北極域における研究・観測究拠点の整備
Expansion of research base/station in the Arctic

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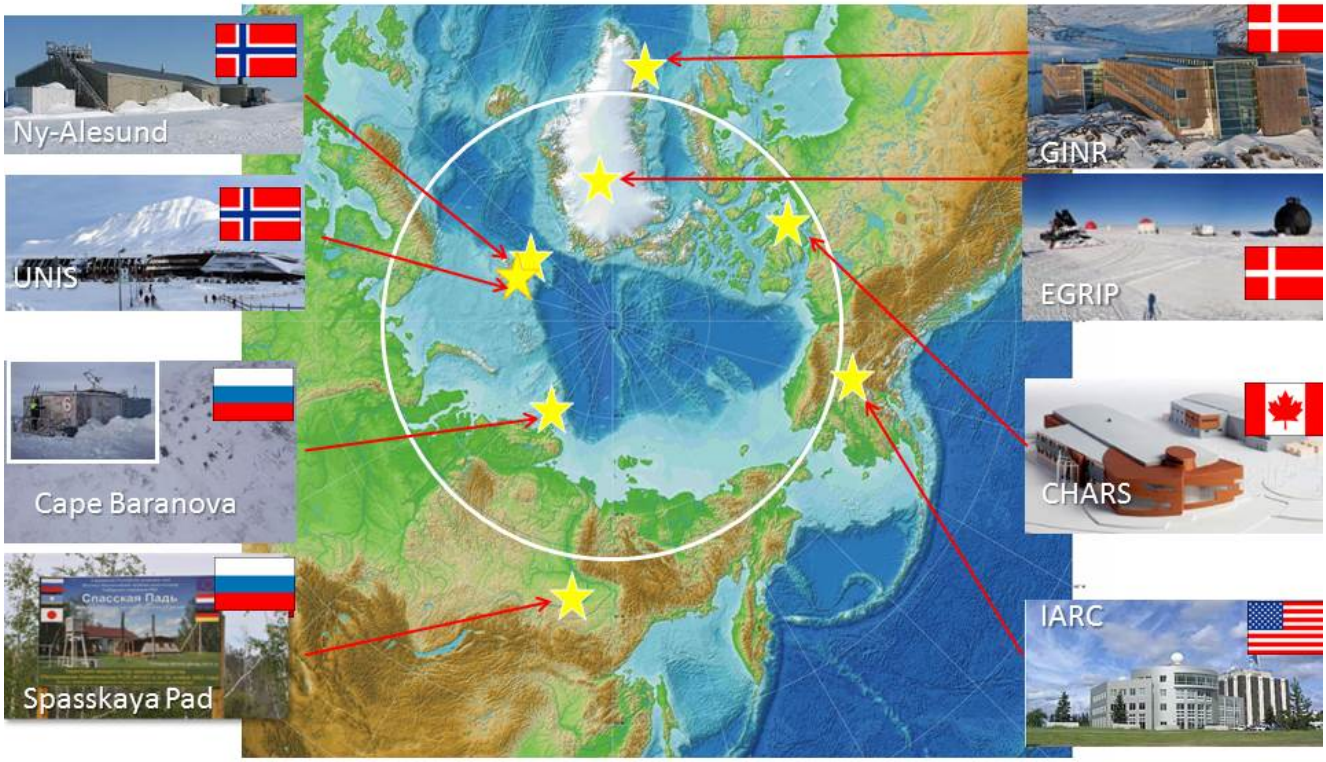
北極域研究推進プロジェクト（ArCS）では、北極域に於ける研究・観測究拠点の整備を行ない、ArCS参画研究者をはじめとする我が国の研究者に観測・研究の場を提供することを目的としている。
整備を行なっている地域は、米国：アラスカ大学IARC(International Arctic Research Center)研究拠点、ポーカーフラット観測拠点、カナダ：CHARS(Canadian High Arctic Research Station), CEN（Centre for Northern Studies）観測拠点、ロシア：ケープ・バラノバ観測拠点、スパスカヤパッド観測拠点、ノルウェー：スバールバル諸島ニーオルスン観測拠点、ロングイヤービンUNIS（The University Centre in Svalbard）、デンマーク（グリーンランド）：氷床上EGRIP観測拠点、ヌークGINR（Greenland Institute of Natural Resources）研究拠点である。それぞれ、調査活動、研究活動や若手育成の場として活用を目指している。
これらの汎北極的な拠点の地理的な分布と焦点を当てる自然科学の対象、さらにその情報の社会への貢献について解説し、北極域研究活動おける有効性についても考える。

キーワード：北極、観測拠点、国際共同研究、国際協力
Keywords: Arctic, research sites, International scientific colaboration, international partnership

Japanese approach to the Arctic

Expand research base/collaborations



Improving the basic research facilities for long-term stay and/or monitoring studies, which can be used by international collaborative studies.

海洋中の栄養塩と溶存酸素データが示す北極海循環と物質循環
Water structures and circulation along with bio-geochemical processes in the Arctic Ocean suggested with nutrients and oxygen distributions

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流速データが限られる北極海で、旧ソ連が海氷キャンプを設置して収集したHydrochemicalデータ(**HACC**)を解析し、地球化学トレーサを用いて循環場を確認・推定した。また有機化合物からリン酸ができる再無機化での保存量としてPO_4*を用いた。その保存則は、リン酸（PO_4）の増加に伴い溶存酸素（DO）が減少する比が$P:O_2 = 1: -175$である（Anderson and Sarmiento, 1994）。式で表すと

$PO_4^* = PO_4 + DO/175 - 1.95$ (μmol/L, Broecker, 1991)

となる。もし２つの水塊のPO_4*が等しいと、それらは同一の起源を持つ可能性が高い。

北極海上層（500m深以上）において、太平洋起源水はケイ酸が豊富で、またリン酸が高く、溶存酸素が少ないので、大西洋起源水との違いは明瞭である。太平洋起源水と大西洋起源水は海面において北極点を通る135°E－45°Wの境界線を持ち、深くなるに従って境界線は反時計方向に回る。表層（200m深以上）で太平洋起源（含む河川水）の低塩分水が高気圧性循環し、亜表層（200－500m深）で大西洋起源の高塩分水が低気圧性循環する状態は、北極海と北大西洋の密度差によって駆動される海洋循環であることを示している。以上の確認によって、HAACデータは半世紀に渡る海洋状況を調べるための信頼性を持つことが示された。

下層（1500m深以下）では、ロモノソフ海嶺によって分けられる太平洋側（Canadian海盆）が大西洋側（Eurasian海盆）より低い溶存酸素を持っている。大西洋側で特に低リン酸と高溶存酸素の海域は、バレンツ海とフラム海峡の近くに限られる。グリーンランド海で形成される北大西洋深層水が流入し、北極海におけるリン酸の降下によって酸素が低下していることと整合的である。太平洋側においては、シベリア陸棚からの海水降下も加わって、2000m深周辺でリン酸を高めていると考えられる。

PO_4*分布（Table参照）から以下の有効な情報が得られた。その値は太平洋側の方が大西洋側より低いが、3500m深で同程度であり、太平洋側2000m深の一部で高い。太平洋側下層の海水は２つの流入経路を持っている。ひとつは大西洋の上層から流入した海水が、シベリア沖までの陸棚近くを通り、陸棚斜面を降下して太平洋側の下層に入るもの、もうひとつは大西洋側下層のNordic Sea Deep Waterが底層で太平洋側に流入するものである。前者は大西洋側から太平洋側までPO_4^* ＝0.65～0.67の値を持って反時計回りに進み、特に太平洋側南端ではシベリア陸棚水の影響も受けてPO_4^* ＝0.86になり2000m深まで達する。後者はPO_4^* ＝0.72で、海底沿いに3500m深周辺を太平洋側に拡がる。

中層（500m～1500m）では、太平洋側でリン酸がわずかに高く、溶存酸素が少ない。PO_4*の差は小さい。すなわち、亜表層と下層から入る大西洋起源水に表層から生物起源物質が沈降して分解され、溶存酸素を使った後に大西洋へ戻る。

Anderson and Sarmiento, 1994: *Global Biogeochemical Cycles*, **8**, 65-80.
Broecker, 1991: *Oceanography*, **4**, 79-89.

Table: 水平分布図からまとめたPO_4 と DOの値（２％の誤差）。単位は μmol/L。

キーワード：北極海、地球化学トレーサ、再無機化、海洋循環
Keywords: Arctic Ocean, geochemical tracer, remineralization, ocean circulation

Location	PO_4	DO	PO_4*
Northern boundary of Barents Sea (200m & 500m)	0.85	310	0.67
Canadian Basin excluding high PO_4 area (2000m) & all (2500m)	1.00	280	0.65
Canada Basin in high PO_4 area (2000m)	1.15	290	0.86
Eurasian Basin (2000m & 2500m)	0.95	300	0.72
Greenland Sea Fram Strait (500m)	0.70	340	0.69
Greenland Sea Fram Strait (2000m)	0.70	310	0.52

太平洋側北極海における栄養塩と植物プランクトンの分布についての観測研究

Nutrient Dynamics Affecting Phytoplankton Distributions in the Pacific Arctic Region

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北極海の太平洋側に位置するチャクチ海とカナダ海盆には、栄養塩の豊富な太平洋起源水が流れ込んでおり、これが植物プランクトン分布に大きく影響している。本研究では船舶観測や係留観測により植物プランクトン分布を特徴づけている海洋の物理・化学環境について調査した。太平洋側北極海の玄関口となるチャクチ海南部では、海氷融解期に植物プランクトンの春季ブルームが起こるのに加えて、秋季にもブルームがあることが観測された。春季ブルームが太平洋起源水による栄養塩供給で維持されているのに対して、秋季ブルームは海底に蓄積された有機物の分解により生じる栄養塩が支えていることが示された。一方、カナダ海盆の栄養塩と植物プランクトンの分布は海洋循環と密接に関係していることが分かった。カナダ海盆アラスカ沖では、近年の海氷減少に伴い、高気圧性のボーフォート循環が強化され、その表層に淡水が蓄積される。このため貧栄養化が進行し、大型の植物プランクトンが減少している。この海域では渦が栄養塩輸送に大きく寄与していることも分かってきた。カナダ海盆のアラスカ沖とは逆に、シベリア沖では表層の栄養塩濃度が増加している。これは、秋季開放面水域の増大に伴い東シベリア海で形成される冬季水が増加し、この水がシベリア沖に栄養塩を運んでくるためと考えられる。この海域のデータはまだまだ不足しており、栄養塩変動と植物プランクトン分布の関係解明については、今後の観測に期待される。

キーワード：北極海、海氷減少、海洋循環、渦、栄養塩、植物プランクトン
Keywords: Arctic Ocean, Sea ice reduction, Ocean circulation, Eddy, Nutrients, Phytoplankton

Species invasion and diversity in benthic macrofaunal communities in the Pacific Arctic

Species invasion and diversity in benthic macrofaunal communities in the Pacific Arctic

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There is growing evidence of increased Pacific water transport into the Arctic that is influenced by variations in atmospheric forcing. One of the empirical and theoretical predictions for a future Arctic impacted by increased Pacific water transport is that new taxa will expand or invade the Arctic ecosystem. However, well-documented examples are still scarce due to the limited number of time-series measurements in the Arctic, particularly for benthic organisms. Although benthic organisms are normally stationary and less mobile than fishes, seabirds and mammals, it seems relevant that benthic organisms with pelagic life stages will be less limited in their expansion abilities. In this study, the relationship between the number of benthic macrofaunal taxa and atmospheric forcing was investigated in the Pacific Arctic. Average taxon number of benthic macrofauna for 2010–2012 has increased significantly compared to 2000–2006 on the continental shelf area from south of St. Lawrence Island in the northern Bering Sea to just north of St. Lawrence Island in the Chirikov Basin, likely caused by the difference in magnitude and location of the Aleutian Low. By comparison, the biomass-based Shannon-Weaver diversity index did not reflect the changes in taxon number of benthic macrofauna. These results indicate increased invasion of new taxa into the region for 2010–2012 compared to 2000–2006, but the biomass of new taxa is negligible when compared with the total benthic macrofaunal biomass. Our findings demonstrated indications of ongoing changes that could continually be facilitated by climate change to future Arctic marine ecosystems in the Pacific Arctic region.

