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Comprehensive Observational Study in the Seasonal Ice Zone: Role of Air-sea Interaction for Arctic Amplification

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Executive Summary: With recent rapid decline of summer Arctic sea-ice, the air-sea interaction over the seasonal ice zone (SIZ) is expected to be much more vigorous, significantly contributing to Arctic Amplification (AA). AA in turns modifies mid-latitude jet streams toward a much wavier pattern, causing extreme weather events over many mid-latitude regions. Our preliminary assessment in this paper demonstrates that high heat flux event (HHFE), much intense heat exchange events during a cold air outbreak in the SIZ, is in particular a key interest, because of its connection to AA and in turn extreme weather in the mid-latitude, especially if we are to improve our seasonal and decadal predictability of the impacts of future Arctic climate changes. Here we propose a comprehensive observational study centered at Korea Polar Research Institute (KOPRI)'s major infrastructures, aiming at accurate evaluation of HHEFs and potentially unveiling their linkages to AA and large-scale circulation. Our proposal includes land-based camp at the northern Barents/Kara Seas and Korean ice-breaker ARAON's excursion in the Chukchi shelf and northern East Siberian Sea. The paper also contains the description of observation techniques for both physical and bio-geochemical parameters within the atmosphere-ocean-sea-ice system. Accurate measurements of such parameters would reveal the entity of air-sea interaction and the way in which air-sea interaction contributes to AA. In the long run the proposed observations can lead to the improvement of numerical models' capability of the Arctic simulation.

1. Motivation

In recent decades, Arctic sea-ice cover has been declining at the unprecedented rate at least over the past thousand years [*Comiso et al.*, 2008; *Kinnard et al.*, 2011]. In late summer in 2012, the extent of sea-ice reached a new minimum. As thicker multi-year sea-ice is being replaced by thinner first-year sea-ice, the extent of seasonally sea-ice covered area, the seasonal ice zone (SIZ), has ever been increasing.

Coincident with such large reduction in sea-ice in these decades, pronounced Arctic warming, often called as Arctic amplification (AA), has been detected by previous studies [*Overland and Wang*, 2005; *Screen and Simmonds*, 2010; *Serreze and Francis*, 2006]. There exist growing evidences that the impact of AA is not just confined within the Arctic Ocean, but influences globally to the upper-level atmospheric circulation. Circulation anomalies influenced by AA can propagate downstream along the sub-polar jet and often brings cold extremes over Eurasian continent and North America [*Francis and Vavrus*, 2012; *Overland and Wang*, 2010]. Especially, the Korean Peninsula, which situates over the East Asian coastal region where the meandering of the jet is usually amplified, is known to be sensitive to enhanced *Air-Sea Interaction in the Arctic Ocean* (ASIA) and associated AA. Therefore, accurate evaluation of the energy fluxes over source regions is crucial for better understanding of not only Arctic climate change but also the recent extreme weathers in highly populated regions.

Why recent Arctic warming is occurring in such an amplified manner? Since this question is the focal point in understanding Arctic climate change, quite a few studies have examined various aspects of the feedback mechanisms for AA. The proposed mechanisms include the local snow-ice feedback [*Hall et al.*, 2005], longwave feedbacks by water vapor and clouds [*Graversen and Wang*, 2009], poleward energy transport by atmosphere [*Alexeev et al.*, 2005; *Graversen et al.*, 2008] and by ocean [*Carmack and Melling*, 2011; *Levitus et al.*, 2009], and biological feedbacks that can affect heat budget of upper-ocean from biological heating [*Edwards et al.*, 2004]. The relative importance of each factor [*Screen et al.*, 2012] however is still in debate and, more importantly, how enhanced ASIA is linked to AA has not been fully elucidated yet. All the involved physical processes might be complexly interweaved and the decline of Arctic sea-ice is not mere a consequence but a major component of various feedbacks that can significantly accelerate overall changes in Arctic climate and ecological-system. This requires a comprehensive understanding of ASIA, which should be realized from intensive observations of the atmosphere, ocean, and sea-ice.

Many of the previous studies on this issue heavily relied on the reanalysis data. As the reanalysis data is largely dependent on model outputs especially in the Arctic, its accuracy is often challenged [*Budikova*, 2009]. In addition as its primary application is rather for long-term seasonal variability, detecting abrupt changes (e.g. in turbulent heat exchange) occurring in much shorter time scale is difficult to achieve from the reanalysis data. As discussed in section 2, intensive, abrupt heat exchange in the SIZ, referred as high heat flux event (HHFE), can occur during short period of time. This localized and short-lived event is thought to play a key role in maintaining AA. To evaluate such events correctly, the reanalysis data alone would not meet the requirements, so it demands comprehensive *in-situ* observations of atmosphere, ocean and sea-ice parameters at wide range of temporal and spatial scales.

