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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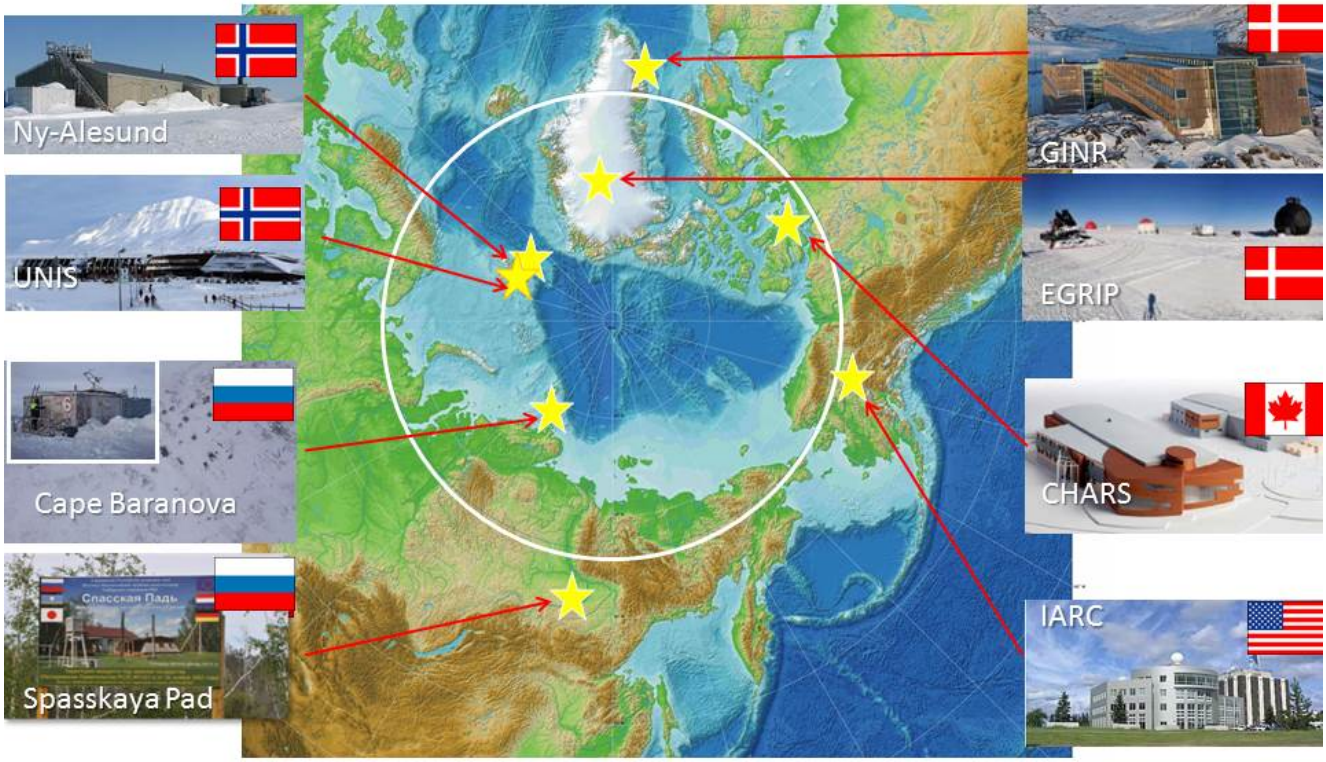
北極域研究推進プロジェクト（ArCS）では、北極域に於ける研究・観測究拠点の整備を行ない、ArCS参画研究者をはじめとする我が国の研究者に観測・研究の場を提供することを目的としている。
整備を行なっている地域は、米国：アラスカ大学IARC(International Arctic Research Center)研究拠点、ポーカーフラット観測拠点、カナダ：CHARS(Canadian High Arctic Research Station), CEN（Centre for Northern Studies）観測拠点、ロシア：ケープ・バラノバ観測拠点、スパスカヤパッド観測拠点、ノルウェー：スバ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。

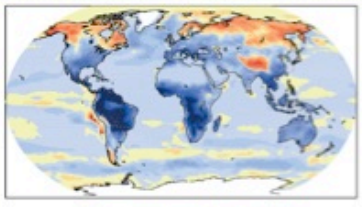
キーワード：高含氷永久凍土融解、メタン、気候変動、ティッピング・ポイント
Keywords: Ice-rich permafrost degradation, Methane, climate change, tipping point

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.

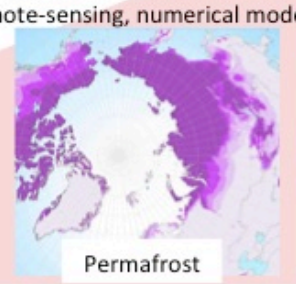


Carbon release [kgC/m^2/K]

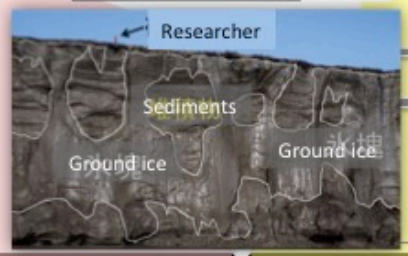
Previous studies
Incremental and kinetic degradation
→Need to incorporate local but dynamic degradation

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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*Teruo Aoki[1,2], Rigen Shimada[3], Tomonori Tanikawa[2], Masashi Niwano[2], Hiroshi Ishimoto[2], Masahiro Hori[3], Knut Stamnes[4], Wei Li[4], Nan Chen[4]

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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

