気候モデルMIROCを用いた北極海における海氷変動のメカニズムと予測可能性
Mechanisms and Predictability for Arctic Sea-Ice Variability with the MIROC Climate Model

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The Arctic environment has markedly changed due to the rapid decline of sea ice in summer Arctic Ocean. The retreat of sea-ice cover could be associated with the Arctic amplification and an increase in the frequency of severe cold winters in the Northern Hemisphere mid-latitudes. Accurate predictions of sea-ice variability on seasonal to decadal time-scales and its mechanisms would be useful for further progress in science as well as socio-economic activity. To examine the mechanisms and predictability for Arctic sea-ice variability, we analyze the control simulations from the Arctic Predictability and Prediction On Seasonal to Inter-annual Timescales (APPOSITE) project. The model used for the APPOSITE is the climate model MIROC 5.2 in which external forcing is fixed in 2005. The time evolution in sea-ice extent and volume shows that an extreme reduction event occurs one or two for a century even without the global warming trend. The spatial feature in sea-ice distribution and its reduction mechanisms resemble those in 2007. This suggests that an anomalous sea-ice loss could be caused by only natural variability. We have currently investigated the key factors closely related to the sea-ice variability.

キーワード：北極、海氷、気候モデル
Keywords: Arctic, Sea ice, Climate model

アラスカ沖バロー沿岸ポリニヤにおける海氷生産量の経年変動

Interannual variability of sea ice production in the Barrow Coastal Polynya off Barrow, Alaska

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Recently, it has been proposed that the Barrow Coastal Polynya (BCP), previously considered to be a latent heat polynya, is a “wind-driven” hybrid latent/sensible heat polynya, with both features caused by the same northeasterly wind (*Hirano et al*., 2016). In this study, we examine the interannual variability of sea ice production in the BCP from 2002/03 to 2010/11 during AMSR-E operation period, with focus on the northeasterly wind that characterizes the BCP as a hybrid coastal polynya. Throughout the ice-growth season (November–May), sea ice production was the highest in 2003/04 and the lowest in 2010/11. In 2003/04, amount of the suppressed sea ice production was also highest, when ~30% of the BCP ice production was suppressed by the ocean heat transport associated with warm water upwelling. Wind pattern around the BCP region varies from year to year, and frequency and magnitude of the northeasterly wind correlate well with sea level pressure difference between the Beaufort High and Aleutian Low. Compared with climatology, the northeasterly wind in the BCP was more frequent and stronger in 2003/04 due to strengthening of the Beaufort High. In contrast, it was less frequent and weaker in 2010/11 due to weakening of both the Beaufort High and Aleutian Low. Frequency and magnitude of the northeasterly wind, mainly regulated by variabilities of the Beaufort High and Aleutian Low, are considered to be major factors of the interannual variability of sea ice production in the BCP.

キーワード：ハイブリッド潜熱・顕熱ポリニヤ、海氷生産、経年変動
Keywords: hybrid latent/sensible heat polynya, sea ice production, interannual variability

バレンツ海における水塊変質過程とその経年変動に関するモデリング研究
A modeling study on water modification and its interannual variability in the Barents Sea

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The sea ice is not found in the southern half of the Barent Sea even in winter due to the warm Atlantic Water inflow through the Barents Sea Opening. Recent several studies have shown the significant relationship between sea ice extent in the Barents Sea and winter air temperature in some mid latitude regions of northern hemisphere. Therefore, it is important to investigate the inflow and modification of the Atlantic Water in the Barents Sea for getting a better understanding of climate change in mid-latitude regions. In this study, we utilize a high resolution realistically configured ice-ocean general circulation model to examine the mechanism of water modification and its interannual variability.
The modeled routes of the Atlantic Water are affected by the oceanic bottom topography and consistent with observations and previous modeling studies. The cooling and freshening of the Atlantic Water by the atmosphere and sea ice melting, respectively, are also well simulated. Calculated heat flux at the Barents Sea Opening is ~ 87TW (1 TW = 10^{12} Watt) is in range of observational estimates (73-103TW). The sea ice formation at the coastal polynya, which contributes the increasing of salinity in the Barents Sea, is slightly underestimated compared with satellite observation. The interannual variability of Atlantic Water modification and its mechanism are currently under investigation.

キーワード：バレンツ海、海氷-海洋大循環モデル、海面熱フラックス
Keywords: Barents Sea, Ice-Ocean General Circulation Model, Sea surface heat flux

北極温暖化増幅下での天候レジームの変化
Change in persistent extratropical regimes under an Arctic amplified climate

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The Arctic surface air temperature has warmed more than twice as fast as the global average (e.g., Cohen et al. 2014), which is known as Arctic Amplification (AA). All the fifth Coupled Model Intercomparison Project (CMIP5) model projects that the warming become more and more conspicuous toward the end of this century, which is one of the most robust climate change signal projected by the models. Therefore, it is important to clarify the extent to which the AA influences the Northern Hemisphere mid-latitudes extreme events, especially recurrent and persistent circulation pattern which causes the heat wave and cold spell.
Here we use a 100-member ensemble of historical simulations and future projections with a hi-resolution atmospheric general circulation model to show that as a result of change in the climatological atmospheric flow induced by the AA, the probability of occurrence of a specific circulation anomaly pattern will increase in future. This circulation pattern is strongly tied to winter cold spell over the Northern Hemisphere mid-latitudes in present climate, but not necessarily in the Arctic amplified future climate. This is because a reduced climatological meridional temperature gradient in lower troposphere acts to weaken the variance of surface temperature.

