The Second International Advisory Board of Arctic Challenge for Sustainability

February 2019

The Second International Advisory Board of Arctic Challenge for Sustainability (ArCS)

Submitted by ArCS International Advisory Board

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Issue date March 2019
Issue, edit ArCS secretariat
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Abbreviations

PD	Project Director
SPD	Sub-Project Director
PI	Principal Investigator
IAB	International Advisory Board
CDN	Coordinator

I Position of IAB meeting

ArCS has two essential aims. The first one is to make information from scientific facts and to deliver it to internal and external various stakeholders so that they can make appropriate decisions for the sustainability of the vulnerable Arctic. The second one is to promote the presence of Japan within various international legal discussions for harmonized and sustainable development of the Arctic. In order to keep and to secure the step of ArCS toward these aims, ArCS prepared International Advisory Board (IAB). Advices from IAB are expected for us to promote the international presence of ArCS and to seek a way of possible cooperation with the society. Members of IAB are Professor Klaus Dethloff, Dr. Gail Fondahl, Dr. Larry Hinzman, Professor Stein Sandven, and Dr. Jeremy Wilkinson. All of them are not only excellent scientists themselves but also leaders of international Arctic projects.

The first assembly of advices from IAB was carried out though an e-mail based procedure in 2017. Advices as recommendation from IAB were much valuable for us to plan 2019-2020 actions of ArCS. However, it is also found that a face to face meeting between IAB members and ArCS researches are desirable to expect more significant and comprehensive advices to ArCS and to Japan's Arctic research even in future.

So, position of this meeting is of the spontaneous action of ArCS, however, IAB and its role is defined in the ArCS Guideline approved by MEXT in 2016 including possible face to face meeting implicitly. Advises and recommendations from the meeting are to be issued by IAB to ArCS which is the undergoing Japan's Arctic project.

II Summary overview

Arctic Challenge for Sustainability (ArCS) is a multi-sectoral Arctic research programme that covers a number of very complex topics associated with Arctic change and its global implications. The aim of this report, the second by the International Advisory Board of ArCS, is to provide a rigorous collective assessment of ArCS programme to date. In particular, we have focused on ensuring the aims of ArCS are being met, the scientific progress, rigor, orientation and output of the programme is appropriate, international developments and collaborations are being effectively developed, and the effective dissemination of results is being achieved. We highlight areas of strength, but also provide recommendations where needed.

The Second International Advisory Board was held at the Auditorium, National Institute of Polar Research (NIPR), Tachikawa, Tokyo on 4th – 6th February, 2019. All IAB members and Management and Theme Leaders of ArCS were present, as well as representatives of the Japanese Ministry MEXT. Much of the information provided for this assessment was supplied through paper/digital documentation delivered to IAB members, as well as through oral presentations (each followed by a Q&A) during the meeting. This format worked well as it not only provided a good opportunity to assess the achievements and progress of ArCS, but also as provided an opportunity for close interaction between the ArCS and the members of the IAB.

Role of Japan in International Arctic Science

Climate change does not respect international boundaries, nor do the changes we are witnessing in the Arctic. If we are to achieve a much-improved understanding of the regional and global effects and long-term implications of Arctic change we must take a holistic, multidisciplinary approach to our science: one that strengthens the links between science, policy and society, but also one that provides connections to the peoples of the region, supports businesses to make strategic investment decisions, and enables policy-makers to develop evidence-based decisions to mitigate climate change while ensuring sustainable economies. Outward-looking transdisciplinary projects, like ArCS, are at the vanguard of this approach.

We congratulate MEXT for the vision of a multidisciplinary research programme of such dimension that it unites the natural sciences with the social sciences, but also works in partnership with indigenous populations, industry and policy makers to provide a holistic understanding of the impact and opportunities of Arctic change. Since ArCS began, transdisciplinary research has gained traction and the International Arctic Science Committee (IASC) has been pushing strongly in this direction. Japan is providing scientific leadership in this regard.

Through the scientific advancements made formerly within GRENE and now by the ArCS programme there is quantifiable evidence that Japanese researchers have earned and taken a prominent international standing in Arctic science. Their scientific output is making substantive contributions to understanding the complexity of the Arctic as a system. Their engagement within prominent non-governmental organizations, such as IASC, SAON, GEO, the Arctic Council Working Groups and others, is clear evidence of the growing stature of Japanese Arctic science. One of the important contributions that the ArCS program is making is in the field of Arctic Observing: this may be one of the greatest legacy products of the ArCS program over the next century. Our analyses and models will continue to advance, but we only get one chance to complete measurements at a point in space and time. Given the speed of the changes we are witnessing in the Arctic the importance of these measurements should not be underestimated. Some of the results presented to the IAB were very significant, and thus it is important that there is a coherent strategy to continue to collect data over the long term. Given the growing prominence of Japanese Arctic science the time may be right for Japan to further capitalize on investments in capacity building (Arctic observations and modelling) by establishing a national committee for Arctic Research. This committee could further strengthen the links between research, industry needs, and Japan's policy in the Arctic.

High Level View of ArCS Progress, and Contributions

The ambitious nature and sophistication of interdisciplinary research projects within ArCS does make it a challenging programme to manage, but the rewards are high. The IAB members were unanimous in their agreement that the research being conducted is impressive and worthy of support. Given that ArCS is nearing the end of its tenure, it may be time for ArCS research themes to review the results of other groups which are doing similar studies but in different areas of the Arctic. Such a review would not only put ArCS results in context, but provide a basis, through combination of the studies, for a powerful Pan-Arctic overview of change.

One of the strengths of a holistic programme like ArCS is that it focuses on issues that are timely and societally relevant.

It is laudable that ArCS research is looking beyond climate change to also consider shifting social issues, demographics, ecosystem dynamics, and political pressures. By addressing these big challenges, it is sometimes easy to lose sight of original goals. The leads of all themes should spend some time reflecting on the primary goals of the ArCS program, and make certain their team's efforts are focused on making valuable contributions towards those goals.

We were struck by key ways in which ArCS outputs are contributing to international calls for priority research needs, as described in the ICARP-III Strategic Roadmap, the Arctic Council's Sustainable Development Working Group (including in their 2017 Framework for priorities) and the Second Arctic Human Development Report in its identification of gaps in knowledge. It is important to connect with those documents, and to underscore and publicize how your research fulfils these internationally generated priorities. The exchange of early career researchers was a positive initiative within ArCS as it creates better science in the short term and stronger capacity in the long term. The efforts to promote capacity building within Japanese institutions should be applauded. ArCS, NIPR, JAMSTEC and Hokkaido University should work with researchers to preserve intellectual property, scientific expertise and attempt to commercialize operational products where possible.

ArCS is making significant gains in the physical sciences, but the work in the social sciences is also impressive. For example, the work on the Northern Sea Route trajectories and oil & gas resource development in Russia, contributions to understanding of human environment interactions in Eastern Siberia and Greenland, and ArCS work on international Arctic governance is being recognized internationally. One increasing demand of all Arctic research is that it makes meaningful contributions to Arctic residents. ArCS has made good strides here. Examples include the workshops convened with Greenland locals to communicate research and the teaching material developed to improve people's understandings of climate change in Sakha Republic. In the next phase Japanese scientists may consider how this can be expanded. What other Arctic audiences would be interested in these analyses? Japan may play a special role in providing research on and in Russia, and with Russian colleagues develop cooperation over Eurasia, a key region for Arctic-mid latitude linkages and human-environment interaction.

In many areas of Arctic research there is a growing emphasis on collaborative research with Arctic residents. If possible, they should be involved at all stages, including the co-planning and co-generation of research questions. We encourage continued work to increase the number of women among Japanese Arctic scholars across all fields. The integration of social sciences and natural/physical sciences came through clearly in ArCS structure; this is important and praiseworthy. One must not be complacent as the process of interdisciplinary science is still developing, and this approach is critical for understanding paths toward sustainability. The IAB encourages ArCS to equally promote projects with social and physical scientists leading and defining the research.

The broad scope of ArCS means that there is a policy dimension to many of the results. It was encouraging to see researchers presenting not only an excellent overview of the changes that are occurring in the Arctic, both on land and in the terrestrial environment but also highlighting how these changes can impact food security and other Sustainable Development goals. A particular link between ArCS output and policy was the interaction with the Sakha government on a proposed winter sanctuary: this is an excellent example of a productive link between science and evidenced-based policy. Dissemination and outreach to a range of stakeholders including indigenous communities has been outstanding. The science within the themes is exceptionally strong, but it was sometimes difficult to evaluate the effectiveness of the science that cuts across the themes. This is an area that the management team of ArCS may need to explore further. The work in Qaanaaq (NW Greenland) is a good example of cross cutting science, as it brings together glacial dynamics, ocean physics, ecosystem dynamics and community needs. In the same vein the research on seabird mortality is a good example of pulling in information from a number of different sources in order to better understand the underlying causes of the deaths of these birds.

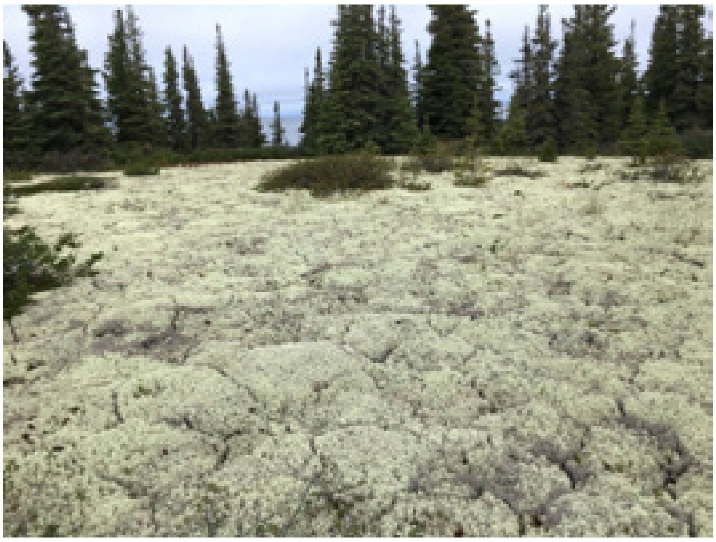
The work on data archiving and visualisation is very impressive. Development of enhanced visualisation tools are very well-advanced. A project as complex and diverse at ArCS needs this. To achieve over 3 million webpage views signals tremendous outreach. Explaining the relevance of Arctic science to society is a prerequisite for large programmes like ArCS. Public engagement is key and ArCS developing a number of avenues to ensure this occurs is laudable. It is important to keep metrics on such interactions to understand what works, what doesn't and how to improve interactions for the future. The IAB acknowledge and applaud ArCS' interactions with industry early in the program. This will certainly ensure greater value of products developed and probability of acceptance into daily operations. It is encouraging to see the development of products for enhancing ship navigation and public use of the data for climate change analysis.

Particular Strengths Across the Program:

- Engagement with the Arctic Council through dispatching experts to their Working Groups was a particular strength. This seems to be working very well; Japanese researchers are well represented and respected.
- Establishing links to research and observation stations in the 10 Arctic regions will certainly enhance capacity building for Japanese researchers, but also cement scientific ties with host nations. Efforts with Russia are particularly commendable and we feel the extra effort will be well worthwhile as presently interactions with Russian Arctic scientists needs to increase.
- Program for Overseas Visits by Young Researchers holds great promise. This is a great vehicle to ensure interaction for younger Japanese scientists with international groups. The importance of establishing these connections early in one's career cannot be underestimated.
- The project's success on cross-discipline collaborations through uniting social scientists and natural scientists, as well as directly involving indigenous communities and other key stakeholder stands out also as a strength.
- The project has exemplary scientific output, including through the publication of ArCS results in peer-reviewed journals.

ArCS has undoubtedly made huge strides in Arctic science, both nationally and internationally. Possibly the most notable success of ArCS is the tremendous output of scientific papers: this reflects well on the team and the quality of science within the project. The programme must be careful not to spread itself too thinly. Now is the time to consolidate on these successes, in order to ensure that ArCS has a long-term vision regarding the science it aims to achieve from these collaborations, and how it links with Japanese Arctic policy. With just over a year to go we would encourage the management team to think about the legacy of ArCS. What are the main outputs that the programme wants to achieve? And how will these be accomplished in the time still allocated to the programme?

III Comments on Specific ArCS Research themes and Programs



III-1-1 Research theme 1: Weather and sea ice predictability

PI: Jun Inoue (NIPR)

1. Achievements

We focused on three research topics. The first is Arctic cyclones and their impact on sea-ice and wave forecasts. The second is the impact of extra observations on predictability over the Arctic and beyond, and the last is the interaction of providers and end users of forecasts. The following subsections describe the details.

1.1 Arctic cyclones

Cyclones over the Arctic Ocean are influential for navigation because the strong winds cause rapid ice drifts, high waves, icing on ships by sea spray, and low visibility due to clouds. The decrease in sea-ice cover also increases the frequency of coastal erosion by waves, which is a threat for the indigenous people in the Arctic coastal region. Therefore, precise prediction of cyclones is desired in spite of the sparse observing network.

To understand the current operational predictability of extreme Arctic cyclones (ACs) observed over the Arctic, Yamagami et al. (2018) investigated extremely developed cyclones using the TIGGE (THORPEX Interactive Grand Global Ensemble) database. It was found that the average existence probability of the predicted ACs was >0.9 at lead times of ≤3.5 days among five operational weather centers (ECMWF, ECCC, UKMO, NCEP, and JMA). The forecast skill for extraordinary ACs is lower than that for midlatitude cyclones in the northern hemisphere partly due to less observation data in the Arctic region. ECMWF has 1–1.5 days advantage compared with the other centers in predicting existence probability, central pressure, and position.

TOPAZ4, the sea-ice reanalysis and forecasts forced by the ECMWF operational forecast, was assessed in order to understand the impact of atmospheric forcing on the skill of sea-ice thickness (SIT) prediction over the East Siberian Sea, which is one of the key regions for navigation of the Northern Sea Route (NSR). Pattern correlation analysis of the SIT forecast data over 3 years (2014–2016) reveals that the early summer SIT distribution is accurately predicted for a lead time of up to 3 days, but that prediction accuracy drops abruptly after the fourth day, which is related to a dynamic process controlled by synoptic-scale atmospheric fluctuations (Nakanowatari et al. 2018). We further investigated the impact of the skill of atmospheric forcing on sea-ice predictability. Ono et al. (2016) found that atmospheric forcing assimilating the extra Arctic observations is effective in improving the forecast accuracy of sea-ice distribution in cases of extreme ACs. Therefore, errors in weather forecast data would have a substantial impact on safe navigation and knowledge of sea-ice distribution.

The uncertainty of atmospheric forcing also influences the skill of wave height in the Arctic Ocean. Based on the field campaign of the RV *Mirai* in September 2016, we deployed two wave buoys in the Beaufort Sea. Two high-wave events of more than 4m associated with cyclones were observed. Although ERA-Interim wave height generally captured those features (Waseda et al. 2018), the wave event in October was underestimated. The results from the Wave Watch III model forced by ERA-Interim and the other reanalysis (ERA5 and CFSR) had the same feature. Finally, we found that the number of surface observation data in October assimilated into the reanalysis was almost one-fifth of that in September, amplifying the uncertainty of surface winds in the atmospheric forcing data (Nose et al. 2018).

1.2 Impact of extra Arctic observations

Although extra Arctic observations are basically useful for improving the skills of weather and sea-ice forecasts in the Arctic region (e.g. Ono et al. 2016), their impact on atmospheric circulations in midlatitudes during winter and summer has been poorly understood. Considering the societal benefit of Arctic research activities, it is important to understand how Arctic observations can be useful for human activities in the midlatitudes (e.g. reducing the risk caused by extreme weather events).

We investigated the impact of extra Arctic radiosonde observations on the predictability of two typical weather events during winter and summer. The winter topic is related to two cold-air outbreak cases in East Asia and eastern North America (Sato et al. 2017). It was found that the observational signal that originated from the Arctic region has a flow-dependent characteristic driven by a movement of tropospheric potential vorticity, improving the strength and track of an extratropical cyclone in each case in the medium-range forecast. This idea was also applied to summer weather events, tropical cyclones observed in East Asia and eastern North America (a typhoon and hurricanes). The prediction skill of their tracks in cases of a lead time longer than four days was improved when the extra Arctic radiosondes were assimilated into the initial fields (Sato et al. 2018).

Although filling the gap of the Arctic observation network is desirable based on the results above, it costs a lot to manage research bases, logistical transport, and human resources. Therefore, the cost-benefit observing frequency is one of the issues to be solved. Based on observing system experiments and special radiosonde observations aboard RV *Mirai*, Inoue et al. (2015) proposed that four-launches per day is effective to obtain skillful weather forecast over the Arctic Ocean. This result contributed to giving guidance to the Year of Polar Prediction in order to decide the frequency of radiosondes at the existing Arctic stations during Special Observing Periods (SOPs).

1.3 User engagement

The uncertainties of forecasting weather, waves, and sea ice are fundamental information along with the forecasts themselves for navigating the Arctic Ocean. However, the end users of weather services seem to rely on the product provided by a single weather center without information on uncertainty. It is desirable to demonstrate how useful multicenter products can be on a ship with a limited internet connection.

An early-winter expedition on board the research vessel RV *Mirai* was made in November 2018 in the Chukchi Sea. It was the first trial for the RV *Mirai* to enter the Arctic Ocean in the winter season. Frequent radiosondes, wave buoys, and daily conductivity-temperature-depth (CTD) cast near the marginal ice zone were conducted during the cruise to investigate the predictability of weather, wave, and sea ice in the Arctic during the period of freezing. To succeed with this challenging mission to carry out valuable research activities, precise weather and sea-ice forecasts are necessary for safe navigation. The chief scientist of this Arctic winter cruise aboard the RV *Mirai* received substantial support by the European Centre for Medium-Range Weather Forecast (ECMWF) and Environmental and Climate Change Canada (ECCC), who provide the team aboard with daily operational forecasts. In addition, NIPR has developed a Vessel Navigation Unit support System (VENUS) to receive and automatically process forecast data on the ship based on the effort from ArCS Research Theme 8.

Real-time forecasts are used during the expedition to manage the cruise schedule on time scales from a day to a week. Because closing of the Bering Strait by sea ice is critical for the RV *Mirai* as an ice-strengthened ship, several parameters, such as air temperature, winds, and sea ice cover, as provided by ECMWF and ECCC, need to be compared in order to decide when to escape from the Arctic Ocean through the freezing Bering Strait. During daily meetings, the chief scientist trains the captain and the ice-pilot of the RV *Mirai* on how valuable multiple centers' high-resolution forecasts can be for their daily decisions.

2. Outcomes

The researchers in ArCS Theme 1 published several important peer-reviewed papers, as described above. Press releases have been issued based on five of them (Inoue et al. 2015, Sato et al. 2017 and 2018, Nakanowatari et al. 2018, and Waseda et al. 2018). Those papers were also introduced in AAAS EurekaAlert! Science News. It is obvious that most of our successful papers have been coauthored based on the several international collaborations by the Alfred Wegener Institute (AWI), the Korean Polar Research Institute (KOPRI), the Norwegian Polar Institute (NPI), the Nansen Environmental and Remote Sensing Center (NERSC), Environment Canada, and the Arctic and Antarctic Research Institute (AARI). Those research projects have been highlighted in WMO-related meetings (YOPP summit, PPP SG, etc.), IASC-related meetings (IASC AWG, POLAR 2018, MOSAiC WSs, etc.), and other conferences (AOS, Arctic Circles, etc.).

Our research activities influenced several communities. One in particular is the YOPP community, to decide the frequency of radiosonde observations (four launches per day) during the Special Observing Periods of YOPP, based on the optimal frequency proposed by Inoue et al. (2015). The other aspect is communication with indigenous people. We attended the Alaskan Eskimo Whaling Commission in January 2019 to introduce the preliminary results of our Arctic cruise in 2018 and our future plan (fall 2019).

We consider that feedback by end users of weather services to the operational weather centers is very important. The radiosonde data obtained aboard RV *Mirai* is transferred in real time so it can be used for operational weather forecasts as a contribution to YOPP. Daily repeated CTD casts in open waters and the marginal ice zone is valuable data to evaluate coupled atmosphere-ice-ocean models that are being further developed in the frame of YOPP. In the view of the YOPP Consolidation Phase, which will start by mid-2019, this Arctic winter cruise will serve as a good example of how to interact with users of weather services and to seek their requirements for safe polar navigation. We have been invited by ECMWF to attend the Workshop: Observational Campaigns for Better Weather Forecasts, held June 10–14, 2019, which should be an excellent opportunity to address our efforts.

3. Remaining issues

So far, it has been difficult to communicate with private-sector entities like shipping companies, and it is uncertain whether they need a route-searching system for navigation support over the NSR. Based on the progress in the last 3.5 years of this project, we strongly suggest a change in their way of thinking as end users of forecasting services. Understanding the large uncertainties that forecasts hold is critical for their navigation. Based on the lessons we learned during our Arctic research cruise in 2018, researchers should try to demonstrate how to use the forecast data with a user-friendly tool like the VENUS system. Without such a demonstration, end users tend to rely on easily accessible products (e.g. cheaper and visually attractive systems, etc.) in spite of lower accuracy.

