Arctic observation initiatives of Korea Polar Research Institute for monitoring and understanding Arctic climate change

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Abstract

The Arctic is responding quite sensitively to the increase in atmosphere greenhouse gases. In particular, the Arctic sea ice is decreasing substantially and the permafrost is changing rapidly as well, influencing the local Arctic climate and resulting in a severe weather in mid-latitudes. Korea Polar Research Institute (KOPRI) has the Arctic research station (Dasan) at Ny Alesund and the icebreaker Araon launched in 2009. Utilizing these infrastructures, KOPRI has given a big effort in understanding the Arctic climate change mechanism through various monitoring and numerical simulations. We performed atmosphere environment monitoring at Ny Alesund and several Araon expeditions towards the Pacific sector of the Arctic. Through these activities, KOPRI was able to obtain past climate records and to understand ocean biogeochecmical cycles. Understanding the Arctic-midlatitude teleconnection is critical in predicting a severe weather in mid-latitudes. To deepen our understanding of the teleconnection mechanism, KOPRI plan to undertake the observation for the cloud over the Arctic.

1. Introduction

The Arctic environment is well known to be particularly sensitive to perturbations of the radiative budget. During the last century the temperature increase in the Arctic has been observed to be two times larger than the global average (IPCC, 2013). Climate feedback is important in the understanding of global warming because feedback processes may amplify or diminish the effect of each climate forcing, and so play an important part in determining the future climate status. Dimethyl sulfide (DMS) is a climatically important sulfur compound produced from oceanic biological activities. DMS in the atmosphere gives rise to the formation of aerosol which can act as cloud condensation nuclei (CCN), and has important consequences on the radiative budget of the earth. Therefore, increase in oceanic DMS emission into the atmosphere could diminish the effect of global warming. However, there remain crucial uncertainties in the pathway of atmospheric DMS and its contribution to aerosol-CCN population. Arctic Ocean is the hotspot for the emission of DMS due to its distinct biological properties and thus it is important to identify changes of DMS emission and key processes that influence DMS-aerosol-cloud formation in the Arctic environment.

The region including the Chukchi Borderland, northeastern East Siberian Sea, and Mendeleev Ridge is the hotspot for detecting sea ice retreat, hydrographic and biochemical responses to Arctic climate change. This region is characterized by the local complexity in topography and intersection of Pacific-origin waters from the south and Atlantic waters from the west. The Pacific water inflow through the Bering Strait is a key conveyor for heat, salt, nutrients, and biological material to the upper layer of the Pacific Arctic region. Recently, rapid decline of sea ice extent has been observed and its monthly average rate in September is -13.3% decade^{-1} compared to the 1981–2010 average (Perovich et al., 2015). The August sea surface temperature (SST) anomaly in the Chukchi Sea increases at a rate of about 0.5°C decade^{-1} compared to the 1982–2010 average (Timmermans and Proshutinsky, 2015). These can influence on the ocean environment change, such as circulation pattern, water mass, halocline formation, nutrients, primary production, and zooplankton ecosystem. The greatest increases in primary production during 1998−2010 occurred in the East Siberian Sea (+112.7%), Laptev Sea (+54.6%), and Chukchi Sea (+57.2%) (Petrenko et al., 2013). Recent studies emphasize the importance of nutrient availability as a critical driver for primary production in Arctic Ocean environment. Increases in nutrient drawdown coincided with a deepening of the nitracline during 2003−2011 in the southern Beaufort Sea (Bergeron and Tremblay, 2014; Frey et al., 2014). In recent years, 30−50% of nutrients and approximately 40% of integrated chlorophyll-*a* concentration decreases have been observed in the northern Chukchi Sea (Lee et al., 2015). In addition, Arctic climate change leads to increase dissolved organic carbon (DOC) export to the Arctic Ocean due to increased river runoff and the thawing of permafrost. The transport and fate of DOC in the Arctic therefore is a potentially important carbon system component that could have a significant impact on the global carbon cycling. Besides, Arctic climate change has profoundly affected marine ecosystem, from plankton to predators. Understanding the mechanisms by which climate variability impacts mid-trophic level is critical for determining the Arctic marine ecosystem's response to climate change. In order to identify how rapidly ocean environmental parameters alter in response to Arctic climate change, it requires comprehensive *in-situ* field measurements of ocean and sea ice variables in high-resolution spatial and temporal scales.

