Synthesis and Legacy of GRENE Arctic Climate Change Research Project

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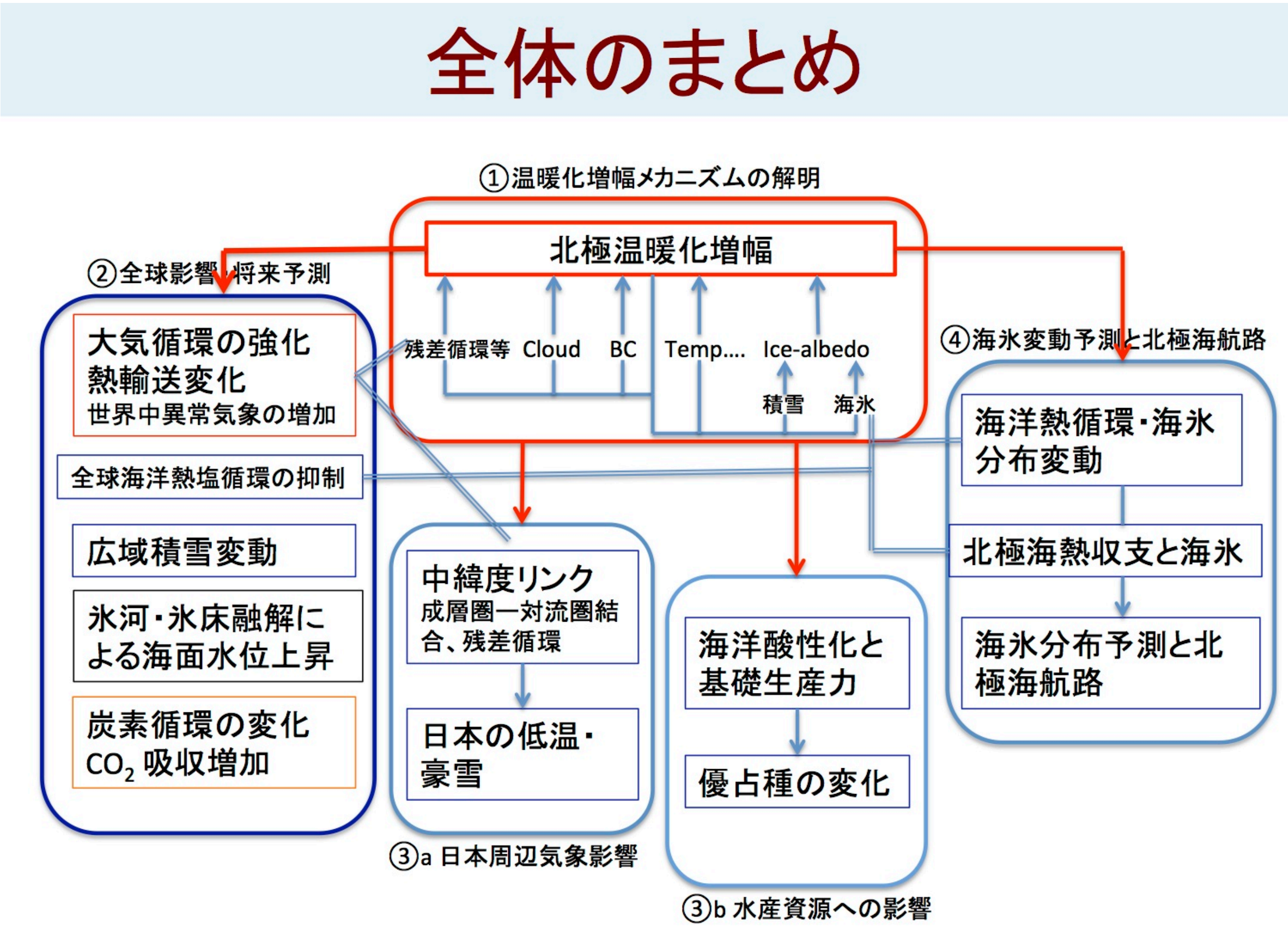
Green Network of Excellence Program (GRENE) Arctic Climate Change Research Project “Rapid Change of the Arctic Climate System and its Global Influences” had been conducted from Fy 2011 to 2015, and was the first Japanese interdisciplinary and model-observation collaborating project, advanced by many participants under a system that encompasses nearly all of Japan. Four Strategic Research Targets were presented:
1. Understanding the mechanism of warming amplification in the Arctic,
2. Understanding the Arctic climate system for global climate and future change,
3. Evaluation of the impacts of Arctic change on weather and climate in Japan, marine ecosystems and fisheries,
4. Projection of sea ice distribution and Arctic sea routes.
In order to analyze these targets, seven bottom up Research themes were selected:
1. Modeling Theme,
2. Terrestrial Theme,
3. Atmosphere Theme,
4. Cryosphere Theme,
5. Greenhouse Gas Theme,
6. Marine Ecosystem Theme,
7. Sea Ice and Arctic Sea Routes Theme.
It was such a unique structure that bottom up research themes answer the top down strategic research targets.
In the project, field observations were conducted at pan-Arctic sites such as Svalbard, Russian Siberia, Northern Canada, Greenland and Arctic Ocean. A high precision Cloud Profiling Radar (95 GHz) was established at Ny-Ålesund, Svalbard and intensive atmospheric observation campaigns had been held. In the Arctic Ocean, research cruises by RV “Mirai” and other ice breakers were conducted and mooring buoys were deployed. Observational data were collected in the Arctic Data archive System (ADS) and opened to the public with interfaces for the analysis. Modeling studies were carried out using various types of the models from the principal physical models to the general circulation models.
Through these observation, analysis and modeling studies, plenty of outcomes have been produced, typically as:
Identification and quantitative evaluation of the feedback processes with the seasonal cycle that cause Arctic warming amplification,
Mid-latitude link of the Arctic warming and sea ice reduction through the troposphere-stratosphere interaction including the effect to extreme weather in Japan such as cold winter and heavy snow,
Projection of sea ice distribution and possibilities of Arctic sea routes,
Changes in terrestrial ecosystems and strengthening of atmospheric CO_2 sink,
Impacts of marine environment change including ocean acidification to the marine ecosystems and change in superior species,
Contributions of glacier and ice sheet collapse to the sea level rise.
However, still many issues remain unsettled such as cloud behaviors according to the warming, advancing polar prediction capabilities, improvement of understanding water cycles and methane

emission from permafrost and offshore region, and extensive future research activities are waited. It is greatly welcomed to further research programs using Cloud Profiling Radar as a basic infrastructure and interdisciplinary study circumstances cultivated during the project as a legacy of GRENE. Already ArCS (Arctic Challenge for Sustainability) has been started and study aimed at joining YOPP (Year of Polar Prediction; WMO/PPP) is planned, it is expected to proceed with much more new research studies on Arctic climate change.