The task team of the Societal and Economic Research and Applications in the Polar Prediction Project (PPP-SERA) does research that also deals with decision-making processes by a diverse range of actors in polar regions and providers of environmental information. Knowing maritime users in the Arctic and their needs is also an issue in PPP-SERA. The limited interaction between producers (i.e. weather operational centers) and end users (i.e. crew on ships) is considered a bottleneck. To fill the gap, researchers can translate from integrated scientific perspectives to the understandable importance of meteorological knowledge for the end users. Serving societal needs better, which is also one of the WMO's long-term goals and strategic objectives in 2020–2023, is a challenging task for our research theme; however, developing awareness of our activities in the community (i.e. data providers and end users) through the ArCS project should continue during the remaining period by reporting our successful experiences.

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III-1-2 Comments for research theme 1

This is an excellent and outstanding research approach, which delivers extremely useful information about the added value of extra radiosonde observations over the data-sparse Arctic Ocean. Adding spatially limited observations, like those performed within this theme, improve short-term weather, sea ice and cyclone forecasts (with the help of data assimilation techniques).

Advanced knowledge of Arctic cyclones are very important for local communities, fisheries the shipping industry, and other socio-economic activities. This is because strong surface winds impact on low level clouds, the sea ice drift, and can lead to high ocean wave heights. The decrease in sea-ice cover increase Arctic coastal erosion by ocean waves which is a threat for the living population. This theme shows that extra radiosonde observations in different regions over the Arctic Ocean improve the short-term weather predictions in different target areas, but there are also regions with larger forecast errors due to an atmospheric flow dependent error evolution. The predictive skill of an atmospheric model forced by initial conditions can be improved by four launches of extra radiosondes per day. These studies served as pilot studies for the preparation of the Year of Polar Prediction and are of unique value for the predictability of extreme weather events connected with synoptic cyclones in the Arctic and mid-latitudes. They are very essential for improved short-term sea ice predictions and ocean wave forecasts for the development of Northern Sea Route navigation systems in the High North.

Strengths:

The estimate of observation uncertainty in Arctic regions using data assimilation techniques has a big potential to improve weather forecast models. This theme produced an outstanding list of high quality scientific papers, developed international collaboration with leading Arctic research institutions, including the Russian Arctic and Antarctic Research Institute, and contributed greatly to the enhanced visibility of Japan's Arctic research. The PI, a member of the WMO Polar Prediction Project Steering Group, also plays an important role as PI for cyclone and sea ice forecasts in the upcoming international MOSAiC project (Multidisciplinary Observatory for the Study of Arctic climate). The theme demonstrates excellent relations between researchers and stakeholders and users, e.g. shipping companies and maritime safety and warning services. The Vessel Navigation Unit Support System (VENUS) installed on the Japanese RV MIRAI will be of great value, including during the international MOSAiC drift experiment from September 2019- September 2020.

Recommendations:

The topic should further focus on the identification of shortcomings in the numerical description of Arctic processes and the sources of error forecast in the Arctic and contribute to an improved physical understanding of Arctic-mid-latitude linkages due to a better description of baroclinic-planetary scale feedbacks. This topic could cooperate with topic 5 with respect to data assimilation techniques.

III-2-1 Research theme 2: Variations in the ice sheet, glaciers, ocean and environment in the Greenland region

PI: Kumiko Goto-Azuma (NIPR)

The Greenland ice sheet and the glaciers, ocean, climate, and environment in and around Greenland have been experiencing drastic changes. Mass loss of the Greenland ice sheet could lead not only to sea-level rise but also to abrupt changes in the global climate and ocean circulation, which would influence human societies and economies, including those of the local communities of Greenland. In these circumstances, we have been carrying out studies on two subthemes: (1) variability of the Greenland ice sheet and climate, which will focus on Greenland's interior areas; and (2) ice sheet/glacier–ocean interaction in Greenland, which will focus on the coastal regions of Greenland.

1. Variability of the Greenland Ice Sheet and climate

1.1 Scientific achievements

We participate in the international ice coring project (East Greenland Ice Core Project, EGRIP) and collaborate with Denmark, the United States, Norway, France, Switzerland, etc. A deep ice core to the bed is being drilled at the onset of the North-East Greenland Ice Stream (NEGIS). We carry out analyses of the EGRIP core as well as ice cores previously drilled in Greenland, borehole observations, and modeling studies. Major scientific achievements are as follows.

- Analyses of the snow-pit samples from EGRIP yielded surface mass balance in the past 10 years, which show much less variability compared to northwestern coastal sites (figure 1). In fiscal 2019, we will further study spatial and temporal variations of surface mass balance by adding new data.
- An ice core from northwest Greenland showed that changes in mineral dust composition in 1920–1950 and 1990–2013 are likely due to warmings. During the warm periods, dust sources from coastal Greenland likely became more important than those in Asian deserts. In fiscal 2019, we will confirm this by further analyses of dust, atmospheric circulation, and meteorological conditions.
- Using high-resolution and accurate black carbon (BC) data from an ice core drilled in northwest Greenland, we found increases in BC sizes as well as BC concentrations during the first half of the 20th Century due to anthropogenic input. In fiscal 2019, we will analyze impacts of warmings on wildfires. We are also analyzing BC in the EGRIP core, participating in international analysis campaigns at the University of Bern. In fiscal 2019, we will compare the results of the two cores.
- From the NEEM ice core drilled in northwest Greenland, we found that source concentrations of terrestrial biogenic and dust aerosols were not affected by 1.5–2°C warmings in the mid-latitude northern hemisphere source regions. We also found that summer melting had not frequently occurred in northwest Greenland during early Holocene, when the temperature was higher than the present-day by 2–3°C.
- We analyzed the NEEM borehole data and calculated the flow enhancement factor to incorporate impurity and anisotropy effects into ice flow modeling. The flow enhancement factor was found to be very large for cold periods with high impurity concentrations, even on a millennial time scale, which corresponds to several meters in depth scale. We also implemented ice stream physics in the ice sheet models. We performed spin-up simulations to reproduce the present-day state of the Greenland ice sheet with the improved ice sheet models, including ice stream physics and a depth-dependent flow enhancement factor. Comparison with observations (topography, surface velocity) showed good agreement.
- Deformation tests in a cold laboratory using artificial ice show that microparticles enhance ice deformation for fine-grained ice, while they suppress deformation for large-grained ice (figure 2). Preliminary experiments using NEEM ice-core samples suggest that impurity concentrations do not directly affect deformation of ice-sheet ice, but regulate grain sizes, which affect ice deformation. In fiscal 2019, we will perform more experiments on ice-core samples and confirm the preliminary finding. We will then formulate a new flow law for ice sheet ice.
- We analyzed physical properties of the EGRIP ice core and found that characteristic crystal preferred orientation (COF) developed in much shallower depth compared to previous drill sites in Greenland. In fiscal 2019, we will continue the analyses and study ice stream dynamics.
- We incorporated the effect of Earth rotation change to glacial isostatic adjustment (GIA) modeling for precise estimation of crustal deformation induced by ice sheet changes. Using this model, we reconstructed the past relative sea level along the Greenland coast and inferred the deglaciation history of the Greenland Ice Sheet. We also compared the simulated present-day crustal motion with the satellite geodetic observations and revealed the relation with ice mass balance. In

fiscal 2019, we will develop a GIA–ice sheet coupled model to improve the model's performance.

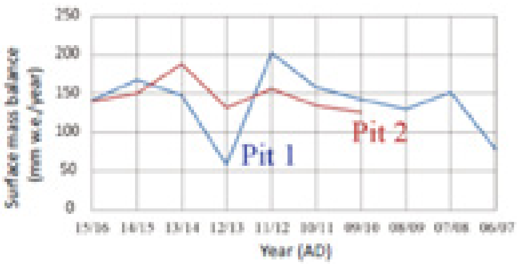


Figure 1. Surface mass balance at EGRIP.

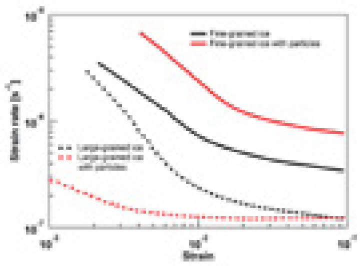


Figure 2. Results of mechanical tests.

1.2 Outcomes so far, and prospects and expectations in the future

The data obtained in this study will be made available on public websites so that they can be used for validation and calibration of satellite data, and for assessments of impacts of warming on terrestrial and marine environments. Our GIA model provides important boundary conditions to constrain the ice sheet models for precise reconstruction of the past ice sheet. The improved ice sheet models and GIA–ice sheet coupled models built in this study, together with the results of the mechanical tests, will play important roles in better projections of future mass loss of the Greenland Ice Sheet and its impact on sea level. The new insights gained by this study will provide stakeholders with essential information for assessment and mitigation of future risks on societies and economies.

In addition to the scientific outcomes, EGRIP has contributed to outreach, training of early career scientists, building of international networks, and exchange of knowledge on drilling technology between private sector entities and academia.

1.3 The way forward

We need more data from ice core analyses, borehole measurements, and morphological observations to assess the impacts of warmings on sea level and the environment. We also need present-day observations in the field and from satellites. Furthermore, we need to improve ice-sheet, GIA, and climate models for better future projections. Interdisciplinary studies and close collaborations among ice-core scientists, geologists, satellite experts, atmospheric scientists, meteorologists, oceanographers, ice-sheet modelers, climate modelers, and GIA modelers are strongly needed.

2. Ice sheet/glacier–ocean interaction in Greenland

2.1 Scientific achievements

In the study of glaciers and ice caps, we quantified retreat, thinning, and speed change of all calving glaciers in the Qaanaaq region since the 1980s (figure 3, left). This study was performed in collaboration with the University of Copenhagen. We also performed field-based observations. Monitoring of Qaanaaq Ice Cap has been repeated for the last 6 years. Fjord and glacier bed geometries were surveyed with local collaborators to search the mechanism of the recent rapid retreat of Bowdoin Glacier (figure 3, middle). In collaboration with ETH Zurich, we utilized new technologies (UAV, terrestrial radar, seismicity, tsunami) on glacier calving processes.

Another important study area is the ocean. In close collaboration with local residents, we performed oceanic measurements, sampling and long-term observations in glacial fjords in the Qaanaaq region. Physical and geochemical observations in Bowdoin Fjord revealed upwelling of subglacial meltwater discharge and its distribution into the marine environment (figure 4, left). The measurements are extended for several years by operating mooring devices in the fjord. In collaboration with the ArCS Theme 6, we surveyed seabirds and plankton and found significant influence of glaciers on marine ecosystems. Field data are utilized to develop a numerical model for fjord circulations.

The glacier and ocean changes are relevant to the life of 600 residents in Qaanaaq Village. We work together with social scientists to investigate the impact of environmental changes on society. Such impact was clearly observed during our visit to Qaanaaq as floods of glacial streams and landslides. Sea ice is declining, which we have started monitoring with satellite data and UAV survey. Social scientists from the University of Calgary as well as from ArCS Theme 7 help us to identify problems in the society. Every summer since 2016, we organized workshop with local residents to start conversation with the locals (figure 3, right).

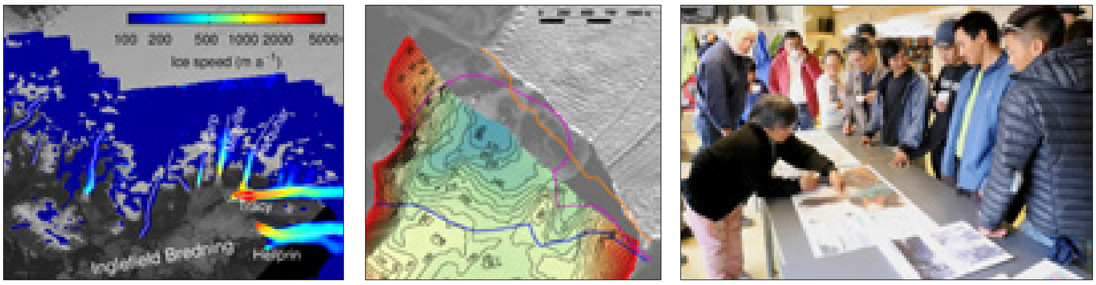


Figure 3. Left: Ice speed of calving glaciers in the Qaanaaq region (Sakakbiara and Sugiyama, 2018). Middle: Retreat of Bowdoin Glacier and fjord bathymetry. Right: Workshop in Qaanaaq in 2017.

2.2 Outcomes so far, and prospects and expectations in the future

An important achievement in the glacier study is 6-year-long monitoring of Qaanaaq Ice Cap. We provided the data to contribute to a scientific community paper. The data are shared with the community through the World Glacier Monitoring Service. In the ocean study, we published a paper on the importance of glacier meltwater in nutrient transport in a glacial fjord (figure 3, left). This effect has recently been recognized, and is quantified for the first time in this project. The paper has a significant impact on the glacier–ocean science community, so the study was highlighted by a bulletin of AGU and public media. A series of workshop in Greenland, public events in Japan, and research meetings in Sapporo, Japan, are key achievements of our project. The residents in Qaanaaq are fully aware of the changing climate and are willing to learn about the future of their living environment. The workshop provides us an opportunity to introduce our project, share scientific data, learn local knowledge, and exchange ideas for the sustainable future of the Arctic. We also organized several public events and research meetings in Japan (figure 4, middle). These events offer the public the opportunity to learn the importance of a changing Arctic, as well as help the integration of researchers for interdisciplinary Arctic study.

Figure 4. Left: Upwelling meltwater plume at the front of a calving glacier (Kanna et al., 2018). Middle: Public event with Greenlandic musicians. Right: ILTS special issue on Greenland.

2.3 The way forward

In 2015 and 2016, we witnessed floods of glacial streams after intensive ice and snow melting and heavy rainfall (figure 5, left). The floods destroyed a road connecting Qaanaaq Village to its airport. In 2016 and 2017, buildings in a nearby smaller village, Siorapaluk, were damaged by a landslide (figure 5, middle). We initiated field surveys on the stream discharge and slope stability. Preliminary results confirm the influence of warming and an increasing amount of liquid precipitation. Collaboration with engineers to prevent and mitigate the disaster is our next challenge. We also need more conversation with local residents and government to allow them to understand and take action on future risks.

Figure 5. Left: Flood of stream in Qaanaaq in August 2016. Middle: Landslide in Siorapaluk. Right: Numerical modeling of glacier discharge.

III-2-2 Comments for research theme 2

The dynamics of the Greenland Ice Sheet and the physical impacts it imparts to global sea level rise as well as influence on regional and global climate make these research efforts very important to Japan and to all other coastal nations. There are many international research efforts ongoing on Greenland and it is important that Japan continues to engage in these important collaborations.

2.1 Variability of the Greenland Ice sheet and climate

Strengths:

ArCS is well integrated with the international group working with the East Greenland Ice Core Project, EGRIP. This suggests that there is good coordination of fieldwork between the groups. The ArCS team provides valuable contribution to ECRIP by drilling a deep core to the bedrock, supplementing the existing deep cores. Analysis of the cores provides reconstruction of black carbon, terrestrial biogenic and dust aerosols. ArCS also contributes with deformation tests of ice cores as input to ice stream dynamics studies and ice sheet modelling. Another valuable contribution from theArCS team is the collection of snow-pit data which is important for ice mass balance studies. Furthermore, it is much appreciated that the ArCS team works with glacial isostatic adjustment (GIA) modelling, which is an essential component of sea level studies. It is noted that collaboration with Theme 3 and Theme 5 shows that the team seeks cross-theme collaboration. The publication record is very strong, including many joint papers with partners outside of ArCS documenting that international collaboration is very good. It can be concluded that there is good progress on all three objectives stated for this sub-theme

Recommendations:

In the plan for further work the team intends to continue all the research activities of this sub-theme. This is fully supported since melting of the Greenland Ice Sheet and sea level change is one of the most severe climate change factors.

2.2. Ice sheet/glacier – ocean interaction in Greenland

Strengths:

The calving glaciers in the Qaanaaq region have been studied with different observation methods since the 1980s; ArCS has contributed in the last 6 years with new observation technologies, including oceanic measurements. A paper presenting the results has been well received in the scientific community. The ArCS team, in collaboration with partners, has been in dialogue with the locals in Qaanaaq. This is an excellent example of scientists organizing public events to share scientific results with local communities, who in turn share local knowledge. After Qaanaaq experienced flooding and severe damage of infrastructure in 2015-2016. ArCS and collaborators have allocated some research efforts to map stream discharge and slope stability, as a direct response to the damage. This is much appreciated and shows how research can be directly beneficial for local communities.

Recommendations:

This work should continue and be strengthened, as suggested in “The way forward”, especially to enhance work related to risks for natural hazards, such as earth slides and flooding. It is recommended that the collaboration with the Qaanaaq community continues as a joint effort with the other research partners. Further research plans should be developed in collaboration with the Qaanaaq community.

III-3-1 Research theme 3: Atmospheric climate forcers in the Arctic

PI: Makoto Koike (NIPR/the University of Tokyo)

1. Summary of the Research

The aim of this study is to characterize behaviors of SLCFs (short-lived climate forcers, such as BC and CH_4) and other GHGs in the Arctic atmosphere and to quantify contributions of individual sources and sinks or fluxes of these compounds. We measure atmospheric BC (at selected sites, by aircraft and ship) in the Arctic using high-accuracy instruments such as COSMOS, which we have developed. A technique to measure BC in precipitation (rain and snow) and snow on the ground has also been developed, and we evaluate wet deposition flux of BC in the Arctic. Using advanced numerical models, we evaluate contributions of individual BC sources (regions and source types). We also characterize behaviors of clouds using in situ, radar and lidar, and satellite measurements.

To study GHG flux, we combine top-down and bottom-up approaches. In the former method, we estimate fluxes from atmospheric concentration measurements using numerical models. In the latter method, we directly measure fluxes at a number of representative sites and estimate fluxes from a wide area over the Arctic. By conducting these high-accuracy measurements and using advanced numerical models, we characterize temporal and spatial variations in sources and sinks of GHGs. We also estimate responses of sources and sinks with respect to climate and environmental changes.

2. Scientific Achievements

(A) BC aerosol

- We conducted continuous observation of BC in the atmosphere at Barrow and Ny-Ålesund using a high-precision BC measuring instrument, COSMOS, that we developed. At these two sites, NOAA in the United States and Stockholm University have been measuring BC for many years using another type of BC instrument, PSAP. Their measurements have been widely used for evaluations of numerical model calculations as well as various reports, such as AMAP reports. By comparing simultaneous measurements of COSMOS and PSAP, we found that PSAP measurements overestimate the BC mass concentrations at Ny-Ålesund (figure 1), and provided conversion coefficients to derive BC mass concentrations from the previous PSAP measurements. This outcome was summarized in a joint paper with researchers from NOAA and Stockholm University. This is an important outcome in that it offers the BC value to be used in various assessments of Arctic BC.

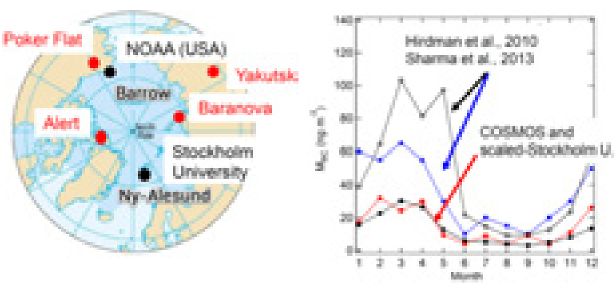


Figure 1. Left: Network of BC measurement using the COSMOS instrument. Right: Comparison of BC mass concentrations measured with COSMOS (this study) and PSAP (previous study) in Ny-Ålesund.

- Following the success of the BC measurements at Barrow and Ny-Ålesund, BC measurements using COSMOS were started in Alert (Canada), Baranova (Russia), Yakutsk (Russia), and Poker Flat (US) (figure 2). Using reliable instruments, behaviors of BC in the atmosphere are being monitored. We are demonstrating that COSMOS can be used as a standard instrument for BC measurements.
- We successfully measured BC concentrations over the Pacific sector in the Arctic Ocean between 2014 and 2018 during RV *Mirai*'s Arctic cruises. Because no other measurements were made in this region, these data are unique.
- We also measured vertical profiles of BC on board the AWI Polar 5 aircraft during the (AC)^3 PAMARCMiP 2018 aircraft experiment, which was made from Station Nord in Greenland in March–April 2018. These shipborne and airborne data are being analyzed to study sources and transport processes of Arctic BC.
- In addition to BC in the atmosphere, BC in precipitations was measured by collecting falling snow and rain in Ny-Ålesund. BC in snowpack was also measured. Good agreement was found in BC concentrations between falling-snow

and snowpack measurements, suggesting that contributions from the dry deposition of BC were small. These results provide new methods to validate numerical model calculations.