2. Observation activities

(1) Arctic Aerosol Studies in Ny-Ålesund

Objectives:

The overall main research objective of KOPRI aerosol research team is to address the question: **will future changes of the Arctic climate induce positive or negative feedbacks with respect to DMS-aerosol-cloud interactions?** To improve knowledge gaps regarding these issues, KOPRI aerosol research team has been carrying out the analysis of physicochemical property of Arctic aerosol in collaboration with Pohang University of Science and Technology (POSTECH), Stockholm University, Norwegian Polar Research Institute (NPI) and Norwegian Institute for Air research (NILU):

Research Activities in Ny-Ålesund

The Zeppelin observatory is located in the Arctic on Zeppelin Mountain on the island archipelago of Svalbard (79°N, 12°E). The observatory is located in an undisturbed Arctic environment, away from major pollution sources. The unique location of the observatory makes it an ideal platform for the monitoring of global atmospheric change. Korea aerosol research team has been carrying out the aerosol research program since 2007. Currently, we are observing numerous aerosol parameters (e.g., CCN, DMS, number of nano-size particles, and size distribution of aerosol particles) at an observation site.

Figure 1. (a) CCN counter, (b) DMS analyzer installed in Zeppelin observatory, (c) high volume sampler installed on the roof of Gruvebadet laboratory

(2) 2015 6th RV ARAON Arctic Expedition (ARA06C) into Eastern-Siberian and Chukchi continental margin

Objectives

The 6th Arctic expedition of RV ARAON (ARA06C) started on August 25, 2015 in Barrow, Alaska and returned to Nome on September 09, 2015. The overall objective of the marine geology program during the ARA06C was to obtain records of undisturbed long glaciomarine sediments with JPC system to constrain, and thus better understand the timing and chronology of marine glaciations along the East-Siberian and Chukchi continental margins. The selection of sampling sites was based on hydroacoustic and sediment-core data obtained during previous RV ARAON cruises, ARA02 to ARA04 (2011 to 2013) as well as RV Polarstern cruise PS72 in 2008.

Methods and approaches

A total of 10 geological stations were chosen for the ARA06C cruise based on previously collected data for geophysical records, providing age control, and investigating paleoceanographic environments. The sub-bottom profiler (SBP) survey was carried out for detailing the position of coring sites. Cores were collected in water depths between 100 and 2,250 m using several coring devises (e.g. Box corer, multiple corer, gravity corer and jumbo piston corer). Once retrieved on deck, gravity cores and JPC cores were cut up in lengths of 1.5 m and labeled, transported to the laboratory for the MSCL logging.

Expected outcomes

The data collected will provide new insights into glacial history and sediment stratigraphy of the Chukchi-East Siberian region of the Arctic Ocean. A combination of MB bathymetry and SBP records, collected on this and earlier cruises, is expected to allow identification of glacial deposits and glacigenic seafloor features as well as depocenters of undisturbed marine/glacimarine sediments. Sediment cores taken from carefully selected locations will help ground-truth geophysical records and to add the age control and information on sedimentary environments.

Figure 2. About 14 m long glaciomarine sediment cores were taken with JPC system installed on RV Araon during 2015 Arctic Expedition.

(3) Strategic ocean observations in a rapidly changing environment in the Pacific Arctic region

Objectives

Our observation aims to improve our understanding of following specific issues:

Despite long-term decline of sea ice extent, its interannual variation has been observed. Then how much this variation is related with the release of substantial heat within the Pacific-origin water layer? What is the long-term trend of vertical distributions and lateral/temporal variations of heat and freshwater contents over the Chukchi Borderland?

The western Arctic Ocean is currently experiencing rapid environmental change due to natural and anthropogenic factors that include accelerated warming and decrease in sea ice cover extent. They may have a major impact on ecosystem functioning and biogeochemical cycling of the western Arctic Ocean. The second aim of this study is to characterize the biogeochemical consequences and ecosystem alterations directly related to loss of sea ice in rapidly warming the Chuckchi Sea.