キーワード：Arctic、Benthic community、Pacific water transport
Keywords: Arctic, Benthic community, Pacific water transport

北極海モデリングにおける河川熱流入の影響評価
Evaluation of riverine heat inflow in the Arctic Ocean modeling

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River water is known as important sources of freshwater and nutrients in the Arctic Ocean. Its spatial distribution has been widely visualized using observed chemical properties and numerical tracer experiments. However, continuous monitoring of the volume flux is limited only at major river stations. A substantial amount of uncertainties still remains particularly on ungauged rivers. We compared a couple of river water discharge datasets in the Arctic Ocean modeling. The Arctic Ocean Model Intercomparison Project (AOMIP) traditionally adopted monthly climatology of 13 major rivers, which was based on the R-ArcticNET data archive. The ungauged inflow was added under simple assumption. A daily discharge dataset covering most Arctic sea coasts and multiple decades was recently developed by combining land runoff of the Japanese 55-year reanalysis for driving ocean and sea ice models (JRA55-do) and drainage of the Catchment-based macro-scale floodplain scheme (CaMa-Flood). Another daily discharge dataset was provided using the coupled hydrological and biogeochemical model (CHANGE) and the Total Runoff Integrating Pathways scheme version 2 (TRIP2). An originality of the third dataset is explicit calculation of river ice and snow loading so that the gridded data of river water temperature are also available.
In this study, to evaluate an impact of riverine heat inflow on sea ice in the Arctic Ocean, decadal experiments for 1979–2013 were performed using the Center for Climate System Research Ocean Component model version 4.9 (COCO4.9) in the pan-Arctic regional framework. The horizontal grid size was set to approximately 25 km, and atmospheric forcing components were constructed from the National Centers for Environmental Prediction–Climate Forecast System Reanalysis (NCEP–CFSR). First, the riverine volume inflow was given by three datasets, respectively, so that the sensitivity of sea ice and hydrography was checked. The model results in these cases showed similar interannual variability of sea ice thickness and sea surface salinity in each sub-domain (e.g., Kara and Beaufort seas). We then incorporated the river water temperature into the model experiment. The annual mean sea ice thickness in this case produced negative anomaly over the Siberian shelves and in the southern Canada Basin. The seasonal transitions in sea ice concentration and sea surface temperature indicated that riverine heat inflow into the Arctic Ocean accelerated summer sea ice opening and sea surface warming in the vicinity of major river mouths.

キーワード：北極海モデル、陸-海相互作用、河川水温、海氷融解
Keywords: Arctic Ocean model, land–ocean interaction, river water temperature, sea ice melting

Variability of sea-ice thickness in the northeastern coastal Chukchi Sea revealed by a moored ice-profiling sonar

Variability of sea-ice thickness in the northeastern coastal Chukchi Sea revealed by a moored ice-profiling sonar

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Using a moored ice-profiling sonar, time-series ice-draft data were obtained in a coastal region of the northeastern Chukchi Sea during 2009-10 for the first time. Time-series data show seasonal growth of sea-ice draft, which is occasionally interrupted by the appearances of coastal polynya and upwelled Atlantic Water.The sea-ice draft distribution indicates the abundance of thicker ice comparable or less than in the adjacent Beaufort Sea.The rapid increase of thicker ice from December to January corresponded to the minimal offshore drift in January and the resulting rapid decrease of level-ice fraction indicating dynamical thickening processes.The mean draft and its converted thickness are 1.27 and 1.54 m, respectively. Heat losses are calculated with ice-thickness data averaged over various time scales corresponding to various spatial scales. Comparing to the estimate with ice-thickness data every second, these estimates are roughly two thirds and a half for the cases with spatial averaging over ~20 and 100 km, respectively.The heat-loss estimate based on thin-ice data derived from the AMSR-E corresponds well with the estimate based on the 1-second observed ice-thickness data, indicating the validity of a thin-ice thickness algorithm and the resulting heat-loss estimate based on the AMSR-E data.

キーワード：sea-ice thickness、Chukchi Sea、ice-profiling sonar
Keywords: sea-ice thickness, Chukchi Sea, ice-profiling sonar

Can the anticyclonic eddy trap and amplify near-inertial waves in the Arctic Ocean?

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The hydrographic data obtained by the Ice-Tethered Profiler with Velocity (ITP-V) were utilized to reveal the eddy-internal wave interaction in the Canada Basin, Arctic. The ITP-V is an autonomous drifting instrument that collects profiles of hydrographic data and velocity concurrently in depths of 10-250 m at 3-hr interval. The observation using the ITP-V, installed on the multi-year sea ice, was operated for 9 months from August 2014. We focus on a specific event in mid-October, when a near-surface anticyclonic eddy was observed in depths of 50-100 m. The anticyclonic eddy showed vertically stretched isopycnals with anomalously warm water in its core. It is noted that the near-inertial internal waves were trapped and amplified near the bottom of the eddy, where the horizontal and vertical wave lengths were approximately 10 km and 60 m, respectively. The parameterized turbulent diffusivity (Gregg, 1989) reached up to 10^{-5} m^2/s near the bottom of the eddy while the background diffusivity was around 10^{-7} m^2/s. Our results demonstrate that near-inertial waves can be trapped and amplified within the anticyclonic eddy in the Arctic and can enhance the ocean mixing like mid latitudes.

Keywords: Near-inertial internal waves, anticyclonic eddy, fine-scale parameterization, Canada Basin

ベーリング海峡通過流量と関連した北西ベーリング海の経年塩分変動
Interannual salinity variations in the northwestern Bering Sea associated with the Bering Strait throughflow

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The relationship between the Bering Strait throughflow (BTF) and sea surface salinity (SSS) in the Bering Sea was investigated mainly using an atmosphere-ocean-ice coupled model, MIROC4h, which includes an eddy-permitting ocean model. The MIROC4h simulated well the seasonal cycle of BTF transport, although it overestimated the transport compared with mooring-based estimates. The interannual variations of SSS in the Bering Sea were correlated with those of BTF transport: SSS in the northwestern Bering Sea was high when BTF transport was large. And there was seasonality in the relationship between SSS and BTF. The SSS anomaly associated with the BTF anomaly became evident from winter to spring, and SSS lagged behind the BTF by a few months. Similar relationship between the BTF and SSS can be seen in an observation dataset and two kinds of ocean data assimilation product, although there were some differences from the MIROC4h in the spatial distribution and the timing of large *r*. Sea surface temperature (SST) also became higher with the larger BTF transport in the cold season, however, the surface density were affected by the SSS anomalies more than the SST ones. BTF transport was strongly correlated with SSH in the eastern Bering Sea, the southwestern Chukchi Sea (CS), and the East Siberian Sea (ESS); there was no time lag between the BTF and SSH. The low SSH along the Siberian coast was uncorrelated with the high SSH in the Bering Sea. The Arctic SSH affected BTF transport and the SSS in the northwestern Bering Sea independently of the SSH in the Bering Sea. The *r* between the SSH and zonal wind stress suggested that shelf waves might be excited by zonal wind anomalies in the Laptev Sea or north of the New Siberian Islands to propagate to the Bering Strait. The low SSH along the Siberian coast associated with high SSS in the northwestern Bering Sea, however, was not confirmed in 10 years of satellite-derived SSH data. The relationship between the Arctic SSH and SSS in the Bering Sea still needs to be further investigated.

We evaluated the salt budget in the northwestern Bering Sea using the MIROC4h data. When the BTF transport in October–March was large, the horizontal salt advection increased and meltwater decreased; both changes contributed to the mixed-layer salinization, but the horizontal advection term dominated north of 62.5˚N, and the sea-ice melting term did south of 62.5˚N. The residual term, which mainly represented eddy diffusion, had a role to suppress the magnitude of the salinity tendency. The same features can be seen when the SSH in the southwestern CS and the ESS was low in the cold season. In these cases, the near-surface current anomalies across the contours of salinity were reinforced, and the horizontal salt convergence occurred in the northwestern part of the Bering Sea. Furthermore, the anomalous southerlies and currents contributed to the sea-ice retreat. The SSH anomalies in the Arctic Ocean affected the currents in Bering Strait and the northwestern Bering Sea, perhaps through the propagation of shelf waves, to lead to the salinization. The current anomalies in the northwestern part associated with the BTF or SSH anomalies became weaker in the warm season, which produced the seasonality of the correlation.

キーワード：ベーリング海峡通過流、海面塩分、海面高度、MIROC4h
Keywords: Bering Strait throughflow, sea surface salinity, sea surface height, MIROC4h

Subglacial meltwater discharge and its impact on water properties in Bowdoin Fjord, northwestern Greenland

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Meltwater runoff from the Greenland ice sheet to the ocean has increased in recent years. Thus, it is important to assess the impact of meltwater runoff on the oceanic structure. In marine-terminating glaciers, subglacial meltwater discharge occurs at the grounding line depth and forms an upwelling plume. To understand the impact of subglacial meltwater discharge on water properties, we carried out CTD observations in Bowdoin Fjord, northwestern Greenland in the summers of 2014 and 2016. A numerical experiment of subglacial meltwater plume was also performed with a non-hydrostatic ocean model to examine the effects of freshwater flux changes.
In ocean observations of 2014 and 2016, a significantly high turbidity layer (> 5 FTU) was observed at the subsurface of 20–40 m depth, which was caused by subglacial meltwater plume. Moreover, the level of turbidity and potential temperature showed interannual variations: turbidity was higher and temperature was lower near the surface (5–15 m depth) in 2016, whereas turbidity was lower and temperature was higher at the layer below (50–100 m depth). The observed structure suggests that a larger discharge of turbid subglacial meltwater in 2016, with a larger buoyant force, mixed with the fjord water at the grounding line depth and extended at the relatively shallower depths. The situation is consistent with the fact that the sum of positive degree days at Qaanaaq Airport, a proxy for meltwater runoff in this region, was approximately 20% greater in 2016 than in 2014. In the numerical experiment with 20% greater amount of freshwater flux, concentration of a meltwater tracer near the surface increased by roughly 20% from that of the control case, whereas the tracer concentration decreased at the layer below. The difference in the vertical distribution of tracer concentration with and without increasing the freshwater flux was consistent with that of turbidity in the two years. These results indicate that the change in amount of subglacial meltwater runoff affects the behavior of turbid subglacial meltwater plume and material transport, which might further impact on biogeochemical cycles.