キーワード：北極域、北極温暖化増幅、異常気象
Keywords: Arctic region, Arctic Amplification, extreme event

20km、60km格子全球大気モデルで予測された北極圏の降水変化

Changes in precipitation over the Arctic projected by global atmospheric models with 20-km and 60-km grid sizes

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A set of global warming projections was conducted using global atmospheric models with high-horizontal resolution of 20-km (MRI-AGCM3.2S, the 20-km model) and 60-km (MRI-AGCM3.2H, the 60-km mode) grid sizes. For the present-day climate (1983-2003, 21 years), models were forced with observed historical sea surface temperatures (SST). For the future climate (2079-2099, 21 years, RCP8.5), models were forced with future SST distributions projected by the models of the Fifth phase of Couple Model Intercomparison Project (CMIP5). The uncertainty of projection was evaluated by ensemble simulations for four different SST distributions and three different cumulus convection schemes.
The annual mean precipitation (PAVE), the simple daily precipitation intensity index (SDII), and the maximum 5-day precipitation total (R5d) averaged over the Arctic increased in the end of the 21st century. The increases in PAVE, SDII, and R5d can be partly attributed to an increase in water vapor associated with increasing temperatures, and to an increase in the horizontal transport of water vapor from low to high latitudes. These results are consistent with Kusunoki et al. (2015).

キーワード：北極圏、地球温暖化予測、全球大気モデル、降水量
Keywords: Arctic, Global warming projection, Global atmospheric model, Precipitation

雲解像モデルCReSSを用いた北極海低気圧の再現実験

Simulation on low pressure systems over the Arctic Ocean using a cloud-resolving model

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これまでに雲解像モデルCReSS を用いて日本周辺（温帯域）や熱帯域での数値実験を実施しているが、寒冷域での再現性の確認は行っていない。本研究では、2013年9月に海洋研究開発機構の海洋地球研究船「みらい」による北極海域観測MR13-06期間中に観測されたポーラーローを対象として、CReSSを用いて実施した数値実験の結果と特徴を紹介する。「みらい」で観測されたドップラーレーダデータ・高層気象観測データ・船上観測データを用いて、CReSSの再現性の評価と改善点を示すことを目的とする。
水平解像度2.5 kmのCReSSを用いて、「みらい」定点観測点（西経168.25度・北緯72.75度）を含む2000 kmx 2000 kmで数値実験を実施した。鉛直は32層でモデルの上端高度は12.8 kmである。「みらい」のレーダで複数のポーラーローが観測された事例を対象として、2013年9月23日00時（世界時）を初期値として72時間にわたって計算を行った。GSM予報値を大気の初期値・境界値として、海面水温（SST）と海氷分布の初期値はOISSTを使用した。CReSSでは海中温度と地中温度を1次元熱伝導方程式を解くことにより、地表面からの顕熱・潜熱フラックスを現実的に表現することができる。また、海氷のパラメタリゼーションは含んでいない。
再現実験では、計算開始51時間後（9月25日03時）に、弱い降水（雪）を伴う総観規模の低気圧と、その南側に渦状の雲域を確認できる。同時刻のNOAA-AVHRRの可視画像（衛星画像）でもメソスケールの渦状擾乱が確認できることから、再現実験で少なくとも一つのポーラーローの再現に成功したと考えられる。「みらい」のドップラーレーダによる観測結果では、この渦状擾乱に伴ってエコー頂高度が4 kmに及ぶ対流性の降水域を観測した。しかしながら、再現実験では、この渦状擾乱に伴う雲域の厚さは1.5 kmと低く、深い対流性降水雲は再現されなかった。対流性降水雲の高さを確認するために、衛星搭載雲レーダ（CloudSat-CPR, 95 GHz）による20経路分の観測結果と、再現実験の結果に衛星シミュレータSDSUを適用して衛星観測と同じ鉛直断面における反射強度分布の比較を行った。この結果、衛星観測で観測される高度3 km以下における0 dBZ以上の大きな反射強度域が再現実験では見られないことから、今回の実験では深い対流性降水域の再現を行えていないことを確認した。
「みらい」定点観測点における海面水温（SST）の時間変化と再現実験の結果の比較を行った。初期時刻においては再現実験（OISST）のSSTは観測結果に比べて0.2℃低かった。その後、観測結果ではSSTがほぼ一定である一方、再現実験の結果では顕熱・潜熱フラックスの放出によりSSTが徐々に低下し、計算終了時（72時間後）には約1.0℃の乖離を示した。観測結果でSSTが一定であったのは、ベーリング海峡（南側）からの暖水が南寄りの風によって移流されてきたことによると考えられる。CReSSはこのような表層海水の移流を表現することはできない。再現実験におけるSSTの再現の失敗により、海面からの潜熱フラックスが観測結果よりも過小となるとともに、実験の最後の24時間にわたって海面付近に非現実的な飽和層（霧）を形成する結果となった。海面水温の再現の失敗と海面からの潜熱フラックスが過小であることによって、ポーラーローに伴う深い対流性降水雲の再現に失敗したと考えられる。これらの結果から、北極域において、高解像度の3次元海洋モデルを結合した大気海洋相互作用を再現する実験を実施することで、メソスケールの現象の再現性の向上を図れる可能性がある。

キーワード：北極圏、大気海洋相互作用、雲解像モデル、ポーラーロー
Keywords: Arctic region, air-sea interaction, a cloud-resolving model, mesoscale polar low