Proposed strategy for observations

Study area

Since 2010, KOPRI has carried out ship-based campaigns aboard Korean ice-breaking research vessel ARAON during the summertime period of July to September. The ARAON has repeatedly visited the northern sites of the Pacific Arctic region including the Chukchi Borderland, the East Siberian Sea, and the Mendeleev Ridge. Thus KOPRI's oceanic observations will be continued to accumulate long-term data acquired in this region.

Parameters to be measured and observation methodology

The observation variables will be classified into hydrographic, biochemical, and meteorological categories and observation methodology will be proposed as integrated observation systems which consist of vessel-based, mooring-based, and ice-based observations as described below:

1) Vessel-based observation: Ship-borne oceanographic equipment allows us to measure various parameters: water temperature (T), salinity (S), pressure, ocean current, dissolved oxygen (DO), nutrients, dissolved and particulate organic matters, primary productivity, phytoplankton and zooplankton biomass with usage of the carousel water sampler equipped with a conductivity-temperature-depth (CTD) profiler, lowered acoustic Doppler current profiler (LADCP) and other sensors, acoustic instruments (i.e., EK60), plankton net samplers (i.e., Bongo Net), and expendable instruments (expendable CTD, expendable current profiler).

2) Mooring-based observation: Ocean mooring system sustains long-term observation on the properties of water column and sea ice, which include T, S, ocean current, ice bottom tracking motion, ice thickness, phytoplankton/zooplankton biomass with usage of ADCP, T-logger, MicroCAT CTP recorder, acoustic zooplankton fish profiler (AZFP), Ice Profiling Sonar (IPS), sediment trap, and PAR/fluorometer. The long-term mooring system is essential to monitor the fate of Pacific- and Atlantic-origin waters in terms of heat and mass balance in the upper ocean because sea ice retreat is partially influenced by warm water inflow from the Pacific and Atlantic Oceans.

3) Ice-based observation: Sea ice camps will provide us with various opportunities to carry out melt

pond studies, under-ice observations, and sea ice dynamics from the ice-tethered buoy deployment. A melt pond is the most distinctive feature of Arctic sea ice during July-September because it is formed by snow/ice meltdown driven by solar radiation on the sea ice surface. In the melt pond studies, we can understand potential physical, chemical, and biological processes in the different types of melt ponds. Those processes will involve physical evolution of the melt ponds, food-web interactions under environmental change, plankton's composition, diversity and physiology, and distinctive distribution of nutrients. Under-ice mooring systems can offer continuous record of temperature, salinity, ocean current, heat and freshwater fluxes in the surface mixed layer, vertical distribution of zooplankton, and under-ice primary production of phytoplankton and sea-ice algae. KOPRI has been collaborating with international research partners in deploying in-floe buoys during the sea ice camps. The buoys will be Ice-Tethered Profiler (ITP), wave buoy, autonomous ocean flux buoy (AOFB), Ice Mass Balance Buoy (IMB), high-precision GPS buoy (SATICE), upper layer temperature of the Polar Oceans (UpTempO) buoy, and Ice-Atmosphere-Arctic Ocean Observation System (IAOOS).

International collaborations

With KOPRI's major infrastructural supports we plan to collaborate with national and international research groups and institutions. The Pacific Arctic Group (PAG, pag.arcticportal.org) is proposing the Pacific Arctic Climate Ecosystem Observatory (PACEO) across the oceanic Beaufort Gyre to understand the shelf-basin exchange and the regional ocean-sea ice interaction over the Chukchi Borderland. The key collaborative partners will be Inha University, Incheon National University (INU), Tokyo University of Marine Science and Technology (TUMSAT), Ocean University of China (OUC), UK Scottish Association for Marine Science (SAMS), British Antarctic Surveys (BAS), Applied Physics Laboratory/University of Washington (APL/UW), UPMC (LOCEAN-LATMOS), ICM-CSIC/MIT, CRREL, and ONR-MIZ team.

(4) Climate manipulation experiment in the Arctic tundra

Objectives:

The Arctic ecosystem is undergoing dramatic changes due to climate change. Since 2012, through long-term monitoring of the Canadian Arctic tundra, changes in ecosystem structure and function have been examined. The study aims to observe the effects of climate warming and increased precipitation on the structure and functioning of plant and soil microbes.

