆広[5]、中村 俊夫[6]、伊村 智[7]、井上 源喜[8]
*IJIN KANG[1], Kaoru Kashima[2], Koji Seto[3], Yukinori Tani[4], Takahiro Watanabe[5], Toshio Nakamura[6], Satoshi Imura[7], Genki I. Matsumoto[8]

1. 九州大学大学院理学府地球惑星科学専攻、2. 九州大学大学院理学研究院地球惑星科学部門、3. 島根大学汽水域研究センター、4. 静岡県立大学環境科学研究所、5. 国立研究開発法人日本原子力研究開発機構、6. 名古屋大学年代測定総合研究センター、7. 国立極地研究所、8. 大妻女子大学社会情報学部
1. Department of Earth and Planetary Sciences, Graduate School of Sciences, Kyushu University, 2. Department of Earth and Planetary Sciences, Faculty of Sciences, Kyushu University, 3. Research Center for Coastal Lagoon Environments, Shimane University, 4. Institute of Environmental Sciences, University of Shizuoka, 5. Japan Atomic Energy Agency, 6. Center for Chronological Research, Nagoya University, 7. National Institute of Polar Research, 8. School of Social Information Studies, Otsuma Women’s University

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標としている。

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、沿岸海の環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、沿岸海の環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氷分布の復元

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

*石野 沙季[1]、加藤 悠爾[1]、須藤 斎[1]
*Saki Ishino[1], Yuji Kato[1], Itsuki Suto[1]

1. 名古屋大学大学院　環境学研究科
1. Graduate School of Environmental Studies, Nagoya University

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，海氷分布域の復元は，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氷関連珪藻の産出量変動にもとづいている．しかし，これまでに海氷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氷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氷指標種群には，分布域が夏季海氷域に概ね限られる種（夏季海氷種）と冬季海氷域まで広域に多産する種（冬季海氷種）が見られる．そこで本研究では，海氷指標種群を夏季・冬季海氷種に細分化し，その産出量変動から長期にわたる夏季・冬季海氷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（夏季海氷縁近傍）およびODP Leg 119 Hole 745B（冬季海氷縁近傍）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・冬季海氷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、海氷、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

*加藤 悠爾[1]、石野 沙季[1]、須藤 斎[1]
*Yuji Kato[1], Saki Ishino[1], Itsuki Suto[1]

1. 名古屋大学大学院環境学研究科
1. Graduate School of Environmental Studies, Nagoya University

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

*陳 永利[1]、阿部 彩子[1,2]
*Wing-Le Chan[1], Ayako Abe-Ouchi[1,2]

1. Atmosphere and Ocean Research Institute, The University of Tokyo、2. Dept. of Integrated Climate Change Projection Research, JAMSTEC, Yokohama
1. Atmosphere and Ocean Research Institute, The University of Tokyo, 2. Dept. of Integrated Climate Change Projection Research, JAMSTEC, Yokohama

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.

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

*齋藤 冬樹[1]、阿部 彩子[2,1]
*Fuyuki SAITO[1], Ayako Abe-Ouchi[2,1]

1. 独立行政法人海洋研究開発機構、2. 東京大学大気海洋研究所
1. Japan Agency for Marine-Earth Science and Technology, 2. Atmosphere Ocean Research Institute, University of Tokyo

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

*小長谷 貴志[1]、阿部 彩子[1,2]、齋藤 冬樹[2]
*Takashi Obase[1], Ayako Abe-Ouchi[1,2], Fuyuki SAITO[2]

1. 東京大学理学系研究科地球惑星科学専攻、2. 海洋研究開発機構
1. The University of Tokyo, Department of Earth Planetary Science, 2. Japan Agency for Marine-Earth Science and Technology

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.

*Yoshihiro Nakayama[1,2]、Timmermann Ralph[1]、Hellmer Hartmut[1]
*Yoshihiro Nakayama[1,2], Ralph Timmermann[1], Hartmut H Hellmer[1]

1. Alfred Wegener Institute、2. NASA Jet Propulsion Laboratory
1. Alfred Wegener Institute, 2. NASA Jet Propulsion Laboratory

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

*北出 裕二郎[1]、嶋田 啓資[1]、尾方 雄貴[1]、青木 茂[2]、小林 大洋[4]、溝端 浩平[1]、田村 岳史[3]、須賀 利雄[5]、大島 慶一郎[2]
*Kitade Yujiro[1], Keishi Shimada[1], Yuki Ogata[1], Shigeru Aoki[2], Taiyo Kobayashi[4], Kohei Mizobata[1], Takeshi Tamura[3], Toshio Suga[5], Kay I. Ohshima[2]

1. 東京海洋大学大学院海洋科学技術研究科、2. 北海道大学低温科学研究所、3. 国立極地研究所、4. 海洋研究開発機構、5. 東北大学大学院理学研究科
1. Tokyo University of Marine Science and Technology, 2. University of Tokyo, 3. National Institute of Polar Research, 4. Japan Agensy for Marine-Earth Science and Technology, 5. Tohoku University

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.

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

*小林 大洋[1]
*Taiyo Kobayashi[1]

1. 海洋研究開発機構
1. Japan Agency for Marine-Earth Science and Technology

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

*嶋田 啓資[1]、北出 裕二郎[1]、青木 茂[2]、大島 慶一郎[2]、溝端 浩平[1]、田村 岳史[3]
*Keishi Shimada[1], Yujiro Kitade[1], Shigeru Aoki[2], Kay I. Ohshima[2], Kohei Mizobata[1], Takeshi Tamura [3]

1. 東京海洋大学、2. 北海道大学低温科学研究所、3. 国立極地研究所
1. Tokyo University of Marine Science and Technology, 2. Institute of Low Temperature Science Hokkaido University, 3. National Institute of Polar Research

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.

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

*八木 雅文[1]、轡田 邦夫[2]、永延 幹男[3]
*Masafumi Yagi[1], Kunio Kutsuwada[2], Mikio Naganobu[3]

1. 東海大学大学院地球環境科学研究科、2. 東海大学海洋学部海洋地球科学科、3. 国際水産資源所
1. School of Geo-environmental Science, Tokai University, 2. School of Marine Science and Technology, Tokai University, 3. NRIFSF/Fisheries Research Agency

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ー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が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に関係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

*二橋 創平[1]、大島 慶一郎[2]、田村 岳史[3]
*Sohey Nihashi[1], Kay I. Ohshima[2], Takeshi Tamura[3]

1. 苫小牧高専、2. 北大低温研、3. 国立極地研究所
1. National Institute of Technology, Tomakomai College, 2. Institute of Low Temperature Science, Hokkaido University, 3. National Institute of Polar Research

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

*中田 和輝[1]、大島 慶一郎[1]、二橋 創平[2]
*Kazuki Nakata[1], Kay I. Ohshima[1], Sohey Nihashi[2]

1. 北海道大学低温科学研究所、2. 苫小牧工業高等専門学校
1. Institute of Low Temperature Science, Hokkaido University, 2. National Institute of Technology, Tomakomai College

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