完新世中期と将来の北極温暖化メカニズムの比較

A Comparison between the mid-Holocene and the future in the Arctic warming mechanism

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観測事実から、近年の地球温暖化は北極域で顕著である。また、気候モデルのシミュレーション結果から、北極域の温暖化傾向は将来さらに強まると予測されており、生態系や地球規模の気候への影響が懸念されている。しかし、予測された温暖化の程度は気候モデルにより異なるため、不確実性がある。
Shmidt et al.(2013)では、現在より北極域が温暖であった過去の時代を利用し、将来予測の不確実性低減の可能性を示唆した。しかし、多数の大気海洋結合モデルにおける古気候シミュレーションの結果と将来気候のシミュレーション結果のばらつきに対して統計的相関を示しているのみで、両者の北極温暖化メカニズムに共通性があるかについては言及されていない。したがって、将来予測の不確実性低減に利用できる根拠は十分ではない。
そこで本研究では、過去と将来の北極温暖化メカニズムの共通性、相違性を調べ、過去の気候を用いた将来予測の不確実性低減の可能性について考察することを目的とする。方法としては、多数の大気海洋結合モデルにおける大気CO_2濃度を4倍に増した実験と完新世中期実験の結果を、産業革命前の気候シミュレーション結果を基準として比較する。なお、完新世中期はおよそ6000年前の時代で、地球の軌道要素の違いにより現在と比べて北極域が温暖であったことがわかっている。
まず、各実験における北極温暖化について、地表面エネルギー収支に基づいてその支配的プロセスを調べ、その際、海氷や雲、水蒸気、海面水温に着目した。その結果、両実験ともに、主に夏に北極域に入力された過剰なエネルギーは直接大気を暖めるのにほとんど使われず、海氷を融かすのに使われたり、海洋に吸収され蓄えられており、数カ月後に露出した暖かい海水から熱が放出されることで北極温暖化が引き起こされていることがわかった。またそれに伴う海氷、雲、水蒸気の変化も共通していた。つまり、完新世中期と将来は異なる原因により北極温暖化が引き起こされているが、そのメカニズムには共通性が多く見られる。
次に、4倍CO_2実験と完新世中期実験における地表面温度のモデル間のばらつきに対する各プロセスの寄与を、それぞれの実験について明らかにした。4倍CO_2実験では年平均温度のばらつきには地表面アルベドフィードバック、10〜12月平均温度のばらつきには海洋からの放熱量が最も寄与していた。完新世中期実験ではどちらの期間の温度のばらつきに対しても晴天時の下向き長波放射の寄与が最大であったが、年平均温度のばらつきに対しては地表面アルベドフィードバック、10〜12月平均温度のばらつきに対しては海洋からの放熱量の寄与も比較的大きく、統計的にも有意であった。ステファンボルツマンの法則により、地表面温度と地上気温、つまり下向き長波放射は強く結びついているため、他のプロセスを正確に表現できれば、同時に晴天時の下向き長波放射の不確実性の制約も期待される。したがって、完新世中期実験の北極温暖化が精度よく再現できていれば、地表面アルベドフィードバックや海洋のエネルギー放出プロセスの表現に対する信頼性が高まり、同時に将来予測におけるそれらのプロセスの表現に対する信頼性も高まると考えられる。
以上から得られた北極温暖化メカニズムの理解を基に、完新世中期の北極温暖化に関する古環境情報は、将来の北極温暖化予測の不確実性にとって有用となることが考察される。

キーワード：気候モデル、古気候、将来予測
Keywords: Climate models, Paleoclimate, Future projections

長期気象陸域観測データから探るスバールバル諸島ニーオルスン・ロングイヤービンの気候変化
Climate changes in Ny-Ålesund and Longyearbyen, Svalbard based on long-term meteorological and terrestrial dataset

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北極域では全球規模の温暖化の進行により様々な気候要素の変化が起きている。気温上昇率は全球平均と比較して２倍程度大きく，永久凍土の融解や海氷面積の減少といった影響が出始めている。北極域の気候システムは大気循環や，陸域水文プロセス，海氷変動などの相互作用の上に成り立っているため，大気-陸域（雪氷）-海洋間のフィードバックを明らかにすることが，温暖化に伴う環境変動を理解する上で重要となる。そのためにも各気象要素や大気海洋成分のモニタリングを複数地点で行い，長期的な傾向を明らかにすることが重要である。
スバールバル諸島は北極研究の代表的な拠点であり，スピッツベルゲン島のロングイヤービンとニーオルスンでは多くの観測・調査が行われてきた。特にニーオルスンは人的擾乱が少ないため，世界各国の研究機関がモニタリングを行っている。ロングイヤービンではスバールバル大学（UNIS）がAdventdalenなど各所で気象・凍土の観測を行っている。またニーオルスンでは国立極地研究所（NIPR）やドイツのアルフレッドウェゲナー研究所（AWI）がウェザーステーションによる気象要素のモニタリングをしており，数十年スケールの変動を監視している。我々はNIPR，UNIS，AWIが観測してきた数十年の気象・凍土データを収集・整理し，ノルウェー気象局（NMI）の1970年代からの降水・積雪データとあわせて短期・長期的な変動や要素間の相関関係などを調べてきた。時系列データを解析した結果，冬季気温と降水量に顕著な傾向が見られた。この20年余りでニーオルスン，ロングイヤービンともに冬季気温は上昇しているが，３月の気温は減少傾向を示していることがわかった。また，降水量に関して，ニーオルスンでは目立った変化が見られないのに対して，ロングイヤービンの降水量は夏冬ともに明らかな減少傾向を示している。本発表では様々な気象・凍土時系列データから北極域の変化傾向を探るとともに，要素間の相関関係についても議論する。