- BC concentrations in snowpack over a wide area in the Arctic were accurately measured (figure 2). The previous measurements were found to overestimate BC values by 5–10 μg/L (factors of 2–20). Accurate measurements can be utilized for validation of numerical model calculations as well as various scientific assessments.

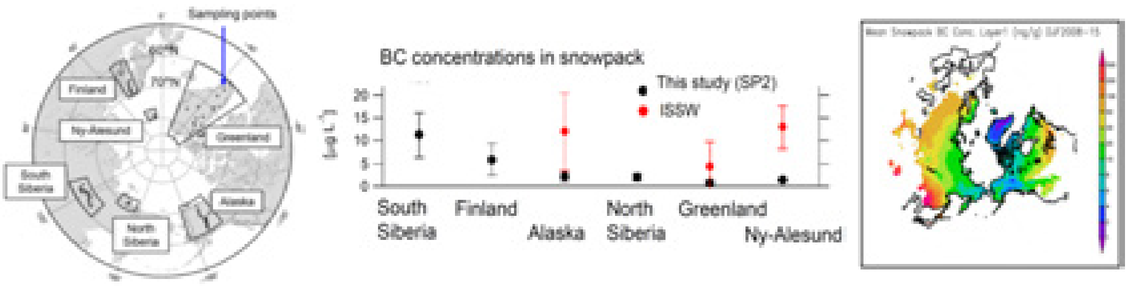


Figure 2. Left: Locations where snow sampling was conducted. Center: Observed BC concentrations in snowpack. Right: Model calculated BC concentrations in snowpack (MRI-ESM model for DJF).

- For accurate numerical model calculations, removals of BC by precipitation during transport are a critical step. A parameterization to calculate the BC aging process (changes in BC mixing state from bare hydrophobic BC particles to coated hydrophilic BC particles), which we developed, has been implemented into the MRI-ESM2 model. The improved model successfully captures a tendency of the observed seasonal variation of BC in the Arctic atmosphere. The model calculations also successfully reproduced the tendency of spatial distribution of BC in snowpack that we measured (figure 2).
- A new global aerosol model, which can represent the BC mixing state, has been developed and implemented into the NCAR community model (CAM-5). Using observed knowledge on BC removal processes by precipitation, BC concentrations in the Arctic increased more than a factor of 10 in winter and spring seasons, leading to a better agreement with observations. The improved model is being used to evaluate contributions of individual BC sources.

(B) CH_4 and other GHGs (top-down approach)

- As the top-down approach, we have conducted systematic observations of the concentrations and isotope ratios of atmospheric greenhouse gases and related constituents, such as carbon dioxide (CO_2), methane (CH_4), and oxygen (O_2), at ground stations, on-board the RV *Mirai,* and over the Eurasian continent. Furthermore, we are also developing and improving numerical models and analyzing the observed data using the models.
- Temporal variations of the concentration and isotope ratio of CO_2 and CH_4, and O_2 concentration observed at Ny-Ålesund, Svalbard, were analyzed (figure 3). The CO_2 budget was estimated based on the CO_2 and O_2 concentrations and CO_2 isotopes. We found that terrestrial CO_2 uptake rates decreased in 1997–98 and 2002–03, when ENSO events occurred. We also found that the oceanic CO_2 uptake is increasing in recent years. From the long-term records of CH_4 and its isotopes at Ny-Ålesund, it is suggested that the temporal pause of the CH_4 concentration around 2000 is attributed to reductions of CH_4 release from the microbial and fossil fuel sectors. On the other hand, the increase in CH_4 after 2006 could be ascribed to an increase in microbial CH_4 release.

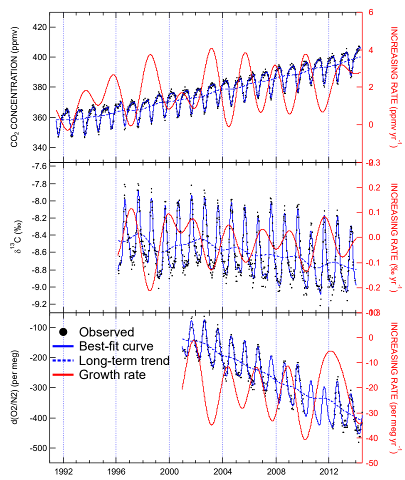


Figure 3. Temporal variations of the atmospheric CO_2 concentration (upper), C isotope of CO_2 (middle), and O_2 concentration (lower) observed at Ny-Ålesund, Svalbard.

- We analyzed the CH_4 concentration and its isotopes observed at Churchill, Canada. By comparing the observed CH_4 concentrations with those simulated by the chemical transport model, it is revealed that CH_4 emissions from the Hudson Bay Lowland used for this study could be overestimated.
- The CH_4 concentrations observed on board the RV *Mirai* Arctic cruise was compared with simulations by a “forward” model. When a CH_4 release rate

of 4.5 TgCH_4/yr from the East Siberian Arctic Shelf (ESAS), proposed by Berchet et al. (2016), was used, the CH_4 concentrations observed from *Mirai* were overestimated, as shown in figure 3. This result suggested that the CH_4 release rate from ESAS, as previously proposed, was overestimated.

- Systematic observations of the greenhouse gases over the Eurasian Continent revealed their characteristic seasonal variations and long-term trends. The observed CH_4 isotope data showed that air masses with CH_4 destructed in the upper-middle stratosphere were transported downward from winter to spring.

(C) CH_4 and other GHGs (bottom-up approach)

- As the bottom-up approach, a canopy-scale CH_4 flux measurement over a larch forest in eastern Siberia was conducted by eddy covariance method using an open-path CH_4 gas analyzer. The CH_4 flux showed a clear diurnal variation with emission in the daytime and near zero in the nighttime. This diurnal variation was mostly explained by the atmospheric stability and friction velocity. Daily mean of the canopy-scale CH_4 fluxes were positive (emissions of CH_4), although absorptions were observed at the forest floor. These results were consistent with several previous studies obtained in other boreal forests.

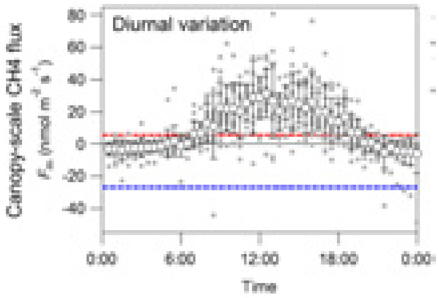


Figure 4. Diurnal variation of canopy-scale CH_4 flux observed at Spasskaya Pad in eastern Siberia in May–June.

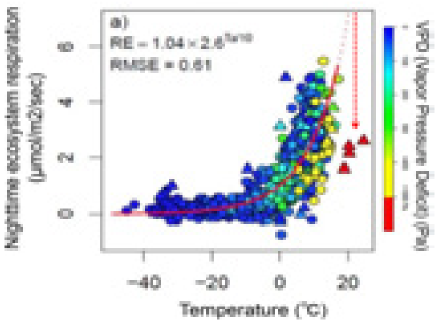


Figure 5. A scatter plot of nighttime ecosystem respiration (ER) with temperature observed in Alaska. Triangles denote data obtained in 2013 under dry and warm conditions, while circles denote data obtained in 7 other years.

- Nighttime ecosystem respiration (ER) generally increased with temperature, but the increases were suppressed under dry conditions in 2013. The down-regulation of RE implies possible negative feedback for the carbon budget of boreal forests in response to climate warming.
- We measured CH_4 content in near-surface permafrost to study its ranges and spatial variations. We sampled and analyzed permafrost (ground ice) from approximately 200 samples at 9 sites in Alaska. We found that average CH_4 gas concentrations in bubbles in ice varied by three orders (50–14,000 ppmv) depending on the sample site, although gas contents were generally similar (3–4 cc/100 g). Carbon isotope compositions ($\delta^{13}C$) of CH_4 and CO_2 indicate that CH_4 originates mainly from the methyl-fermentation pathway. Our results provide isotopic signatures of GHGs in near-surface permafrost, and critical information to estimate GHG content in permafrost regions in danger of future thawing.

(D) Clouds and aerosols serving as CCN and INP

- Two years of continuous in situ measurements of Arctic low-level clouds have been made at the Mt. Zeppelin Observatory in Ny-Ålesund. Cloud particle number concentration (N_c) showed a clear seasonal variation, with a maximum in summer. Aerosols with diameters as small as 30 nm likely serve as cloud condensation nuclei (CCN) due to the low CCN concentrations in the Arctic. The aerosol-cloud interaction (ACI) index for CCN-controlled clouds was estimated to be approximately 0.22, and it does not show a clear seasonal variation.
- We developed a new method to measure the ability of ice nucleating particles (INP), called CRAFT, with a wide temperature range to −30°C, which could not be achieved by the conventional water-drop freezing method. When aerosols sampled at Mt. Zeppelin were analyzed, INP concentrations were found to be a factor of 10 higher in summer as compared with those in winter-spring. The INP concentrations in winter-spring are consistent with those in the marine boundary layer reported previously, while high values in summer were probably due to dust emissions from the Svalbard Islands and their surroundings.

- We improved the method of estimating the microphysical properties of ice particles based on satellite data. As a result, it was found that the increase and decrease in the lower clouds in the Arctic region may correspond to the increase and decrease in the sea ice.

3. Outcomes so far, and prospects and expectations in the future

- Accurate measurements of BC, CH_4, and other GHGs obtained during the ArCS project provide reliable datasets that can be utilized for validation of numerical model calculations as well as various scientific assessments.
- We are demonstrating that COSMOS can be used as a standard instrument for BC measurements.
- Improved numerical model calculations and budget analyses will provide the scientific bases to formulate strategies of reduction of SLCFs in the Arctic.
- We have been contributing to the following projects:

  AMAP: We have been participating in AMAP SLCF meetings. We will contribute the next AMAP BC assessment report as authors.

  EGBCM: We have also been participating in EGBCM meetings. We have contributed to the 2017 report and will contribute to the next 2019 report.

  GCP (Global Carbon Project): We have contributed to the global CH_4 budget estimates within the GCP.

  IPCC: Our publications and numerical model calculations (CMIP6) are expected to contribute to the next IPCC report.

  We have also provided our knowledge and new finding to the public through various methods.

4. The way forward

- We need better understanding of the microphysical processes controlling BC deposition by precipitation and BC emission sources within the Arctic (e.g., gas flaring).
- We need to investigate aerosol impacts on temperature and precipitation that are required by the public. Radiative forcing is not enough.
- We need better understanding of land ecosystems, especially possible changes in GHG fluxes in response to future climate changes. This knowledge can then be utilized with the dynamic vegetation model to construct the Earth system model.

III-3-2 Comments for research theme 3

This theme characterizes short-lived climate forcers, such as black carbon and methane and long-lived greenhouse gases in the Arctic atmosphere and tries to quantify contributions of their sources and sink terms. The behavior of clouds is investigated by in-situ, radar and lidar and satellite measurements. Year-round, in-situ measurements of Arctic low-level clouds, their microphysical properties and their relationships with aerosols were carried out at Ny-Ålesund, Spitsbergen since 2013. The monthly cloud particle number concentration shows a seasonal variation with a maximum in the summer (May–July), and low values in the winter (October-March). At temperatures warmer than 0°C, a correlation with the concentrations of aerosols exists with dry diameters larger than 70 nm, which are proxies for cloud condensation nuclei.

Strengths:

A technique to measure Black Carbon in precipitation (rain and snow) and snow on the ground has been developed, and data were compared to model simulations by the updated version of the MRI-ESM2 model, with improved representations of clouds and aerosol–cloud interactions by Kawai et al. (2017). The treatment of the Wegener–Bergeron–Findeisen process was modified, taking into account a relationship between liquid/ice ratio and temperature. This modification resulted in an increase in the ratio of supercooled and liquid clouds and reduced the shortwave radiation bias. To study GHG fluxes a combination of top-down and bottom-up approaches is applied. In the former method, fluxes from atmospheric concentration measurements using numerical models are determined. In the latter method, directly measured fluxes at a number of representative sites and fluxes from a wide area over the Arctic are estimated. By conducting these high-accuracy measurements and using advanced numerical models, temporal and spatial variations in sources/sinks of GHGs are computed.

Recommendations:

The theme's research has significant potential to improve cloud-aerosol interactions and their microphysical description in climate models. Until now this topic seems a little isolated from the other ArCS topics. Cooperation exists mainly with Theme 2: Cryosphere Study in Greenland. There is potential to improve the cross-cutting activities of this theme with the other modelling efforts in ArCS with respect to cloud-aerosol and vegetation interactions.

III-4-1 Research theme 4: Ocean observation

PI: Takashi Kikuchi (JAMSTEC)

1. Scientific achievements

The overall goals of "Theme 4: Observational Research on Arctic Ocean Environmental Changes" are to elucidate the status and trends of ongoing Arctic Ocean environmental changes and evaluate their impact on the Arctic marine ecosystem and the global climate system. The specific topics of our research theme are to [1] understand ongoing changes in physical and biogeochemical conditions in the Arctic Ocean and seasonal/interannual variability in interactions between Arctic environmental changes and climatological/hydrological systems, [2] evaluate the effects of ocean warming and acidification on the marine ecosystem in the Arctic Ocean, [3] understand seasonal/interannual variability in the freshwater budget in the Arctic Ocean, and [4] understand variability in sea-ice dynamics, especially for the region off the northern Alaska.

To achieve these scientific goals, we plan to carry out (1) field observations, mainly in the Pacific sector of the Arctic Ocean, by using the RV *Mirai* and icebreakers under international collaboration, (2) year-long mooring observations at key areas of ongoing Arctic changes, (3) on-site and laboratory experiments to evaluate the impact of changes in the Arctic environment, and (4) numerical modeling to address details of changes in the Arctic environment. International collaboration is indispensable for our research activities. Our main target area is the so-called Pacific Arctic Region (PAR). The reason for this selection is that PAR has already become a seasonal ice area and the impact of recent sea-ice reduction there has been significant. In the PAR, "Pacification", which is caused by an increase in the impact of Pacific water inflow through the Bering Strait, is another interesting topic. Based on our previous experience, we are continuing our collaboration with the United States, Canada, Norway, Germany, Russia, and other countries. In particular, the theme relates to observation and research on the Arctic Ocean and the surrounding sea area conducted through the Pacific Arctic Group (PAG), Distributed Biological Observatory (DBO), Ecosystem Studies of Sub-Arctic and Arctic Seas (ESSAS), and so on.

As of January 28, 2019, we have published 72 articles in English-language peer-reviewed journals. This number includes 32 papers involving international collaboration. Some of these articles have been press-released and presented though mass media (newspapers, journals, television, the web, and so on). An outline of the selected research topics is provided below.

The southern Chukchi Sea, which is north of the Bering Strait, is one of the biological hot spots in the PAR. We conducted a 2-year mooring observation to monitor the oceanographic conditions in this region, e.g., temperature, salinity, dissolved oxygen, chlorophyll-a, and turbidity, between July 2012 and July 2014. The mooring data show the first observational evidence of autumn bloom in September in the southern Chukchi Sea as well as spring/ice-edge bloom between May and July. The maintenance mechanism for the autumn bloom was also investigated through hydrographic and biogeochemical surveys by the RV *Mirai*. Nutrient-rich water flowing from the Bering Strait supplies nutrients to this area, and the high nutrient content associated with the dome-like structure of the bottom water may maintain the high primary productivity via vertical nutrient supply from the bottom water (Nishino et al., 2016). Using the same mooring data, Yamamoto-Kawai et al. (2016) reconstructed seasonal variation of calcium carbonate saturation state (Ω), which is one of the indicators of ocean acidification, of the bottom water in the southern Chukchi Sea. The reconstructed Ω was high in spring and early summer, decreased in later summer, and remained relatively low in winter. We found frequent occurrences of aragonite undersaturation ($\Omega < 1$) in the bottom water of the Chukchi Sea, not only in summer/autumn but also in the winter months. It has been shown that calcium carbonate under-saturation has a negative impact on calcifying organisms. With the increasing anthropogenic CO_2 in recent years, and that projected for future years, quantification of the responses of local calcifying organisms to low Ω is an urgent issue for future study.

We have been monitoring volume, fresh water, and heat flux at the mouth of Barrow Canyon, which is one of the important gateways of Pacific-origin water masses flowing into the Canada Basin of the Arctic Ocean. Recent mooring data show that large heat input through Barrow Canyon into the Canada Basin has occurred more frequently in the 2010s, mainly because of larger solar heating in the eastern Chukchi Sea, due to the recent early retreat of sea ice (Itoh et al., 2015; Tsukada et al., 2018). Analysis of hydrographic observation data in the Canada Basin revealed drastic warming of the subsurface water in the Canada Basin, which coincided with the recent larger heat input through Barrow Canyon. Regarding the pathway of the subsurface warm water, mooring data from the western side of the Canada Basin show winter subsurface warming. To address the detailed pathway and processes of subsurface warm water transport, an interannual numerical experiment was performed using a pan-Arctic sea-ice ocean model, configured in a high-resolution framework. The model result captured the similar seasonality of subsurface temperature in the Chukchi Borderland and Chukchi Abyssal Plain where are in the western side of the Canada Basin and produced the interannual variability of the ocean heat content associated with the shelf-origin water distribution around the Chukchi Borderland. In addition to the Barrow Canyon throughflow, westward jets along the steep flank of the Chukchi shelf break constituted a primary pathway for the subsurface warm water transport toward the Chukchi Borderland in the model experiment (Watanabe et al., 2017).

The spatial and temporal distributions of CO_2 flux in the Arctic Ocean and its adjacent seas have not been fully understood due to insufficient data coverage in the heterogeneous area. To address this issue, Yasunaka et al. (2016, 2018) applied a self-organizing map technique, which is a kind of neural network, to estimate monthly air–sea CO_2 fluxes in the Arctic Ocean and its adjacent seas for 18 years from January 1997 to December 2014. These results revealed that the annual Arctic Ocean CO_2 uptake is 180 ± 130 TgC, which corresponds to about 10% of the total in the world's oceans. In addition, their successful quantification of the air–sea CO_2 flux in the area also found large spatial and temporal variability and long-term trends of CO_2 uptake.

Sea-ice retreat causes high biological productivities on the nutrient-rich shelves and enhances eddy activity and ocean currents in the deep basin area (e.g., Harada et al., 2016). To monitor and evaluate the effects of ocean warming and acidification on the marine ecosystem in the Arctic Ocean, we have been conducting a long-term sediment-trap mooring observation in the western Arctic Ocean. Previous results have shown that plankton habitat is expanding along the eddy pathway along the Beaufort shelf break and in the western Canada Basin (Watanabe et al., 2014; Onodera et al., 2015). The influence of warming and ocean acidification on the marine ecosystem will be investigated using the new mooring observation results.

The freshwater budget, which is closely related to sea-ice melt, ocean circulation (dynamic height), biogeochemical conditions, and global ocean circulation, is another important topic in the Arctic Ocean. Mizobata et al. (2016) estimated the monthly dynamic ocean topography in the Arctic Ocean using satellite observation data (the Synthetic Aperture Radar [SAR]/Interferometric Radar Altimeter [SIRAL] onboard CryoSat-2). The data show the interannual and monthly variability of the Beaufort Gyre (BG) during winter between 2010/2011 and 2014/2015 and suggest that the winter BG presents significant variations in response to sea-ice motion, thus indicating the importance of BG barotropic responses during winter.

To understand variability in sea-ice dynamics, especially off the northern Alaska, ice-draft time series data were obtained from a moored ice-profiling sonar in the coastal northeastern Chukchi Sea (Fukamachi et al., 2017). The time series data show seasonal growth of sea-ice draft, occasionally interrupted by the occurrence of a coastal polynya. The overall mean draft and corresponding derived thickness during the 2009/2010 season were 1.27 and 1.38 m, respectively. We are continuing to monitor the ice draft in this region and will release new data during the ArCS project period. The nature of the Barrow Coastal Polynya (BCP), which forms episodically off the northern Alaska in winter, was examined using mooring data, atmospheric reanalysis data, and satellite-derived sea-ice concentration and production data (Hirano et al., 2016). It is proposed that the BCP, previously considered to be a latent heat polynya, is a wind-driven hybrid latent and sensible heat polynya, with both features caused by the same northeasterly wind. In addition, Hirano et al. (2018) investigated the water properties and formation processes of Alaskan Coastal Winter Water (ACWW) over the eastern Chukchi shelf along the Alaska coast, the so-called Barrow Canyon pathway. The result shows that, even in the Pacific sector of the Arctic Ocean, the ACWW properties are strongly influenced by both Atlantic-origin and Pacific-origin waters in combination with northeasterly winds over the BCP area.