Keywords: Arctic, sea ice, warming amplification, mid-latitude link, Arctic sea routes



Mid-winter transport of subsurface warm water in western Arctic Ocean

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Ocean heat transport is a possible important factor for recent sea ice decline, especially in the western Arctic Ocean. It has been indicated that vertical hydrographic profiles in the Canada Basin were characterized by three temperature maxima. The near-surface temperature maximum was the shallowest one arising from summer solar heat absorption and subsequent autumn Ekman downwelling. The subsurface temperature maximum reflected intrusion of Pacific summer water. The deepest maximum was located in the Atlantic layer. Substantial parts of upper ocean heat would eventually affect sea ice freezing/melting. However, spatial and temporal variabilities of these warm layers still remain uncertainties. Recently, year-long moorings in Chukchi Abyssal Plain detected mid-winter subsurface warming, plausibly caused by lateral advection of shelf-origin water. In this study, a pan-Arctic sea ice-ocean modeling was performed to address overwinter transport of subsurface warm water. The horizontal grid size was approximately 5 km to resolve mesoscale eddies and narrow jets. The interannual experiment from 2001 to 2014 demonstrated that Barrow Canyon throughflow and westward shelf-break jet established primary pathways of subsurface heat transport toward Chukchi Borderland. Shelf-break heat was partly lost by event-like wind mixing but remained under highly stratified surface layer until mid-winter.

Keywords: Arctic Ocean, Subsurface temperature maximum, Shelf-break jet

Wintertime variability of the Beaufort Gyre in the Arctic Ocean derived from CryoSat-2/SIRAL measurements

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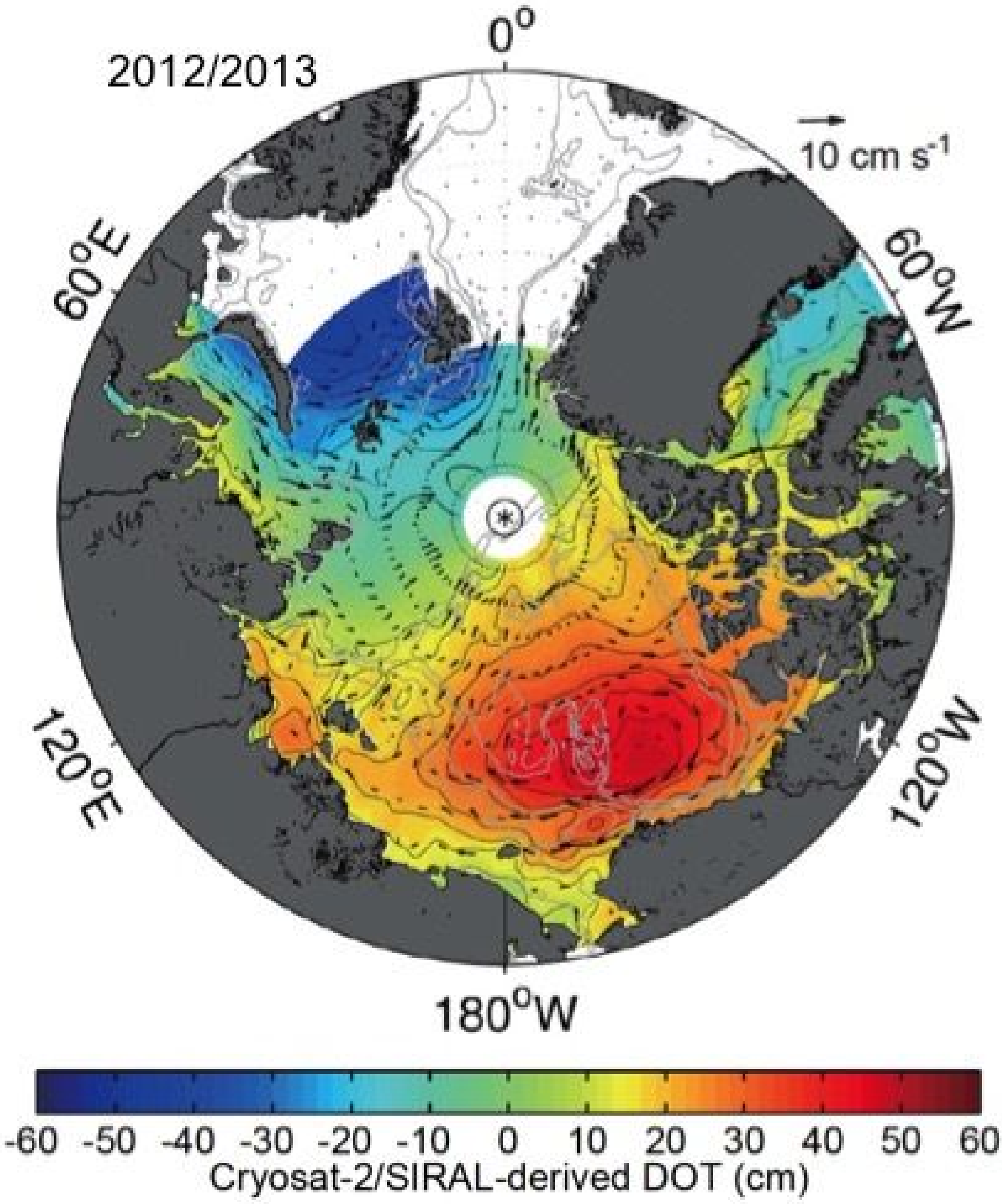
The monthly dynamic ocean topography (DOT) of the Arctic Ocean was successfully estimated .by using the sea surface height measured by the SAR / Interferometric Radar Altimeter (SIRAL) on board CryoSat-2 (CS-2). The CS-2 monthly DOT showed the interannual and monthly variability of the Beaufort Gyre (BG) during winter between 2010/2011 and 2014/2015. Estimated BG in the Pacific Sector of the Arctic Ocean indicates that the northward flow at the western edge of the BG was primarily estimated over the Chukchi Borderland (CBL). However, in the winter of 2012/2013, the BG extended across the CBL (see figure). Our analyses revealed a significantly variable BG in response to changes in the sea surface stress field. Our analysis suggests that 1) sea ice motion, driven by wind fields, acts as a driving force for the BG when sea ice motion was intensified during winter and 2) sea ice motion can also act as an inhibiting force for the BG when sea ice motion is weakened during winter. In addition, the relationship between the DOT, steric height and ocean bottom pressure implied that the DOT during winter responded to varying wind stresses through baroclinic and also barotropic adjustments. According to a tracer experiment based on our monthly CS-2 DOT and derived geostrophic velocity field, we inferred that in the winter of 2012/2013, the Pacific-origin water carried into the BG through the Barrow Canyon was transported to the northern shelf and shelf break of the Chukchi Sea rather than the CBL, which is where the Pacific-origin water had been transported in the other years of the observation period.