キーワード：気候変化、スバールバル
Keywords: climate change, Svalbard

ユーラシア大陸の春季積雪面積変化が東アジアの夏季降水量に及ぼす影響の再考
Revisiting impacts of spring Eurasian snow cover change on the East Asian summer precipitation

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The Eurasian snow cover extent (SCE) anomaly in spring has been considered as one of the important factors affecting East Asian summer monsoon (e.g. Wu and Kirtman, 2007; Wu et al., 2009; Yim et al., 2010). In these studies, the authors analyzed traditional SCE dataset of National Oceanic and Atmospheric Administration (NOAA). Recently, Japan Aerospace Exploration Agency (JAXA) has developed a new long-term SCE product using Advanced Very High Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectroradiometer (MODIS) data spanning from 1980's to 2014. This new product (JAXA/SCE) has higher spatial resolution and smaller commission error compared with NOAA/SCE. Continuity of the algorithm is another strong point in JAXA/SCE. Here, we revisit impacts of spring Eurasian snow cover change on the East Asian summer precipitation by using the new JAXA/SCE dataset. Climatological mean fields of spring SCE is not largely different from each other. On the other hand, interannual variability of spring SCE has somewhat different spatial distribution over the Eurasian region (45°N-70°N, 20°E-140°E); NOAA/SCE shows a dipole pattern but JAXA/SCE shows monopole pattern. We will present analyzed results on relationships between spring SCE anomaly over the Eurasia and the East Asian summer rainfall anomaly.

東シベリアに優占するカラマツ林は、今後予測される気候変動の元で存続できるか？
Endurance of larch forest ecosystems in eastern Siberia under warming trends

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The larch (Larix spp.) forest in eastern Siberia is the world’s largest coniferous forest. Its existence is considered to be depending on near-surface permafrost, which increases water availability for trees, and the boundary of the forest closely follows the permafrost zone. Therefore, the degradation of near-surface permafrost due to forecasted warming trends during the 21st century is expected to affect the larch forest in Siberia. However, predictions of how warming trends will affect this forest vary greatly, and many uncertainties remain about land-atmospheric interactions within the ecosystem.
We developed an integrated land surface model to analyze how the Siberian larch forest will react to current warming trends. This model analyzed interactions between vegetation dynamics and thermo-hydrology and showed that, under climatic conditions predicted by the IPCC's RCP scenarios 2.6 and 8.5, annual larch net primary production (NPP) increased about 2 and 3 times, respectively, by the end of 21st century compared with that in the 20th century. Soil water content during larch growing season showed no obvious trend, even after decay of surface permafrost and accompanying sub-surface runoff. A sensitivity test showed that the forecasted warming and pluvial trends extended leafing days of larches and reduced water shortages during the growing season, thereby increasing productivity.

キーワード：シベリアのカラマツ林、気候変動、植生モデル
Keywords: Siberian Larch Forest, Climatic Change, Vegetation Model

樹木年輪、及び生態系モデルを用いた気候変動に対する周北極域森林生態系樹木の応答の推定
Tree-ring and modeling estimates for tree response to climate change over circurmpolar forest ecosystems

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Arctic and boreal ecosystems are exposed to rapid and strong increases in temperature and related environmental changes under Arctic amplification. Yet, there is uncertainty how trees in these ecosystems respond to the changes due to an insufficiency of such long term records and this is where tree-rings can provide an advantage. Early dendrochronological studies in the region focused on the positive growth of trees to warmth (D'Arrigo and Jacoby, 1993, Clim. Change). However, A number of more recent studies have demonstrated a reduced sensitivity of tree growth to rising temperatures (now referred to as "divergence problem")at least since the 1960s (e.g.,Wilson et al., 2007, J. Geophys. Res). Although several studies (e.g., Barber et al., 2000, Nature) suggested that temperature-induced drought may limit tree growth under the limited availability of soil moisture, the underlying processes for the phenomenon are not well understood.
We here investigated past tree response to climate changes, especially to warming, using retrospective analyses from tree-ring width and carbon isotope ratios (delta-^{13}C) of three genera (*Larix*, *Picea* and *Pinus*) in 6 forest sites with a strong gradient of temperature and precipitation, reaching from northern Europe to northern America; Kalina (59N, 27E), Yakutsk (62N, 129E), Ust'Maya (60N, 133E), Chokurdakh (70N, 148E), Inuvik (68N, 133W) and Fort Smith (60N, 112W). The results suggest that tree response to past climate changes have varied with regions. The tree responses to warming are negative in eastern Siberia forests, resulting in decreasing trend of tree growth over past 60 years. On the other hand, the negative effect of warming is not seen in European and Canadian forests, where no decrease trend of growth is observed. The results then have been used in testing a dynamic global vegetation model (SEIB-DGVM, Sato et al., 2007, Ecol. Model). The simulated annual net primary productions (NPP) show no decreasing trend over the study period and discrepancy from tree-ring based long-term (more than half-decadal) growth variations in eastern Siberian forests, although relatively better reproductions of the model for the variations are obtained in European and Canadian forests.
The observed discrepancy in eastern Siberian forest may become more severe for future projection. We developed a climate-driven statistical growth equation that uses regional climate variables to model tree-ring width values for each site and then applied these growth models to predict how tree growth will respond to twenty-first-century climate change (RCP8.5 scenario). Although caution should be taken when extrapolating past relationships with climate into the future, we observed future continues reduction of the growth in central part of eastern Siberia, which is opposite trend from the DGVM based estimate. Our results imply that the negative effect of warming override the expected positive effects i.e., warming-induced lengthened growing season and increase in photosynthetic ratio, in arid region such as eastern Siberia, suggesting further reduction of tree

growth by future warming, and no reproduction of the negative effect in the DGVM seems to be a cause for the observed discrepancy between tree-ring and DGVM estimates. The negative effect of warming for tree growth is a key process for accurate future projection of ecosystem functions and therefore further field and modeling investigations are essential to deep understanding of the underlying processes for the phenomenon.