2. Outcomes to present and prospects/expectations for the future

One of the objectives of ArCS is to provide scientific information for internal and external stakeholders who are interested in Arctic environmental changes, as well as various kinds of Arctic issues, and sustainable development of the Arctic region. The Arctic Council and the Working Group are recognized as one of these stakeholders. Based on our scientific output, we have contributed to AMAP assessment reports, such as the Snow, Water, Ice, and Permafrost in the Arctic (SWIPA) 2017, Adaptation Action for Changing Arctic Bering–Chukchi–Beaufort regional report (AACA BCB report), among others, as contributing authors and as one of the reviewers. Additionally, we have contributed discussions to the AMAP Expert Group on SWIPA and the Climate Expert Group.

In Japan, public interest in global and Arctic warming, recent rapid sea-ice reduction in the Arctic, and consequent Arctic environmental changes is increasing, so we have many opportunities to join/hold outreach events in various places. For example, we held outreach events at “Miraikan”, the National Museum of Emerging Science and Innovation, and introduced our research activities to visitors from children to adults. It is of interest that we are now developing a learning tool for Arctic Science in collaboration with “Miraikan”. The learning tool is like a board game, which can be used to learn about Arctic changes and their impact on society. It will be completed in FY 2019, i.e., by the end of the ArCS period.

Another outcome is that JAMSTEC, which is one of the main research institutes of ArCS, had an offer from the Arctic Geophysical Union (AGU) to make an introductory short movie for the AGU 2018 Fall Meeting. As a result, we undertook to make the movie, which was presented at the AGU 2018 Fall Meeting and released by the AGU TV 2018 channel (https://www.youtube.com/watch?v=4zzbL1_CjrE&t=43s).

3. The way forward

Toward the end of ArCS, we will conduct field missions as planned. In October, the RV *Mirai* will conduct another Arctic Ocean cruise; the mission will be mainly focused on theme 1, together with themes 3, 4, and 6. Several moorings in the southern Chukchi Sea, the Alaskan coast region, Barrow Canyon, and the western Canada Basin should be recovered in the coming field season (summer 2019). These observation data should be available from the data center, such as the Arctic Data archive System (ADS). We plan to produce a synthesis/review paper of theme 4. Continuous contributions to AMAP and other working group activities of the AC are also important. Regarding outreach activities, we will conduct seminars/lectures for the public, as in the previous years.

Accurate future predictions of Arctic climate and environmental conditions are indispensable to internal and external stakeholders interested in Arctic issues. From the point of view of observational research, there are two important points relating to more accurate future prediction. First, we need to understand the gaps in knowledge of some of the important parameters and processes. For instance, some sea-ice parameters, such as ice thickness, snow depth, and ice–ocean interaction, are very important for freezing and melting processes. However, there are significant gaps in the data and knowledge, especially in the central Arctic Ocean. Development of technology to collect such information on and beneath sea ice is needed. Second, although there has been some data accumulation, an accurate and comprehensive dataset of the Arctic Ocean have not yet been constructed for numerical simulation. A dataset of sea-ice concentration and extent is a good example. Since satellite measurement began in 1979, sea-ice concentration and extent data have been provided as a very useful gridded, long-term dataset. To construct a reanalysis dataset of sea-ice thickness, ocean temperature, and salinity, data assimilation should be conducted. We also need to undertake accurate and comprehensive observations across the Arctic Ocean. International collaboration will be indispensable. Japan should take a leading role in such field observation of the Arctic Ocean, based on previous experience not only of the Arctic Ocean but also the world’s oceans.

III-4-2 Comments for research theme 4

Of all the regions of the Arctic the marine environment has witnessed the most dramatic changes, from the loss of sea ice, through to ocean acidification, and changes in ecosystem dynamics. These changes have serious local impacts on the livelihoods of local communities, as well as regional and global impacts through changes in weather patterns, and more. However, change also provides economic opportunities and challenges, such as the ability to better utilise the Arctic's abundant natural resources, and the development of Arctic shipping routes. Importantly, these commercial activities offer real opportunities for sustainable development for the region, and for socio-economic prosperity. This theme both pushes forward our understanding of the marine environment and delivers knowledge to key stakeholders so that sound evidence-based decisions and investments can be made. Understanding the Arctic Ocean today, and how it will evolve in the future is complex. It requires a multidisciplinary observational effort, one that involves physical oceanographers, sea ice physicists, biologist, chemists, satellite remote sensors and others. Theme 4 does a superior job in this regard.

Strengths:

- The four areas chosen to address in Theme 4 are some of the most pressing challenges in Arctic Ocean research. Importantly, ArCS scientists address these pressing challenges in a holistic and multidisciplinary way. Multidisciplinary research can be a difficult, but Theme 4 has overcome these challenges and is making good progress, with excellent scientific output.
- The research is characterized by a strong use of different observational techniques across the disciplines (e.g. physical, biogeochemical etc.), such as shipborne measurements, moorings, and remote sensing data. Together these give a broader picture and greater understanding of the Arctic marine environment. There is good international collaboration on research cruises.
- The Theme has a clear vision of how to proceed during the last period of ArCS, and where these observational measurements and time series need to go in the future.
- The theme has produced substantial scientific output: 72 manuscripts accepted in English peer reviewed journals.

Recommendations:

- Given the pressing research questions tackled by Theme 4, there are a number of national and international research programmes that are looking at similar themes. Establishing close contact and building synergies with these research programmes not only benefit our scientific knowledge base, but may provide opportunities for young researchers within the ArCS exchange programme to exploit. There is the opportunity to link to SAON.
- The science within Theme 4 is exceptionally strong, but ArCS needs to think about the science across the Themes. It was not clear how Theme 4 is contributing to cross-theme interactions: the interactions between Theme 4 and the other themes should be documented. The work in Qaanaaq is a good example of cross-theme interaction, bringing together glacial dynamics, ocean physics, ecosystem dynamics and community needs.

The scientific knowledge gained with in Theme 4 is of high calibre: it would be good to provide more information on how this knowledge is disseminated to key stakeholders.

III-5-1 Research theme 5: Study on Arctic climate predictability

PI: Hiroyasu Hasumi (JAMSTEC/the University of Tokyo)

0. Introduction

It is being demonstrated that the Arctic environment is rapidly changing with global warming, and that it influences global climate variability. In order to know how the Arctic environment will change in the future, we need to reveal how the various factors in the Arctic environment, such as the atmosphere, the ocean, and the cryosphere, interact with one another. On the other hand, it is thought that understanding how the Arctic environment is linked to the climate at low and middle latitudes would lead to better predictability of the climate on seasonal to decadal timescales. Furthermore, for long-term projection of the climate on multidecadal timescales, we also need to precisely evaluate changes in the Arctic environment, as exemplified by the importance of sea-level rise due to melting of the Greenland ice sheet.

The goal of our theme is to evaluate the predictability of Arctic-related climate variations, wherein we aim to: (1) establish the scientific basis of climate predictability; and (2) develop a method for predicting and projecting medium- and long-term climate variations.

Variability in the Arctic environment remotely influences middle latitudes, including our country, along with the whole world. Since some of the processes specific to the Arctic environment, such as those in the cryosphere, function as a long memory of the state of the climate, understanding the process of remote connections is expected to lead to higher-precision and longer-term prediction of global climate variations. Furthermore, the Arctic region is experiencing the largest changes in the context of the warming climate, and changes in the cryosphere are deeply related to the acceleration of warming and irreversible changes in the global climate.

Numerical models are widely utilized for studies of the climate, but conventional climate models commonly have large uncertainty in the Arctic region. By making Arctic processes in climate models more sophisticated, we aim to clarify the role of multisphere interaction in the Arctic environment. We also aim to reveal the mechanism of remote connections between the Arctic environment and the global climate by conducting climate simulations with the climate models we develop, and by analyzing various types of climate data sets. Furthermore, we aim to predict variability and project changes in the Arctic environment on interannual to multidecadal timescales and assess their influences on the global climate by developing a method to assimilate observed data into climate models, developing a climate model with special high resolution in the Arctic region, and incorporating the ice-sheet process in climate models.

1. Scientific achievements

1.1 Relationship between cold extremes over the northern hemisphere continents and the Arctic (Johnson, Xie, Kosaka, and Lie, 2018, *Nature Communications*)

Observations show that the occurrence of cold extreme weather events is increasing in winter over the northern hemisphere continents since the beginning of the 21st century. The cause of this increase is investigated by using a multiple-regression analysis. The time series of the yearly frequency of cold extremes is regressed on the ENSO index, the volcanic aerosol optical depth, and a linear trend. It is found that these components do not account for the increase of cold extremes. In the residual component, it is found that the variability associated with the so-called warm-Arctic cold-continent (or warm-Arctic cold-midlatitudes) pattern best accounts for the increase of cold extremes. This pattern is known to be triggered by a decrease of Arctic sea ice. Thus, this result indicates that the increase of wintertime cold extremes over the northern hemisphere continents is a consequence of the decrease of Arctic sea ice.

1.2 Atmospheric response to the Arctic sea ice decline (Nakamura, Yamazaki, Iwamoto, Honda, Miyoshi, Ogawa, Tomikawa, and Ukita, 2016, *Geophysical Research Letters*; Nakamura, Yamazaki, Honda, Ukita, Jaiser, Handorf, and Dethloff, 2016, *Geophysical Research Letters*)

Previous studies have shown that decline of Arctic sea ice, especially in the Barents and Kara Seas, induces a negative phase of the Arctic Oscillation (AO) and severe winter weather in the northern hemisphere midlatitudes. Our study using an atmospheric general circulation model (AGCM) shows that the interaction between the Arctic troposphere and stratosphere, namely propagation of planetary waves from the troposphere to the stratosphere, is essential in inducing such a negative-AO response to the decline of Arctic sea ice. We further investigate what will happen when the decline of Arctic sea ice further progresses by conducting AGCM experiments with various possible situations for the Arctic sea ice. It is found that further decline of Arctic sea ice reinforces the negative-AO response until the sea ice completely disappears from the Arctic Ocean. When the sea ice completely disappears, however, the modeling results show that the upward propagation of planetary waves is suppressed and the atmospheric response is confined within the troposphere.

1.3 Influence of land surface processes on Eurasian heat waves (Erdenebat and Sato, 2016, *Atmospheric Science Letters*; Sato and Nakamura, submitted)

The occurrence of warm extreme weather events, or heat waves, has been increasing since the beginning of the 21st century. In the region around Mongolia, for example, our analysis of meteorological station data shows that the yearly frequency of heat waves is strongly correlated with the variability of soil moisture, indicating an important role played by dried soil in inducing heat waves. We further analyzed the climate reanalysis data set called d4PDF, which is a set of 100 ensemble hindcasts for 60 years between 1951 and 2011. The empirical orthogonal function (EOF) analysis of detrended summertime surface air temperature over the Eurasian continent (0–180°E, 20–90°N) extracts a zonal wavelike pattern of warm and cold anomalies as the first principal component. The regression of soil moisture on the time series of this EOF-1 exhibits a highly significant correlation with the soil moisture in the preceding spring over the region from Ukraine and western Kazakhstan. Furthermore, the springtime soil moisture therein is found to be controlled by the snow amount in the preceding winter. This analysis shows the predictability of Eurasian summertime warm extreme weather events based on the snow amount in the preceding winter.

1.4 Oceanic heat transport into the Arctic (Kawasaki and Hasumi, 2016, *Journal of Geophysical Research*)

The subsurface Arctic Ocean, around 300 m deep, is occupied by relatively warm water. This warm layer, called the Atlantic Water Layer, is fed by the warm current flowing through the Fram Strait. Variability of this warm current into the Arctic Ocean could have a large influence on Arctic sea ice and climate. However, conventional ocean and climate models could not reproduce this warm current due mostly to the lack of model resolution. Our newly developed, high-resolution model for the Arctic Ocean, driven by surface air conditions taken from atmospheric reanalysis data, reasonably simulates this warm current and the consequent Atlantic Water Layer. The model also reproduces observed interannual variability of temperature across the Fram Strait, and it is revealed to be the consequence of variability in heat transport by the warm current. It is also found that the variability of this oceanic heat transport into the Arctic Ocean is significantly correlated with synoptic-scale atmospheric features such as the North Atlantic Oscillation and the Siberian High.

1.5 Influence of the tropics on the Arctic climate (Kosaka and Xie, 2016, *Nature Geoscience*; Wang, Xie, Kosaka, Liu, and Zheng, 2017, *Journal of Climate*)

Our model experiments using an atmosphere-ocean coupled general circulation model (CGCM) demonstrate that the tropical Pacific sea surface temperature works as a pacemaker of observed past acceleration and deceleration of global warming. Our analysis of the results of multiple CGCMs submitted to CMIP5 further demonstrates that the influence of SST variability in the tropical Pacific on surface air temperature in extra-tropical regions appears stronger on decadal timescales than interannual timescales, and such decadal influence is especially conspicuous in the Arctic Ocean and the northern North Pacific. It implies that decadal variability of Arctic sea ice is under the strong influence of SST in the tropical Pacific.

1.6 Influence of the southern hemisphere on the Arctic climate (Tanaka, Nishii, and Nakamura, 2016, *Journal of Climate*; Sekizawa, Nakamura, and Kosaka, 2018, *Geophysical Research Letters*)

Our analysis of climate data sets reveals that the interannual variability of Australian summer monsoon (AUSM) is not forced by the SST in the tropical Pacific but is locally sustained, differing from various modes of climate variability that are under the strong influences of the tropical Pacific SST. Further analysis indicates that influences of this interannual variability of AUSM appear in air temperatures and winds around the Arctic Ocean with statistical significance. This link from AUSM to the Arctic region is found to be triggered by reinforcement of the local Hadley cell around Australia. It then excites the western Pacific pattern, a dynamical mode of atmospheric variability whose centers of action are in the subpolar and subtropical latitudes in the western North Pacific.

1.7 Prediction and predictability of Arctic sea ice (Ono, Tatebe, Komuro, Nodzu, and Ishii, 2018, *The Cryosphere*)

The skill is assessed for seasonal to interannual prediction of Arctic sea ice using a data-assimilated climate model, and the processes controlling the predictability therein are investigated. High skill is obtained for wintertime sea ice extent with a duration of about 11 months (i.e., the wintertime sea ice extent has predictability for up to 11 months). This high skill is attributed to the oceanic subsurface heat content in the North Atlantic, which is transported to the Barents Sea in a year and affects wintertime freezing of seawater therein. On the other hand, the summertime sea ice extent is found to be less predictable: high skill is found for lead time of up to two months. The predictability of summertime sea ice extent is found to be associated with the persistence (mass or volume) of sea ice on the Pacific side of the Arctic Ocean.

1.8 Prediction and predictability of Arctic cyclones (Kubokawa, Sato, Kawasaki, Kimura, and Hasumi, in prep.)

The Arctic cyclone of August 2012 is simulated by a stand-alone AGCM and an atmosphere-ocean coupled general circulation model (CGCM). This Arctic cyclone is known to develop extraordinarily strongly, stay for a long time near the north pole, and contribute to a drastic retreat of the sea ice edge on its passage. Both of our AGCM and CGCM reasonably simulated the track and development of this Arctic cyclone, and the development (how low the central pressure develops) is slightly more realistic with the CGCM. The drastic retreat of the sea ice edge, observed in the Beaufort Sea on its passage, is also simulated, but the dominant mechanism is different between the modeling result and the inference from satellite observation. While the satellite data indicate that the retreat is mainly realized by the melting of sea ice, the motion of sea ice is the principal contributor in the modeling result. The oceanic subsurface stratification, especially warm water below the sea surface mixed layer, is not well reproduced in the model, which leads to a lack of heat supply from the ocean to sea ice under turbulence induced by the passage of the cyclone.

2. Outcomes so far, and prospects and expectations

We have been clarifying what kinds of phenomena and processes in the climate system induce predictability into the climate both for the Arctic region and the whole globe. Better representation of such phenomena and processes in numerical climate models would lead to better skill in climate prediction. We have also actually been improving the representation of Arctic climate processes in numerical climate models. We hope our achievements are utilized by operational prediction of weather, climate, and sea ice to raise prediction skill.

Our study has also clarified that the ongoing changes in the Arctic climate are closely linked to the weather and the climate, especially extreme events, in Japan. We hope our activity leads to a better understanding by Japanese citizens on how important the Arctic environment is, even for people living in Japan. On the other hand, ongoing and future changes in the Arctic environment are, of course, a very important factor for the people living in the Arctic region. We hope our achievements help them obtain information with regard to the causes of the ongoing changes and the possible future of their living environment.

Our scientific findings have been and will be published in major scientific journals, and they are to be cited by international reports on climate change by entities such as IPCC and AMAP. Through such a process, we hope our activities contribute to policy-making related to mitigation and adaptation to climatic and environmental changes.

3. Possible legacies

We have been investigating various phenomena and processes that lead to predictability of the climate, but there remain a number of phenomena and processes to be investigated. As for multisphere interaction, we have studied the ice-atmosphere interaction and the land-atmosphere interaction relatively well, but the ocean-atmosphere interaction has not been well investigated. We need to lay a stronger emphasis on it in the future. As for the remote connection, we need to study much more about the link between the tropics and the Arctic, as the tropics are known to be the strongest driver of global-scale atmospheric circulation and also the largest source of atmospheric variability.

In terms of the development of methods for climate prediction, we have focused on sophistication of climate processes, including employing higher resolution. For actual prediction, however, we also need to develop new ways to initialize climate models. Our development so far has mostly been limited to assimilating sea ice concentration. In the future, we should think of utilizing other Arctic climate data, such as sea ice thickness and snow depth, which are becoming observable over the whole Arctic region. In this regard, we not only have to develop modeling methods to adequately assimilate such data, but also must construct good data sets. For longer-term prediction and projection, development and utilization of Earth system models, wherein nonphysical components of the climate such as the carbon cycle are included, are necessary both for better results and a better understanding of fundamental processes. This aspect should be pursued more in the future.

Finally, we would like to emphasize the importance of continuing big projects for Arctic research in Japan. In the Japanese community of climate modeling and climate data analysis, a lot of scientists are strongly interested in the Arctic region, but most of these scientists are not specialists in the Arctic region. Theme 5 of the ArCS project provided an unprecedented opportunity for such scientists to gather, and progress has been made at an unprecedented pace. Maintaining (or continuing to fund) such a gathering point is essential for accelerating, or at least maintaining, our pace in Arctic research in the field of climate modeling and climate data analysis.

III-5-2 Comments for research theme 5

Current climate models have the largest uncertainties in the Arctic region. By making Arctic processes in climate models more sophisticated, this theme aims to clarify the role of multi-sphere interaction in the Arctic for improved understanding and predictability of mid-latitude climates, including for Japan.

This is a very strong and unique effort to improve the scientific background of potential climate predictability by multi-sphere interactions in a global Earth system modelling approach on seasonal-to-decadal and multi-decadal time scales, and to understand the remote connectivity between the Arctic, mid-latitudes and the Tropics. The group further investigated the role of land surface processes on Eurasian heat waves and correlations with soil moisture content over western Eurasia. This moisture content strongly depends on synoptic cyclones and the hydrological cycle.

Strengths:

The group reached interesting results with respect to the role of warm Arctic cold Continent pattern for the occurrence of cold extremes and the role of the Atlantic Multi-decadal Oscillation.

A unique scientific result is the clarified role of tropo-stratospheric interactions for the reinforced negative Arctic Oscillation phase in winter due to Arctic sea decline in late autumn by Nakamura et al. (2016). The results from this model experiment with a high top at 60 km suggests a critical role of the stratosphere in deepening the tropospheric annular mode and modulation of the Arctic Oscillation in mid to late winter through stratosphere-troposphere coupling. A newly developed, high-resolution model of the Arctic Ocean, driven by atmospheric reanalysis data, reasonably simulates a warm current and the consequent Atlantic water layer inflow into the Arctic Ocean. The variability of this oceanic heat transport into the Arctic Ocean is correlated with atmospheric circulation patterns as the North Atlantic Oscillation and the Siberian High.

Recommendations:

Overall the topic made very good progress. With respect to sea ice impacts on tropo-stratospheric interactions the results are internationally outstanding. The atmospheric interactions between sea ice and land-surface processes with ocean processes should be improved and tackled in the next program phase. A very important issue are memory effects between different subsystems, e. g. stratosphere, soil and ocean. The use of new data assimilation techniques was suggested by the PI, but needs further clarification.

III-6-1 Research theme 6: Response and biodiversity status of the Arctic ecosystems under environmental change

PI: Toru Hirawake (Hokkaido University)

Theme 6 is constructed from two subthemes, (A) study on the marine ecosystem and (B) study on the terrestrial ecosystem and biodiversity. The former aims to investigate response mechanisms of marine biology in the northern Bering and the southern Chukchi Seas with respect to environmental changes such as sea ice reduction and human impacts such as fisheries and marine pollution, and then make suggestions on the sustainable use and protection of marine biological resources in the near future. The latter study is investigating three levels of biodiversity—genetic, species, and ecosystem—with an emphasis on less advanced fields of study (e.g., plant pathogenic fungi). The research also promotes a greater understanding of animal behavior and the structure and function of the tundra ecosystem as it relates to climate change. The information will be translated into a form that will be useful to stakeholders.