キーワード：氷河海洋相互作用、氷河融解水起源のプルーム、水塊特性、フィヨルド、グリーンランド
Keywords: Glacier-ocean interaction, Subglacial meltwater plume, Water properties, Fjord, Greenland

Characterizing landscape-scale distribution of sparse larch forest and surrounding wetland in Taiga-Tundra boundary ecosystem, Northeastern Siberia

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Vegetation cover is essential information for upscaling GHG emission in local to regional scale. Taiga-Tundra boundary ecosystem consists of sparse Larch forest and polygonal wetland in eastern Siberia, and it is no easy task to know the structure of heterogeneous landscape. Field observation and high resolution satellite image provide information for vegetation cover on a microtopographic level, while coarser resolution image contains mixed pixels. To evaluate fraction of small vegetation patch, subpixel classification has been applied at coarser resolution satellite image. In this study ALOS AVNIR2 (JAXA) reflectance image (70 x 70 km) was classified into landscape unit and then subpixel vegetation cover was obtained by linear spectral unmixing (LSU) method based on vegetation endmember of field reflectance and tree distribution survey in Indigirka lowland eastern Siberia (70°N, 148°E) in July summer. Result was validated by higher resolution vegetation map that was derived from WorldView-2 (Digital Globe) for 10 x 10 km.
AVNIR2 image was classified into 15 landscape units by ISODATA unsupervised classification. Each landscape unit in 10m resolution AVNIR2 image contained usually 2 to 4 dominated vegetation classes in 2-0.5 resolution WorldView-2 vegetation map. For example, a landscape unit near tributary consisted of Sedge, Shrub and smaller fraction such as Tree and Salix endmembers. After endmember collection, subpixel vegetation cover was estimated for 70 x 70km scale, and it revealed landscape-scale distribution and zonation of vegetation cover in Taiga-Tundra boundary. Prior to this study, we have investigated CH4 emission and biomass production of willow bush for 10 x 10km local scale in this observation area. This subpixel vegetation data will allow us to upscale these parameters on biogeochemical cycles for larger spatial scale.

キーワード：植生、景観、サブピクセル分類
Keywords: vegetation, landscape, subpixel classification

Highly Dynamic Methane Emission from the West Siberian Boreal Floodplains

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Methane production from riparian wetlands may cause significant CH4 emissions to the atmosphere. However, seasonal floodplains of many high-latitude rivers are still not represented in studies on methane emissions. A major river in West Siberia is Ob River; it is one of the longest rivers in the world. Despite its potential importance, field observations of the CH4 fluxes in that domain were mainly focused on peatlands and lakes. The present study is a first attempt to estimate variability of methane fluxes from West Siberian boreal floodplains. Results of the study can be used for further data upscaling, especially in combination with floodplain area data.

Methane emission measurements were made by static chamber method during 2015-16 summer periods. Test sites were located at the Ob River floodplain near Khanty-Mansiysk city, Russia, as well as within smaller floodplains in taiga zone.

Flux medians varied in two orders of magnitude from zero to 17.5 mgC/m^2/h. Aiming at further upscaling, we managed such heterogeneity by classifying studied environments with following criteria: i) floodplain width (small or large), ii) microrelief (elevated or depressed), iii) inundation during the measurements («wet» or «dry»). Within this framework, several classes were found to be similar in CH_4 emission rates: i) «wet» and «dry» depressions of large floodplains had highest fluxes of 4.21 mgC/m^2/h with interquartile range (IQR) of 5.17 mgC/m^2/h, ii) «wet» elevations within large floodplains and all small «wet» floodplains had lower flux median of 1.47 mgC/m^2/h with IQR of 2.99 mgC/m^2/h, iii) «dry» elevations within large floodplains and all small «dry» floodplains had the lowest median of 0.07 mgC/m^2/h with IQR of 0.26 mgC/m^2/h.

This observations highlight high variability of emission, which is most evident in depressions within large floodplains, where a few rare but large emission events can contribute significantly to the total emission rates. It was also found that there were only slight difference between emissions from «wet» and «dry» depressions. It can be related to the presence of constant overwetting due to close position of underground waters or water accumulation after precipitation periods.

Besides the common variability of methane fluxes, we also observed «hot moments» of methane emission. In particular, time-series measurements at Ob floodplain revealed sudden peak in emissions just after the main water subsiding (comparing to the fluxes during the flooding period). Results also indicated gradual decreasing of emissions and its dispersion from 5.89 mgC/m^2/h to 3.51 mgC/m^2/h during two weeks of soil drying. We hypothesize that gas bubbles were initially accumulated in soil during the inundated period when the gas diffusion rate was limited and hydrostatic pressure was high. Such accumulation was confirmed by dissolved CH4 concentration measurements in sediments revealing 10 times higher CH4 concentration in comparison with the water column. We suggested that further methane release could be triggered by abrupt hydrostatic pressure decrease induced by water drawdown. Since the threshold concentration of dissolved methane correlates with the water column depth, water level drop might lead to gas generation from the solution and the enlargement of the volume of the gas phase with further

ebullition.
As the next step, we need systematic measurements of methane fluxes and their combining with floodplain mapping for further data upscaling.

Keywords: welands, methane, greenhouse gasses, arctic, Siberia

永久凍土不可逆融解による温室効果ガス放出量の現状評価と将来予測
Assessing and projecting greenhouse gas release from dynamic permafrost degradation

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永久凍土は有機炭素の巨大な貯蔵庫（全球地下有機炭素量の約半量）であり、地球温暖化により融解とそれに伴う有機炭素の放出が進行していると考えられるが，その変動機構やハザード分布などの実態解明は不十分で、気候変動予測モデルへの組み込みは遅れている。また炭素循環における大きな不確定要素として永久凍土の変動を理解することの重要性が認識されている一方で、現状把握を含むその詳細な知見は充分ではない．高含氷な永久凍土の融解によって生じるサーモカルストとは比高60mにも達する地盤陥没を引き起こす現象であり，このような現在進行中の大規模かつ不可逆的な沈下は地形・土地被覆変化を通して北極陸域の社会や生態系に直接の影響を及ぼしている。さらに地下氷や凍結堆積土中に閉じ込められていた温室効果ガス（特にメタン）の放出や有機炭素の分解により，温暖化が加速される可能性も指摘されている．本研究（環境省「環境研究総合推進費」2-1605. H28-30）では、サーモカルストによる永久凍土の不可逆的な融解による温室効果ガス放出量の現状評価と将来予測について現地調査や衛星データ解析，また数値モデル等を有機的に組み合わせて行い，当該過程に関する脆弱性分布や気候変動に対する相対的な寄与を解明することを目標としている。

H28年度は、地下氷と有機炭素を大量に含む永久凍土が広く分布するアラスカと北東シベリアを対象に、永久凍土融解過程の現状を把握するために衛星画像解析と現地調査を行った。また、現地で採取した氷および土壌のコア分析を行い，融解前の永久凍土が含有する有機炭素（メタン）量とその分布について解析した。その結果，試料100g中のガス含有量は数ccで地域間での差異は少ない一方で，地下氷気泡中のメタン濃度は大気中濃度（約2ppm）と同程度から数万倍のものまで大きな幅があった．周囲の土壌のメタン含有量も同程度であった．また，メタンの安定同位体組成は，土壌・地下氷コア中のメタンが概ね微生物起源であることを示唆する結果であった．本報告では，これらの現地調査・分析結果を提示するとともに、含有地下氷・有機炭素の分布を組み込んで不可逆的な永久凍土融解から放出されるGHGが全球に及ぼす影響の寄与を評価する試みについて現状と計画を述べる。

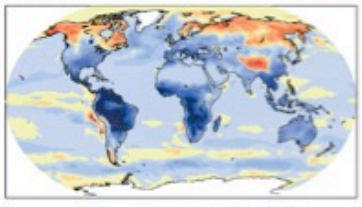
キーワード：高含氷永久凍土融解、メタン、気候変動、ティッピング・ポイント
Keywords: Ice-rich permafrost degradation, Methane, climate change, tipping point

Assessing and projecting greenhouse gas release from dynamic permafrost degradation 【ERTDF 2-1605 FY2016-18】

環境省

Model improvement, Projections

・Quantification of potential methane release
・Refined future climate projections
etc.

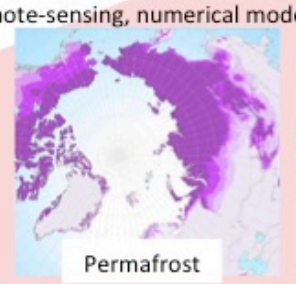


Carbon release [kgC/m^2/K]

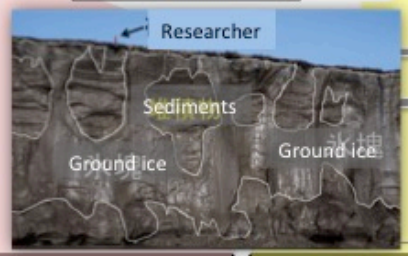
Previous studies
Incremental and kinetic degradation
→Need to incorporate local but dynamic degradation

Sub theme 3 :
Projecting future gas release by integrated land surface model with explicit permafrost dynamics (NIES)

Understanding of vulnerability (remote-sensing, numerical modeling)



Ice-rich permafrost



Sampling and lab-analyses of methane in ice cores

Sub theme 1 :
Assessing dynamic permafrost degradation mechanism and vulnerability (JAMSTEC)

Sub theme 2 :
Quantifying organic carbon content (GHG) in large permafrost ice and sediments (Kitami Inst. of Technology)

Impact of Arctic sea ice decline on recently observed climate change: a coordinated multi-model study

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To what extent the recent sea-ice decline influenced Northern Hemisphere climate trends remains an open question. To address this we perform two atmospheric general circulation model experiments: In both experiments observed daily sea ice cover variations are prescribed for the period 1982 to present, while for SST, one experiment uses observed daily variations and the other the observed climatology. The experiment is performed by six different state-of-the-art AGCMs. Our results show that the observed wintertime temperature trend near the surface is poorly reproduced. The impact of SIC variation seems to be confined near the surface, while SST variation seems a key for temperature trend above. This suggests a necessity to consider the atmospheric poleward energy transport associated with SST variation to understand the observed arctic amplification. The simulations fail to reproduce the observed changes in the Siberian High and Eurasian wintertime cooling. Northern hemisphere surface and zonal mean tropospheric temperature trends are better reproduced in boreal autumn, but the impact of sea ice decline remains limited to the lower troposphere. Other aspects of SIC/SST impact on the observed circulation change such as NAO shall also be discussed.

Keywords: Sea ice decline, Climate Change, Sea ice impact

北極海の海氷偏差に対する大気応答の評価
Evaluation of Atmospheric Response to Arctic Sea Ice Anomalies

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During the last decade, severe winters occurred frequently in mid-latitude Eurasia, despite increasing global- and annual-mean surface air temperature. Statistical analyses of observational data have suggested that some part of these cold winters were forced by Arctic sea-ice decline. However, numerical modelling studies have shown different conclusion depending on the used model and experimental settings, and whether or not the cause is due to sea ice reduction is controversial. Therefore, it is important to clarify the cause of the diversity of simulation results, especially the extent to which sea ice anomaly controls the atmospheric circulation.
In this research, we successfully detected the signature of Eurasian cold winters excited by sea-ice decline in the Barents-Kara Sea, by generating a four kind of long-term historical and large-member ensemble simulation based on atmospheric general circulation model (AGCM). The sea ice reduction tends to increase occurrence frequency of cold winter over the central Eurasia, but its effect may have been underestimated in the AGCM. We conclude that this is one of the big reasons that conclusion change depending on model experiments.