Keywords: Beaufort Gyre, CryoSat-2/SIRAL, Dynamic ocean topography


2012/2013
0°
10 cm s-1
60°E
60°W
120°E
120°W
180°W
-60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60
Cryosat-2/SIRAL-derived DOT (cm)

Medium-range prediction of the Arctic sea ice

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INTRODUCTION

The summer Arctic sea-ice extent has decreased in this several decades. This reduction has accelerated maritime transport using the Arctic sea route. Sea ice prediction is essential to realize safe and sustainable use of the route. Especially, medium-term forecast looking several months ahead is necessary to determine whether or not the shipping route through the Arctic will be navigable.

The Arctic Ocean is nearly fully covered by sea ice until April or May, after which time interannual differences in ice area become noticeable. One possible cause of the interannual difference of ice retreat is ice thickness in spring before the start of melting. However, observations of ice thickness are insufficient in their spatial and temporal coverage, observation period or their accuracy to resolve the interannual difference of the thickness. Recently, Krishfield et al. (2014) shows the way to derive the daily sea ice thickness from the satellite microwave data.

To estimate the spatial distribution of spring ice thickness, we focus on the winter ice motion and redistribution. Our prediction is basing on the relationship between the ice thickness in spring and ice area in the following summer. We predict the summer ice area based on this relation.

DATA

We prepare a daily ice-velocity product on a 60 km resolution grid for 2003-2015, calculated from data of the satellite microwave sensors Advanced Microwave Scanning Radiometer-Earth Observing System (AMSR-E) and AMSR2. The procedure for detecting ice motion is based on the maximum cross correlation method (Kimura et al., 2013). Ice thickness is calculated from AMSR-E and AMSR2 images using the algorithm by Krishfield et al. (2014). This study also uses satellite derived daily ice concentration on a 10 km resolution grid, distributed by Arctic Data archive System (https://ads.nipr.ac.jp/index.html).

METHOD OF ICE PREDICTION

To investigate the dynamic redistribution of sea ice during winter, movement of particles spread over the ice area is calculated. About 20000 particles having initial ice thickness are arranged at an interval of 30 km over the ice area on December 1 of each year. Daily displacement of the particles is calculated from the satellite derived ice velocity on one-day time steps up to April 30.

Provisional ice thickness on April 30 is estimated by 1) particle density only, 2) particle density multiplied by the initial ice thickness, 3) particle density multiplied by the initial ice thickness only in the thick-ice (>1.5m) area. We found the highest correlation between the spring ice thickness and summer ice cover in the case of 3. We can predict the summer ice area based on the relationship between the provisional ice thickness and summer ice area. Based on the analysis, first report of the summer ice prediction showing the ice concentration map for July 1 to September 11 is released in May on our website.

The medium-term forecast looking several months ahead should be useful for safe and efficient use of the Arctic sea route. As a next step, we are trying to predict the ice thickness distribution.

ACKNOWLEDGEMENTS
We wish to thank the Arctic Data archive System for the gridded AMSR-E and AMSR2 data. This study was supported by the Green Network of Excellence Program Arctic Climate Change Research Project.

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Keywords: Arctic, Sea ice, Satellite remote-sensing

Impact of radiosonde data over the Arctic ice on forecasting winter extreme weather over mid latitude

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In February 2015, the Arctic air outbreak caused extreme cold events and heavy snowfall over the mid latitude, in particular over the North America. During the winter, special radiosonde observations were made on the Norwegian RV Lance around the north of Svalbard under the N-ICE2015 project. We investigated the impact of the radiosonde data on forecasting of a cold extreme event over the eastern North America using the AFES-LETKF experimental ensemble reanalysis version2 (ALERA2) data set. ALERA2 was used as the reference reanalysis (CTL) while the observing-system experiment (OSE) assimilated the same observational data set, except for the radiosonde data obtained by the RV Lance. Using these two reanalysis data as initial values, ensemble forecasting experiments were conducted. Comparing these ensemble forecasts, there were large differences in the position and depth of a predicted polar vortex. The CTL forecast well predicted the southward intrusion of the polar vortex which pushed a cold air over the eastern North America from the Canadian Archipelago. In the OSE forecast, in contrast, the trough associated with southward intrusion of the polar vortex was weak, which prevented a cold outbreak from Arctic. This result suggested that the radiosonde observations over the central Arctic would improve the skill of weather forecasts during winter.

Keywords: Arctic, polar vortex, ensemble forecast

Relationship between the Arctic Oscillation and Surface Air Temperature in Multi-Decadal Time-Scale

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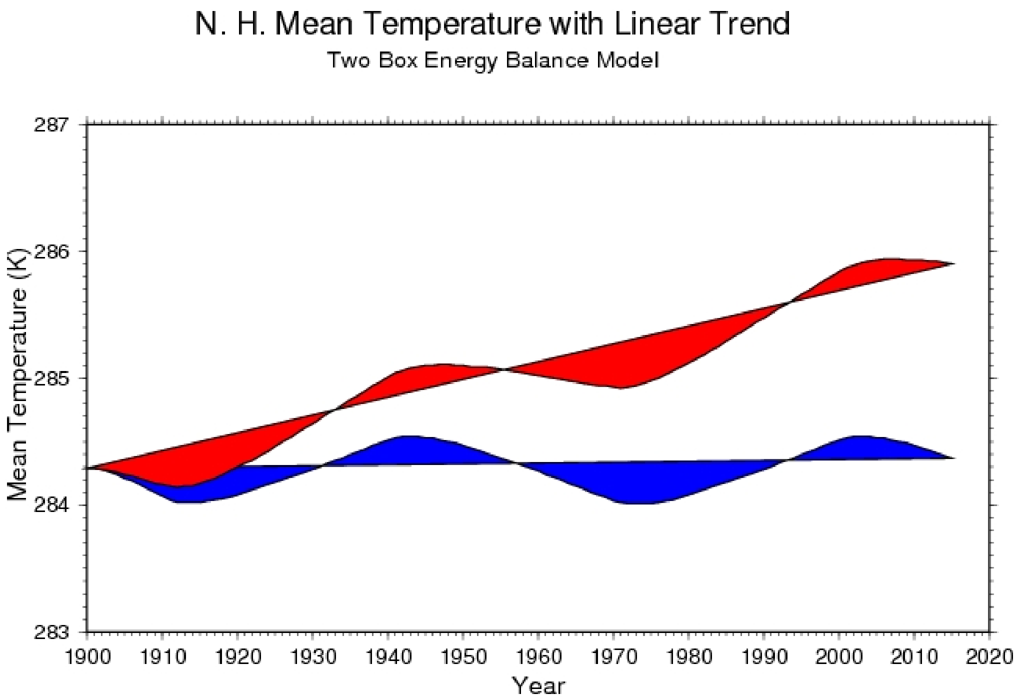
In this study, a simple energy balance model (EBM) was integrated in time, considering a hypothetical long-term variability in ice-albedo feedback mimicking the observed multi-decadal temperature variability. A natural variability was superimposed on a linear warming trend due to the increasing radiative forcing of CO2. The result demonstrates that the superposition of the natural variability and the background linear trend can offset with each other to show the warming hiatus for some period. It is also stressed that the rapid warming during 1970 to 2000 can be explained by the superposition of the natural variability and the background linear trend at least within the simple model.
The key process of the fluctuating planetary albedo in multi-decadal time scale is investigated using the JRA-55 reanalysis data. It is found that the planetary albedo increased for 1958 to 1970, decreased for 1970 to 2000, and increased for 2000 to 2012, as expected by the simple EBM experiments. The multi-decadal variability in the planetary albedo is compared with the time series of the AO mode and Barents Sea mode of surface air temperature. It is shown that the recent AO negative pattern showing warm Arctic and cold mid-latitudes is in good agreement with planetary albedo change indicating negative anomaly in high latitudes and positive anomaly in mid-latitudes. Moreover, the Barents Sea mode with the warm Barents Sea and cold mid-latitudes shows long-term variability similar to planetary albedo change. Although further studies are needed, the natural variabilities of both the AO mode and Barents Sea mode indicate some possible link to the planetary albedo as suggested by the simple EBM to cause the warming hiatus in recent years.