北極圏北東シベリアのインディギルカ川低地におけるヤナギの分布様式
Spatial distribution pattern of willows in Indigirka river lowland of northeast Siberian Arctic

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温暖化と生育期間の増加は、北極圏の落葉性のツンドラ低木のより高い一次生産や生育域の拡大をもたらすことが知られている。しかし、高頻度で攪乱を受けるヤナギやハンノキなど優占する河岸生態系は生産力の高い植物種からなるため炭素循環に重要であると考えられているが、その広がりは十分に理解されているとは言えない。北東シベリアの低地氾濫原にはヤナギが大きな面積を占め、地上部バイオマス大きいと考えられるが、正確な見積もりはなされていない。そこで、本研究では北東シベリアの河川氾濫原において、両岸に広がるヤナギ植生を衛星画像分類とGISによって捉え、氾濫原のヤナギの分布様式とNDVIについて知見を得ることを目的とする。
東シベリアのチョクルダ周辺の10km四方において2013年7月に観測されたWorldView-2衛星画像を、地上植生観測データを基に分類し、高解像な植生図と衛星観測したNDVI値を得た。ヤナギ植生の分布と河川からの距離の関係をGISの空間解析によって示した。ヤナギ植生が10km四方の観測地域の約1/6を占めインディギルカ川本流周辺に特に大きな広がりを見せた。このことは、本流沿いの広いエリアに春の洪水の影響が及び、そこにヤナギが分布していることを意味している。また、河川沿いヤナギ植生のNDVIは他の植生クラスに比べて大きな値を示し、この地域の生産量に大きな影響を及ぼしていると考えられる。

キーワード：植生、氾濫原、NDVI、GIS
Keywords: vegetation, floodplain, NDVI, GIS

北東シベリアタイガ - ツンドラ境界域湿地土壌のメタン酸化ポテンシャル
Methane Oxidation Potential of Arctic Wetland Soil of a Taiga-Tundra Ecotone in Northeastern Siberia

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Arctic wetlands are significant sources of atmospheric methane and the observed accelerated warming of the arctic causes increased methane formation in water-saturated tundra soil with deepened permafrost thawing. Methane oxidation is the key process to regulate methane emission from wetlands. In this study we determined the potential methane oxidation rate of the wetland soils of a Taiga-Tundra transition zone in Northeastern Siberia. Peat soil samples were collected in the summer from depressions that were covered with tussocks of sedges and *Sphagnum* spp. and from mounds vegetated with moss and larch trees. The potential methane oxidation rate was estimated by a bottle incubation experiment in which homogenized soil samples were incubated with methane at the initial concentration of 0.5-0.8 %v/v. Soil samples collected from depressions in the moss- and sedge-dominated zones exhibited active methane oxidation with no lag. The potential methane oxidation rates at 15 ºC ranged from 270 to 190 nmol h^{-1} g^{-1} dw. Methane oxidation was active over the depths including the water-saturated anoxic layers. The maximum methane oxidation rate was recorded in the layer above the water-saturated layer: the surface (0-2cm) layer in the sedge-dominated zone and in the middle (4-6 cm) layer in the moss-dominated zone. The methane oxidation rate was temperature-dependent and the threshold temperature of methane oxidation was estimated to be -4 to -11 ºC, which suggested methane oxidation at subzero temperatures. Soil samples collected from the frozen layer of *Sphagnum* peat also showed immediate methane consumption when incubated at 15 ºC. The present results suggest that methane oxidizing bacteria keep their activity in the wetland soils even under anoxic and frozen conditions and immediately utilize methane when the conditions become favorable. On the other hand, difluoromethane, the inhibitor of methane oxidation, did not alter the methane flux from the sedge and moss vegetation, indicating the undetectable levels of methane oxidation associated with the peat plants.

キーワード：メタン酸化、泥炭、凍土、酸素
Keywords: Methane Oxidation, Peat, Permafrost soil, Oxygen

北東シベリア・インディギルカ低地における湿潤化がCH_4フラックスに及ぼす持続的影響
Multi-year response of CH_4 efflux to wetting at Indigirka Lowland in Northeastern Siberia