キーワード：海氷、北極、寒冬
Keywords: sea ice, the Arctic, cold winter

北極温暖化増幅に伴う傾圧不安定波の応答について

Baroclinic Wave Response to the Arctic Amplification of Global Warming

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近年の温暖化は北極域で顕著に現れ、特に秋季から冬季の北極域の気温上昇率は全球平均と比較して約2倍大きくなっている。この現象は北極温暖化増幅(Arctic Amplification: AA)と呼ばれている。AAの要因には、アイス・アルベドフィードバック、雲のフィードバック、中緯度から北極域への熱や水蒸気の輸送などが重要と考えられている。中緯度から北極域への熱輸送は、傾圧性擾乱が担っているが、AAに伴い傾圧性は弱くなると推測される。本研究の目的は、地球温暖化によりAAが進行し、中緯度の傾圧性が低下する中で、傾圧不安定波の増幅率や構造がどのように変化し、傾圧性擾乱による熱輸送や運動量輸送がどのように変化するのかを理論的に調べることである。AAに伴う高温偏差は北極圏の大気全体で生じるが、海氷とのフィードバックにより大気下層で特に顕著である。線形不安定解析によると、AAに伴い寒帯ジェットは広域で弱化し、それに伴い傾圧不安定波の増幅率は減少する。また、擾乱による高緯度の運動量輸送は北向きから南向きに変化するような構造変化を伴うことから、寒帯ジェットはさらに弱化するという正のフィードバックが傾圧性擾乱に見られた。

キーワード：北極温暖化増幅、傾圧不安定波、線形安定性解析、傾圧性擾乱、渦運動量輸送
Keywords: Arctic amplification, Baroclinic instability waves, Linear stability analysis, Baroclinic eddies, Eddy momentum transport

MODISデータから抽出したグリーンランド氷床上の積雪粒径の年々変動 - TerraとAqua及びそれらのコンポジットの違い -

Interannual variation of snow grain size on Greenland ice sheet retrieved from MODIS data –difference between Terra, Aqua and their composite –

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Surface albedo in accumulation area of Greenland ice (GrIS) sheet mainly controlled by variation of snow grain size because snow impurity concentration is low. Recent warming in the Arctic could accelerate snow metamorphism and thus bring snow grain growth. Possible cause of recent darkening in accumulation area of GrIS is snow grain growth, which has a positive feedback to the further warming in the Arctic. Satellite remote sensing is an efficient tool for monitoring of snow parameters. However, long-term variation of satellite sensor sensitivity may affect the retrieval result of grain size as well. MODIS onboard Terra and Aqua is one of the most suitable satellite sensors to retrieve snow grain size, but it is reported that the sensor degradation of Terra/MODIS is more significant than Aqua/MODIS (Polashenski et al., 2015). Hence, it could affect the long-term variation of snow grain size retrieved. Recently, sensor sensitivity-corrected data set of Terra and Aqua/MODIS (C6) were released (Lyapustin et al., 2014). Using these data, we retrieved surface snow grain size (Rs1) on GrIS from Terra and Aqua independently, with the algorithm based on a look-up table (LUT) method (Stamnes et al., 2007) at the wavelength of 1.24 μm. The LUT for bidirectional reflectance distribution function was calculated with a radiative transfer model for the atmosphere-snow system (Aoki et al., 2000) using a snow shape model employing Voronoi columns and aggregates (Ishimoto et al., 2012).

To analyze long-term variation of Rs1, monthly mean for all snow-covered area in GrIS was calculated from monthly mean image of Rs1, which is calculated from the daily images of Rs1 on GrIS. Comparing monthly mean Rs1 between Terra and Aqua, the monthly mean values of Rs1 derived from Terra were slightly smaller than those from Aqua. The differences are almost less than 10%. Since the year of launch differs between Terra and Aqua, we compared the interannual trend of Rs1 during the same period from 2003 to 2016 for Terra and Aqua. Both interannual trends from April to September agree well each other. Then, we calculated composite Rs1 from Terra and Aqua, by which we investigated variation of Rs1 for 2000-2016. The result shows that interannual trend of Rs1 is the largest (+32 μm/decade) in July and small positive in April, May, June and August, and negative in September. However, this situation changes for plateau area higher than 3 km, for which the largest interannual trend of Rs1 is relatively small (+14 μm/decade) in July and furthermore small positive in April, May, June and August, and small negative in September. These results means the snow surface grain size on GrIS has an increasing tend except for

September during 2000-2016 and thus contributes to albedo reduction.

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キーワード：積雪粒径、アルベド、グリーンランド氷床、衛星リモートセンシング、MODIS
Keywords: snow grain size, albedo, Greenland ice sheet, satellite remote sensing, MODIS

Sr-Nd同位体比から明らかになったグリーンランド西部沿岸域の氷河上クリオコナイトに含まれる鉱物の起源

Variations in Sr and Nd isotopic ratios of mineral particles in cryoconite in western Greenland

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近年，グリーンランドの氷河において急速な表面の暗色化が報告されている．暗色化に伴う雪表面アルベドの低下は，氷河の質量収支に影響を与えていることが明らかになっており，近年の北極域の氷河氷床の縮小は単に温暖化による気温上昇だけでなく表面の暗色化の影響も受けている可能性がある．この暗色化の主な要因として，氷河上に堆積する暗色の不純物，クリオコナイト（鉱物粒子と有機物）の堆積量の増加が考えられているが，その起源や輸送過程について明らかにした例はほとんどなく，増加のメカニズムについてもわかっていない．本研究では，地球化学的な物質循環トレーサーであるSr-Nd同位体比を用いて，グリーンランド西部の複数の氷河暗色域表面に堆積するクリオコナイトを分析し，含まれる鉱物粒子の起源を明らかにすることを目的とした．グリーンランド氷床上の鉱物の起源としては，1. モレーンやツンドラなどの氷河周辺堆積物，2. 氷体内ダスト（過去に氷河上流域に堆積した鉱物粒子が氷体内を取って下流へと運ばれ，表面に露出したもの），3. 遠方の砂漠からの長距離輸送ダストの3つの可能性が先行研究で示されていることから，これらの堆積物のSr-Nd同位体比と比較することで暗色域の鉱物の起源を推定した．

鉱物の同位体比は，氷河の地理的位置によって大きく異なる値を示した．北に位置する氷河では Sr が高く，反対に南に位置する氷河では低い値を示した．このことは，各氷河上の鉱物の起源が地域によって異なることを示している．しかしながら，この値を各地の堆積物の値と比較すると，同位体比はいずれの氷河においても氷河周辺に堆積するモレーンおよび氷体内ダストに比較的近い値を示し，アジアやアフリカなどの乾燥域の砂漠とは著しく異なる低い Nd 比を示した．このことから，各氷河のクリオコナイトに含まれる鉱物は，遠方の砂漠から供給された風成塵ではなく，主にそれぞれの氷河周辺から供給されたものであることがわかった．地域による同位体比の違いは，各氷河周辺地域の地質条件を反映していると考えられる．

同位体比は1つの氷河内でも標高によって異なる値を示した．これは，氷河上の鉱物粒子がただ1つの起源から供給されているわけではなく，複数の起源から供給されていることを示している．北部のカナック氷河では，上流域は氷河周辺のモレーンに近い値を示したのに対し，中流域は氷体内ダストに近くなった．カナック氷河の中流域には他の地点に比べて鉱物粒子が多く堆積しており，表面に黒い縞状の模様を形成していることから，カナック氷河では氷体内ダストの供給が表面の暗色域形成に重要な役割を果たしている可能性が示唆された．また，南部のラッセル氷河では，下流域の更新世の氷表面と中上流域の完新世の氷表面に堆積する鉱物の同位体比が大きく異なったことから，この2つの時代で鉱物が異なる起源から供給されていた可能性が示唆された．

キーワード：グリーンランド、氷河暗色化、Sr-Nd同位体比、鉱物起源
Keywords: Greenland, Darkening of glaciers , Sr and Nd isotopic ratios, Mineral source

グリーンランド北西部カナックで発生した氷河融解水による洪水の表面質量収支モデルによる検証

Meltwater floods at Qaanaaq ice cap in northwestern Greenland investigated by using a surface mass balance model

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海水準上昇への寄与といったグリーンランド氷床変動の全球的な影響については，これまでに数多くの研究がなされてきた．しかしながら，グリーンランド氷床の変化がそこに住む人々の生活に与える影響についてはあまり着目されていない現状にある．グリーンランド北西部に位置するカナック村は人口約500人の集落であり，これまでGRENE北極気候変動事業およびArCS北極域研究推進プロジェクトで氷床観測の拠点となってきた．このカナック村では2015年7月21日と2016年8月3日に洪水が発生し，集落と空港とを結ぶ道路が流出した．この洪水は村の北側に位置するカナック氷帽からの流出水によって発生したものである．過去にも数年に一度同様の災害が発生しているが，2016年の洪水は特に大規模なものであった．この洪水災害は北極域における氷河氷床の変化がその地域の人々の生活に影響を与えた事例のひとつである．

そこで本研究では，2015年と2016年にカナック村で発生した洪水災害の検証を行った．カナック氷帽からの流出水量の推定には表面質量収支モデルNHM-SMAP(*Niwano et al.*, 2012, 2014)の5 kmグリッドの出力結果を使用した．その出力結果を*Noël et al.* (2016)の方法により融解量の標高依存性を考慮して，300 mグリッド上に統計的にダウンスケーリングした．ダウンスケーリングにはByrd Polar and Climate Research Centerが公開している数値標高モデルと氷河領域マスクを使用した(*Howat et al.*, 2014)．はじめにダウンスケーリングされた出力結果と2012–2016年にカナック氷河で観測した表面質量収支との比較を行った．続いてダウンスケーリングされた流出水量についてカナック氷帽での総和を計算することで総流出水量を推定した．

解析の結果，どちらの事例においても洪水の発生当日もしくは前日に顕著な流出水量が推定された．2015年の洪水当日にあたる7月21日には，その夏で2番目に大きな流出水量が推定された．洪水当日から2日後の23日までは，その夏に最も高い日平均気温が観測された．洪水当日には高標高域において，その夏で最大となる融解量が計算されていた．しかし，それ以降は顕著な融解量は計算されていなかった．2016年の洪水前日にあたる8月2日には，その夏で3番目に大きな流出水量が推定された．この日はどの標高帯においても，その夏で最大となる降水量が計算されていた．以上の解析から，2015年の洪水は顕著な融解が，2016年は多量の降水が洪水を引き起こしたことが示唆された．どちらの事例でも融解期の終わりに洪水が発生していたことが判明した．

キーワード：グリーンランド、氷河、表面質量収支モデル、洪水
Keywords: Greenland, Glacier, Surface mass balance model, Flood

Validation of soil moisture contribution to near surface temperature by numerical sensitivity experiment in Northeastern Asia

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Variations of near surface temperature of June-August due to difference soil moisture (SM) product is investigated by numerical experiments utilizing WRF model in Northeastern Asia. A 30-year (1981-2010) numerical experiment has conducted using ERA-interim reanalysis data as an initial and boundary condition to clarify the importance of SM contribution to the JJA extreme temperature and heat wave (HW). SM is known to be an important parameter to influence temperature by regulating surface energy balance through latent and sensible heat fluxes. To evaluate SM contribution to JJA temperature under similar atmospheric circulation, two experiments, reanalysis-SM (R-SM) as a control and satellite-SM (S-SM), have been compared. Both experiments were conducted during 20th May through 1st September. The S-SM experiment used initial SM condition derived from European Space Agency-Climate Change Initiative (ESA-CCI) dataset. During the numerical integration, SM can evolve as a result of atmosphere-land interaction. The model experiment has successfully generated the increasing trend of HW for frequency and intensity in R-SM. The result shows that S-SM experiments have improved the maximum surface air temperature and HW by 1.1˚C and 0.7 days year^{-1} on average during 1981-2010 in Mongolia. The amount of rainfall is reduced due to using S-SM as an initial condition in comparison to R-SM. In addition to rainfall, enhanced interaction of land and atmosphere is simulated in S-SM run, which higher positive anomaly at 500 hPa has developed in S-SM than R-SM by major HWs. Therefore sensitivity experiments confirm that ERA-interim estimates more SM in Northeastern Asia which results underestimate temperature and overestimates rainfall by model.