Keywords: Arctic Oscillation, Arctic Amplification, Energy Balance Model, Planetary Albedo, Multi-decadal Variability


N. H. Mean Temperature with Linear Trend
Two Box Energy Balance Model
Mean Temperature (K)
287
286
285
284
283
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year

Cooperation between the arts and science ----Integration of disintegration----

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Integration of research in the arts (humanities) and science is the focus of attention, both in academia and the media. However, little attention has been given to the fundamental differences in methodology and research posture between the two. This difference can, and often does hinder productive cooperation, as well as becoming the grounds of distrust in research results. Based upon personal experience as an Arctic anthropologist, I discuss instances of success and failure in cooperative research. As a contribution to further cooperation, I conduct natural scientists on a journey into the mysteries and pitfalls of anthropological field research.

Observation of Atmospheric Environment over The Arctic and West Siberia using ROSHYDROMET Airplane

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The Arctic, including West Siberia, is the most sensitive region in the world to the global warming. Continuous and synthetic monitoring of the atmospheric environment has been desired in this region. For this and related purposes, airplanes are extremely useful for environmental observation. Recently, the Federal Service for Hydrometeorology and Environmental Monitoring (ROSHYDROMET) has deployed a new airplane, the Yakovlev-42D (photo), a so-called “Airplane-Laboratory”, and has entrusted the Central Aerological Observatory (CAO) with its operation. This is the only airplane that can fly over the Arctic and Siberia in Russian domain for scientific studies. On the other hands, Japanese organizations have on-going and future satellite missions, e.g., GOSAT and GCOM-C1. It is expected that the synergetic use of the satellite data and the “Airplane-Laboratory” can contribute to comprehensive monitoring of the Arctic environment. To promote the synergetic operation of the satellites and the airplane, AORI/UT and CAO entered an agreement for scientific cooperation on November 7, 2014, and within the framework, we co-organized a kick-off meeting on 23–24 November 2015 in Moscow and started discussion on its flight schedule and usage of the observational data. The cabin of the “Airplane-Laboratory” is divided into six sectors, i.e. 1)Meteorology, 2)Gas and aerosol (including a lidar), 3)Radiation (including an imager), 4)Radioactivity, 5)Cloud microphysics, and 6)Radar, and each sector is equipped with various types of instruments to measure the gaseous and particulate matters in the troposphere. Many gaseous species, CO_2, CH_4, O_3, NO, NOx, NOy, can be measured not only by exclusive sensors for each but also Cavity Ring-Down Spectroscopy (CRDS) operated onboard. Size distribution of aerosols of which size ranging 0.06-3.0μm can be measured by particle counters, and cloud condensation nuclei (CCN) and black carbon (BC) are also measured simultaneously. As for cloud microphysics, size distribution of cloud particles can be measured by various types of probes as well as detection of cloud crystal habits. The radiometers measure up- and down-welling radiation in the spectral range from ultra violet (UV) to thermal infrared (TIR). Up-looking lidar and down-looking imager whose spectral band covers UV through near infrared (NIR) are also equipped. Russian side expects Japanese community to contribute to calibrate CRDS and Single Particle Soot Photometer (SP2) instruments for more precise measurements of gaseous species and BC. Total flight time was 200 hours in 2014, and 500 hours are scheduled to be allotted in 2015-2033 (totally 20 years). We are negotiating over how much amount of flight time will be allotted to the joint observations with Japanese side in future.

Keywords: The Arctic, Airplane, Atmospheric Environment, ROSHYDROMET, West Siberia

Tropical Forcing of the Early Twentieth Century Warming over the Arctic

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Land air temperature over the Arctic had warmed by about 1.5C during the early twentieth century (20C). We examine a remote forcing of tropical oceans on the early 20C warming over the Arctic, analyzing new sea surface temperature (SST) products and comparing SST-forced atmospheric general circulation model (AGCM) simulations. The new SST products feature a significant warming in the equatorial Pacific during the early 20C while conventional ones exhibit a broad warming over the tropics and subtropics. Only AGCM simulation forced with the new SST product successfully reproduces the observed Arctic warming and atmospheric teleconnection patterns triggered by the equatorial Pacific warming. They effectively transport heat from the subtropics to the higher latitude, contributing to the Arctic warming during the early 20C.

Keywords: Arctic warming, Interdecadal Pacific Oscillation

On the mechanism of vegetation feedback to the Arctic warming amplification

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It is well known that the Arctic climate is sensitive to the external radiative forcing and its response is generally larger than the rest of the world. Observations show that the Arctic is indeed warming at about twice the speed of the global average, and climate model simulations also projects that the Arctic warming amplification continues to the future. Various physical processes have been listed as important contributors to the amplification, but the feedback effect of vegetation distribution change in response to the climate change is not always taken into account. Here, we extend the study of O’ishi and Abe-Ouchi (2009) in which the vegetation change is internally predicted in a coupled climate-dynamic vegetation model. In the current study, a calibration for the model’s systematic bias against present-day observations is added. This is important as the present-day vegetation distribution impacts on how the vegetation changes under the perturbed climate, and that the vegetation responds to the temperature itself and not to the temperature anomaly. Detailed energy transport and energy balance analysis are conducted for the doubled and quadrupled CO_2 equilibrium experiments.
In the experiment of atmospheric CO_2 increase, much of the current tundra area is replaced by the boreal forest, and the temperate forest expands as the boreal forest migrates to the north. Arctic land surface warms the most in spring due to albedo increase through vegetation-type changes and earlier snow melting. The effect of vegetation feedback is, however, not confined to the land warming. The large warming occurs in the Arctic Ocean in winter. Part of the excessive energy over land is cancelled by the increased evaporative cooling and part of it is transported to the Arctic Ocean in spring. This transport is accomplished by the mean meridional circulation (polar cell) in the atmosphere. This increased heat transport induces sea ice albedo feedback in summer and large heat release from the ocean in winter, causing the Arctic warming amplification.