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Under the amplified Arctic warming climatic response of CH_4 emission from the wetlands needs to be understood and predicted because of possible influence to the global climate. Indigirka Lowland in Northeastern Siberia has wetlands in a taiga-tundra boundary on permafrost, whose ecosystem are possibly sensitive to the climate change. Though environmental controls on CH_4 efflux have been found such as water level (soil moisture), soil temperature and vegetation, the quantitative relationship between the controls and CH_4 efflux are still unclear, which depends on region and timescale (Olefeldt et al., 2013, Global Change Biol.; Treat et al., 2007, JGR). One difficulty is that CH_4 emission is composed of 3 processes, i.e. CH_4 production, oxidation and transport; they can respond to environmental controls and affect CH_4 efflux in different ways. These processes are reflected by stable isotope ratios of CH_4 (delta-^{13}C-CH_4, delta-D-CH_4), which can associate field observation and knowledge from laboratory incubation experiments on CH_4 production and on oxidation.
In this study we assessed interannual variation in chamber CH_4 efflux and in delta-^{13}C-, delta-D-CH_4 near Chokurdakh (70.62 N, 147.90 E) over summers of 2009-2013 to understand relationship between CH_4 efflux and environmental factors based on the 3 processes of CH_4.
CH_4 efflux was around the detection limit at dry tree mounds through the observation period, while large interannual variation was observed at wet areas of sphagnum moss and sedges. Wet event concurrent with the highest precipitation occurred in 2011 and CH_4 efflux increased at wet areas in the same year. Although water level decreased from 2011 to 2013, large CH_4 emission continued. Moreover, dissolved CH_4 concentration in soil pore water (at 10-15 cm depth) increased by 1 order of magnitude from 2011 to 2012 and kept high till 2013. CH_4 isotopes implies that CH_4 oxidation was depressed in 2012 after the wetting in 2011, suggesting soil reduction induced by the wetting proceeded over multiple years, which may have affected dissolved CH_4 concentration and CH_4 efflux. Such variation in CH_4 efflux and in dissolved CH_4 concentration will be discussed in relation to the 3 processes in this presentation.

キーワード：メタンフラックス、年々変動、同位体比、タイガ - ツンドラ境界
Keywords: methane flux, interannual variation, isotope ratio, taiga-tundra boundary

フェアバンクスおよびヤクーツクの北方林における着雪氷の発生頻度

Occurrence frequency of ice and snow accretion in the boreal forest regions, Fairbanks and Yakutsk

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Generally snow covers the ground, even if the ground type is different in such as tundra and taiga. Erosion/deposition of the snow cover and growth/decay of ice and snow accretion to vegetation occasionally occur, and the surface albedo changes and will affect the atmosphere. Previous research has demonstrated the high variations of the surface albedo in winter/spring in snow-covered forest regions in various global climate models. In this study, we focused on the surface albedo over snow-covered forest regions, and carried out field observations to verify the occurrence frequency of ice and snow accretion in the boreal forest regions. Using interval cameras installed on the observation tower at the site located to the north of Fairbanks (USA) and on the observation tower at the site located to the north of Yakutsk (Russia), ice and snow accretion in the boreal regions were monitored. It was found that the boreal forest at the Yakutsk site is covered with snow in comparison with the boreal forest at the Fairbanks site for a long term. After calculating using a one-dimensional mathematics model about the energy flow including atmospheric multiple scattering, it was shown that the mean surface temperature rises approximately 0.5 [K] when the boreal forest is not covered with snow. In this presentation, the snow albedo parameterization and the one-dimensional mathematics model are discussed to contribute to a better understanding of the role of snow in the climate system.

キーワード：着氷、着雪、アルベド、北方林
Keywords: ice accretion, snow accretion, albedo, boreal forest

MIROC－ESMの将来気候変化予測にみられるシベリアでの積雪アルベドフィードバックにおける植生マスキング効果

Vegetaion masking effect on snow albedo feedback in Siberia during future global warming simulated by MIROC-ESM

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We have investigated future change in snow amount and vegetaion masking effect on snow albedo feedback (SAF) in Siberia, boreal forests region of the northern Eurasia, in the futute climate change simulation by Earth System Model, MIROC-ESM. Under the future scenario, RCP8.5, snow amount during fall-spring over the northern Eurasia decreases due to global warming. The significant reduction of snow amount is found in western Eurasia during fall-spring. On the other hand, although reduction of snow amount over Siberia in fall and spring occurs, winter snow amount over Siberia increases due to increasing snow fall, which is attributable to more water vapor with higher air temperature. Relating to such snow changes, then, surface air temperature (SAT) changes are enhanced through SAF. During spring, particularly, future SAT increases largely over Siberia, boreal forest region, although snow cover decreases less than that in western Eurasia. The dominant increase in SAT over Siberia is attributed to strong SAF which is caused by both reduced snow-covered surface albedo and reduced snow cover fraction. Further, to evaluate an effect of future LAI change on the surface albedo reduction, we have conducted an additional future climate change simulation, in which change in LAI is not included. The comparison between the future climate changes with and without the LAI changes suggests growing vegetation in the future may be a potential factor of the future strong warming through the vegetation masking effect on snow-covered surface albedo change.

キーワード：積雪アルベドフィードバック、植生マスキング効果、地球システムモデル
Keywords: snow albedo feedback, vegetation masking effect, Earth system model

東シベリアインディギルカ川低地における積雪特性

Snow cover properties observed in Indigirka lowland near Chokurdakh, Northeastern Siberia