Time-lag effects of forest ecosystem response to climate change in continental dry climate zones over the circum-Arctic; a multiple approach using satellite images and tree-rings analyses

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Circumboreal forest ecosystems are exposed to a larger magnitude of warming in comparison with the global average, as a result of warming-induced environmental changes. Understanding the sensitivity of tree growth to climate in these ecosystems is an important factor in the accuracy of future projections of the terrestrial carbon cycle, and also of global climate. However, it is not certain how these ecosystems respond to these changes.
In this study, we compared past 30 years spatio-temporal variation of Global Inventory Modeling and Mapping Studies (GIMMS) satellite derived normalized difference vegetation index NDVIg, its recent successor version NDVI3g, and tree-ring width index (RWI) on International Tree-Ring Data Bank (ITRDB) over circum-arctic region (>50N) with respect to relationship with climate change. The comparisons are conducted for linking those indices each other and for obtaining better estimate of vegetation activity response to climate change.
We calculate correlation coefficients between those indices and both previous and current year meteorological data, for each grid/site, and higher correlation coefficients were considered as actual response of forest ecosystem. Given the time lag effects of RWI or NDVI response to climate change, above indices in continental dry regions such as inner Alaska and Canada, southern part of Europe and southern sections of the Rena river basin in eastern Siberia tend to show significant negative correlation with summer temperature of previous year, suggesting further reduction of ecosystem carbon uptake with future warming.
Our findings highlight that the time lag effects of forest ecosystem response to climate change significantly affects relationships between both NDVI and RWI, and climate variables and it therefore should be incorporated into future carbon cycle studies. Otherwise, future projection of forest ecosystem carbon uptake may be overestimated under expected future further warming.

キーワード：周北極圏陸域生態系、炭素循環、樹木年輪、リモートセンシング
Keywords: Arctic and sub-Arctic ecosystems, carbon cycle, tree ring, remote sensing

The role of vegetation change upon polar amplification in warm climate by feedback analysis

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Previous studies revealed that vegetation change in high latitude (e.g. from tundra to forest) in warm climate strengthen a polar amplification. This is due to lower vegetation albedo of forest then tundra, snow-albedo feedback caused by early snow melt due to forest coverage and ocean heat emission in autumn and winter. In the present study, we run a vegetation–coupled general circulation model with a slab-ocean, MIROC-LPJ, for two kinds of warming experiments. One is due to higher atmospheric CO2 concentration (2xCO2 and 4xCO2) and the other is due to the difference of the Earth’ s orbit (mid-Holocene and the Last Interglacial). The result shows different mechanisms of warming amplification between CO2-induced vegetation feedback and orbit-induced vegetation feedback. We also try to apply a feedback analysis (Cai and Luo 2009; Yoshimori et al. 2014) to result of MIROC-LPJ experiments.

キーワード：極域増幅、植生、古気候
Keywords: polar amplification, vegetation, paleoclimate

凍土動態を考慮した全球陸面-植生モデルによる将来予測
Projecting future greenhouse gas release by global land surface-vegetation coupled model with explicit permafrost dynamics

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永久凍土は、寒冷な高緯度域に広く分布している。高緯度域は特に地球温暖化の影響を受けやすく、凍土層の温度が上昇し、夏に解ける上部の層（活動層）が深くなるという現象が、すでに観測されている。また近年「エドマ層」と呼ばれる非常に高い割合で氷を含んでいる永久凍土が、急激に融解し、大規模な地盤陥没が起こっていることなども報告されている。永久凍土には、氷河期の頃から分解せずに堆積された多くの有機物が含まれており、その炭素総量は、不確実性が大きいものの、大気中炭素の2倍程度、陸域土壌炭素と同程度の量であると推定されている（IPCC 第5次評価報告書）。永久凍土の融解は、土壌中の有機炭素を大気に放出し、大気の温室効果ガス濃度を上昇させる。これにより地上気温が上昇することで、永久凍土の融解がさらに加速するという、正のフィードバックがある。しかし、その実態解明は不十分であり、特に近年観測されているエドマ層の不可逆的な融解がもたらす影響については、これまで十分に研究がなされていない。そこで本研究（環境省「環境研究総合推進費」2-1605, H28-30）では、エドマ層のような高含氷な永久凍土の不可逆的な融解による温室効果ガス放出量の現状評価と将来予測を行う。アラスカやシベリアにおける現地調査、衛星データ解析、全球陸面過程モデル•陸域生態系モデルの改良を有機的に組み合わせて行うことで、永久凍土の融解過程に関する脆弱性分布や、気候変動に対する相対的な寄与を解明することを目標とする。

全球モデル開発に関しては、陸面過程モデルMATSIROおよび陸域生態系モデルVISITの改良を行っている。陸面過程モデルの開発に関しては、土壌の熱物理過程を評価する際に、凍結土壌水分•土壌有機層•不凍結水を考慮すること、また土壌の鉛直解像度を増やすことにより、凍土融解過程の高度化を行った。土壌物理を高度化することにより、地下氷の量が減少すること、また凍土の季節進行に関して、より現実的な分布が得られる傾向にあることが分かった。また、陸域生態系モデルの開発に関しては、永久凍土融解による温室効果ガス放出過程の定式化の検討を行った。二酸化炭素の放出に関しては、凍土融解によって生じた有機物を、土壌微生物が従属栄養呼吸することによって放出される項を追加する。またメタンに関しては、永久凍土の融解による湿原の拡大によって、追加的に放出されるメタンの量を評価する。発表では、全球モデル開発によって得られた知見を報告する。

キーワード：永久凍土、温室効果ガス、気候変動
Keywords: Permafrost, Greenhouse gas, Climate change

領域モデルWRF/Chemを用いた2016年9月のシベリア森林火災由来のBCおよびオゾン輸送推定

Estimation of the Siberian fire in September 2016 on the concentration of ozone and BC in the Pan-Arctic region using a regional chemical transport model

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ブラックカーボン(BC)粒子は化石燃料やバイオマスなどの不完全燃焼により発生する黒色のエアロゾル粒子で、PM2.5の一成分として知られている。BCは大気中で光を吸収する性質を持ち、IPCCなどでも二酸化炭素やメタンなどに次ぐ主要な温室効果気体の一つとして考えられている。とくに高緯度域においてはBCを含むことにより雪や氷のアルベドが大きく変化し、その融解を加速させることから、気候変動に大きな影響を持つことが示唆されている。BCの発生源としては全球的には工業、輸送、家庭などでの化石燃料や薪などに由来するものと森林火災とがそれぞれほぼ同程度と推定されている(cf. Lamarque et al., 2010)が、周北極域内での放出源としてはシベリア、北米大陸高緯度域などでの森林火災の寄与がかなり大きいと考えられる。これら周北極域でのBCの気候および環境への影響を評価するため、周北極域を対象とした領域化学輸送モデルWRF-Chem version 3.8.1 を用いた数値計算を実施した。気象場の初期条件、境界条件はNCEP-GFSを利用した。また人為起源エミッションについては EDGAR4.2を使用した。森林火災エミッションについては NCAR FINNを用い、かつ森林火災由来の熱対流による鉛直分布も考慮している。生物起源エミッションについてはモデル内でオンラインモジュール化されたMEGAN2.1を用いた。気相およびエアロゾルモジュールはそれぞれRACMおよびGOCARTを使用した。BCについては疎水性BCとして放出され、2.5日の時定数で親水性BCに変換されるものとした。NCAR FINNのシベリア域での森林火災エミッションについて2014年以降を比較したところ、2016年9月は過去3年間の中でも顕著なイベントが見られていたため、対象期間を 2016年8月から9月の2か月間として計算を行った。また領域内での森林火災の影響を評価するため、人為起源、生物起源、森林火災のすべてを考慮した場合と人為起源および生物起源のみ考慮した場合の２ケースの実験を行った。当該計算期間は観測船「みらい」の北極航海期間中であり、モデルによる気象場(風速、風向、気圧、気温)を「みらい」による観測値と比較したところ概ね妥当な再現性を示していた。また9/25以降ベーリング海周辺でBC濃度の増加が見られていたが、２ケースを比較したところ、9/20以降にバイカル湖周辺で見られた森林火災に由来すると推定された。当該火災域ではBC以外にもNOxおよびCOなどのオゾン前駆物質の濃度も森林火災により顕著に増加していたため、モデル結果ではオゾン濃度も最大で40ppbv程度、森林火災により増加していた。

キーワード：ブラックカーボン、領域化学輸送モデル、周北極域、森林火災
Keywords: Black Carbon, regional chemical transport model, Pan-Arctic, biomass burning

シベリアでの大規模森林火災期間中の気象条件　-　サハ南部での条件
Weather Conditions During Large-Scale Widespread Forest Fires in Siberia: Conditions in Southern Sakha