Keywords: Arctic warming amplification, vegetation feedback, climate model, dynamic vegetation model

Comparison of CO_2 fluxes estimated by top-down and bottom-up methods -- a case study at Yakutsk, Siberia --

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Carbon balance of the forested ecosystem is widely recognized as an important component in climate change research, but remains uncertain at the same time. Attempts have been made, recently, to understand the origin of the uncertainty by comparing estimates of carbon budgets with bottom-up and top-down methods. In the Green Network of Excellence (GRENE) Arctic Climate Change Research Project (hereafter as, GRENE Arctic project), terrestrial and atmospheric observations are conducted in the Arctic regions, where observational data were not available otherwise, e.g., in Siberia. At the same time, CO_2 fluxes are estimated using process-based terrestrial ecosystem,models and atmospheric CO_2 inversion models as a part of the GRENE Arctic project.
In the terrestrial sub-program, observation on energy-water-carbon balances are conducted in the Circum-Arctic, and the fluxes are estimated by a suite of terrestrial ecosystem models at four super-sites in the GRENE-TEA model intercomparison project (GTMIP) (Miyazaki et al., 2015). In the greenhouse gas sub-program, atmospheric CO2 concentration is measured at high accuracy using aircrafts and at surface stations and top-down/inverse modeling is performed for estimating regional CO_2 fluxes. We have compared the CO_2 fluxes estimated from tower observation at Yakutsk, Siberia with the CO2 flux estimates by the land-surface models for Yakutsk and CO_2 surface fluxes estimated by inverse models around the Yakutsk region (area ~500 x 500 km^2). The Net Ecosystem Production (NEP) or Net Biome Production (NBP) are considered for this analysis at monthly time intervals over the period of 1980 - 2012 (from 2004 - 2011 for flux observation).
We find that the seasonal cycle of CO_2 flux consists of a large drawdown in June-August from the atmosphere, and weaker emissions or absorptions in other months. This result agrees well among the models and observation. As for the long-term changes, the model variation is smaller in summer (June-August) than for the annual values. That is because respiration takes a dominant part of CO_2 flux in winter, that would have large uncertainty both for the observation and the model estimation. Thus the large uncertainty in CO_2-flux estimates in winter would affect the large fluctuation for the annual values. The year-to-year variations in summer by some models agree, at least in part, with the observation, but the reasons for the agreement/disagreement should carefully be investigated. At first, the difference in the horizontal scale represented by each method should be considered. Besides, different treatments of forest fire are identified as one of the possible causes for model-to-model differences. The extreme climate, such as very humid or hot-and-dry summer, resulted in year-to-year changes in NEP/NBP with the tower observation, but some models do not agree to those changes. Making thorough examination of each case is required to identify the causal process of the disagreements and to reduce the uncertainty in CO_2 balance.

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Keywords: CO2 balance, boreal forest region, topdown and bottomup hethod, tower observation

Weather Conditions During Large-Scale Widespread Forest Fires in Alaska

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Global maps of wildfires show large-scale widespread fire zones throughout the world. One major fire zone is in the boreal forests of Alaska. The boreal forest in Alaska encompasses about 0.47×10^{6} km^2 (i.e. 32% of the total Alaskan land area) and has experienced large-scale widespread fires more frequently in recent years, most notably in 2004, 2005, 2009, and 2015. The total burnt area by wildfires in 2004 was largest on record. The burnt area by wildland fires was approximately 26,700km^2 in 2004 (the largest burnt area on record) and 20,900km^2 in 2015 (the second-largest burnt area). The total burnt area in just these two fire years comprised approximately 10.5% of the entire Alaskan boreal forest.
In this study, we analyzed the daily fire weather conditions during recent severe fire-periods. Synoptic-scale weather conditions were analyzed using upper (500hPa) and near surface level (1000hPa) atmospheric reanalysis data. Synoptic-scale weather maps based on the atmospheric reanalysis data were used to document the severe fire weather conditions leading to extensive wildfire activity under both high- and low-pressure conditions. For high-pressure conditions, wind direction change from south-westerly to north-easterly associate with high-pressure system movement from south to north was discussed using weather events related to Rossby waves breaking (RWB). We discussed relationship among weather events related to RWB and fire activities.
The results are summarized as follows:
1. Fire weather conditions of the high-pressure type occurred under unique weather phenomena related to RWB. RWB occurred in easterly wind flow with large Jet stream meandering (JSM) occurring near Alaska. The high-pressure system at the lower level (1000hPa) moved toward the north under a ridge and blocking high over Alaska at the upper air level (500hPa). During the movement of the high-pressure system from south to north, two severe fire weather conditions the first hotspot peak (1) and second (largest) hotspot peak (2) appeared.
2. Two distinctive hotspot peaks, the first peak (1) and second peak (2) during each fire-period, occurred under two different synoptic-scale fire weather conditions. Fire weather conditions during first hotspot peak (1) consisted of a ridge in the Gulf of Alaska at the lower- and upper-levels. The ridge in the Gulf of Alaska supplied south-westerly wind into inland Interior Alaska. The weather conditions during the second hotspot peak (2) were dominated by the Beaufort Sea High (BSH) after high-pressure system passed over Alaska related to RWB phenomena.
3. The BSH occurred in conjunction with a blocking high aloft and supplied easterly wind into Interior Alaska. The BSH located at northern coast of Alaska resulted in relatively stronger easterly wind than the south-westerly wind during the first hotspot peaks (1) due to large pressure difference between the BSH and Interior Alaska. This is likely a key reason that the second hotspot peak (2) is larger than the first during the top four fire-periods.
4. A low-pressure fire weather type also occurs with south-westerly wind in Interior Alaska that results in a single large hotspot peak. This wind condition occurs due to the large pressure difference between a low-pressure system in the Arctic Ocean and a high-pressure system in the Bering Sea.
5. The onset of the high- and low-pressure fire weather types in Alaska may both be predictable. This study suggests that : (a) onset of large Jet stream meandering in the west of Alaska may indicate the high-pressure fire weather type, (b) onset of low-pressure system development

(cyclogenesis) in the Arctic Ocean and a high-pressure system in the Bering Sea may precede the low-pressure fire weather type.