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Quantifying the spatial and temporal variations in snow depth, density, and snow water equivalent (SWE) is essential for many applications in hydrology and ecology. Snow survey including observation on the water isotope ratios of snow was conducted in Indigirka lowland near Chokurdakh (70.62 N, 147.90 E), Northeastern Siberia. Isotopic composition of water is powerful tool for investigation of hydrological processes such as discerning of source water for river discharge, ground ice, etc. The purposes of this study are (1) to know the spatial variations in snow depth, density, SWE and stable isotopic composition in this area, and (2) to estimate SWE in areal or reginal scale, by scaling-up based on topographic and vegetative controls on SWE.
Snow survey was conducted in April 2014 and April 2015. Two transects from Chokurdakh to south and southwest, which are approximately 40 km and 20 km in length respectively, were set, and observation and sampling were made at 7 points and 4 points in 2014, respectively, and 12 points on the 40 km transect in 2015. In addition, snow survey was conducted at 25 points in 2014 (24 points in 2015) in total in the area measured approximately 1.2 km east to west at site K where various observations are conducted for taiga-tundra boundary ecosystem. The ranges of snow depth, density, SWE and $\delta^{18}O$ in this area observed in 2014 were 30 to 90 cm, 0.137 to 0.318 g/cm^3, 70 to 200 mm and -36.5 to -22.9‰, respectively, whereas those observed in 2015 were 12 to 83 cm, 0.131 to 0.325 g/cm^3, 20 to 160 mm and -31.2 to -22.8‰, respectively. Although the values and the ranges were slightly different between 2014 and 2015, observed snow cover properties depended on vegetation type and showed consistencies: snow cover was the deepest at the site covered by dense and tall shrub, while snow density was the highest on ice over a lake. The SWE was the highest at shrub site, whereas that was the lowest at the site of sedge and/or sphagnum wetland. Spatial variation in delta-values of snow was observed, however there was no correlation with vegetation type, snow depth and snow density. Since clear relationship between SWE and vegetation type, SWE was estimated using a data on fraction of each vegetation obtained from a vegetation map drawn with high resolution satellite data (world view 2) and in situ observation (Morozumi et al., in preparation). The local average SWE values in observation area (10 ×10 km) were estimated to be 100 mm in 2014 and 78 mm in 2015.

キーワード：積雪水量、水安定同位体比、北東シベリア
Keywords: snow water equivalent, water isotope ratios, Northeastern Siberia

グリーンランド北西部における溢流氷河の表面高度変化
Surface elevation change of outlet glaciers in northwestern Greenland

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Ice discharge from calving glaciers has been increasing in the Greenland ice sheet (GrIS) since 2000s. This increase plays important roles in the volume change of GrIS and its contribution to sea level rise. To investigate the mass loss of GrIS calving glaciers, ice surface elevation change has been studied by differencing digital elevation models (DEMs) derived by satellite remote-sensing. Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) images of Advanced Land Observing Satellite (ALOS) have a spatial resolution of 2.5 m, which is fine enough to measure several meters of elevation change on glaciers. The large spatial coverage of the images (1225 km^2) is suitable for studying glaciers distributed over a large area.

In this study, we measured surface elevation change of 14 outlet glaciers near Inglefield Bredning in northwestern Greenland (77°47′–78°10′N, 65°00′–72°47′W). These glaciers flow into the ocean except for two land-terminating glaciers. We processed stereo pair ALOS PRISM images acquired in summer 2007 and 2010 with a digital map plotting instrument (Leica Photogrammetry Suite) to generate DEMs with a 25 m grid mesh. Elevation data from ALOS DEMs were calibrated on ice-free terrain, and compared to calculate ice surface elevation change between 2007 and 2010.

The surface elevation of all the studied glaciers decreased and the magnitude of the elevation change increases downglacier. The mean elevation change rate ranged from −0.4 to −4.9 m a^{-1}. Marine-terminating Tracy and Bowdoin Glaciers thinned at rates of −4.9 and −4.1 m a^{-1}, which were larger than those at other glaciers. The rate at Tugto Glacier, a land-terminating glacier located near Bowdoin Glacier, was −2.8 m a^{-1}. This result confirms that recent thinning of GrIS outlet glaciers is more significant at marine-terminating glaciers as compared to land-terminating glaciers. Rapid thinning of marine-terminating outlet glaciers observed in this study suggests the importance of ice dynamics and/or ice-ocean interaction in the mass loss of GrIS.

キーワード：北極圏雪氷学、氷河表面高度変化、氷河ダイナミクス
Keywords: Arctic glaciology, Glacier thinning, Glacier dynamics

グリーンランド北西部における氷河前縁海洋の水塊特性

Water properties and circulation in front of tidewater glaciers in northwestern Greenland

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Tidewater glaciers in Greenland are rapidly retreating, and it contributed global sea-level rise during the twentieth century. Studies have been carried out to understand the mechanisms of the glacier retreat. Previous studies suggested the importance of submarine melting, but physical processes relevant to submarine melting (e.g. heat source of the melting, water circulation and bathymetry) are not understood well. This is because in-situ observations are difficult in front of a glacier where icebergs usually cover the ocean. In addition to this, there is no hydrographical observation in front of tidewater glacier in northwestern Greenland. To better understand the ice-ocean interaction, we measured ocean temperature, salinity, turbidity, chlorophyll, dissolved oxygen, $\delta^{18}O$, d-excess and bathymetry in front of Bowdoin and Sun Glaciers, tidewater glaciers in northwestern Greenland, in 2014 and 2015 summer. We also performed high spatial (2560×1920 pixel) and temporal (10 s) time-lapse photography in front of Bowdoin Glacier in 2015 July.Below the depths of 280 m (2014) and 250 m (2015) in the Bowdoin Fjord, we observed Atlantic Water (AW), which is believed as the heat source of submarine melting. The mean temperature and salinity within the layer of AW was 1.2°C and 34.4 g kg^{-1} in 2014, and 1.1°C and 34.5 g kg^{-1} in 2015. The results suggested that warm water flows into the Bowdoin Fjord from the open ocean. Contrasting to these observations at Bowdoin, AW was missing in front of Sun Glacier and relatively fresh and cold water mass was found. It was suggested that relatively shallow bathymetry (~100-m deep) and existence of sill (~10-m deep) inhibited entering warm water from the open ocean. Near the surface in the vicinity of plume of Sun Glacier (~200 m away from the front), water mass properties were completely different from those in the open ocean. Water was highly turbid, fresh and cold, suggesting subglacial discharge of meltwater as the origin of the water.The time-lapse photographs revealed fjord circulation near the ice-ocean interface. It was clear that the circulation was driven by buoyant plume, which was generated subglacial discharge and/or submarine melt. In early July, waters emerged by buoyant plume was always visible along the surface approximately 5 km from the front, but it was only visible near the front in late July. The change from early July to late July may be explained by amount of subglacial discharge and the stability of stratification near the ocean surface as reported by recent modelling studies.Our observations water mass structures and circulation in the fjord in front of the tidewater glaciers in northwestern Greenland, which are important properties to calculate submarine melting rate in two different types of tidewater glaciers.