Here we propose comprehensive interdisciplinary observation plan, centered on Korea Polar Research Institute (KOPRI)'s major infrastructural supports as well as international collaborations. This paper synthesizes the strategies and thoughts from the scientists from KOPRI, Pusan National University, Seoul National University, Korea Maritime University, and UK Scottish Association for Marine Science (SAMS), and also describes proposed collaborative works with US Office of Naval Research (ONR) funded scientists and Arctic Ocean Drift Study (AODS) to achieve common objective as described in Section 3.

2. Preliminary Study: High Heat Flux Events in 2012

The lack of observational data calls for the need for comprehensive fieldworks encompassing the atmosphere, sea-ice and ocean. In this way we can better define the role of HHFEs in the context of the conspicuous AA. Here we present a preliminary case of the HHFE that occurred in winter of 2011/12 using the pre-existing reanalysis data, vertical sounding and satellite images.

During the winter of 2011/12, central and eastern Europe was hit by its worst cold snap in at least 26 years. For instance, the cold snap in Ukraine started with heavy snowfall on 24 January, lasted for almost a month, and finally eased on 20 February (Fig. 1). More than 650 people died as a direct result of the frigid conditions. During the period, a large high-pressure anomaly occurred over the Eastern Europe and blocked the warm Atlantic maritime air from reaching this area.