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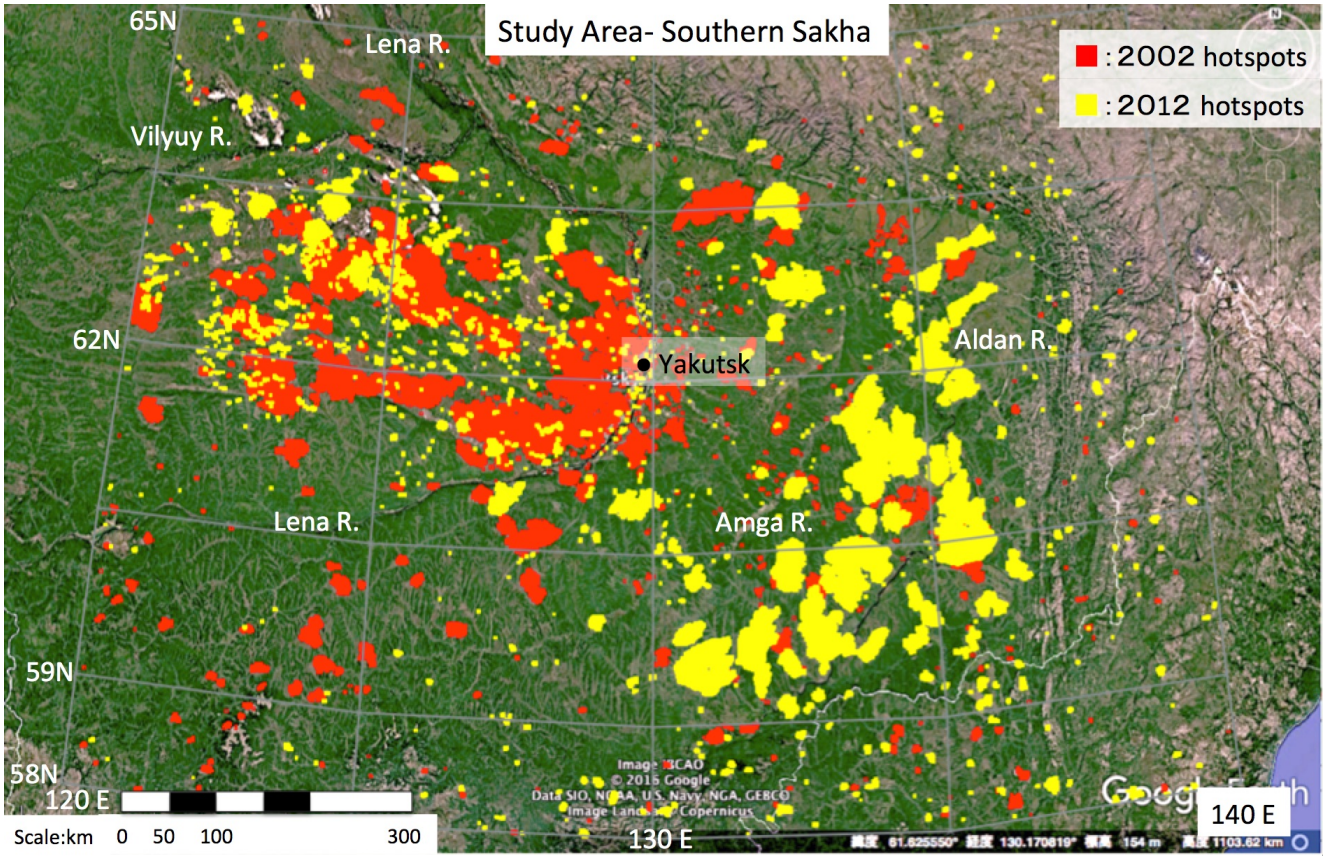
北方林（タイガ）の総面積は約12,000万km^{2}で，世界の森林面積の約3分の1を占めている．世界の北方林の約70%がユーラシアにあり，ロシアには北方林約6,200,000 km^{2}がある．この広大なロシアの北方林では，毎年，いろいろな所で森林火災が発生している．10年以上のMODISのホットスポット・データ（HSと略）を解析することで，ロシアの北方林での火災頻発域が次第に明らかになってきている．今回は，サハ南部の北方林での大規模森林火災の気象条件を分析した結果を報告する．大規模な森林火災は火災発生後の気象条件に依存している．著者らは既にアラスカの総観的大規模火災の気象条件をMODISのHSデータ（2003~2015年）解析で明確にし，報告済みである．アラスカでは，上位4つの大火災期間は，ロスビー波砕波（Rossby wave breaking (RWB)）に関連した類似した独特な高気圧火災気象条件下で発生した．火災の発生後，RWB現象に関連する典型的な火災気象条件下で，高気圧システムがアラスカを南から北に移動する前後に2つのHSピーク（大火災）が生じた．最初のHSピークは，アラスカ湾の気圧の尾根による南西風で生じた．2番目のHSピーク（最大の火災）は，RWB条件下で高圧システムが北に移動した後，ビューフォート・シー高気圧（Beaufort Sea High）が発達し，アラスカ州内陸で比較的強い東寄りの風を吹き込み，発生した．これらの気象現象に加えて，北極での低気圧発達に伴う低気圧関連で発生する火災気象条件下でも，南西風が単一の大きなHSピークを伴って高い火災活動を引き起こしていた．

サハ南部の北方林では，2002年と2012年に大規模森林火災が発生した．両年の7月と8月のホットスポットのピークの気象条件を調べた結果，アラスカと同様に高気圧と低気圧の二つのパターンが確認された．高気圧タイプでは，ヤクーツク北方に気圧の尾根が形成されていた．低気圧タイプでは，北極海の低気圧が重要な役割を果たしていることが明らかとなった．

キーワード：広域森林火災、MODISホットスポット、ジェット気流蛇行
Keywords: Widespread fires, MODIS hotspot, Jet stream meandering



Interannual variability of summer precipitation over northern Eurasia in multiple climate models

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Global warming is projected to be amplified in high-latitude region. Because the Arctic sea ice loss has been already beginning to appear, hydrological cycle in the northern part of Eurasia may be affected by the global warming and the Arctic sea ice reduction. Fujinami et al. (2016) showed summer precipitation increased after 1980 in northern Eurasia, and Hiyama et al. (2016) discussed a possible effect of the recent Arctic sea ice reduction on the modulation of interannual variability of summer precipitation. Such changes are important issues for the current environment including the ecosystem over northern Eurasia In addition, the reliable future projection and understanding of the hydrological cycle system are also important for mitigation and adaptation of future environmental changes.
In this study, we investigated characteristics of interannual variability of summer precipitation in northern Eurasia in 16 climate/earth system models, which have been used for the projection of future climate change, to assess whether recent global warming and the Arctic sea ice reduction affect realistically the northern Eurasian environment in the models. To reduce uncertainty related to oceanic change, we used data of the historical simulations of CMIP5 from 1979 to 2008 with observed sea surface temperature (SST) and sea ice conditions.
The spatial distribution of precipitation averaged for summer (June-July-August) in northern Eurasia in each model is similar to the observed one. Unlike the observed increase in summer precipitation in Siberian region (Fujinami et al. 2016), there is no model showing a remarkable increase trend of summer precipitation averaged over Siberian region. EOF analysis was performed for each model to extract the leading modes of interannual variability of summer precipitation in northern Eurasia. Although the EOF spatial patterns differs among the models, the first three EOF patterns of many models includes a pattern similar to the east-west seesaw pattern, which is a leading mode of the observed interannual variability. Furthermore, Hiyama et al. (2016) showed difference in the interannual variation pattern of observed summer precipitation in the northern Eurasia between the two periods before and after 1990, and also discussed the relationship between this difference and the Arctic sea ice reduction. Then we compared the frequency of EOF score values between the first 10 years (1979-1988) and the last 10 years (1999-2008) in each model. In many models, the mean or variance of score values at an EOF mode changed significantly between the periods. However, the spatial pattern of the EOF where the frequency change of the score value occurred was not similar between models.
As a result, the characteristics of interannual variability in northern Eurasia differ greatly among the models. However, it turned out that the observed east-west seesaw mode was included as one of the interannual variability in almost all of the models. In addition, some models revealed that the interannual variability of summer precipitation in northern Eurasia modulated after 1980, as discussed in Hiyama et al. (2016). In this presentation, atmospheric circulations related to the EOF modes are also shown.

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キーワード：夏季降水量の経年変動、ユーラシア北部、地球温暖化
Keywords: Interannual variability of summer precipitation, northan Eurasia, global warming

How Predictable Summer Arctic Cyclones in 2012 and 2016 Were?

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Arctic cyclones (ACs) have a long lifetime and a wandering track in the Arctic region. The structures of the ACs are characterized by the warm and cold cores at upper and lower levels, downward and upward drifts at upper and lower levels, and barotropic relative vorticity. ACs have large impacts on the Arctic systems like the sea water temperature and the sea ice. ACs also have social impacts on the Northern Sea Route of ships and the Polar Route for airplanes. Therefore, accurate predictions of ACs are important for environmental and social concerns.
Extreme ACs occurred in August 2012 and 2016. The AC in 2012 (AC2012) was generated over the north of the Eurasia on 2 August 2012. The minimum sea level pressure (SLP) of 964 hPa for the AC2012 was recorded on 6 August 2012. On the other hand, the cyclogenesis of the AC in 2016 (AC2016) was over the north of the Scandinavian Peninsula on 11 August 2016. The minimum SLP of 967 hPa for the AC2016 was recorded on 16 August 2016. Although the positions of the cyclogenesis were different, both ACs recorded the minimum SLP over the Pacific sector of the Arctic Ocean. In both cases, the AC merged with a cyclone connecting with an upper polar vortex over the Arctic Ocean few days before the development of the AC. Some previous studies indicated that the AC2012 contributed greatly to the record low sea-ice extent in that summer. Similarly, it is thought that the AC2016 could have an influence on the decrease in sea-ice cover, since sea ice extent in early September of that year was the second lowest on record.
In this study, we investigated the predictability of the extreme ACs in August 2012 and 2016, using operational medium-range ensemble forecasts provided by The Interactive Grand Global Ensemble (TIGGE). The minimum SLP of the AC2012 on 6 August was well predicted by CMC, ECMWF, and JMA (NCEP and UKMO) members 2 (3) days in advance. Some ECMWF and NCEP members initialized in late July 2012 also predicted the development of the AC2012. On the other hand, the minimum SLP of the AC2016 was more predictable than that of the AC2012. The development of the AC2016 was well predicted by ECMWF members 6 days in advance and by CMC, JMA, NCEP and UKMO 3 –5 days in advance. Comparisons between higher- and lower-skill members revealed that the accurate prediction for the development of the upper warm core could lead to the accurate prediction of the AC development in both cases. Baroclinic growth and subsequent nonlinear dynamics during the merging contributed to the development of the upper warm core. Even if the baroclinic growth was predicted well, predicted AC did not develop when the merging was not predicted accurately. Therefore, a correct prediction of for the AC track is one of the important factors for accurate prediction of the AC development. The predicted cyclone track was similar to the observed cyclone track when the upper-level wind was predicted well. In conclusion, the accurate prediction of the upper-level wind can lead to the correct prediction of the ACs through the development of the upper warm core.