Methods and approaches:

The study site is Cambridge Bay (69°07′48″N and 105°03′36″W) which is located on the southeast coast of Victoria Island, Nunavut, Canada. Average temperature is 4.2°C and -23.8°C in summer and winter, respectively. Precipitation is low with an average precipitation of 140 mm annually. This area is classified as prostrate dwarf-shrub, herb tundra (CAVM Team, 2003) with vegetation dominated by small prostrate shrubs (*Dryas* spp.) and sedges (*Carex* spp.). The climate manipulation experiment was conducted with summer warming and increased precipitation both separately and combined. Hexagonal 2 m-diameter open-top chambers (OTCs) were established to increase air temperature of 1-2°C and 2 L of water was added to sites every week to manipulate the increased precipitation of additional 4 mm per year. The manipulation experiment was conducted during summer season from late June to early October each year. Changes in plant and soil microbial community structure as well as soil ecosystem functioning such as microbial biomass, soil respiration and extracellular enzyme activity were monitored on a biennial basis.

(5) Atmosphere observation to enhance weather and climate prediction capabilities

Backgrounds and Objectives

One of KOPRI's research themes aims at contributing to the enhancement of Arctic–mid-latitude weather and climate prediction capabilities. Among many other things regarded as the high potential to improve the model predictability in the middle-to-high latitudes, Arctic clouds and boundary-layer processes are thought to deserve attention as the kernel of our problem not only because they are always involved in the high-impact weather events but also because they are central to many climate feedbacks resulting in amplified warming in the Arctic (Curry et al. 1996).

The importance of the radiative effects of Arctic clouds led to several intensive field experiments with the main object of understanding them and improving model parameterizations: the First ISCCP Regional Experiment Arctic Clouds Experiment (FIRE-ACE: April–July 1998; Curry et al. 2000), the Surface Heat Budget of the Arctic Ocean (SHEBA: October 1997–October 1998; Uttal et al. 2002), the Mixed-Phase Arctic Cloud Experiment (M-PACE: 27 September through 22 October 2004, Verlinde et al. 2007), and the Arctic Summer Cloud Ocean Study (ASCOS: 2 August–9 September 2008; Tjernstrom et al. 2014). For all that, numerical model simulations in Arctic cloud properties still show a large inter-model spread (Tjernström et al. 2008; Karlsson and Svensson 2013), which means that the Arctic clouds and surrounding processes are one of the least understood components in numerical models. The primary reason is because the widely-used physical parameterizations have been founded on the field observations carried out mostly over the midlatitude and Tropics. As the scarcity of polar observations hinder any further enhancement of understanding and predictability, the scientists are still anxious for abundant observation data in the polar region.

Strategies

Integration of observation and modeling

For the sake of enhancing our knowledge about the Arctic clouds, surrounding processes and also related radiative balance at the surface, our new project will integrate observation and modeling with detailed contents as follows:

Observation. Establish infrastructure for observing Arctic cloud and surrounding processes based on Ny-Alesund (land) and IBRV *Araon* (ocean)
- Addition and stable operation of Ny-Alesund-based equipment for clouds, boundary-layer and radiative processes observations
- Stable operation of *Araon*-based equipment for near-surface meteorology, cloud observation, and regular radiosonde launch for observing atmospheric profile

Modeling, Develop the Arctic–mid-latitude regional weather and global climate prediction system
- Develop an improved cloud microphysics scheme, equipped with the uniquely developed source code for the process
- Construction of sea ice/ocean/land initialization tools for the climate prediction system
- Construction of analysis fields for regional weather prediction with the data assimilation system including available observations from KOPRI infrastructure as well as existing network

Proposed and potential international collaborations

Observation part. Any research activities in Svalbard should be endorsed by the Svalbard Integrated Earth Observing System (SIOS). As South Korea is already the regular member of the SIOS, the planned establishment of new equipment (e.g., eddy-covariance system, Doppler wind lidar, and micro-pulse lidar, cloud particle/aerosol observing equipment on tethered balloon sonde, AWS, radiation sensors, etc.) in Ny-Alesund may not be restricted by the SIOS member countries. Practical issues need to be secured are the selection of optimal site for the observations of clouds, boundary-layer and radiative processes and the stable operation by the international collaboration with the experienced institutes such as AWI (Germany), NPI (Norway), and ISAC (Italy). We discussed our optimal site with the AWI atmospheric research team and received the AWI's current status and revised plan of atmospheric observation network including their proposal for the planned KOPRI's equipment (Figure 3). Since AWI has the most extensive atmospheric observation network in Ny-Alesund, the coordinated selection of our optimal site with AWI would create new synergistic effects