Keywords: Beaufort Sea High, Jet stream meandering, Rossby waves breaking, Widespread fires, MODIS hotspot

InSAR detection of thermokarst after a tundra wildfire, using ALOS-PALSAR

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Through the subsidence of ice-rich permafrost upon thaw (thermokarst), the consequences of permafrost degradation for surface ecology, landscape evolution, and hydrological processes have been of great scientific interest and social concern. Part of a tundra patch affected by wildfire in northern Alaska (27.5 km2) was investigated here, using remote sensing and in-situ survey to understand permafrost thaw dynamics after surface disturbances. L-band InSAR with spatial resolution of less than ten meters detected ground subsidence triggered by the tundra fire. We introduced a calibration procedure comparing burned and unburned areas for InSAR subsidence signals to remove the noise from seasonal surface movement. In the first year after the fire, an average surface subsidence rate of 6.2 cm/year (vertical) was measured. Subsidence in the burned area continued over the following two years with decreased rates. These results suggest that this InSAR-measured ground subsidence is caused by the thaw of ice-rich permafrost (thermokarst), a feature supported by surface change observations from high-resolution optical images and in-situ ground level surveys. InSAR analysis clearly showed spatial variation in thermokarst subsidence at fine scale, enabling us to investigate dynamics of thermokarst processes and quantify permafrost degradation, and leading to accurate estimates of ground ice loss upon permafrost thaw.

Scanning Electron Microscopy (SEM) analysis of Black Carbon in Arctic snow

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Snow and ice on glaciers in Arctic contain various atmospheric depositions, such as soot (black carbon) and mineral dusts. These light-absorbing impurities can reduce surface albedo and affect melting of glaciers. Thus, it is important to understand optical characteristics of the impurities on Arctic glaciers. In this study, we analyzed structure and surface chemistry of black carbon collected from snow in several Arctic regions (Siberia, Alaska, Greenland, and Sapporo) with Scanning Electron Microscope (SEM, QUANTA FEG 450) and Energy Dispersive X-ray Spectrometer (EDS). Microscopic observation revealed that snow samples from Alaska, Greenland and Sapporo contained black carbon particles with chain-like structures and compact aggregate structures as shown in Scarnato *et al.* (2013). However, the proportion of these black carbon structures were different among the samples. For example, snow from Greenland contained higher abundance of chain particles, while that from Alaska contained higher compact particles coated by membrane like material.

Keywords: Black Carbon, SEM, Arctic Snow

Concentrations and depositions of black carbon and insoluble particles in Alaskan snows

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Snow cover in the Arctic is affected by global warming and has strong effects on albedo feedback. Light-absorbing particles such as black carbon (BC) and mineral dust could decrease snow albedo and accelerate snow melt, thus exerts influence on climate. In order to evaluate their impacts on snow albedo, it is important to know accurate concentration and deposition flux of light absorbing particles. Under the GRENE Arctic Climate Change Research Project, we collected seasonal snow cover samples from Alaska. During 2012-2015, we collected snow samples from 22 sites across Alaska in late February or early March. BC particles were measured using a single particle soot photometer (SP2), which is based on the laser-induced incandescence technique. Insoluble particles were measured using a Coulter Counter. From the spatial variations of BC concentrations, our sampling sites can be divided into five regions, i.e. Barrow (71.32°N), Prudhoe Bay (70.19°N), north region (66.56-68.62°N), middle region (63.57-65.9°N) and south region (61.82-63.27°N). The middle region shows the highest BC concentrations. These five regions also show different BC mass size distributions. BC mass size distributions in south region is similar to that in typical ambient air, whereas snow in middle region displays high percentage of large BC particles (>645nm). Mass concentrations of insoluble particles show spatial trend similar to that of BC concentrations. BC and insoluble particle depositions in snow were calculated with snow water equivalent (SWE) and concentrations. Averaged SWE in south region is the highest of three regions, but winter BC depositions is the highest in middle region, as is BC mass concentrations. Winter depositions of insoluble particles show no significant spatial trends.

Keywords: black carbon , Alaska

The sources of nitrogen and its effect on microbes on glacial snow and ice in the northwest Greenland

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The quantity and distribution of insoluble impurities are one of the most significant factors to determine surface albedo and have been reported to affect substantial melting of glacier ice and snow. Supraglacial impurities usually consist of inorganic and organic material accreted on the ice surface by wet precipitation or aeolian deposition. Microbes and organic matter are also dominant biotic constituents of supraglacial impurities. Microbes include cold-tolerant snow and ice algae, cyanobacteria, and heterotrophic bacteria, and they can grow and proliferate on the melting snow or ice surfaces. These microbes and their derivative organic matter often aggregate with mineral particles and form spherical granules called cryoconite. Cryoconite and some pigmented algae usually display a higher light absorbency (i.e. dark colored) compared with pure snow and ice, thus they can efficiently reduce surface albedo of snow and ice. Nitrogen is one of the important nutrients supporting growth of such microbes, however, information on their sources and dynamics on the glacial systems is still limited. We report soluble nitrogen concentrations and the nitrate stable isotopes (18O and 15N) in snow, ice, and meltwater collected in the north-west Greenland Ice Sheet. Nitrate was contained in both of snow and glacial ice. O and N isotopes of the nitrate showed that nitrate in snow is mostly supplied from atmosphere derived from natural origin, while that in glacial ice is from anthropogenic origins. Nitrogen isotope in organic faction in the impurities coincided to that of snthoropogenic nitrogen, suggesting that that microbes on the glacier used mainly anthropogenic nitrogen.

Keywords: Greenland, microbe, nitrogen

Seasonal variations in frontal positions and flow speeds of marine terminating outlet glaciers in northwestern Greenland

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Greenland ice sheet is losing mass due to increase in surface melting and ice discharge from marine terminating outlet glaciers. The mass loss from the Greenland ice sheet accounts for a substantial part of global sea level rise over the last several decades. To accurately include the contribution of marine terminating outlet glaciers in the future projection of global sea level rise, better understanding of mechanisms controlling the glacier dynamics is required. Thus, it is important to study changes of marine terminating outlet glaciers in connection with atmospheric and the ocean conditions. For this purpose, we analysed Landsat images to measure frontal positions and flow speeds of marine terminating outlet glaciers along the coast of the Prudhoe Land, northwestern Greenland between 1987 and 2015. Relationships among frontal position, flow speed, sea ice condition in front of glacier terminus, and air temperature were investigated with special focus on seasonal variations.
All of studied 19 glaciers retreated from the 1980s to 2014. Among those, Heilprin, Tracy, Farquhar, Melville, Bowdoin, and Diebitsch Glaciers retreated by more than 1 km. Most of the studied glaciers began retreat around 2000, as demonstrated by the increase in the mean retreat rate from −1 m a^{-1} in 1980s–1999 to 66 m a^{-1} in 2000–2014. A possible driver of the rapid retreat since 2000 is atmospheric warming because the rapid retreat followed the onset of summer temperature increase in northwestern Greenland. Within 5 km from the studied fronts, ice speed ranged between 14 and 1814 m a^{-1}. Many of the studied glaciers accelerated in the early 2000s. Magnitude of the acceleration was correlated with the retreat rate as demonstrated by rapid retreat and flow acceleration at Heilprin, Tracy, Farquhar, Bowdoin and Diebitsch Glaciers. The acceleration was greater near the front, suggesting the change in the flow regime enhanced stretching of ice along the glacier and induced dynamic thinning. These results indicate that ice thinning due to flow acceleration was the driver of the rapid frontal retreat of the sutdied glaciers.
In general, studied glaciers advanced from spring to early summer, which was followed by retreat in late summer. Then, the front stayed at the retreated positions throughout the following fall. Magnitude of the seasonal front variations ranged in 50–400 m. The timing of the seasonal retreat agreed with the disappearance of sea ice in front of the glacier terminus. Many of the glaciers indicated speedup from spring to mid-summer and deceleration in late summer. Magnitude of the seasonal variations in ice speed was between 80 and 440 m a^{-1}. Because the speed changes were correlated with air temperature in summer season, the seasonal speedups were probably due to enhanced basal sliding driven by meltwater input to the bed.