キーワード：北極低気圧、暖気核、低気圧の併合、アンサンブル予報
Keywords: Arctic cyclone, warm core, cyclone merging, ensemble forecast

シベリアの春季積雪減少が東アジア域の大気循環場に与える影響
Influence of Springtime Eurasian Snow Cover Retreat on Atmospheric Circulation over East Asia

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気候変動に関する政府間パネルの第5次評価報告書によれば、北半球春季の積雪域が1990年以降大きく減少していることが報告されている。また、最近の研究では、この変化が大気循環場に影響を及ぼしている可能性も指摘されている。本研究では、人工衛星観測に基づく広域積雪データおよび客観解析データを用いて、春季シベリアにおける積雪減少が東アジア域の大気循環場に及ぼす影響を調査した。

西シベリアで領域平均した4月の積雪被覆率を基準として、大気場および陸面の合成図解析を行った。積雪被覆率が大きい年に比べ、小さい年には4月だけでなく6月にも日本付近で上層のジェット気流が南へ蛇行することが確認された。また、西シベリア南部から中央アジアにかけて、積雪被覆率が小さい年の6月には地表面温度が有意に上昇し、土壌水分量が有意に減少していることが確認された。さらに、積雪被覆率が小さい年の5-6月には、地表面から大気への顕熱輸送量が有意に増加し、上層の大気温度も有意に上昇していた。以上のことから、積雪減少に伴う融雪水の減少が消雪後の土壌水分を減少させることで、陸面から大気への蒸発を抑制して地表面が加熱されるとともに、地表面から大気への顕熱輸送量が増加して大気を加熱し、大気循環場に影響を与えている可能性の高いことが示唆された。

キーワード：地球温暖化、積雪、大気陸面相互作用
Keywords: Global warming, Snow cover, Land and atmosphere interaction

東グリーンランド深層氷床掘削プロジェクト（EGRIP）キャンプにおける2016年ピット観測から明らかになった近年の堆積量の変動
Variation of recent annual snow depositions estimated on the 2016 pit observation at the East Greenland Ice Core Project (EGRIP) camp

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グリーンランドにおける気候・氷床変動を明らかにするため，デンマークのコペンハーゲン大学が主導して実施する、東グリーンランド深層氷床掘削プロジェクト（EGRIP計画）が2015年より開始されている。日本は北極域研究推進プロジェクト（Arctic Challenge for Sustainability: ArCS）の一環としてEGRIP計画に参加し、各国と共同研究を行っている．本研究では、近年の年間堆積量、季節毎の堆積量、そして積雪中の様々な化学種・ダストの濃度レベルを把握する目的で、2016年7月にEGRIPキャンプ（75° 37' N，35°59' W）の2地点にて、4.02 m深と3.18 m深のピット観測を実施した。ピット観測では、0.03 m毎に雪氷試料の採取と密度測定を行った。現在、4.02 m深のピットについて、積雪の水安定同位体比（δ^{18}OとδD）の測定が終了している。δ^{18}OとδDの深さプロファイルは明瞭な季節変動を示しており、降雪が年間を通じて定期的に生じていることを示唆した。また季節サイクルの数から、4.02 mの積雪は、2008～2016年までの9年間分の堆積に相当することが分かった。年間堆積量は水当量（water equivalent：w. e.）で99～247 mm w.e.の間で推移し、その平均値は167 mm w.e.であった。北グリーンランドの NEEM（North Greenland Eemian Ice Drilling）キャンプで実施されたピット観測では、2006～2008年の年間堆積量の平均値は176 mm w.e.と報告されており、本研究の結果はそれと同程度であった。また、密度の深さプロファイルは、冬に高密度、夏に低密度になる季節変動を示した。同じような傾向がNEEMキャンプやグリーンランドのSummitにおいて確認されており、これら先行研究で議論されているwind-pack effectがその要因の一つとして考えられた。発表当日は、化学種・ダストの分析結果および、3.18 m深ピットの結果についても発表する。

キーワード：グリーンランド、アイスコア、質量収支、積雪、安定同位体比
Keywords: Greenland, ice core, mass balance, snowpack, stable isotope ratio

MODISおよびAMSR-2を用いたグリーンランド氷床表面反射率と輝度温度の季節変化解析

Seasonal variations of Greenland ice sheet surface reflectance and brightness temperature derived from Terra/MODIS and GCOM-W/AMSR-2

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Dark ice area expansion on the Greenland ice sheet is one of the factors to cause albedo reduction and mass loss of the ice sheet in recent years. Dark ice appears on ablation area in summer and accelerates melting of the ice sheet due to its intense light absorption. Dark ice is due to impurities in the surface ice such as mineral particles, glacial microbes, organic matter and their aggregate called cryoconite granules. Cryoconite granules are formed by microbial activities and are darker than abiotic mineral particles. Since the microbes can be active only on melting ice surface, duration of surface melting on the ice sheet possibly affect the microbial activities and thus formation of cryoconite granules. Therefore, spatio-temporal variation in surface melting is important to understand the darkening process.
We report seasonal variations in surface reflectance and brightness temperature derived from Terra/MODIS and GCOM-W/AMSR-2 satellite images in order to understand relationship between darkening and surface melting processes of the ice surface from April to August in 2013, 2014, 2015 and 2016. Reflectance (660 nm) and brightness temperature (18 GHz Horizontal polarization) were investigated at the nearest neighbor pixel of the Automatic Weather Station (67.07N, 48.83W) installed by PROMICE. The brightness temperature showed similar timing of the onset of surface melting in 2013 and 2015. In these years, the melting onset occurred in early June. On the other hand, the melting onset occurred in mid May in 2014 and 2016. The surface reflectance started to decrease down to around 0.4 in mid July 2013 and early July 2015. In contrast, it rapidly decreased down to around 0.4 in the end of June 2014 and early June 2016. These results suggested that earlier onset and prolonged period of the surface melting causes the earlier appearance of the dark ice surface.

キーワード：グリーンランド氷床、衛星リモートセンシング、暗色域
Keywords: Greenland ice sheet, satellite remote sensing, dark ice

北極域における雪氷域面積および海色の長期変動
Long-term variability in land snow cover, sea ice extent and ocean color in Arctic region

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Satellite-based observations revealed that sea ice extent and land snow cover in the Arctic region have decreased since 1979 under the influence of warming trend. Reduced sea ice cover increases open water area, a longer growing season, and annual net primary production (NPP) by phytoplankton. The greatest contribution to the Arctic Ocean’s fleshwater input is the discharge from terrestrial rivers. Because river inflow supplies a large amount of nutrient salts and organic matter to the ocean, change in the discharge affects the Arctic Ocean’s NPP. Thus, successive observations on sea ice extent and land snow cover are crucial to understand the influence of those area reductions on marine ecosystems in Arctic region. In this study, we used multiple optical and microwave radiometric satellite data for 1978–2015 to analyze land snow cover, sea ice extent and ocean color in the northern hemisphere. Sea ice extent deceased during the observation period with the mean rate of 200 km^2 a^{-1}. Snow cover extent decreased in all seasons (winter, spring, summer and autumn) from 1978 to 2015. Decreases in land snow cover and sea ice extent are likely to affect to seasonal and inter-annual variabilities in the amount of freshwater inflow to the Arctic Ocean. However, no clear trend of the ocean color (chlorophyll-a concentration) was observed with statistically significant in this study. To better understand relationship between spatiotemporal variabilities in these factors and other physical parameters, we also analyze variability in sea surface temperature and meteorological parameters and examine their cross-correlation relationship in space and time.

グリーンランド北西部Bowdoin氷河の高濁度融解水流出過程がフィヨルドの基礎生産に与える影響

Effect of subglacial meltwater plume formation on phytoplankton growth in the fjord of Bowdoin Glacier in northwest Greenland

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In Greenland, marine-terminating outlet glaciers discharge turbid subglacial meltwater into fjords. The area influenced by the turbid water near the calving front is well known as an important foraging hotspot for higher trophic animals. Glaciers may therefore play an important role in ecosystem productivity within the fjords by releasing an essential macronutrient for primary producers. However, since there are few available data on the macronutrient delivery with the meltwater inputs, processes of macronutrient supply to surface waters are poorly understood. Here we present a hydrographic and geochemical dataset from Bowdoin Glacier and its fjord in northwestern Greenland during the summer of 2016.
On the glacier, meltwater contained few macronutrients (<0.5 μM NO_3+NO_2) indicating that supraglacial meltwater is not a significant source of macronutrients in the fjord. At the surface of a meltwater plume near the calving front, water properties were largely different from surface waters outside of the plume. The concentration of surface macronutrients inside the plume was an order of magnitude higher (~12.8 μM NO_3+NO_2) than that outside of the plume (<1.6 μM NO_3+NO_2). Additionally, salinity (~33.0) and the content of suspended particles (~132 mg/L) inside the plume were notably higher than those outside of the plume (salinity ~15.4; suspended particles ~22.3 mg/L), suggesting upwelling of nutrient-rich, saline deep water including substantial sediment derived from subglacial weathering. Oxygen isotopic compositions of the glacial meltwater, plume, and fjord water also indicated that the glacial meltwater upwells as a buoyant flow, drawing the nutrient-rich deep water into the fjord. Within a vertical cross-section along the centerline of the fjord, highly turbid water was observed in sub-surface layer at depths of 10–50 m. Less saline water with low macronutrients concentration was on top of this highly turbid water. Phytoplankton blooms (~6.5 μg/L chlorophyll a) was observed near the boundary between the less saline water and the turbid water. The concentration of macronutrients was sufficiently high (~10 μM NO_3+NO_2) in this area to generate the bloom. Overall, our study results show that turbid meltwater discharge from Bowdoin Glacier affects nutrient availability and the subsequent growth of phytoplankton in the fjord. Upwelling and transport of macronutrients associated with subglacial meltwater plume formation is an important process for phytoplankton growth in the near-surface layer.

キーワード：グリーンランド、Bowdoin氷河、主要栄養塩、高濁度融解水の流出
Keywords: Greenland, Bowdoin Glacier, Macronutrient, Turbid meltwater discharge

Fe, Mn, Cd, and Pb Quantitatively Analysed in Sea Ice

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Sea ice plays a significant role in polar oceans. During sea ice formation both dissolved and particulate sea water constituents (trace metals, macro-nutrients, sediments, etc) accumulate through scavenging or suspension freezing (Reimnitz et al., 1992,1993; Nürnberg et al., 1994). This can allow for sea ice to hold trace metal concentrations higher than the underlying water (Grotti et al. 2005; Tovar-Sanchez et al. 2010). Floating (pack) sea ice can then transport incorporated materials into new areas as it melts, seeding the water community below (van der Merwe et al., 2011). Although many studies have looked at sea ice and trace metals, the mechanism and geochemical cycling role for trace metal accumulation is still largely unknown (Kanna et al., 2014). In this study we examined the following metal fractions for Fe, Mn, Cd and Pb: Dissolved (D, <0.2μm), and Labile Particulate (LP, Total Dissolvable - Dissolved) from Chukchi Sea pack ice and the surrounding seawater (shelf and coast). Samples were pre-concentrated utilizing the solid-phase extraction NOBIAS Chelate PA1 resin (Hitachi High-Technologies) following a modification of Sohrin et al. (2008) and Kondo et al. (2016) methods. Finally, samples were analyzed on a Graphite Furnace Atomic Absorption Spectrometer (GFAAS). Applying the modified solid-phase extraction method on sea ice measurements allowed us to accurately detect low levels of trace metals. Utilizing this method allowed us to gain insightful information on the geochemical cycling of trace metals within sea ice.

LPFe, LPMn and LPPb composed 98-99% of Fe, Mn and Pb in Chukchi sea ice where LPCd was 84%. Although Cd and Pb were detectable, the concentrations for the dissolved and labile particulate fractions were very low (0.05±0.04nM –6.3±5.9nM). Overall in sea ice and seawater, the labial particulate fraction had higher concentrations than the dissolved. Sea ice has been shown to have a temporal decoupling of trace metals (i.e. Fe), with the dissolved metals being released with the brine and particulate metals release with advanced melting (van der Merwe et al., 2011). Since our samples were collected during summer, advanced melting could have led to the dominance of the labile particulate fraction.