1. Scientific achievements

A. Marine Ecosystem

The target area of the marine ecosystem group is the northern Bering and southern Chukchi Seas, including the Gulf of Anadyr in Russia. To achieve the research subjects in figure 1, we have carried out ship observations with several vessels and sampling at St. Lawrence Island.

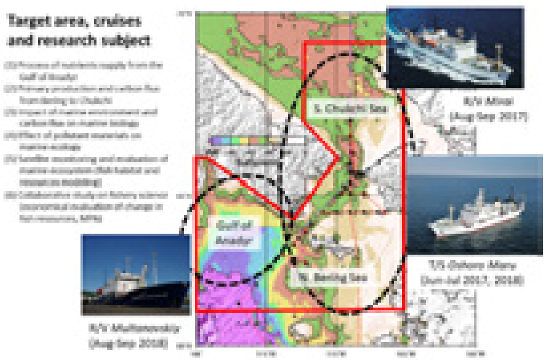


Figure 1. Study sites and research subjects.

Subject 1, 2: Two mooring systems with an ADCP, a sediment trap, and a chlorophyll-turbidity sensor were deployed at the north and south of the narrow trench in the Bering Strait. Results of the mooring showed locally strong barotropic current in the Bering Strait, driving the upward transport of sediment and the subsequent horizontal transport, which may play a vital role in supplying particulate organic matter, phytoplankton, or nutrients to the downstream region of the southern Chukchi Sea, where the formation of biological hot spots is reported. (Abe et al., in review)

Subject 3: A marine ecosystem with high benthic biomass in the shelf region of the study area is maintained by strong pelagic-benthic coupling. However, linkages between phytoplankton in surface water and benthic organisms are not fully understood. A satellite-derived slope of chlorophyll size distribution (CSD slope) showing size structure of phytoplankton revealed that spatiotemporal change in larger phytoplankton size structure during the post bloom period affects distribution of benthic macrofauna.

Subject 5: Little is known about the concentration and distribution of persistent organic pollutants (POPs) in biology in the Arctic region. POPs in seabird preen gland oil at St. Lawrence Island were analyzed and compared with those of seabirds at lower-latitude islands. While differences in polychlorinated biphenyl (PCB) and dichlorodiphenyltrichloroethane (DDT) among latitudes were not found, hexachlorocyclohexane (HCH) concentration at St. Lawrence Island was 100 times higher than at lower-latitude islands. They are semivolatile, and the volatility of HCH is higher than PCB and DDT. Therefore, it is suggested that transported HCH from lower latitudes with large human activities is deposited at high latitudes.

Subject 6: For the future prediction of fish habitat, habitat models of 21 fish and invertebrate taxa in the Bering and Chukchi Seas were constructed, and the responses of each taxon to climate shift was examined. Subarctic species revealed higher habitat sensitivity (loss of their habitat) and exposure to climatic changes than Arctic taxa, as they expand their habitat ranges into suitable regions emerging in the north under warmer conditions. Importantly, the actual rates of climate shifts (climatic velocities) were poorly correlated with both the expected and observed shifts in species distributions across taxa.

B. Terrestrial ecosystem and diversity

Subject 1: Regarding wild reindeer, we have improved a satellite tracking system because the system stopped due to low temperatures and water. We then successfully got tracking data throughout the year. We are analyzing sanctuary for wild reindeer during winter based on the data.

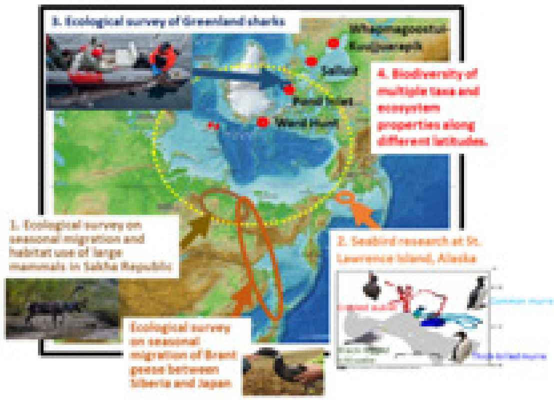


Figure 2. Study sites and subjects.

Subject 2: In the summer of 2016, 2017, and 2018, we conducted field surveys of a seabird breeding area on St. Lawrence Island jointly with researchers from the University of Alaska. We attached a few types of sensors with data loggers for a few different seabird species. We successfully got seabird behavior data throughout the year by geolocators and found that some species migrated more southward than CAFF predicts. We have reported those achievements to “CBird,” an expert group of AMBI at CAFF. Also, we introduced the achievements at the CAFF board meeting in 2018. We plan to analyze the relationship between seabird behavior and shipping routes.

Subject 3: On August 4–25, 2018, we conducted a field survey of Greenland sharks in the sea area around Clyde River on Baffin Island. The sharks have an extremely slow lifestyle, with an estimated life span of 400 years. This means that if the population of this species declines, it would be very difficult to recover. They are a primary bycatch species of longline fisheries targeting Greenland halibut in the Arctic. Thus it is necessary to understand what is happening to the sharks after their release. We caught nine Greenland sharks by longline and then tagged and released them. The sharks showed strange, stressed behavior for the initial 5–10 hours, but then started up-and-down movements in the water column, with occasional burst swimming events, which suggest prey chases. We conclude that Greenland sharks are relatively resilient to capture stress caused by longline fisheries.

Subject 4: We surveyed plant diversity at Whapmagoostui-Kuujjuarapik (KW), Salluit, and Pond Inlet in the summer of 2016, 2017, and 2018, respectively. We also visited Cambridge Bay in the autumn of 2018. We installed line transects, including quadrats. We measured the basic data of soil, plant biomass, and soil respiration at each quadrat. As for Cambridge Bay, we didn’t install a line transect because of continuous snowy days, but we set some quadrats where we could access a vegetation survey supported by CHARS members. We found a significant relationship between vegetation structure and soil microorganism structure at KW. We also found that traits of soil mesofauna could change with latitudinal change. We are writing up these findings. We have published four new fungal species collected in the Canadian High Arctic, and have published a press release on the last two species that appeared in some news in Canada, the United States, and elsewhere.

A mooring system attaching a temperature sensor, a light (PAR) sensor, and a chlorophyll concentration measurement sensor was installed in the summer of 2016 in Ward Hunt Lake on Ward Hunt Island in the Canadian High Arctic, and those data were successfully collected in the summer of 2018. We also collected lake water and sediments, and ice and soil on Ward Hunt Island as well as northern Ellesmere Island in 2016 and 2018. Water temperature data in the lake suggested that the annual water temperature was affected by whether ice covered the lake or not in the summer season. We are investigating the relationship between lake environments and microorganisms in the lakes.

2. Outcomes so far, and prospects and expectations in the future

A. Marine Ecosystem

We provided historical records on fish catch in the Arctic Ocean by the training ship *Oshoro-maru* of Hokkaido University to the Scientific Experts on Fish Stock in the Central Arctic Ocean (FisCAO). Scientific results and knowledge of our members were input into a report of the Working Group on Integrated Ecosystem Assessment for the Central Arctic Ocean (WGICA) through the PICES working group.

Economic evaluation of changes in fish resources in the Bering Sea is now ongoing. We are involving fisheries companies through the Alaska Seafood Marketing Institute, and this study is collaborative research with Themes 4 and 7 of the ArCS project. Results will be provided to fisheries companies, SDWG, and so on.

As an outreach activity, a public lecture was held in Dutch Harbor, Alaska. The mayor, who is a member of the Marine Conservation Alliance, also attended the lecture, and we discussed the present situation and the future of fishery in the Bering Sea.

To contribute to the Arctic scientists community, the fall meeting of the Pacific Arctic Group was hosted in Hakodate.

More than 10 papers will be submitted to the special issue on "Unusual Events in the Bering Sea" in Deep Sea Research II in collaboration with US and Russian scientists. CTD data and some parameters will be provided to the Distributed Biological Observatory (DBO).

B. Terrestrial ecosystem and diversity

We report minutes of CAFF board meetings to the Ministry of Education, Culture, Sports, Science and Technology, the Ministry of the Environment of Japan, and the Ministry of Foreign Affairs of Japan. We also provided data and information to the administrator of Japan's Ministry of the Environment, who attends the CAFF board meeting with us.

We plan to publish a technical book in March, and a member wrote a section of another technical book based on this study. That information will contribute to understanding Arctic microbiology. We have published some books for the public. Also, we published a press release in Japanese and English. Some news companies such as Newsweek ran the article. These achievements are useful for us to inform the public, government, and scientists in the world about our activities.

A Japanese scientist has been added as a Cbird member since 2016. Thus our seabird study achievements are included in Cbird reports and reach the Arctic Council through the CAFF. We also introduced our research activities at the CAFF board meeting in 2018. These activities are also important for us to demonstrate Japanese activities to the CAFF and the Arctic Council.

Some studies hire indigenous people and tell them about our studies. We had opportunities to explain our study to indigenous people in Sakha, Alaska, and Canada as well as collaborators in the Arctic.

3. The way forward

A. Marine Ecosystem

While most of our results support general and usual features in the study area that have been reported in literature in the past, several unusual events have been observed in summer 2018. We need to evaluate the gap between models using the former evidence and the latter events carefully in order to provide more probable information to the public and stakeholders.

B. Terrestrial ecosystem and diversity

To evaluate changing biodiversity under the changing climate and human activities, it is very important to monitor biodiversity and to relate environmental factors. We also need to clarify Arctic ecosystem functions more accurately and to find out how to conserve biodiversity to maintain healthy livelihoods.

III-6-2 Comments for research theme 6

The fragile marine and terrestrial ecosystems of the Arctic are under pressure from both human activities and the effects of climate change. Given these pressures it is of the utmost importance to understand the how the Arctic ecosystem functions today, the biodiversity within this ecosystem and how climate change will impact it. Theme 6 organizes its efforts into two geographic zones: (1) Marine ecosystem (which concentrates on the Bering and Chukchi Seas) and (2) Terrestrial ecosystem and biodiversity (pan-Arctic in nature).

The marine sub-theme has effectively used research cruises, participating on at least three different vessels. Their multi-disciplinary observational techniques were varied and focused on primary production, ecosystem dynamics, and links with the benthos. This approach has led to new scientific discoveries which have been published in peer reviewed scientific journals. The biodiversity/terrestrial sub-theme covered a broad area of expertise, including work in Russia, Canada and USA (Alaska). It dealt with such diverse topics as Greenland shark ecology, reindeer and geese migration routes, seabird mortality, and an important latitudinal study of terrestrial biodiversity. Under each of these topics, ArCS has made significant progress and unique discoveries.

Strengths:

- Excellent scientific progress made within all topics of Theme 6.
- Significant interaction with influential Arctic organisations/programmes, such as FisCAO, WGICA, CAFF and DBO
- Strength in furthering our knowledge of the scientific links between changes in Arctic ecosystems and food security.
- Working with key stakeholders, such as industry and local communities, to provide opportunities for two-way dissemination of knowledge.
- Establishing links between the Sakha government, on a proposed winter sanctuary for reindeer, which provides a good example of sharing scientific knowledge gained and the potential development of evidenced-based policy.
- Gathering of information from several different disciplines and sources to provide a holistic picture of the underlying reasons for seabird mortality within the St Lawrence system. This is a good example of the benefits of inclusive multi-disciplinary science.
- Clear vision of how to proceed during the last period of ArCS, and where these observational measurements and time series need to go in the future.

Recommendations:

- With such a broad array of important topics it is imperative to stay focused and not spread too thinly by trying to do too much. At present the balance seems right.
- It may be fruitful to link up with other teams studying similar topics, but in different areas of the Arctic. Doing so would give the knowledge gained within the region studied by ArCS a Pan-Arctic context.
- Some of the results displayed were very significant, and thus it is important that there is a coherent plan to continue to collect data over the long term.
- Theme 6 naturally has links to Theme 4 ‘Ocean Observations’. It is not clear how strong these cross-theme links are at present, and if they are working efficiently. Also, what are the developed links to other ArCS Themes?

III-7-1 Research theme 7: People and Community in the Arctic: Possibility of Sustainable Development

PI: Shinichiro Tabata (Hokkaido University)

1. Outline of research activities

We have three subtopics in our theme: research for Arctic economic development; research on interaction between humans and the environment; and research on discussions at international organizations and Arctic governance. These subtopics are mutually related.

Our group is unique in the eight themes of the ArCS. We are not expected to carry out any independent research on our own. We are to collaborate with other themes in natural sciences and to inform stakeholders of research results obtained by the ArCS.

2. Scientific achievements and outcomes

2.1 Research for Arctic economic development

Our activities in this topic include the northern sea route (NSR), mineral resource development, connectivity (communications), and marine resources development. In the research on the NSR, we have investigated actual navigation and characteristics of sea ice along the NSR. Based on them, we have estimated navigable ship speed and simulated NSR navigation. Finally, we are making an estimation of the NSR shipping scenario and costs.

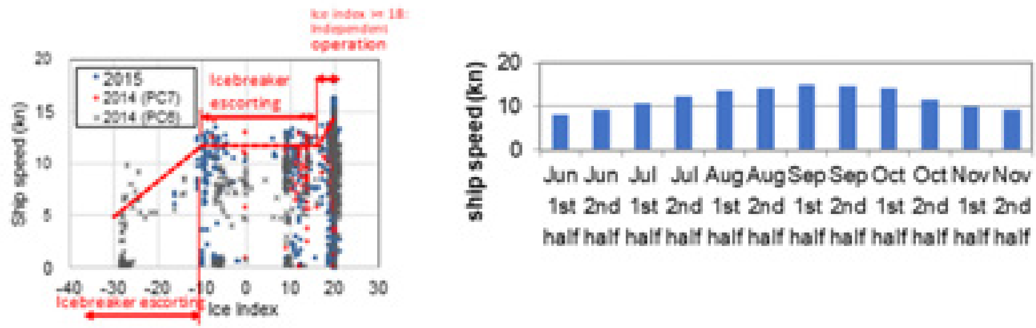


Figure 1. Ship speeds on the northern sea route.

With respect to mineral resource development, we demonstrated that Russian Arctic regions contribute greatly to the federal budget thanks to oil and gas production.

Concerning connectivity, we have examined the possibility of connecting East Asia with Europe through submarine cables.

In our research on marine resources development, we are making an economic assessment.

We carried out these research projects taking into considerations the impact of these developments on indigenous societies and the natural environment in collaboration with other subtopics of Theme 7 and other Themes of ArCS in natural sciences.

2.2 Research on the interaction between humans and the environment

Concerning the joint research in the Sakha Republic, Hiroki Takakura and his colleagues published an article in *Anthropocene* 18 (2017) 89–104, Elsevier, which provides an integrated review and analysis of environmental and socioeconomic trends in a subarctic region by way of an interdisciplinary approach of hydrology, meteorology, and cultural anthropology.

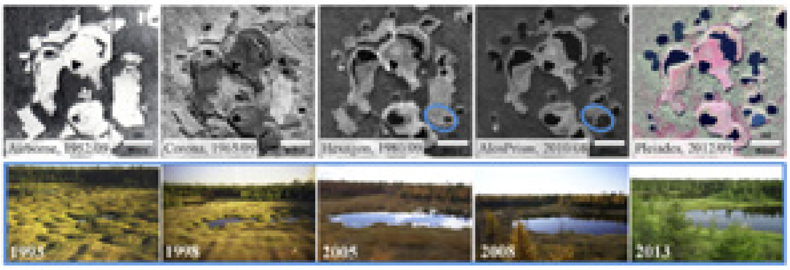


Figure 2. Landscape change at Yukechi study site during recent years. Several thermokarst lakes around the Yukechi alaas have developed rapidly in areas ploughed until the 1950s.

In Yakutia, we conducted a questionnaire survey in villages on their perceptions of climate change during 10 years.

Concerning the research in Alaska, we have illustrated that the views of indigenous peoples and of fisheries management scientists are compatible in spite of their opposing appearance through the application of the concept of keystone species to the example of Alaskan salmon fishery management.

With respect to joint research in Greenland, we have conducted empirical research on the management of marine mammals and research on the national security environment.

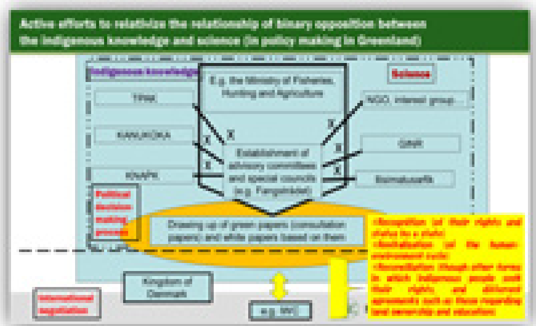


Figure 3. Active efforts to relativize the relationship of binary opposition between indigenous knowledge and science in policy-making in Greenland.

Figure 4. Workshop in Qaanaaq, 2016.

3. Outcomes so far, and prospects and expectations in the future

3.1 Increase of Japan's contribution to the Arctic

We contribute to enhancing the presence of Japan in the Arctic. Two researchers of our group participate in SDWG and PAME, respectively. Domestically, we have promoted collaboration with decision-makers at national and local governments. We have organized roundtable discussions on the Arctic Council and its working groups and a roundtable conference on the Arctic between government officials and researchers. At these meetings, we exchanged opinions and information and discussed concrete measures for increasing Japan's contribution to Arctic research.

Kobe University organized four international symposiums on Arctic policy and law in collaboration with international academia, policy-makers, business sectors, Arctic indigenous communities, and scientists, through which we have established a robust research foundation with close collaboration with international partners. Kobe University will organize a special session at the 12th Polar Law Symposium in Hobart, Tasmania, in December 2019, and will host the 13th Polar Law Symposium in Kobe, Japan, in November 2020.

Figure 5. The 4th international symposium, December 2018.

3.2 Teaching materials for environmental education: Permafrost and Indigenous and Northern Societies in Arctic Region

We are preparing teaching materials based on research results that will contribute to deepening of people's perceptions of climate change.

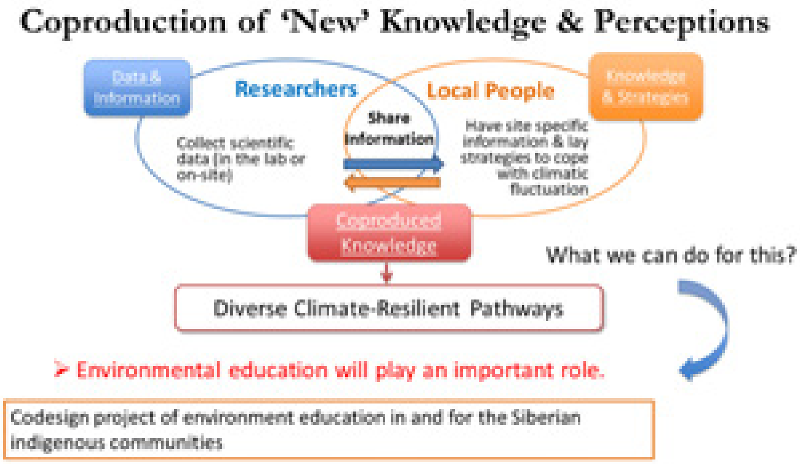


Figure 6. Coproduction of "New" Knowledge and Perceptions.

3.3 Summary symposium in January 2020

In the final year of this project, we have three plans to demonstrate the results of our activities: publication of a book for the general public; release of a report for decision-makers; and organizing of a summary symposium in January 2020. At this symposium, we will widely advertise the above-mentioned book to be published this year, which will summarize the results of research by our group. We will also hold discussions with decision-makers at this symposium in order to make a final version of the above-mentioned report, in which we discuss various topics along with statements on Japan's Arctic Policy announced by the Headquarters for Ocean Policy in 2015.

4. The way forward

a) NSR: we will further investigate scenarios of its use and feasibility.
b) Communications: feasibility and international cooperation shall be investigated further.
c) Fishery: its possibilities, international cooperation, and regulation in the Arctic Sea shall be studied.
d) Socioeconomic development of Arctic regions: finding the appropriate size of human settlements, and the interaction of indigenous societies with energy resource development are two examples of further studies.
e) Research on indigenous people: interregional comparison of fishing and other livelihoods in Alaska, Siberia, and Greenland shall be made in the future.

f) Arctic governance: the influence of environmental change on international relations in the Arctic shall be analyzed. Security and military issues in the Arctic and the interplay of the national security environment and governance of the entire Arctic region are topics for future research.

III-7-2 Comments for research theme 7

Theme 7 represents the only social science theme of ArCS. A key mandate of this theme is to collaborate with the other seven themes, to facilitate the interface between the natural scientists and 'stakeholders'. Theme 7 also involves three research sub-themes: 'Arctic Economic Development', 'Interactions between Humans and Environment' and 'Discussions at Arctic International Organizations'.

Strengths:

Within the 'Arctic Economic Development' subtheme, Theme 7 has made substantial contributions to research on the Northern Sea Route, research that has application for the business community (shipping), including through its scenario and cost estimations.