Keywords: Glacier, Greenland

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.

Keywords: Arctic, Sea ice, Climate model

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.

Keywords: hybrid latent/sensible heat polynya, sea ice production, interannual variability

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.

Keywords: Barents Sea, Ice-Ocean General Circulation Model, Sea surface heat flux

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.

Keywords: Arctic region, Arctic Amplification, extreme event

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).

Keywords: Arctic, Global warming projection, Global atmospheric model, Precipitation

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

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Nagoya University continues to develop Cloud Resolving Strom Simulator (CReSS). CReSS is applied to analyze the structure of precipitation systems in the tropics and mid-latitude regions. However, we have never conducted the simulation around the Arctic region, except for a case of the cloud-streak structure over the Labrador Sea during a cold-air outbreak. The R/V Mirai (MR13-06) of Japan Agency for Marine-Earth Science and Technology (JAMSTEC) made an intensive observation using a Doppler radar, upper-air soundings, and instruments for surface meteorological parameters at a fixed observation point (168.25W, 72.75N) in the Arctic Ocean in 2013. To confirm the performance of CReSS in the Arctic region, we conducted a simulation to reproduce low pressure systems observed by the R/V Mirai.

A numerical experiment using CReSS is examined. The horizontal grid spacing is 2.5 km, and the domain has an area of 2000 km times 2000 km, including the fixed observation point of the R/V Mirai. The vertical grids are consisted of 32 layers and the top of the domain is set at 12.8 km. The numerical experiment is conducted for 72 h, starting at 00Z on September 23, 2013. Data of the Global Spectral Model (GSM: Horizontal grid resolution was 0.5 degree) provided by Japan Meteorological Agency (JMA) are used as the initial and boundary conditions of the simulation. Sea surface temperature (SST) is initialized using the Optimum Interpolation Sea Surface Temperature (OISST) data provided by National Oceanic and Atmospheric Administration (NOAA). Vertical heat transfer below the land and sea surfaces are calculated, as a result, time variation of sea surface temperature (SST), sensible and latent heat fluxes (SHF, LHF) from the surface are calculated. No sea ice parameterization is included.

A synoptic scale low pressure accompanying weak precipitation (snow) less than 1 mm/h is reproduced in the north of Wrangel Island. A mesoscale low pressure around the synoptic scale one is confirmed by a satellite observation. The simulation can reproduce a vortex-like structure related to the mesoscale low pressure. Using the Mirai Doppler radar, deep convective clouds whose echo-top height reaches a height of 4 km are observed around the mesoscale low. However, the cloud-top height in the simulation is restricted only below a height of 1.5 km, thus the deep convective clouds cannot be reproduced. To compare the simulation result with the satellite observation, 3-dimensional distribution of the reflectivity in the frequency of the CloudSat-CPR (95 GHz) is calculated using Satellite Data Simulator Unit (SDSU). The low reproducibility of the depth of convection is confirmed by the composite analysis using 20 flight paths. High reflectivity greater than 0 dBZ with the convective structure is observed by the CloudSat-CPR, however, the simulation cannot reproduce the high reflectivity region.

Time series of SST at the R/V Mirai between the observation and simulation are analyzed. At the initial time, OISST are 0.2 degree Celsius lower than that of the observation. SST is almost constant in the observation during the period, however, that of the simulation decreases gradually by the SHF and LHF. As a result, SST difference increases 1.0 degree Celsius at the end of the simulation. The constant SST would be attributed to the northward horizontal advection of warm water by southerly surface wind and heat loss by the SHF and LHF. CReSS cannot reproduce the wind-driven ocean flow, thus we fail to reproduce time series of SST. The failure of the SST at the R/V Mirai influences on the LHF from the sea surface and unrealistic saturated atmospheric boundary layer (fog) in the last 24 hours. The weak forcing from the sea surface would contribute to the

failure of the development of deep convection. The air-sea interaction and three-dimensional ocean simulation would be important to reproduce the meteorological phenomena in the Arctic region.

Keywords: Arctic region, air-sea interaction, a cloud-resolving model, mesoscale polar low

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

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From the climate model simulations, it is projected that the Arctic warming will be strengthened in the future.
However, the degree of projected warming varies with climate models and there are substantial uncertainties in the future projections of Arctic warming.
Shmidt et al.(2013) suggested a possibility of constraining uncertainty in the future climate projections by using information from past periods when the Arctic region was warmer than today. In their study, however, only a statistical correlation between paleoclimate and future climate simulations across models is presented. Therefore, the underlying mechanism causing the correlation is unclear. As they are well aware, the sound physical explanation is necessary in order for us to apply their method to constrain the future climate projections.
The principle aim of this study is to investigate commonality and difference of Arctic warming mechanism in the past and in the future, and to obtain insight into the possibility of constraining uncertainty of future climate projections by using paleo-climate data. We use the outputs of pre-industrial control, the quadruple of atmospheric CO_2 concentration(4×CO_2) and mid-Holocene experiments from 11 CMIP5/PMIP3 atmosphere-ocean general circulation models. The mid-Holocene here refers to 6000 years ago and the Arctic region was warmer than today because of the difference in earth’s orbital parameters.
First, we identified predominant processes of Arctic warming in each experiment based on the surface energy balance, and also investigated sea ice, clouds, water vapor and sea surface temperature response. In both experiments, most of the anomalous energy input into the Arctic region in summer is used for melting of sea ice, absorbed into the ocean. Consequently, the surface warming is moderate during summer. Several months later, the heat is released from the exposed warm sea surface and it causes the Arctic warming. In addition, the role and approximate timing of sea ice, clouds and water vapor changes are common in the two experiments. We found that there are many commonality in the Arctic warming mechanism in the future and in the mid-Holocene even though they are caused by completely different external forcing.
Next, we quantified that contribution of individual processes to the inter-model variance of the surface temperature changes in the Arctic region for each experiment. In the 4×CO_2 experiment the largest contribution to the variance of annual mean (ANN) surface temperature change is the surface albedo feedback. As to the October - December (OND) mean surface temperature change, on the other hand, it is the heat release from the ocean. In the mid-Holocene experiment the largest contributions to the variance of both ANN and OND surface temperature change in the Arctic region are made by the differences in downward clear-sky longwave radiation. Also, the contribution of the surface albedo feedback to the variance of ANN surface temperature changes and the contribution of the oceanic heat release to the variance of OND surface temperature changes are relatively large and statistically significant. As the surface temperature and near-surface air temperature which determines the downward longwave radiation are tightly coupled, it is expected that constraints of other processes would result in a reduction of total uncertainty. In other words, if the Arctic warming in the mid-Holocene is simulated accurately, the reliability of the model’s representation of surface albedo feedback, the process related to oceanic heat release, and hence the future projections would increase.