Chukchi seawater (shelf and coast) samples also showed the same trends where Fe and Mn had higher concentrations than Cd and Pb. LPFe and LPPb composed 99-100% of Fe and Pb in Chukchi seawater. One interesting point was that Pb was detectable in sea ice for both the dissolved and labile particulate factions but only detectable as LPPb in seawater. Mn and Cd composition in Chukchi seawater was dominated by the dissolved fraction (75% and 43% respectively). DFe is removed from seawater by oxyhydroxide formation and particle scavenging, which can give it have lower concentrations than DMn (Landing and Bruland, 1987).

Keywords: Sea Ice, Trace Metals, Dissolved, Labile Particulate

アナディール湾からベーリング海峡にかけてのアナディール水の分布
Distribution of the Anadyr Water near the Gulf of Anadyr and the Bering Strait

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Primary production in the Bering Strait (BS) especially in the Russian side is extremely high and it is found not only in spring but also in summer and autumn seasons. It has been suggested that the continuous high phytoplankton activity is attributed to rich amount of nutrients in the Anadyr Water (AW). Although some literatures reported higher nutrients concentration in the Gulf of Anadyr (GA), similar level of primary production as the BS is difficult to be observed in the GA. In this study, we obtained a historical CTD dataset (1930–2005) compiled at the Far Eastern Regional Hydrometeorological Research Institute (FERHRI) in Russia and investigated water mass structure form the GA to the BS. We analyzed the dataset climatologically because stations of each cruise distribute sparsely. In August, while the AW with high salinity (>35 PSU) distributed near the bottom of the GA, the Bering Shelf Water was covered the surface of the Gulf. The AW was spread along coast of Russia and a part of it was found in the surface of BS. The water mass structure in this study suggests that the AW from the AG continuously supports high primary production in summer of the BS.

キーワード：アナディール湾、アナディール水、ベーリング海峡
Keywords: Gulf of Anadyr, Anadyr Water, Bering Strait

Interannual variability of bottom oxygen concentration and primary production in the southern Chukchi Sea biological hotspot

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Hope valley located in the southern Chukchi Sea is known as one of the biological hotspot (southern Chukchi Sea hotspot, SCH). Large benthic biomass in the SCH is supported by high primary productivity of the water column. The dissolved oxygen (DO) sharply decreases at the bottom toward fall as a result of the high sediment community oxygen consumption in the benthic fauna, while it is saturated during winter. We examined annual/inter-annual variability of bottom DO and its mechanisms analyzing ship-board and mooring hydrographic data, satellite derived primary production, and ecosystem model. The bottom DO showed large interannual variability (104–300 μM) and it was negatively and significantly correlated with cumulative primary production (r = -0.66, $p < 0.05$). Such negative correlation suggests organic carbon flux to the sea floor drives the activity of the benthic community. Environmental process of decreasing in DO was assessed using one box ecosystem model optimized for the SCH bottom layer. The model also captured bottom DO is sensitive to the flux of primary production from the upper layer. Our results suggest inter-annual variability of primary production is a key factor determining the recent changes in biomass and distribution of the benthic organisms.

キーワード：生物学的ホットスポット、基礎生産、底層溶存酸素濃度
Keywords: biological hotspot, primary production, bottom oxygen concentration

西部北極海バロー峡谷沖における陸棚物質の水平輸送の通年モニタリング
Annual monitoring on lateral advection of shelf materials off the Barrow Canyon, western Arctic Ocean

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北極海カナダ海盆南西部において陸棚から海盆への熱や物質の水平輸送は、当該海域の生態系や物質循環を理解するうえで重要である。当海域の海洋物理モデルによると、バロー沖で形成される海洋渦は陸棚物質を取り込み、その渦のボーフォート海洋循環に沿った西方への移動はノースウィンド深海平原南部Station NAP (75˚N165˚W）における一時的な沈降粒子フラックスの増加に寄与している。そこでStaion NAPの上流域であるバロー沖における海洋物理と沈降粒子フラックス変動との関係を観測するため、2015年10月から2016年9月にかけてバロー沖Station NBC15t（72.47˚N 155.41˚W）にセジメントトラップと各種センサーを投入した。セジメントトラップに捕集された粒子は陸源砕屑物を多く含んでいた。トラップを係留した深度約243mにおける全粒子フラックスは、セジメントトラップが詰まった2016年6月以降を除くと14.6-3413.9mg m^{-2} d^{-1}で推移し、その最大値はStation NAPより1桁高かった。全粒子フラックスの極大は2015年10月5-18日と2016年5月12-24日に観測された。またセジメントトラップが機能しなかった2016年9月にも、トラップに取り付けた水中カメラ映像に多くの粒子が記録されていた。各種係留センサーや水中カメラ映像の記録から、2015年10月と2016年9月の粒子フラックス極大期の陸棚起源物質は、セジメントトラップ係留深度より浅い亜表層の水平流の強化によって供給された可能性が高い。2016年5月の粒子フラックス極大は、ADCPを係留した約125mとセジメントトラップ係留深度との間のより限られた深度帯で流速が増加することで形成されたことが推測された。

キーワード：北極海、カナダ海盆、沈降粒子フラックス、陸棚-海盆間相互作用
Keywords: Arctic Ocean, Canada Basin, Settling particle flux, Shelf-basin interaction

海氷減少に対する河川水の熱フラックスの影響
Impacts of terrestrial river heat flux on the declining Arctic sea ice

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In the Arctic, the recent warming speed of surface air temperatures are the fastest among the past historical records. The consequent influences are found in changes in the Arctic freshwater system, such as increasing river discharge, changing river-ice phenology, and warming of river water temperature. The warming water temperature can result in higher heat flux flowing into the Arctic Ocean, combining with the larger river discharge, which likely enhances the melt of sea ice in the shelf area. However, very few studies quantitatively assessed influences of the river heat flux on the Arctic sea ice are available. A land surface model (CHANGE) coupled with models of river discharge, ice-cover, and water temperature through channel network was applied to the Arctic river basins over the period 1979–2013, and then we assessed influences of the river processes on sea ice, including trends of river discharge, water temperature, and heat flux. The simulation indicated obvious increases in river discharge and water temperatures over the pan-Arctic rivers, consequently flowing considerable amount of heat to the ocean. The heat fluxes were significantly correlated with changes of sea surface temperature and sea ice concentration in the coastal areas of the Arctic Ocean, especially in the spring season when the sea ice begins to melt. This emphasizes that the heat flux of terrestrial freshwater is an important factor influencing the melting process of sea ice at specifically seasonal and local scales.

キーワード：河川熱フラックス、海氷減少、陸面過程モデル、海氷密接度
Keywords: river heat flux, sea ice retreat, land surface mode, sea ice concentration

Interannual variation of solar heating in the Chukchi Sea, Arctic Ocean

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Arctic sea ice cover in summer has declined rapidly over the past few decades. The albedo of sea ice is much higher than that of open water; reduction of sea ice cover is associated with increase of solar heating in the Arctic Ocean. In this study, we focus on solar heating in the Chukchi Sea located in the Pacific side of the Arctic Ocean where remarkable sea ice reduction has occurred. The Chukchi Sea is a pathway of Pacific Water from the Bering Strait to the Arctic Basin. The heat transport of the Pacific Water through the Bering Strait, which has increased recently, plays an important role in a decrease in sea-ice formation during winter as well as sea-ice melt in summer in the Canada Basin. Although the Pacific Water heat transport through the Bering Strait is becoming clearer, we expect that solar heating significantly modifies the Pacific Water in the Chukchi Sea. Therefore, we estimate solar heating in the Chukchi Sea through analysis of satellite-derived sea ice concentration data as well as reanalysis data of shortwave radiation, and discuss the role of the solar heating in the Chukchi Sea in the heat transport into the Arctic Basin. We also use in-situ shortwave radiation data obtained by R/V Mirai to validate the reanalysis data of shortwave radiation in the Chukchi Sea.

キーワード：チャクチ海、太陽放射加熱
Keywords: Chukchi Sea, solar heating

バロー海底谷における太平洋水のフラックスと北極海の温暖化への影響
Pacific water fluxes through the Barrow Canyon and its effect on warming in the Arctic Ocean

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近年の北極海における夏季の海氷減少は、太平洋側の海盆域で特に顕著で、ベーリング海峡から流入する太平洋水の増加が原因の一つと指摘されている。チャクチ海北西部に位置するバロー海底谷は、太平洋水の海盆域への主要な流出口である。本研究では、バロー海底谷における流量、熱、淡水フラックスの定量的な見積もりと、そのカナダ海盆の温暖化への役割に注目している。JAMSTECでは、バロー海底谷で2000年から20016年まで通年の係留系観測を実施しており、年平均の流量、淡水、熱フラックスは、0.43 Sv、31 mSv、2.12 TWであることを明らかにした。熱フラックスは非常に経年変動が大きく、年平均で0.93 TW から3.34 TWの幅があった。係留系によるバロー海底谷の熱量と、衛星によるバロー域の海面水温を比較することで、北向き熱フラックスのほとんどが観測される夏季の熱量の長期変動を調べた。その結果、1980年代から2010年代の間に、熱量は1.5倍に増加したことが示唆された。海盆域の海洋観測データから、カナダ海盆域の亜表層は、1990年代以降に水温上昇傾向があり、特に2010年以降は急激に水温上昇が観測されていることが分かった。これは、2007、2010、2012年にバロー海底谷の熱フラックスが多かったことの影響と考えられる。

キーワード：北極海、海洋温暖化、海氷減少
Keywords: Arctic Ocean, Ocean warming, Sea ice reduction

Seasonal variability of near-inertial internal waves and its kinetic energy in the ice-diminishing Arctic Ocean

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In the Arctic ocean, the internal wave activity and its contribution to the turbulent mixing has been considered to be quite low. In the modern era, the Arctic sea-ice extent has been dramatically diminishing, and therefore there is an increased chance of kinetic energy input from the air at ocean surface. In this study, the seasonal change of near-inertial internal wave (NIW) kinetic energy is examined in comparison with local sea ice compactness and draft thickness. The local sea-ice information was obtained using an ice profiling sonar mounted at top of a moored instrumentation in the Northwind Abyssal Plain. The band-passed kinetic energy was recorded with a moored ADCP for depths within upper 110 m. The data clearly documented that the depth-integrated NIW kinetic energy varied in line with the ice seasonality, i.e., ice thickness and mobility. During ice covered months, the upper water NIW kinetic energy was approximately 1/10 of the Garrett-Munk (GM) canonical level. In the meantime, during the ice absent months of September and October, the kinetic energy levels built up closer to the GM level. The fine-scale parameterization (Gregg, 1989) estimates the turbulent mixing dissipates the incident wave energy at a rate of $O(10^{-10} - 10^{-9}$ W kg$^{-1})$. According to a mixed layer slab model (Pollard & Millard 1970), the energy input from the ice movement was 1.6 kJ m^{-2}, in which 13% was presumably dissipated through the wave-wave interaction in the upper 110 m. The ice-water combined velocity data also indicated that the mobility of sea ice floes can affect the kinetic energy amount in the upper water, suggesting the occurrence of increased turbulent energy as more unconsolidated ice exists in the future.

Keywords: Arctic Ocean , Near-inertial internal wave, Sea ice retreat