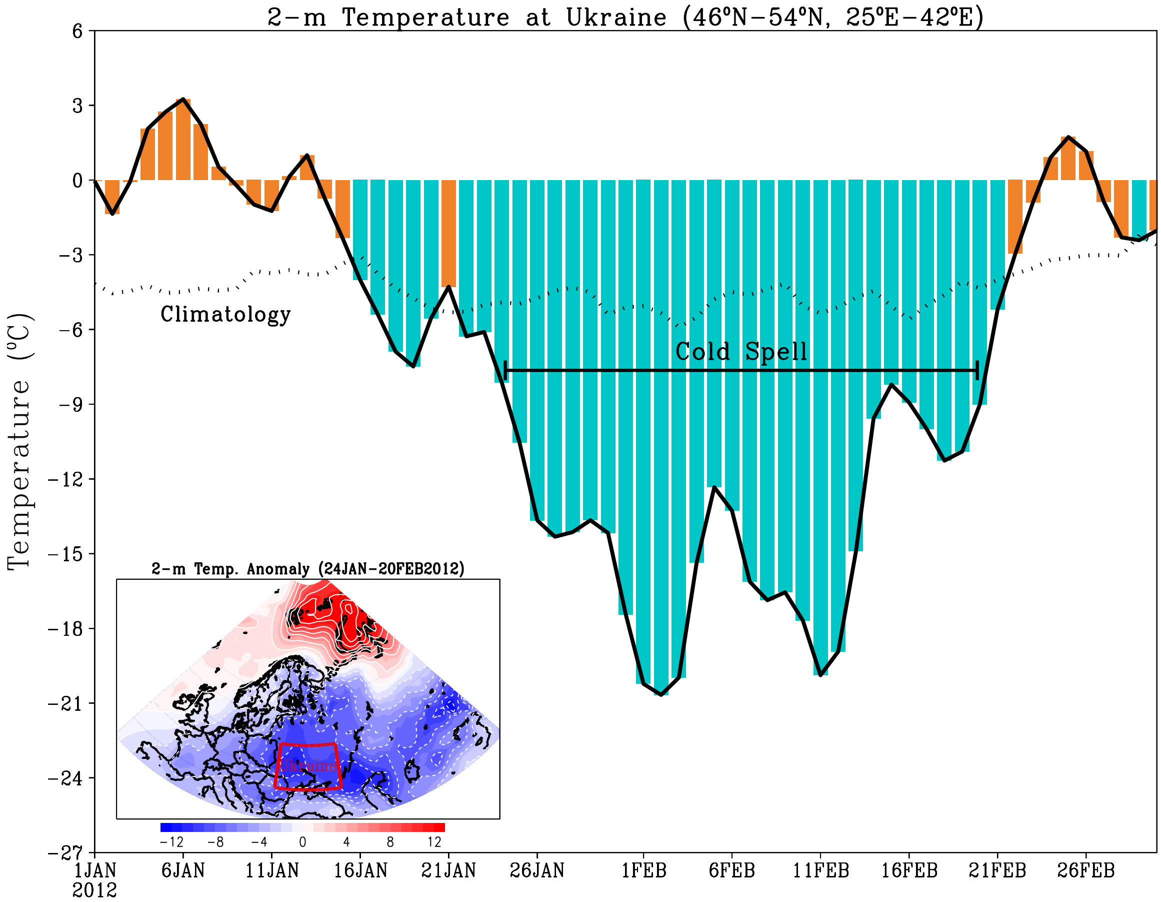

Figure 1. Time series of daily 2-m air temperature (solid line and bars) over Ukraine (46°-54°N, 25°-42°E) in January and February 2012. The daily climatology over the same area is plotted with a dotted line. Light blue (Orange)-colored bars denote the days when the temperature was below (above) climatology. Inset displays the 2-m temperature anomaly averaged over the cold spell (24 January – 20 February 2012).

Here we show some preliminary results that provide us with a clue of the possible connection between the extreme event and the HHFE in the nearby Arctic Ocean (viz., the Barents/Kara Seas). In this preliminary study, we employ the daily ERA-interim reanalysis data to examine the HHFEs and other related variables. As shown in Fig. 2, during the winter of 2011/12, both the sensible and latent heat fluxes averaged over the box area in the upper-right inset show several peaks, indicating several large intermittent HHFEs during that time. Among these events, the last big peak occurred at the end of December. During this time, a sudden drop of air temperature (green curve) was observed, which can be associated with the passage of storm accompanying the cold front (not shown).