The 'Interactions between Humans and Environment' sub-theme has not only greatly expanded our understanding of thermokarst-based socio-ecological systems, but also serves as an outstanding model for fruitful collaboration between social and natural scientists and local populations. Research on local perceptions of climate change (Siberia), marine mammal management (Greenland), fisheries management (Alaska), and national security issues, all have direct relevance for policy makers.

Sub-theme 3 has actively brought academics and policy-makers from around the circumpolar north together in several symposia, to discuss international legal developments in the Arctic and their function in sustainable development, including non-arctic states' roles; Japan has situated itself as a leader in this regard.

All elements of this theme have attended to Indigenous issues; Theme 7 also is responsible for assisting other themes with their interactions with Indigenous communities.

Outputs of this theme include imaginative contributions such as a board game for Japanese high-school students and adults (in collaboration with Miraikan), teaching materials on climate change for Siberian students, and a popular book on changing arctic environments. Theme 7 has also been prolific in more usual scholarly output of symposia, journal articles, and specially edited volumes (books and journal).

Recommendations:

While connecting Theme 7 with all other ArCS themes facilitates the connection between scientists and the communities with which they interact, as Arctic social sciences develop in Japan, future projects may want to ensure a more independent role for social science initiatives as well.

III-8-1 Research theme 8: Arctic Data archive System (ADS)

PI: Hironori Yabuki (NIPR)

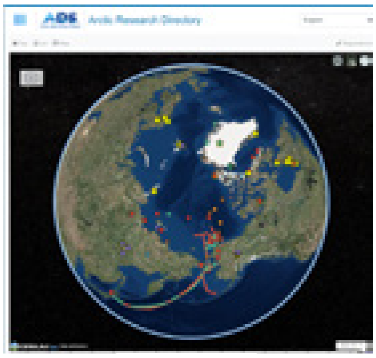
1. Summary of research

The Arctic Data Archive System (ADS) aims to develop an open science infrastructure for Arctic research, and will promote the mutual distribution of the big data of Arctic research. Furthermore, ADS will develop analysis and visualization Web services for integrated big data, and intends to generate new value with big data.

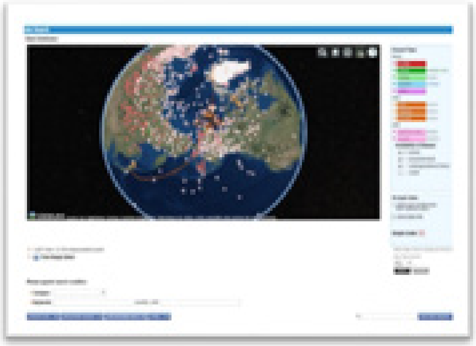
2. Scientific achievements

2.1 Arctic Data Archive System (ADS)

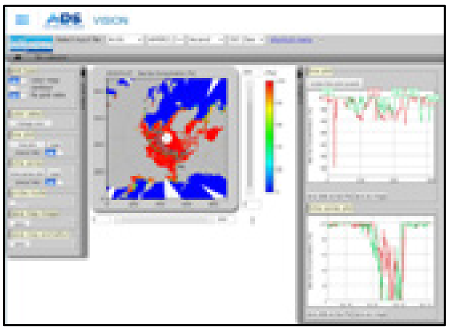
We have enhanced the ADS database (KIWA). We expanded the metadata to correspond to ArCS. We also improved the database system and expanded the service for data registrants. We built arDirectory and operated services for collecting and browsing the observation and model information of ArCS. For the purpose of strengthening the data visualization search tool, it was changed to the implementation of the general Cesium plug-in more than the Google Earth plug-in we have been using. We strengthened the retrieval tool for data visualization, enabling data to be retrieved in the form of polar stereo projections.



arDirectory



ADS database (KIWA)



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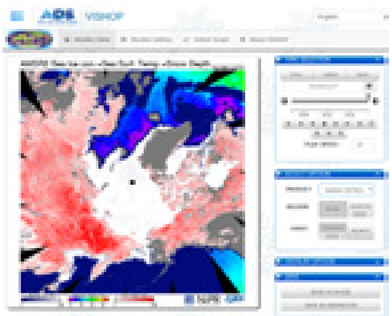


VISHOP

Figure 1. ADS service component.

As a derived application of VISION development, we developed an identification site for multiple time series and multiple points of satellite data (satellite data getter). We also developed a tool that can display AWS (automatic weather station) data as a VISION graph. We developed an identification and visualization site for global weather forecast data and GPV data (GPV data getter). We upgraded VISHOP and expanded the service to handle various data (MPL Micro Pulse LiDAR, All Sky Camera, and Phenological Eyes Network [PEN]) representations in addition to JAXA satellite data.

2.2 Open science and development of data collaboration tool

In order to understand the climate system in the Arctic, field observation data covering the Arctic is necessary. Field observation data in the Arctic region requires cooperation among various countries. ADS implemented a tool to coordinate metadata. Registered data is expected to improve reusability. The use of data DOI as a method is an international standard. ADS implemented a tool to assign data DOI.

2.3 Development of VENUS ship navigation support service

For vessels navigating sea ice areas, sea ice information is indispensable. It is necessary to create wide-area sea ice information for navigating the sea ice area using satellite data. ADS has developed a system that visualizes sea ice information on the ship using JAXA's Earth observation satellite.

2.4 Development of data quality control system

For data registered in ADS, it is necessary to ensure the certainty of the value and format. Data quality control takes time and effort. ADS developed a tool that can create metadata, control quality, and convert the format of data by registering data in the system.

2.5 Svalbard satellite image gallery

The National Institute of Polar Research Institute set up a research station at Ny-Ålesund in Svalbard. The ArCS project is promoting research in various fields on the Arctic natural environment. ADS maintained satellite images as basic information.

3. Outcomes so far, and prospects and expectations in the future

3.1 Cooperation with domestic and international data portals

ADS began exchanging metadata with domestic (DIAS: Data Integration and Analysis System) and foreign (GEOSS-Portal: Global Earth Observation System of Systems) data providers.

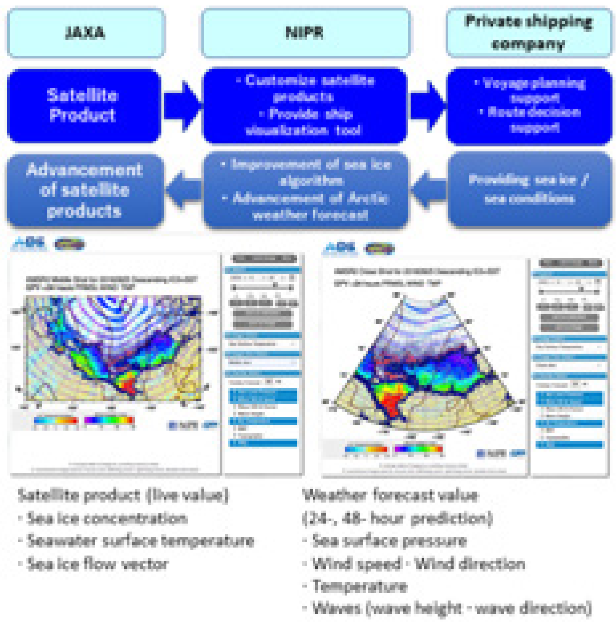
Figure 2. Polar data Journal (PDJ).

3.2 Enhancement of data publication and data citation services

In collaboration with the National Institute of Polar Research Library, we published the Data Journal (PDJ: Polar Data Journal). ADS publishes data as a recommended repository of the PDJ, and ADS provides data DOIs.

3.3 Industry-academia collaboration through the Arctic sea route

ADS is conducting data services not only on private ships by industry-university collaboration but also on domestic research vessels conducting research in sea ice areas. VENUS is an important tool for determining routes in sea ice areas. This system was mounted and used to provide the service to the private shipping company Yamal LNG's ship from 2018, the RV *Mirai* Arctic cruise from 2015 to 2018, the *Oshoro-maru* Arctic cruise in 2018, and the RV *Marutanovsky* Arctic cruise in 2018.



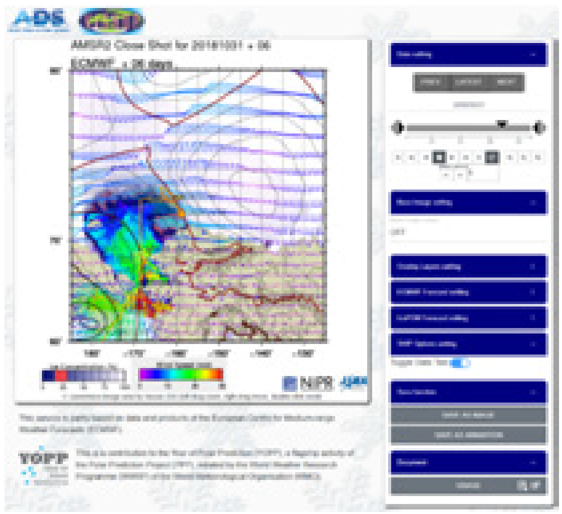


Figure 3 (left). Industry-academia collaboration through the Arctic sea route.

Figure 4 (above). VENUS operation screen on the *Mirai* Arctic Cruise 2018.

3.4 Construction of prototype of Arctic navigation support commercial service and actual operation on the *Mirai* Arctic Cruise 2018

Every day, ADS prepared the Arctic sea route support service that delivers short-term sea ice fluctuation prediction results for 10 days. It actually operated as a ship and land support tool on the *Mirai* Arctic Cruise 2018. Theme 1 cooperated with ECMWF, ECMWF provided real-time 10-day forecasts in the Arctic, and the University of Tokyo developed a sea ice prediction model (IcePOM), which mode calculated 10-day sea ice forecasts (calculation of sea ice concentration, sea surface temperature, etc.). VENUS Integrated forecast data and satellite data, ADS development of the data delivery method, technology and a Web tool as an integration tool.

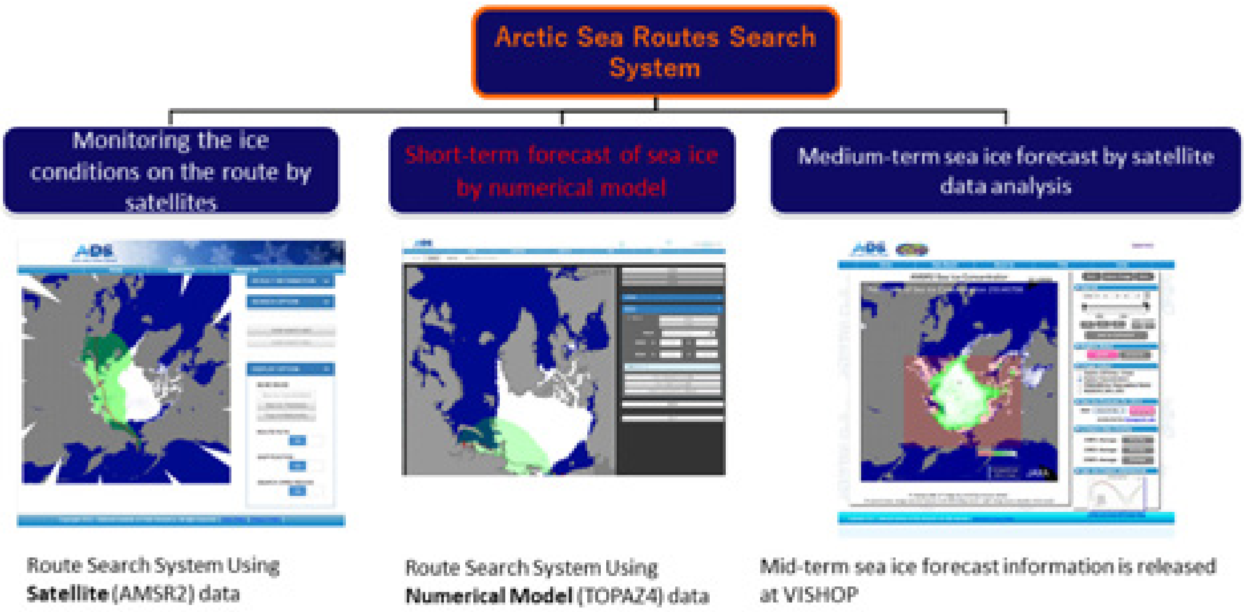


Figure 5. Conceptual diagram of the Arctic Sea Routes Search System.

3.5 Development of the Arctic Sea Routes Search System

Using sea ice data based on satellite data and model results as input values, anyone can search for optimum routes online, avoiding risks such as collisions with sea ice and ship confinement due to sea ice, and contributing to safe and efficient sailing of the Arctic sea route. Among the satellite products, it was difficult to search the route for the areas where the sea ice thickness was not determined. Using the numerical model (TOPAZ), sea ice thickness information became available throughout the Arctic. Short-term forecasts are important when ships actually sail through sea ice areas, and medium-term forecasts are very important for planning the Arctic sea route.

3.6 Improving understanding of the Arctic

We developed the application for representing Arctic creatures by using AR technology and virtual Arctic exploration using 360-degree pictures around Ny-Ålesund for ADS demonstrations. ADS created sea ice and permafrost distribution changes to 2100
by the climate model (MIROC5) RPC8.5 of Dagik Earth content.

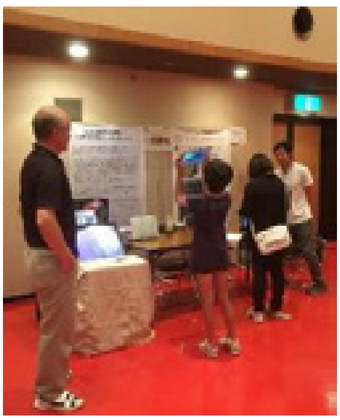


Figure 6. Children's event

Figure 7. Permanent exhibition at the science museum.

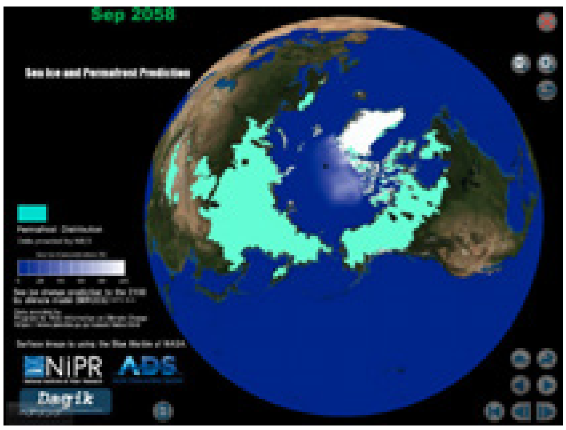


Figure 8. Sea ice and permafrost distribution changes to 2100 by the climate model (MIROC5) RPC8.5.

For demonstrations of ADS, we exhibited these applications at the JpGU meeting exhibition and Snow and Ice Research Conference Children's Event held by the Japanese Society of Snow and Ice. This served as useful outreach on Arctic research to the public. Dagik Earth sea ice and permafrost distribution change to 2100 by the climate model (MIROC5) using scenario RPC8.5 of Dagik Earth content are permanently displayed at the Antarctic and Arctic Science Museum in NIPR.

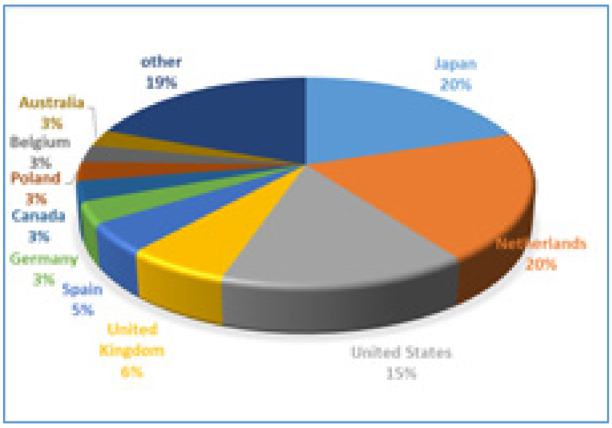
4. The way forward

4.1 Access Analysis of ADS

Table 1. ADS website page views.

fiscal 2016	2.25 million
fiscal 2017	2.62 million
fiscal 2018 (Apr.–Dec.)	2.90 million

Users of ADS are increasing year by year, and it is certain that fiscal 2018 will count 3 million hits. Approximately 80% of users are from outside Japan (the Netherlands, US, UK, Spain, etc.). Many users use VISHOP, and 30% are users of KIWA, the observation data site.



ADS Visitors' Countries

4.2 Registration numbers

Table 2 Registration number to ADS

International collaborative research Registration numbers of arDirectory	78 (ArCS) 187 (total)
Data publication Registration numbers of data to ADS KIWA	metadata: 58 (ArCS) 468 (total) real data: 49 (ArCS) 209 (total)

ADS had a lecture for ArCS participants on how to write metadata and how to register data. It is thought that the amount of registered data is increasing. The use of VISHOP increases awareness of ADS, and it is conceivable that the number of users of KIWA is also increasing accordingly. The use of KIWA is increasing mainly with data DOI's data. It is necessary to further promote data registration through collaboration with PDJ in the future.

III-8-2 Comments for research theme 8

The ADS system consists of several different components which contribute to build an Open Science infrastructure for Arctic research. The components are:

1) The Arctic Data archive system is a web-based system where users can browse, search and download data, upload data, prepare metadata for both observational and model data and registration of publications. Both archived and near-real time data are provided
2) A visualisation tool (VISHOP) is developed for displaying data
3) A tool for open science and data collaboration, including assignment of DOI
4) A ship navigation support service "VENUS", where sea ice data from JAXA, weather and sea ice forecasts can be downloaded and displayed onboard vessels
5) Data quality control system;
6) A satellite image gallery of Svalbard.

Strengths:

This group has interacted with the polar data community, providing insight into their accomplishments for others to emulate. Substantial progress has been made in integrating all themes into the process of archiving data and enhancing methods of accessing data and metadata. This portion of ArCS is not just a data archive but a legitimate research program with substantial and admirable scientific achievements.

Recommendations:

ADS is the central repository for archived Arctic data in Japan developed by NIPR. The development of the ADS system is an important but ambitious task, because the amount and variety of Arctic data develop rapidly. All the components of ADS are important, but it is not clear how developed the different components are. The technical capabilities of the system have not been tested as part of this review, so we cannot comment on the functionalities of the system. A common challenge for all such archiving systems is that they require adequate resources to operate and update the whole system as well as each of the components. It is not known how much effort has been invested in ADS since it started in 2012.

A number of questions can be raised on the status of the ADS:

1) Is it a central or distributed archive, and how is it connected to other data centers in Japan and internationally?
2) Although they have given serious consideration of the metadata used in ADS, and have engaged all researchers in compiling essential metadata, it is not clear if the metadata are following international standards.
3) Are data stored in standard formats, and which formats are used?
4) Is there a data management plan, identifying who has responsibility for various tasks in ADS?

It is recommended to strengthen the ADS system, especially the archiving system with browse, search and downloading capabilities and visualisation. Scientists and data managers have responsibilities for the development. When the system becomes fully operational, it should be run by an agency with 24/7 services and can provide helpdesk to users. It is unknown how the role between science and services is organized in Japan. Other parts of the system, such as VENUS, can potentially be further developed in collaboration with service providers who already produce information packages to ships. Development of various tools for visualisation, use of models and performing statistical analysis of data can also be done in collaboration with specialized institutes or companies.

III-9-1 Maintain and develop platforms for research in the Arctic region Program

PI: Hiroyuki Enomoto (NIPR)

1. Achievements

1.1 Goal and summary

According to Japan's Arctic Policy, there is a demand to strategically establish research and observation stations in the Arctic states as one of the research and development issues that Japan should deal with. In response to this demand, the "Maintain and develop platforms for research in the Arctic region" program of ArCS aims to establish research and observation stations in the Arctic states as infrastructure for international collaborative studies and capacity-building by Japanese researchers. These stations are expected to be used even after the ArCS project ends. This activity is to promote closer international cooperation through on-site observations and joint research projects, and to promote the effective development of human resources by dispatching young researchers to the stations.

Agreements for the use of 10 research and observation stations have been concluded and updated in the five states that border the Arctic Ocean (United States, Canada, Russia, Norway, and Denmark)

1.	International Arctic Research Center, University of Alaska (IARC)	The United States
2.	Poker Flat Research Range (PFRR) Flux Super Site	The United States
3.	Canadian High Arctic Research Station (CHARS)	Canada
4.	The Centre d'études nordiques (CEN) field stations	Canada
5.	Spasskaya Pad Scientific Forest Station	Russia
6.	Ice Base Cape Baranov Station	Russia
7.	Ny-Ålesund Research Station	Norway
8.	University Centre in Svalbard (UNIS)	Norway
9.	East Greenland Ice Core Project (EGRIP)	Denmark (Greenland)
10.	Greenland Institute of Natural Resources (GINR)	Denmark (Greenland)

1.2 Stations and Institutions

- Strategy of site selection; reasoning for support from the project
  A) Newly started collaborations; utilization of Arctic research stations based on observational needs; requirements of Japanese research communities, etc.