キーワード：カービング氷河、グリーンランド、フィヨルド、水中融解

Keywords: Tidewater glacier, Greenland, Fjord, Submarine melting

グリーンランド北西部Qaanaaq氷帽とその周辺氷帽の質量収支
Mass balance fluctuation of Qaanaaq Ice Caps and its vicinity in northeastern Greenland

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Many of glaciers and ice caps (GICs) exist at the margin of the Greenland. The contribution of GICs mass loss to sea level rise under recent warming is large. The northeastern Greenland is one of the areas, which experienced large mass change and has little in-situ mass balance observation. Bolch et al. (2013) estimated that the surface elevation change of ice caps in northeastern Greenland from 2003 to 2008 was -0.6 m a^{-1}. Saito et al. (2015) revealed that the mean surface level change of six ice caps in northeastern Greenland from 2006 to 2010 was -1.1 m a^{-1}.
We have estimated surface mass balance of five ice caps in northern Greenland by a mass balance model constructed by Hock (1999). The model takes temperature index method for calculating ablation. The model computes spatial variation of surface mass balance for the ice caps. The 100m - gridded DEM and surface condition of the ice cap, derived from modified ALOS (Advanced Land Observing Satellite) data, were used for the model calculation. The climate data as input of the model was air temperature and precipitation at Thule climate station (TCS, 77.2N, 68.4W), which is one of the long-term running climate stations in Greenland situated about 100 km south to Qaanaaq. The air temperature at TCS has been increasing after 1990.
The calculation has been done for Qaanaaq Ice Cap (QIC) since 1980s. The mass balance of QIC has been negative since 1980s. The mass balance calculation by the model has been done for other four ice caps for 2006 -2009 and compared with the surface elevation change reported by Saito et al. (2015). Ice caps situated in coastal area show less negative mass balance than those situated inland. The ice caps situated in coastal area show higher albedo (Saito, et al., 2015), which is possibly because higher fraction of precipitation falls as snow.

キーワード：グリーンランド、質量収支、気候変動、氷帽
Keywords: Greenland, mass balance, climate change, ice cap

北極域データアーカイブの新たな展開
New developments of Arctic Data archive System(ADS)

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北極域は地球の中でも温暖化が最も顕著に現れている地域であり、大気・海洋・雪氷・陸域が急速に変化している。北極域研究の積極的な推進は、観測データに担うとことが大きい。
日本の研究者により北極域の研究は数十年前から広く行われており、現地での観測データやサンプルの分析データといった。現業観測では得られない貴重なデータが含まれる。これらのデータは、研究所もしくは研究者個人によって管理がまかされてきたこともあり、系統的に保管管理されてこなかった。
北極域データアーカイブは、各分野間でのデータの相互利用を図り、現場観測、収集データ、衛星データ、数値実験データ等のデータセットの構築を通して北極域の大気―海洋―陸域システムの変動の実態とプロセスの解明、地球温暖化における北極域の環境変動の影響を評価、将来予測精度の向上に貢献する。
北極研究の新たなプロジェクトであるArCS（北極域研究推進）プロジェクトが2015年が開始された。北極域研究推進プロジェクトは、文部科学省の補助事業として、国立極地研究所、海洋研究開発機構及び北海道大学の3機関が中心となって、2015年9月から2020年3月までの約4年半にわたって実施する、我が国の北極域研究のナショナルフラッグシッププロジェクトである。ADSはこのプロジェクトのデータマネージメントを担当する。

キーワード：北極域、環境、温暖化、ArCS、データ
Keywords: Arctic, Environment, Global Warming, ArCS, Data

極域におけるデータ可視化Webサービスのアクセス解析
Access analysis of data visualization web service for polar region

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北極域データアーカイブ(Arctic Data archive System)は、北極域で得られた様々なデータセットを一元的に収集・公開するために構築された研究基盤です。GRENE北極気候変動事業が開始されてから5年間、ADSでは以下のようなWebサービスの開発を行った。1)極域研究に関わる他分野のデータの相互流通を実現するKIWA。2)衛星データおよびモデル計算結果のグリッドデータをブラウザ上で可視化・解析するVISION。3)地球観測衛星データを利用した極域監視ウェブサイトVISHOP。これらのWebサービスは世界中からアクセスされている。本研究では、これらのサービスが開始されてからGRENE終了までの期間を対象にアクセス解析を実施した。本発表では、これらのサービスについて、どれぐらいのアクセスがあり、閲覧者はどのようなデータに興味を持っていたのか、解析結果を紹介したい。

キーワード：ウェブサービス、アクセス解析、可視化、データ
Keywords: Web Service, Access Analysis, Visualization, Data