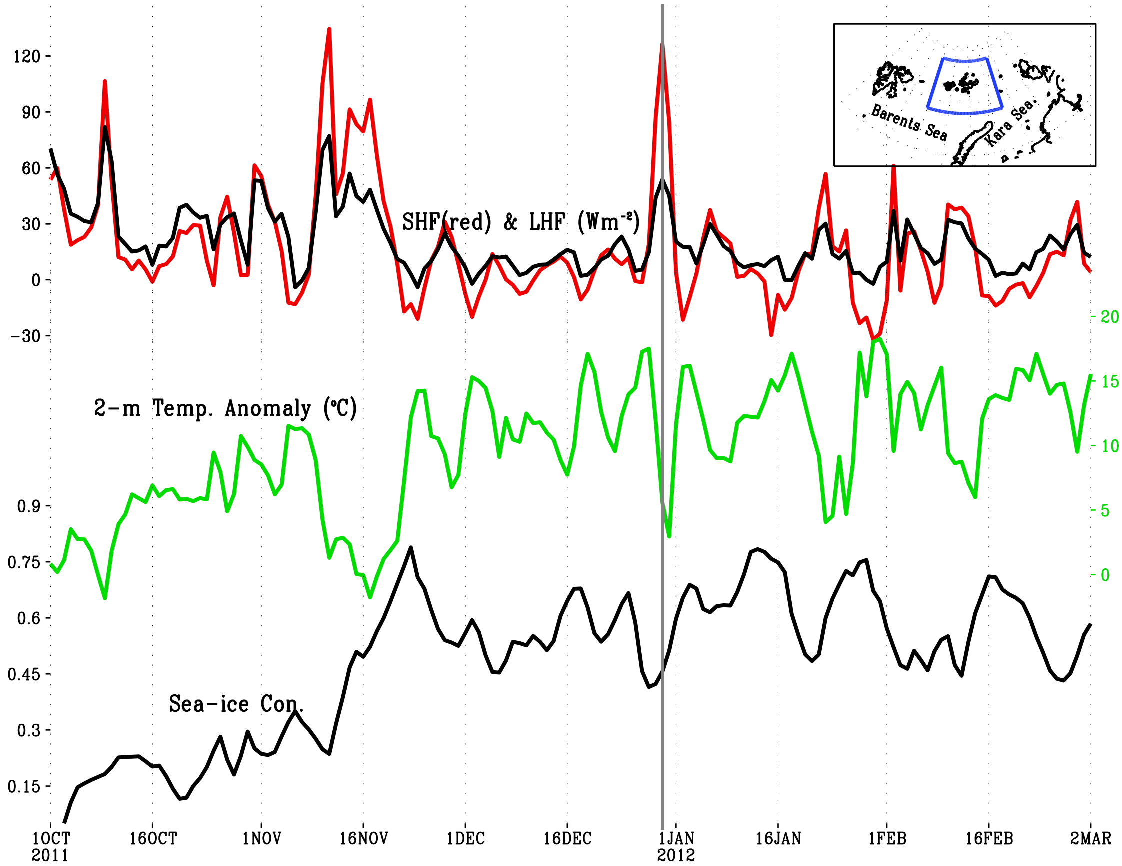

Figure 2. Time series of daily surface sensible (red) and latent heat fluxes (units: W m^{-2}, positive upward), anomaly of daily 2-m temperature (units: °C), and daily sea-ice concentration, averaged over the box region in the inset map. The gray vertical line indicates the date of HHFE in late December 2011. All data are from the ERA-interim.

Serreze and Barry [1988] showed that strong winds and high heat fluxes associated with a single intense cyclone can have a long-lasting effect on the ice cover and physical and biological processes within the underlying water column. The sharp contrasts of temperature and moisture between sea surface and near-surface atmosphere produce favorable conditions for dumping our of large turbulent heat fluxes to the atmosphere, i.e., HHFE. Just before such HHFEs occur, sea-ice concentration tends to decrease (black line), likely associated with cyclone-induced sea-ice divergence [*Brümmer et al.*, 2008]. After HHFE, the sea-ice concentration is quickly regained or increases due to thermodynamic growth and convergence of sea-ice. These periods are also marked by the large supply of heat fluxes that significantly change the lower atmospheric stability[1] (not shown) and provide favorable condition for the convection.

The vertical cloud distribution observed by the Light Detection and Ranging (LIDAR) instrument of the CALIPSO satellite confirms this (Fig. 3). CALIPSO regularly passes over the SIZ of the northern

[1] Vertical radiosonde sounding profiles at the weather station 20046 in Franz Josef Land, Russia, located in the SIZ, reveals the temporal changes in vertical distribution of atmospheric physical properties before and after the HHFE in late December 2011.

Barents/Kara Sea, so it provides invaluable opportunity to monitor vertical distribution of cloud properties (Fig. 3a). On 1 and 2 January 2012 just after the large HHFE, clouds formed and reached 10 km above the surface and occupied most of the SIZ (Fig. 3b). Since the high clouds warm troposphere by longwave radiation, the longwave feedback by cloud might play a significant role for the sustained amplification of warming. Coincidently, the surface air temperature anomaly over this region exhibited large warming (Fig. 2). It should be noted that the warm period in Fig. 2 roughly matches the extreme cold period over the Eastern Europe in Fig. 1. This suggests that the HHFE is not a local event but triggers a large-scale circulation anomaly that can have the remote impact.

While our preliminary assessment and discussion presented above contains large uncertainty, it generally demonstrates the needs for better understanding of HHFE and its connection to large-scale circulation.

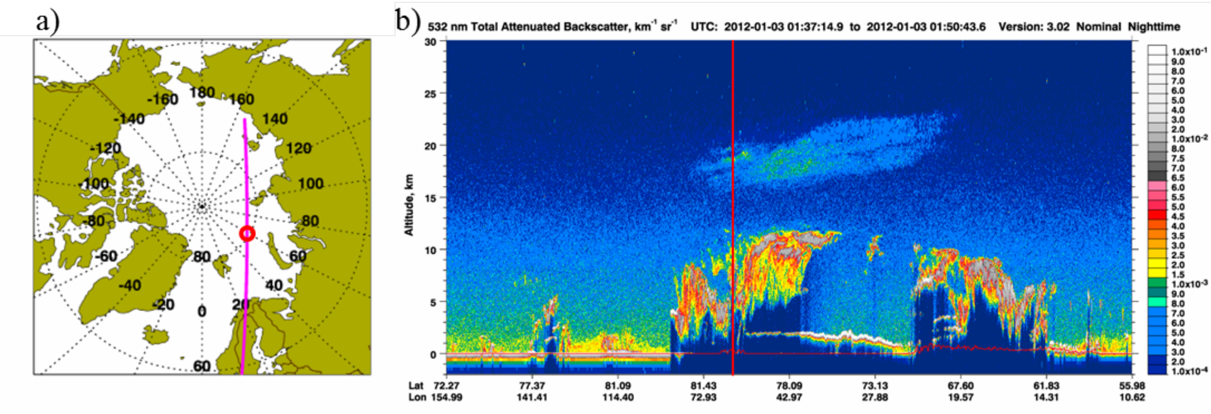

Figure 3. (a) Track (pink) of the CALIPSO from 01:37 UTC to 01:50 UTC on 3 January 2012, and (b) CALIPSO 532 nm LIDAR total attenuated backscatter [units: km^{-1} sr^{-1}]. The vertical red line indicates the position of the Franz Josef Land (red circle in (a)).