Based on the understanding of Arctic warming mechanism from this study, it is considered that paleo-environment information of Arctic Warming in the mid-Holocene is useful for constraining uncertainty in the future projections of Arctic warming.

Keywords: Climate models, Paleoclimate, Future projections

Climate changes in Ny-Ålesund and Longyearbyen, Svalbard based on long-term meteorological and terrestrial dataset

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Arctic has been undergoing various climatic and environmental changes in associated with global warming. Temperature increase rate is almost double that the rate of global average, which causes the melting of permafrost, the reduction of sea ice. Since the climatic system in the Arctic consists of the interactions between atmospheric circulation, hydrological process, and sea ice variation, the understanding of atmosphere-land (ice)-ocean feedbacks is required to reveal the environmental changes due to global warming. Therefore long-term and multi-point monitoring of atmospheric, ocean and terrestrial components are required.
Svalbard is representative area for Arctic research where various institutes have been performing long-term monitoring. Longyerabyen and Ny-Ålesund in Spitsbergen that are located in far from human activity are better suited for monitoring of minor variation components and Arctic climate changes. National Institute of Polar Research (NIPR) and Alfred-Wegener Institute (AWI) have monitored climatic components since early 1990s using Automated weather stations. In Longyerabyen, The University Centre in Svalbard (UNIS) has monitored meteorological and permafrost components at Adventdalen with boreholes and weather stations. In addition to research institutes, Norweigian Meteorological Institute (NMI) has monitored snow cover and precipitation at Svalbard Airport and Ny-Ålesund since 1970s. We have compared various components of climatic system such as air temperature, ground temperature, precipitation, snow cover at several locations using NIPR, AWI, UNIS and NMI dataset. As a result of analysis of time-series variations, some notable trends in air temperature and precipitation were found. Winter temperatures at Longyearbyen and Ny-Ålesund are increased during the last two decades, however, temperatures at March remain mostly unchanged or decrease. As for the precipitation, precipitation amount at Ny-Ålesund remain unchanged, while that at Longyerabyen decreases. In this presentation, we discuss the long-term trend and correlation of meteorological and permafrost components.

Keywords: climate change, Svalbard

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^{o}N-70^{o}N, 20^{o}E-140^{o}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.

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.

Keywords: Siberian Larch Forest, Climatic Change, Vegetation Model

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.

Spatial distribution pattern of willows in Indigirka river lowland of northeast Siberian Arctic

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A warming climate and longer growing season may lead higher primary production and expansion of deciduous tundra shrubs in the arctic. Willows and alders are dominant plants in riparian ecosystem, which is frequently disturbed by river flooding. Because of their high productivity, carbon assimilation in this ecosystem is expected to be important. However, willows distribution and primary production have not be fully understood yet. Willows dominate large area of the floodplain of Yana-Indigirka-Kolyma river lowland in northeast Siberian Arctic. We investigated distribution patterns and NDVI of willows in the Indigirka River floodplain using satellite image classification and GIS.
High resolution vegetation map and satellite derived NDVI were obtained from a WorldView-2 satellite image (10 x 10 km) based on the field observations in July 2013 near Chokurdakh (70^{o}N, 148^{o}E). The willow distribution pattern corresponding to a distance from the river was analyzed. The willow covers 1/6 of lowland in local scale, and showed large extent along mainstream of the Indigirka River. This implies that large area along the main stream is affected by spring flooding, and willows cover this area. Besides, the area covered by willows showed the highest NDVI among the vegetation classes. These results mean the willow vegetation along the main stream and tributaries may greatly affect the primary production in river lowland of northeast Siberian Arctic.

Keywords: vegetation, floodplain, NDVI, GIS

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.

Keywords: Methane Oxidation, Peat, Permafrost soil, Oxygen

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.

Keywords: methane flux, interannual variation, isotope ratio, taiga-tundra boundary

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.

Keywords: ice accretion, snow accretion, albedo, boreal forest

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.

Keywords: snow albedo feedback, vegetation masking effect, Earth system model

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 x10 km) were estimated to be 100 mm in 2014 and 78 mm in 2015.

Keywords: snow water equivalent, water isotope ratios, Northeastern Siberia

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.

Keywords: Arctic glaciology, Glacier thinning, Glacier dynamics

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.

Keywords: Tidewater glacier, Greenland, Fjord, Submarine melting

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.

Keywords: Greenland, mass balance, climate change, ice cap

New developments of Arctic Data archive System(ADS)

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Arctic is the region where the global warming is mostly amplificated, and the atmosphere/ ocean/ cryosphere/ land system is changing. Active promotion of Arctic environmental research, it is large and responsible for observational data. Promotion of Arctic research in Japan, has not been subjected to independent in their respective fields.
In the National Institute of Polar Research, perform the integration and sharing of data across a multi-disciplinary such as atmosphere, ocean, snow and ice, land, ecosystem, model, for the purpose of cooperation and integration across disciplines, we build a Arctic Data archive System (ADS).
Arctic Data archive System (ADS), to promote the mutual use of the data across a multi-disciplinary to collect and share data sets, such as observational data, satellite data, numerical experiment data. Through these data sets, clarify of actual conditions and processes of climate change on the Arctic region, and further contribute to assessment of the impact of global warming in the Arctic environmental change, to improve the future prediction accuracy.
A new project of the Arctic research (ArCS :Arctic Challenge for Sustainability) has been started in 2015. ArCS is a national flagship project funded by the Ministry of Education, Culture, Sports, Science and Technology. The National Institute of Polar Research (NIPR), Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and Hokkaido University are playing the key roles in this project, and will continue to carry it out for approximately four-and-a-half years from September 2015 to March 2020. ADS is responsible for the data management of this project.

Keywords: Arctic, Environment, Global Warming, ArCS, Data

Access analysis of data visualization web service for polar region

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Arctic Data archive System (ADS) has been constructed for archiving or distributing various datasets, which are observed in the Arctic region by Japanese researchers. ADS was developped the following web services during GRENE Arctic Climate Change Research Project.
1. Metadata search service KIWA.
2. Online visualization application VISION.
3. Quasi-real-time polar environment ovservation monitor VISHOP.
These Web services are accessed from all over the world. In this study, we performed the web access analysis to the period of GRENE project. We will present the analysis results, such as the time-series of access number and viewers' behavior on ADS web site.

Keywords: Web Service, Access Analysis, Visualization, Data