  CHARS, CEN, Cape Baranova, EGIP, GINR

B) Support for renovating and maintaining core facilities of the existing stations to enhance international collaborative studies

PFRR, Spasskaya Pad, Ny-Alesund, UNIS

C) Review of the existing framework of collaboration to enhance international collaborative studies

IARC

- Start-up support for the activities at the new stations (category [A] above)

Support for the initiation of new observation and research activities has been provided since fiscal 2017, the third year of the project.

- COSMOS measurements at Cape Baranova
- radiosonde soundings at Cape Baranova
- soil biological measurement at CHARS
- precipitation sampling for stable isotope measurements at CHARS and Cape Baranova

1.3 Workshops and meetings

We have carried out activities with the countries where the stations are located or with other related countries, such as workshops or sessions to explore new collaborative research or to advance existing research projects more effectively. As a result of these activities, new collaborative research projects and observations began mainly at the stations that had been developed after the start of the project. Some examples of the activities are shown below.

- Russia-Japan Workshop on Arctic Research (January 15–19, 2018, Tokyo)

  A two-day workshop especially on the joint research and observation at Cape Baranova Station was held together with members from AARI, including the new director, Dr. Alexander Makarov, and Japanese members from NIPR and other institutions. Some issues on data transfer and extended radiosonde observations were discussed, and plans for future observations were proposed. In the light of the long history of Russian Arctic research and the importance of observation at Cape Baranova Station in a sparsely observed area of the Arctic Ocean, it was a very rare opportunity and worthwhile to hold this workshop.

- Session at ArcticNet Annual Scientific Meeting 2018 (December 12, 2018, Ottawa)

  A session titled "Functions of the Arctic Tundra Ecosystem under Rapid Environmental Change" was held, jointly led by Canadian and Japanese researchers. There were around 80 participants, including researchers from CHARS and CEN, and research progresses and plans were discussed and shared among the participants.

- Workshop for Promoting Arctic Collaboration between IARC/UAF and Japan (March 3–6, 2019, Fairbanks)

  A three-day meeting titled "Japan-U.S. Arctic Science Collaboration: Reflections on the Past Two Decades and Future Opportunities" will be held with members from the United States and Japan, covering various themes such as the Central Arctic Ocean Fisheries Agreement, coordinated sustained observations of Arctic change, Alaska Native perspectives on observing and responding to Arctic change, and so on. During the meeting, ArCS will lead a one-day workshop to promote joint research and observations by researchers of IARC/UAF and Japan, targeting to formulate a concrete research plan on the launch of new research or the progress of existing research.

2. Outcomes so far, and prospects and expectations in the future

2.1 Outcome

- Contribution to the capacity-building of the research community
  - EGRIP station

    Training opportunity for young ice core drillers
  - Spasskaya Pad

    - Field site for RJE3 program* of Hokkaido University

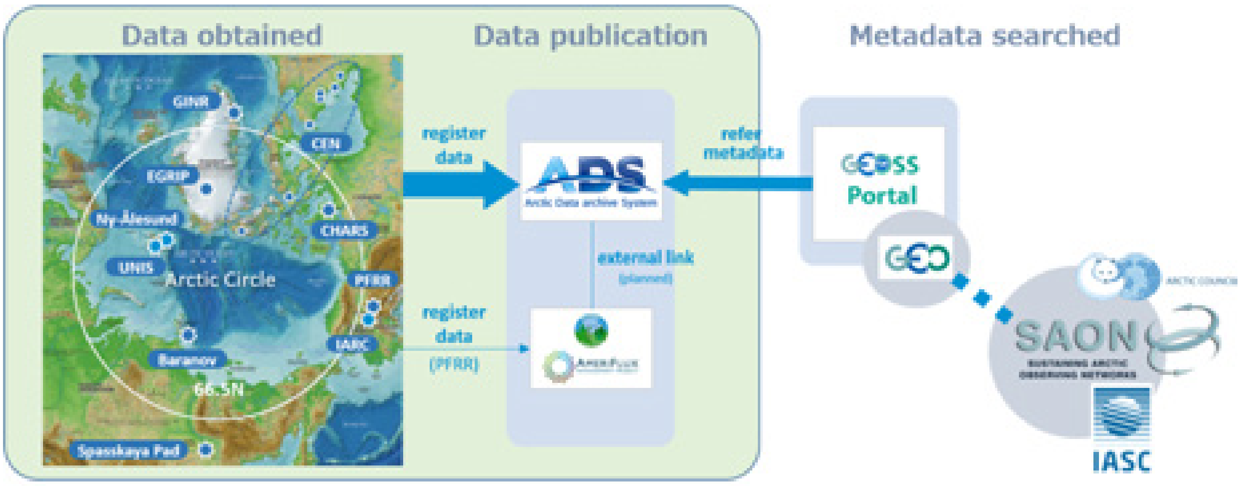
      * East Russia-Japan Expert Education Consortium https://rje3.oia.hokudai.ac.jp/en/

    - Many PhD studies during the past 15 years, not during the ArCS project

• International collaborative research projects

International collaborative research projects were realized at the established stations, some of which are shown in the figure below. Especially, some new research projects and observations were started at the stations that were developed after the start of the project.

2.2 Expectation in the future



Open science infrastructure for Arctic research has been developed by the Arctic Data Archive System (ADS), as shown in the figure below. By using the infrastructure, we will continue to promote publication and sharing of data obtained at the established stations. It is expected that this will enable contributions to international observing networks, which SAON or IASC is aiming to enhance.

The following are some of the data sets that have already been registered to ADS in relation to the international collaborative research projects carried out at the established stations.

- Continuous canopy and understory spectral reflectance measurements of a sparse black spruce forest at Poker Flat Research Range (PFRR), interior Alaska, (Year 2018)
  https://ads.nipr.ac.jp/dataset/A20181212-005
- (Link to Yearly data) Continuous canopy and understory spectral reflectance measurements of a sparse black spruce forest at Poker Flat Research Range (PFRR), interior Alaska
  https://ads.nipr.ac.jp/dataset/A20181212-001
- Forest inventory at larch forest in Spasskya Pad station, eastern Siberia
  https://ads.nipr.ac.jp/dataset/A20181105-001
- Mass concentration of BC (black carbon) measurement by COSMOS at Ny-Alesund
  https://ads.nipr.ac.jp/dataset/A20180402-008
- Glacially sourced dust as a potential significant source of ice nucleating particles—Dataset (Ny-Ålesund)
  https://ads.nipr.ac.jp/dataset/A20180903-001

Black carbon (BC) measurement [1]	Theme 3	PFRR ★	Baranov ★	Spasskaya Pad ★	Ny-Ålesund
CO_2·CH_4 flux measurement [2,3]	Theme 3	PFRR	Spasskaya Pad	Ny-Ålesund	
Terrestrial ecosystem investigation [4]	Theme 6	CEN ★	CHARS ★	Ny-Ålesund	
Isotope analysis of precipitated water	Theme 4	IARC	CHARS ★	Baranov ★	
Permafrost research	Theme 3	IARC	Ny-Ålesund ★		
Greenland ice core research	Theme 2	EGRIP ★			
Survey on politics surrounding marine mammals	Themes 2·7	GINR			
Cloud and ice nucleation particles measurement	Theme 3	Ny-Ålesund			
Radiosonde observation	Theme 1	Baranov ★			

★ = stations where the research has started after the setup of the station by ArCS

3. The way forward

3.1 Expansion of new research activities at the stations

Enhancement of research start-up support

In order to encourage starting new research projects, financial support by the project should be effective as seed money. Although start-up support started from fiscal 2017, the third year of ArCS, especially for the newly established stations, it should be started at the beginning. Also, there should be a system to encourage starting new activities. The INTERACT model is a good reference: an open call for research or observation proposals, provision of small funding for fieldwork, installation of instruments, etc. SIOS is taking a similar approach with the Access Program. The call should also be open to non-ArCS research topics.

Keep the system long-term: Maintain stable funding opportunities

It will automatically be a way to publicize the research platform or observatories. Also, advertising is import to exploit potential users.

3.2 Capacity-building of research community

As a joint activity with a capacity-building program within ArCS, full use and collaboration with the education components of the partner institutions is expected, as follows:

- UNIS: Various courses in Arctic biology, geology, geophysics, and technology for bachelors, masters, and PhD
- IARC: various summer school programs
- Spasskaya Pad: RJE3 program of Hokkaido University

3.3 Securing long-term usability of key facilities

It is required to be prepared for maintenance and update of the facilities at the stations, and for that, a long-term road map for the facilities is needed. However, large-scale maintenance is difficult due to the limitations of financial rules; e.g. a single year budget and the Japanese fiscal year calendar (April to March).

As written in the governmental “Third Basic Plan on Ocean Policy,” approved in May 2018, it is requested to keep the current framework and the 10 current stations. In responding to the request, however, a review process of the stations and platforms should be performed first at the end of the project. As metrics, the overall importance of the station or institution for Japanese research should be reflected.

3.4 Joint research with Russian partners

It would be better to maintain the Cape Baranova station as a monitoring site, in consideration of some facts: continuous measurements, such as BC measurement (COSMOS), can be operated by Russian researchers by agreement; and field studies are difficult, as access to the Cape Baranova station is not stably operated.

To initiate new research projects, especially at the Cape Baranova station, it will be required to have a fully committed partner researcher for better communication. Otherwise, discussion becomes difficult due to poor response, time taken for confirmation, and troubles with data handling, and it must be anticipated that getting permission from the Russian authorities regarding transport or installation of equipment, border security, data transfer, etc., will take a lot of time.

III-9-2 Comments for Maintain and develop platforms for research in the Arctic region program

For many decades, Japanese researchers have been world-class leaders in precise and consistent field observations. The certainty and reliability of these observations have made them a hallmark of global analyses and model validation and verification. Although accuracy of any measurement cannot be maintained continuously, particularly in remote and unmanned field research sites, these data have been honestly and pragmatically reviewed, and freely shared. Achieving no data loss in remote field stations is a worthy goal, but very difficult to accomplish. It is noteworthy that these researchers have been markedly successful in making substantial (meaning large in number) and substantive (meaning important in value) contributions to observations around the circumpolar Arctic.

ArCS has set as one of its goals "*to establish research and observation stations in the Arctic states as an infrastructure for international collaborative studies and capacity building by the Japanese researchers, which are expected to be used even after the ArCS project ends. This is to promote closer international cooperation through on-site observations and joint research projects, and to promote the effective development of human resources by dispatching young researchers to the stations*."

The ArCS program have established or continued observation stations at 10 sites in the five Arctic countries (the United States, Canada, Russia, Norway, and Denmark)

1.	International Arctic Research Center/University of Alaska (IARC)	United States
2.	Poker Flat Research Range (PFRR) Flux super site	United States
3.	Canadian High Arctic Research Station (CHARS)	Canada
4.	The Centre d'études nordiques (CEN) field stations	Canada
5.	Spasskaya Pad Scientific Forest Station	Russia
6.	Ice Base Cape Baranov station	Russia
7.	Ny-Ålesund Research Station	Norway
8.	University Centre in Svalbard (UNIS)	Norway
9.	East Greenland Ice Core Project (EGRIP)	Denmark / Greenland
10.	Greenland Institute of Natural Resources (GINR)	Denmark / Greenland

Strengths:

These observations have already been used to enhance and improve our understanding of the Arctic System, and are highly valued by the international research community. ArCS should also be commended for their complete engagement with the international communities through participation in the key international meetings and workshops. Japanese presence in these meetings is critical to ensure the full value of Japanese Arctic research is known.

Recommendations:

We encourage closer integration with the primary international body responsible for the Arctic Observing Network, SAON (Sustaining Arctic Observing Networks) and to become engaged in their Committee on Networks. We also encourage Japan to establish a national committee for SAON to ensure the full value of these observations is recognized and acknowledged in the international community.

III-10-1 Program for Overseas Visits by Young Researchers(Capacity Building)

PI: Sei-Ichi Saitoh (Hokkaido University)

1. Background

The emerging environmental issues in the Arctic and its adjacent areas have recently been attracting public attention as issues for common efforts by international society. However, an understanding of the mechanism driven by climate change is insufficient to establish a holistic understanding of the Arctic system. It requires a transdisciplinary grasp of the impacts of Arctic environmental changes on society, politics, and the economy. As such, it is inevitable that a general yet comprehensive understanding of the cascading feedbacks of Arctic ecological changes across a wide range of points of view will be required. This is why it is equally important to encourage and forge international cooperation among researchers who can contribute to solutions for Arctic issues. In addition, it is crucial to advance actions to cultivate and fortify collaborations involving various stakeholders, such as government and industry. Therefore, it is indispensable to actively engage the next generation of young researchers who share a concerted field of vision in addressing Arctic concerns well beyond the borders of government, industry, and academia.

2. Overview of the Activity

We will dispatch highly competent young researchers from our country to overseas research organizations dealing with Arctic studies. Consequently, this will advance our expertise on the focus of Arctic research through the acquisition of techniques and the coproduction of knowledge.

Research themes on the Arctic include the disciplines of practical sciences such as engineering, agriculture, and medicine as well as the natural and social sciences.

3. Achievements

For capacity-building of young researchers, graduate students, and practitioners, including business experts and government officials, we will support foreign travel for periods less than half a month and from half a month up to a year, as short-term and mid- and long-term programs (See PowerPoint page 4).

The main objectives of this program are as follows:

- **Sending young talented people overseas**

We send young researchers and practitioners overseas and support the talented individual who deals with a solution to a problem in the future Arctic by supporting a study or a research activity about Arctic issues.

- **Targets are all disciplines**

As well as natural science researchers, we enlarge the footprint of the Japanese Arctic study by dispatching humanities and social science researchers, practical sciences researchers in fields such as engineering, agriculture, and medicine, and practitioners.

- **A follow-up program is provided**

In a results-presentation follow-up after dispatch, we plan to fix the knowledge of the dispatch support person and reinforce the network with the overseas researchers.

- **Connecting the network to the Japanese community**

In addition, we aim at the formation of an information-sharing network among dispatch support people.

Specifically, we will support research activities that involve the following:

- **Short-term program**

(1) international conferences on Arctic studies, such as ASSW and Arctic Frontiers
(2) a training course on Arctic studies, such as the UNIS UArctic program

- **Mid- and long-term program**

(1) data acquisition and sample analyses

(2) exploring novel fields of Arctic studies, including but not limited to the implementation of innovative research approaches
(3) conducting regional comparative studies

We will also clarify the importance of the overseas visit program and facilitate its realization by arranging pertinent orientation before the visit and by conducting follow-up discussions.

We have already dispatched 8 (1) researchers, 18 (8) graduate students, including 10 (5) in masters studies and 8 (3) in PhD studies, and 13 (5) practitioners, including 10 (4) business experts and 3 (1) local governmental officers. The figures in parentheses are the number of women. The gender balance of participants is 36 percent women. Geographical distribution is Nordic countries (16), Russia (6), US (8), and Canada (3) as AC countries and European countries (5). We expect to add 12 participants in fiscal 2019 (see PowerPoint pages 5 and 9).

4. Outcomes so far, and prospects and expectations in the future

Likewise, we plan to establish knowledge, maintain research networks, and further reinforce activities by creating opportunities to present the outcomes of studies. Young researchers who have been dispatched to overseas institutions will plan briefing sessions carried out under the ArCS program and the like to share with the ArCS researchers the knowledge and connections they acquired through international networking.

4.1 Output of achievement during dispatch is requested.

- **Publications**
  Journal papers (including in press): 2
  Books (coeditor, coauthor): 7
- **Presentations**
  Domestic conferences: 5
  International conferences: 17

4.2 There are many facts as outcomes of activities and promotions after dispatching, as follows:

Fact1：Promotion from Research Associate to Assistant Professor
Fact2：Promotion from Post-Doc in Japan to Post-Doc overseas
Fact3：Session subleader in ISAR-5
Fact4：JSPS Foreign Post-Doc (2)
Fact5：Extend from masters to PhD studies (3)

4.3 SNS community and networking

We established the SNS community for those applicants. We manage it as the place where young researchers or practitioners share the latest trends in various fields about the Arctic and aim at forming different field networks of Arctic study.

5. The way forward

We suggest future actions as follows:

- Expanding participation of foreign students and researchers in fiscal 2019
- Introducing relevant training courses or lectures for the short-term program
- Expanding SNS networking
- Following up with participants for evaluation and promoting a future capacity-building program

III-10-2 Comments for Program for Overseas Visits by Young Researchers (Capacity Building)

This program provides an innovative capacity-building facet to ArCS, and addresses directly the enhancement/sustainability of Japanese expertise in the Arctic, by supporting young researchers, to attend conferences and to participate in short- and longer-term research visits. It reaches beyond academia to include representatives from business and government in short-term visits. To date, 18 short term visits (mostly to conferences) and 24 mid-to-long term visits have been arranged, at 13 universities and 6 research institutions across Europe, the Nordic countries, North America, and Russia.

Strengths:

The program actively measures outputs and outcomes, including conference presentations and publications, outreach via the web, and how the program has been instrumental in career development for its participants. In the upcoming year, significant expansions of the SNS networking component is planned. The program plans to introduce training courses, and to have participants evaluate the program. It also plans to expand the number of short-term visits by representatives from industry.

This program has resulted in a greater number of young Japanese researchers participating at key meetings, which, as well as contributing to their careers, increases the profile of Japan as an arctic research force. Given the current gender imbalance among arctic researchers in Japan, it is encouraging to learn that 36% of the participants in this program are female.

Recommendations:

- We encourage that feedback from participants be used to further enhance the utility of the program
- The potential for exchanges into industry or policy-making bodies might be explored for a future research program (cf. MITACS program in Canada).

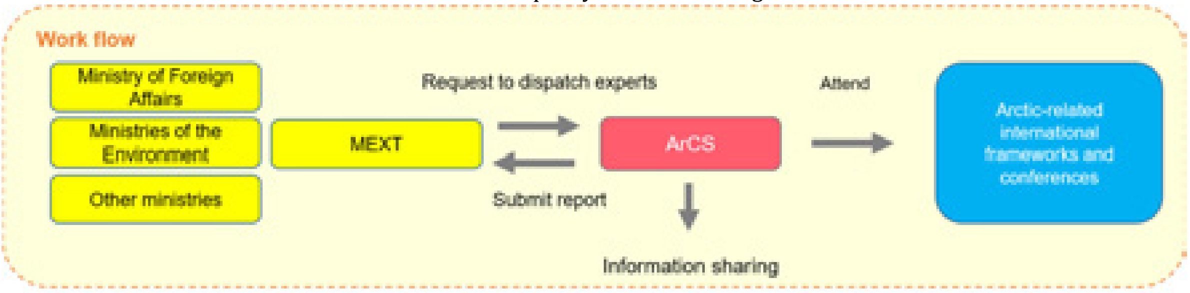
III-11-1 Dispatch of experts to Arctic-related international frameworks and conferences program

PI: Hiroyuki Enomoto (NIPR)

1. Achievements

We are dispatching experts who are able to provide expert opinions from a scientific point of view to Arctic-related international frameworks and conferences such as AC and its working groups. This is to contribute to these meetings through the achievements of the ArCS project as well as Japan's other Arctic research and observation efforts, which will lead to promoting Japan's global reputation and demonstrate a greater presence in the issues of sustainable development and environmental protection in the Arctic.

In addition, promptly providing the latest global trends to researchers as well as policy decision-makers in Japan is expected to contribute to domestic science and various policy-decision settings.



1.1 Progress to date (fiscal 2015 to 2016)

We dispatched 12 experts 23 times in total to 10 meetings over the 2 years, fiscal 2015 and fiscal 2016.

We dispatched experts to the annual meetings of the Arctic Monitoring and Assessment Programme (AMAP), Conservation of Arctic Flora and Fauna (CAFF), Protection of Arctic Marine Environment (PAME), and Sustainable Development Working Group (SDWG), each of which are working groups of the Arctic Council (AC). For AMAP, we provided the knowledge Japan obtained and also introduced the scientific activities of Japan, mainly regarding research results on atmospheric studies and ocean acidification. In addition, researchers who participate in the Arctic Challenge for Sustainability (ArCS) were selected as authors and reviewers of reports such as those on SWIPA and AACA. We participated in CAFF with administrative officials from the Ministry of the Environment and gave them appropriate advice. Up until ArCS started, researchers had not participated or contributed to the PAME and SDWG, but we have started to dispatch experts on humanities and social sciences who are appropriate for discussions on topics such as the Arctic Ocean Marine Protected Area (MPA) and Arctic sustainable development, which are subjects discussed at each working group.

For the AC Task Force, we dispatched experts on international law to the Scientific Cooperation Task Force (SCTF) at the request of the Ministry of Foreign Affairs, which is the competent authority, and made efforts to ensure that the Agreement on Enhancing International Arctic Scientific Cooperation becomes appropriate for non-Arctic countries through delivering relevant speeches and ideas exchange at the final stage of the process leading to an agreement.