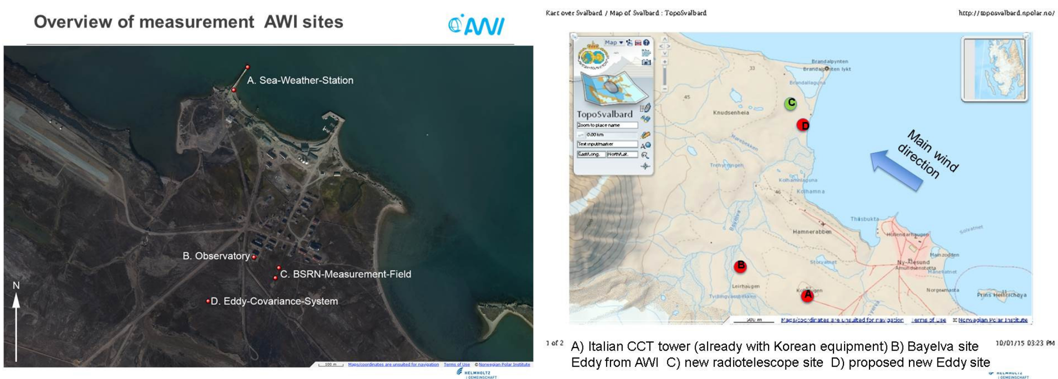

Figure 3. (Left) Overview of measurement AWI sites in Ny-Alesund. (Right) Proposed KOPRI optimal sites by the AWI atmospheric research team (Credit: Christoph Ritter, AWI)

KOPRI Icebreaker *Araon* regularly makes an Arctic expedition every boreal summer from late July through early September. Her voyage across the ice-free and ice-covered ocean enables us to carry out ocean-based observations of clouds and surrounding processes under a variety of surface conditions. ~~Although the full annual observation is not possible,~~ *Araon*-based oceanic observations of clouds and other atmospheric properties in late-summer and early-autumn are the good counterpart in the Pacific Arctic sector where the Ny-Alesund station cannot cover. *Araon*-based observation equipment will be enhanced by including the followings: the eddy-covariance system, cloud/aerosol lidar, all-sky camera, CCN counter, radiosonde, and surface-based meteorological and radiation sensors. Our enhancement of ship-based atmospheric observation mainly targets to prepare the 2017-2019 Year of Polar Prediction (YOPP; polarprediction.net) IOP activities in which KOPRI plans to participate and also contributes to the Pacific Arctic Climate Ecosystem Observatory (PACEO) proposed by the Pacific Arctic Group (PAG; pag.arcticportal.org).

Modeling part. Proposed development of the Arctic–mid-latitude regional weather and global climate prediction system would not be possible without national and international collaborations. KOPRI observed data and other data from the existing network (e.g., ARM Climate Research Facilities) will be applied to the scheme development. The improved scheme will be implemented in both weather and climate version of prediction system. For the regional weather prediction system, the Polar Weather Research and Forecasting (P-WRF) model developed by the Byrd Polar and Climate Research Center will be selected as a first step. The global climate prediction system is based on the NCAR Community Atmospheric Model (CAM) with a new convection scheme (Park 2015) and an improved microphysics scheme to be developed.

3. Conclusion

KOPRI's observing activities has been stronger recently in conjunction with the launch of ice breaker and expansion of pan-Arctic observation sites. With these infrastructures, the international cooperation has been more enhanced. The outcome of the Arctic observation helps understand the status of ongoing rapid Arctic climate change and predict the influence to mid-latitude weather, especially in winter. The continuing KOPRI's observing activities for the Arctic ocean and atmosphere will contribute to the Year of Polar Prediction (YOPP) themes by enhancing our existing activities more intensively during the YOPP period.

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