For the AC expert group, we sent ours to the Expert Group on Black Carbon and Methane (EGBCM) and the Circumpolar Seabird Expert Group (CBird). At the EGBCM, which aims to summarize a report on black carbon (BC) emissions regulation, we contributed greatly through making proposals for external evaluation and translations.

With respect to meetings other than for the Arctic Council (AC), we sent the project director to the Arctic Circle hosted by Iceland, and the Arctic Frontiers hosted by Norway, and introduced the progress of Arctic research in Japan, including ArCS. At the Arctic Circle, at the request of the Ministry of Foreign Affairs and the Ministry of Education, Culture, Sports, Science and Technology, we introduced ArCS as one element of the "Arctic Policy of Japan" that was established in 2015, and explained the research activities in the humanities and social sciences that are specific to ArCS in 2016. At the general meeting of Arctic Frontiers in 2016, as an invited speaker, our project director gave a keynote lecture on the necessity of building a biological database of the Arctic Ocean.

1.2 Progress achieved so far (fiscal 2017 to 2018)

We continued to send experts to the Annual Meetings of each working group of the AC (AMAP, CAFF, PAME, SDWG) and expert group (SLCF EG, EGBCM, CBird). On top of that, with an aim to provide the research results of ArCS widely to international society, we sent experts to the following workshops, which focus on more specialized topics.

- AMAP International Conference on Arctic Science Bringing Knowledge to Action（April 24 to 27, 2017）
- We gathered information on the contributions of each country and the activities of AMAP, with the aim of adding to the study on the direction of the contribution to the AC countries, from the social scientific point of view with scientific achievements and through participation in discussions at various sessions.
- PAME, CAFF, AMAP 6th EA Workshop（January 9 to 11, 2018）
- We gathered information on how to utilize the Ecosystem Approach (EA) in the future at the AC Working Group.
- AMAP Arctic Meteorological and Climate Workshop（November 6 to 8, 2018）
- We gathered information on input from AMAP to WG 1 of IPCC and applied our knowledge gained at ArCS internationally.

In addition to this, following the request from the Japan's Ambassador in charge of Arctic Affairs at the time, our staff accompanied him to the Senior Arctic Officials (SAO) plenary meeting and provided appropriate advice and support. At the annual meeting of CAFF in September 2018, we introduced the research results conducted by ArCS regarding marine birds on St. Lawrence Island, which have been studied under Theme 6; they first discovered that the area of seabird activity has spread beyond CAFF's expectations.

The AC requests observer countries to provide information on a variety of subjects, such as mercury assessment information (for AMAP) and how we understand and apply in practice IMO's Polar Code, so we respond to its inquiries as much as possible as researchers.

With respect to meetings other than the AC, we sent experts mainly consisting of the project director to the Arctic Circle, Arctic Frontiers, Group on Earth Observation (GEO) week, the Arctic Science Summit Week (ASSW) and Arctic Observing Summit (AOS), and Arctic Science Ministerial (ASM) 2. At the Arctic Circle in 2017, we conducted the session with the theme of how research activities in the Arctic contribute to sustainable development goals (SDGs) from the viewpoint of environmental, socioeconomic, and sustainability of human society, and in 2018, we organized the session on the "Arctic Decades Ahead," which explained the future of other fields based on predictions.

We have been strengthening communication with government officials concerned with Japan's Arctic policy in accordance with the directions the first IAB, etc., pointed out. We hold meetings annually for exchanging ideas on the AC and its working groups, and from fiscal 2017 we introduced overseas trends ascertained by researchers who were attending each working group, including government officials from the Ministry of Foreign Affairs and the Ministry of Education, Culture, Sports, Science and Technology. Furthermore, with this ideas exchange meeting, we held meetings on February 5, 2018, for government officials and our researchers to exchange opinions on the topics on the Arctic. From the government, Japan's Ambassador in charge of Arctic Affairs as well as concerned personnel from the Cabinet Office and the Ministry of Education, Culture, Sports, Science and Technology attended to discuss and exchange ideas about the following three topics: (1) recent topics on the Arctic, (2) the AC and its working group, and (3) correspondence to the ASM.

1.3 Achievements we emphasize

- We were able to respond to the expectations of the high scientific and technological capability of Japan, which will increase after Japan obtained AC observer status in 2013, through experts dispatched to the working groups' annual meetings, providing information, and so on.
- We were able to send experts continuously to the Arctic-related international frameworks, which attract attention worldwide, through comprehensive implementation of experts dispatched in a large research project for five years. On top of that, we were able to select capable researchers who could provide the required knowledge beyond the boundaries of the institution to which they belonged.
- With respect to communications with government officials, we investigated the approaches that contribute to the establishment of communication flow, such as implementing meetings for ideas exchange, and we were able to establish a pathway to actively communicate scientific knowledge to government officials.

1.4 Prospects for achievement next year

Like the previous fiscal years, we will send experts who are specialists in the field to timely relevant meetings such as working groups of the AC, and will make an effort so that Japan contributes to international society and so that Japan's role in Arctic diplomacy is to be respected. In addition, in consideration of ASM 3 and others, we continue to have a place of communication with policy makers.

2. Outcomes so far, and prospects and expectations in the future

(1) Increase of the cases in which our experts have been selected as authors or reviewers for the reports compiled by the AC Working Groups; increase of quotations of published papers by our experts; and increase in researchers registered in the expert groups.

(2) The number of Japanese people who have been invited to international Arctic-related research and conventions has been increased.

(3) Domestic researchers and government officials will raise awareness of Arctic issues and conduct new activities.

(4) International cooperation by governments will be promoted.

(5) Human resources capable of hosting advanced international discussions have been and will be trained.

3. The way forward

It was difficult for us to grasp how Japanese government officials involved in Arctic policy expect ArCS and researchers to contribute to the AC. This point remains an issue. Although we were able to establish a system for communicating with government officials, we have not yet developed a mechanism that allows us to examine concrete coping policy for dealing with AC working groups at the level of administrative officers and individual researchers.

One idea proposed for this issue is to establish a secretariat that enables coordination across researchers and Ministries concerning AC issues like the IPCC support office. It is thought to be preferable to create a cooperative framework that is not restricted by the framework of the project or institutions and link it to the Arctic review activity beyond the border of ministries and agencies like the Interagency Arctic Research Policy Committee (IARPC).

III-11-2 Comments for Dispatch of experts to Arctic-related international frameworks and conferences program

An important component of the ArCS program is the explicit intention to engage with the international scientific and policy communities. ArCS has not approached this timidly: not only do Japanese researchers attend important meetings, but they also have played important participatory and leadership roles. It is clearly in the best interests of Japan to not just observe but to engage. Japanese researchers are not only engaging in dialogues with international counterparts to gain insight into the intentions of other nations, but are exerting leadership roles through which they may influence Arctic policy and set the agenda of future international cooperation.

Strengths:

The IAB commends the diverse selection of working groups with which Japanese researchers have engaged. It is very important for representatives of ArCS to participate in assessments and synthesis types of meetings. Efforts such as the AMAP AACA (Adaptation Actions for a Changing Arctic) may require a substantial investment of time and effort; however, it is through such venues that Japanese research efforts are fully integrated into international compilations of findings and outcomes. We are living in a wonderful period of scientific discovery and accomplishments, but this also makes it difficult for some research findings to make its way onto the international stage.

Similarly, it is helpful for ArCS researchers to accompany Japan's policy makers to multi-national meetings such as the Arctic Council and Arctic Science Ministerial. Scientific findings or gaps in knowledge or understanding are frequently the basis of actions taken by such international bodies. Engagement and advice by ArCS researchers can ensure that actions are based on valid evidence, again ensuring that accomplishments of ArCS researchers, and those of other Japanese researchers, are utilized to their full advantage. Such propagation of knowledge, from researchers into the policy community, thus ensures the full value of the investment into research is realized.

Recommendations:

Japan's decision to co-host the third Arctic Science Ministerial and the acceptance of this offer by the international community is predicated upon a strong, engaged, and informed Arctic science capability. The government of Japan recognizes this expertise, in both breadth and depth, of its Arctic research community. The IAB would like to highlight that the Arctic science performed within ArCS (and is associated scientific diplomacy) has a value worth prizing and demonstrating within the Ministerial and beyond. Further, we suggest creating some mechanism of formalizing communications among agencies and ministries engaged in Arctic issues and enabling that forum to solicit input from the Arctic research community and from industry or businesses that have vested interests in the Arctic.

III-12-1 Public Relations

CDN: Tetsuo Sueyoshi (NIPR)

Communication is the key issue in the ArCS project. When the project was funded and launched, it was requested to enhance the function to deliver scientific knowledge on Arctic change to the stakeholders, which differentiates ArCS from its predecessor, GRENE-Arctic. A project coordinator (CDN) was appointed to strengthen this function, and he works directly with the Project Director and the project office to meet this demand.

In ArCS, we consider three types of stakeholders: (a) the international arctic community, including decision makers, scientists, and local people in the Arctic; (b) decision makers in the Japanese government; and (c) Japanese taxpayers. In this document, we mainly report the public relations activities aiming to deliver the information to, or communicate directly with, these stakeholders as well as the academic community. The activities described below are trying to show the excellence of scientific outputs, deliver comprehensive information on recent changes in the Arctic, and show the importance for Japan, targeting stakeholders (a) to (c) as well as the academic community.

1. Project website

For disseminating project information, our main channel to the public is our project website. All information on the activities of the project, including Capacity Building announcements and links to our Arctic Science database (ADS: Arctic Data management System), is accessible from the website, and most of the contents are available both in Japanese and English. As a basic function of the project website, it has the official information of the project: background and goals, structure and participating institutions, list of scientific themes and related activities, and the council and advisory board members. Announcements of public events and press releases are on the top page. Project brochures are also available from the website.

The main content of the website is "ArCS Blog," posted semi-regularly by project members to report and share the daily activity of the project. Entries are on new research findings, project activities (public events, meetings, etc.), reporting from field activities, impressions from the conferences, etc. Emphasis is put on reporting from the scenes of research activities, as they are intriguing for the public and effective to share the actual situations and conditions of Arctic science.

There were several Special Pages for project activities, planned about once a year. "Arctic Photo Album" (2016) was the researchers' special photo page, prepared in collaboration with a news service agency, with pictures for field observation on glaciers, research vessels, etc. This site was viewed more than 100,000 times. A special page of EGRIP (2017) was reporting by a journalist who made a visit to the EGRIP campsite in Greenland. The special page of the RV *Mirai* Cruise (2018) reported on the *Mirai*'s first early-winter cruise to the Arctic Ocean, with daily reporting by Twitter. It gained more than 500 new followers for the institute's Twitter account. In addition to the above, a special page for Sea Ice Prediction is prepared every year in May, reporting the latest sea ice conditions together with predictions by project members. Unfortunately, some of these websites are in Japanese only, but they have successfully gained public interest.

2. Public lecture and seminars

A public lecture on the project is held annually at lecture halls in central Tokyo. The theme of the lecture is chosen with emphasis on the significance and importance of arctic research for Japan. Participants range from 100 to 250. For fiscal 2017 and 2018, the lecture was held on a weekday evening to attract more office workers. An exhibition panel, "Our Activities in the Arctic," was prepared first for these public lectures, introducing the key issues in the Arctic and Japan's research activities to better recognize the topics and their importance. The panel targets the public at high-school students' level and is now available for all museums and schools in Japan via the Science Museum Association.

For more specific issues, there are 5–10 seminars and symposia held per year by the groups of the project researchers. The range of topics is: Arctic shipping, ocean ecosystem, extreme weather and predictability, international laws, etc. Seminars on Arctic shipping gain interest from the industry and constantly have participants from among them. Booth exhibitions showcased the project every year at the Japan Geoscience Union (JpGU), and the Group of Earth Observation (GEO) Assembly. These exhibitions introduce the activity of the project with emphasis on research infrastructure and data management, and the capacity-building program for young scientists (at JpGU).

3. Scientific outputs

As basic outputs from the scientific project, ArCS produces a good number of publications in peer-reviewed scientific journals: 79 for fiscal 2015, 144 for fiscal 2016, 134 for fiscal 2017, and 110 for fiscal 2018, as of November 20, 2018. However, there are two points to note to look at these numbers. First, as an interdisciplinary project, we should be careful with the differences in the style of the output among the research communities. Natural scientists write papers, while social and human scientists write books (16 in fiscal 2015, 26 in fiscal 2016, and 32 in fiscal 2017, including articles in general magazines). Engineers instead place value on proceedings. The numbers themselves therefore are not necessarily meaningful. Second, release of observational data is also important outputs under the current insufficient status of data sharing in Arctic observation. As the data center of the project, ADS has a function to host and publish ArCS data. Official documents for the ministry therefore include all types of these activities as project output. From these scientific papers, there were 19 press releases so far as of November 20, 2018, and we had good amount of coverage by the media: 43 items in newspapers, 9 items on TV, 5 items on radio.

As project public relations in the international community, there were presentations at the international conferences such as Arctic Circle, Arctic Frontiers, GEO Assembly, etc., to introduce the project design at the beginning and to introduce the activities in later years. In the Arctic Circle, especially, we had a Japan session every year since the beginning of the project. The conference is used to communicate not to scientists for scientific information but to local communities and related organization in the Arctic. In the presentation at the Arctic Science Forums of the 2nd Arctic Science Ministerial in Berlin, Sub-PD Dr. Enomoto introduced ArCS as well.

4. Activities for concluding the project

A booklet of about 60 pages titled “Arctic Decades Ahead” is prepared in the fourth year (fiscal 2018). The contents of the book followed a similar structure as the session at the Arctic Circle assembly, with the first part reporting the recent Arctic change and information on near-future prediction, and the second part reporting its possible impacts and consequences. The booklet targets stakeholders, policymakers, and the public, aiming to provide a concise summary of the current status of the Arctic, especially information on future prediction and the possible impacts and consequences from the anticipated changes.

In the final year of the project (fiscal 2019), there is a plan to prepare a special issue on “Polar Science” dedicated to ArCS, in which principal investigators write a review to put their activities in the context of current Arctic change to show perspectives on their final results. As the publishing of scientific results will go on, it should still be a form of interim report with this timing, but it is worth having an overview as an integrated special issue at the end of the project term.

III-12-2 Comments for activities for Public Relations

The outreach to the public, to students, to the academic and research community, and to policy makers, is easily as important as conducting the research itself. Information on the research, including details on how the work was conducted, the research results, and all important findings, must be reported to all these groups within a very short time frame to garner the full value of conducting the work. The public and other researchers consider the information of lower value if too much time has progressed since the conduct of the research, so it must be timely and accurate.

Strengths:

ArCS appears to be utilizing all of the currently popular outlets for such information including the project website, seminars, participation in national and international conferences and symposia, journal publications, public lectures and engagement in community events. It is important to engage popular social media outlets as that is the best contemporary pathway to the minds of the common citizen and student. These people are or will be the voters who must be well-informed of issues related to natural resources management, global climate dynamics, and international policy collaborations.

The web site, popular publications and outreach booths and panels appear to be quite informative and attractive. They should serve their purpose well. The most impressive component of ArCS PR is the remarkable number of publications. That is the first priority of a research scientist and one that was clearly taken to heart by ArCS.

Recommendations:

Some of the target goals of the outreach effort appear to be well-focused and articulated. However, there is no focused goal for reaching international stakeholders. That is an oversight. If a deliberative effort is not made to inform international scientists and stakeholders, then the majority of the users of this information will simply be unaware of these accomplishments.

IV Conclusions

In summing up, we would like to congratulate the entire ArCS team for delivering an exceptional scientific programme. It is not an easy task within such a complex programme of work. We all were very impressed by the accomplishments, as measured by the outcomes and outputs, of what ArCS has achieved in such a short time.

It is therefore important that the Third Arctic Science Ministerial in 2020 provides a real opportunity for Japanese Arctic research to shine. We encourage the ArCS leadership team to begin dialogue with the appropriate Ministries within the Japanese government at an early stage, but also to open the communication channels with US and German colleagues that were involved in the first two ministerial in order to learn from their experiences.

We encourage further sharing of research results with international colleagues to ensure these achievements are used, cited and included in major assessments and syntheses.

We encourage continued awareness of these considerations:

- Long-term climate time series are essential
- Explore and understand changes apparent on decadal time scales
- Clarify involved large scale atmospheric and oceanic dynamical mechanisms
- Engage in international planning of big science projects
- Consider national investments in Arctic shipping & infrastructure as a driving motivation.
- Try to develop more reliable climate scenarios as basis for economic investment and technological development in the Arctic.
- Reduce projection uncertainties of climate models on global and regional scales
- Encourage/enable social science researchers to develop and lead projects as well as to act in service of other projects, as Japanese capacity grows in this area
- Try to broaden spatial coverage of observation of Arctic processes.

The ArCS programme has built up a momentum that suggests Japanese Arctic research has a bright future, both on the national and international stage. This does not happen accidently; it requires hard work combined with good management practices and strong scientific coordination. The IAB commend the ArCS team on their professionalism.

All programmes must come to an end, and as ArCS approaches the completion date it is important to make concrete plans regarding the legacy, and the next steps. Generally, the earlier this planning begins the more successful and broader the impact will be. We encourage the ArCS team to begin this process as early as possible. The next few years will be a busy, but exciting, time for the ArCS programme and Japanese Arctic science.

V Agenda of the meeting

Meeting date / time:	Monday 4th February 2019	18:00 – 21:00 (closed)
	Tuesday 5th February 2019	10:30 – 17:45
		18:00 – 20:00 (reception)
	Wednesday 6th February 2019	10:30 – 15:40
Location:	Monday 4th February 2019 (closed) The Palace Hotel Tachikawa, Tachikawa, Tokyo	
	Tuesday 5th - Wednesday 6th February 2019 Auditorium, National Institute of Polar Research (NIPR), Tachikawa, Tokyo (https://www.nipr.ac.jp/english/outline/summary/access.html)	

● 4th February (closed)

18:00	-	21:00	- Pre-meeting - Ice breaker	IAB member, PD, SPD, CDN, Secretariat

● 5th February

Chair: Secretariat

10:30	-	10:35	1. Welcome address	MEXT	(5 min)
10:35	-	10:45	2. Introduction or background of 2nd IAB	PD (Dr. Fukasawa)	(10 min)

break – 10 min

Progress in ArCS activity I　　Chair: Dr. Fukasawa

10:55	-	11:25	3. Enforcement of Platforms Program name: Maintain and develop platforms for research in the Arctic region	PI (Dr. Enomoto)	(30 min)
11:25	-	11:55	4. Capacity building Program name: Program for Overseas Visits by Young Researchers	PI (Dr. Saitoh)	(30 min)
11:55	-	12:25	5. Expert's dispatch Program name: Dispatch of experts to Arctic-related international frameworks and conferences	PI (Dr. Enomoto)	(30 min)
12:25	-	12:55	6. Public Relations	CDN (Dr. Sueyoshi)	(30 min)

lunch – 75 min

Progress in ArCS activity II-(1)　　Chair: Dr. Enomoto

14:10	-	14:50	7-1. Weather and sea ice predictability Research theme1: Predictability study on weather and sea-ice forecasts linked with user engagement	PI (Dr. Inoue)	(40 min)
14:50	-	15:30	7-2. Climate predictability Research theme5: Study on Arctic climate predictability	PI (Dr. Hasumi)	(40 min)
15:30	-	16:10	7-3. Atmospheric climate forcer Research theme3: Atmospheric climate forcers in the Arctic	PI (Dr. Koike)	(40 min)

break – 10 min

Progress in ArCS activity II-(2) Chair: Dr. Kikuchi

16:20	-	17:00	7-4. Ocean observation Research theme4: Observational research on Arctic Ocean environmental changes	PI (Dr. Kikuchi)	(40 min)
17:00	-	17:40	7-5. Cryosphere study in Greenland Research theme2: Variations in the ice sheet, glaciers, ocean and environment in the Greenland region	PI (Dr. Goto-Azuma)	(40 min)

Photo Session – 5 min

Adjourn

18:00	-	20:00	Reception - Venue: "Southern Cross" (a lounge adjacent to Polar Science Museum on the south of NIPR main building)	(120 min)

- 6th February

Progress in ArCS activity II-(3) Chair: Dr. Saitoh

10:30	-	11:10	7-6. Arctic ecosystem Research theme6: Response and biodiversity status of the Arctic ecosystems under environmental change	PI (Dr. Hirawake)	(40 min)
11:10	-	11:50	7-7. People and community Research theme7: People and Community in the Arctic: Possibility of Sustainable Development	PI (Prof. Tabata)	(40 min)
11:50	-	12:30	7-8. Arctic data management Research theme8: Arctic Data archive System (ADS)	PI (Dr. Yabuki)	(40 min)

lunch – 90 min

Chair: Dr. Fukasawa

14:00	-	15:10	8. Comments from Each IAB member		(70 min)
15:10	-	15:30	9. IAB report preparation (Approval of possible coordinator of report)		(20 min)
15:30	-	15:40	10. Final comment from ArCS	CDN (Dr. Sueyoshi)	(10 min)

End of meeting

Photo session on 4th February, 2019