3. Hypothesis and Proposal for Observations

The purpose of this paper is to provide observation strategy to synthesize various aspects of multiple meso-scale or synoptic-scale HHFEs in the SIZ and reveal the causes of the HHFEs and their linkage to large-scale circulation. The field campaign period spans late summer melting season (August-September) and early- and mid-autumn freezing season (October-early November). In a broader perspective, we aim at obtaining the comprehensive field observation data that enhance the understanding of the various aspects of air-sea interaction in the changing Arctic climate from the viewpoint of both of atmospheric scientists and oceanographers. This will guide us to achieve our long-term goal, an improvement of the physical parameterizations of current climate model and in turn a more reliable prediction of future Arctic climate change.

Overarching hypothesis states: Declining sea-ice, warmer ocean and atmosphere during recent years have increased HHFEs, and the enhanced HHFEs in parts maintain AA and propagate to large-scale circulation via various feedbacks and cause extreme weather events in mid-latitude regions.

Individual scientific hypotheses are:

H1) ***Heat accumulation:*** Before the initiation of the strong HHFE over the SIZ, presumably large heat should be accumulated in the ocean in a relatively mild seasonal condition, which helps to accumulate energy in the upper ocean. Smaller air-sea temperature difference produces a favorable condition for this encapsulation by suppressing turbulent heat release from the ocean. We also assume the phytoplankton blooms that occur concomitantly with the ice retreat along the coastal shelves of the Arctic Ocean play an important role for the heat accumulation by trapping the solar heat flux penetrating in the ocean surface layer.

H2) ***Initiation:*** We assume that the HHFE is initiated by weather events such as cold-air outbreak or strong wind event (e.g., storms).

H3) ***Maintenance:*** During the HHFE, we assume that the stratification in the upper ocean is largely disturbed by strong winds and the SST becomes cooler due to the energy loss. This can provide more intensified ocean mixing which is necessary condition for warm Atlantic Water (AW) injection into the upper layer.

H4) ***Termination:*** The surface warming caused by the HHFE significantly reduces the atmospheric stability and triggers strong convection that can reach the tropopause. Cloud radiative forcing terminates the HHFE but maintains the warm atmosphere by long wave radiation that maintains AA.

H5) ***Restoration:*** Several occurrences of the HHFEs during the winter season (Fig. 2) need some recharge mechanism of upper-ocean heat contents because the HHFE consumes large energy accumulated in the upper ocean where energy should be replenished by some reservoir.

Target observations:

G1) To examine biological feedback that can accumulate heat during the melting, total budget of both of under-ice primary production by phytoplankton biomass and sea-ice algal production in the overall Arctic Ocean will be observed. They have not been extensively documented, mainly due to logistic difficulties of collecting data during sea-ice melt.

G2) Observe several weather events during the campaign and identify the specific weather, ocean, and sea-ice conditions and quantify the dynamical and thermal forcing for the HHFE initiation proposed by H2.

G3) Have the general characteristics of mean state in the atmosphere and ocean changed? Have the characteristics of air-sea interaction in the SIZ changed compared to previous decades? Does the reduction of sea-ice play a significant role for such changes?

G4) Examine how ocean heat contents are replenished after the HHFE events: understanding the role of ocean mixing processes and quantify their roles in transporting AW to the upper ocean layer in the Barents/Kara Seas.

G5) Examine how less Arctic sea-ice cover changes the vertical structure of Arctic planetary boundary layer (PBL) and identify the mechanism on how heat from the Arctic Ocean can be transferred to the upper atmosphere in spite of the stably stratified Arctic atmosphere.

G6) Improve understanding of oceanic mixing and its parameterization in the state-of-the-art models and provide guidance for the design of the Arctic Ocean observational network.

G7) Comprehensive understanding of energy exchanges and balances between the atmosphere, ocean, and sea-ice during the HHFE.

4. Strategy for the Observation

On the selection of target SIZs:

KOPRI research team will set up a land-based coastal research camp within the proper Arctic island over the SIZ (Fig. 4). The Franz Josef Land (Zemlya Frantsa-Iosifa) in the northern Barents/Kara Seas is located at the center where trends in sea-ice concentration show a large declination, and thus provides an ideal place to study whole processes (from the ocean to the atmosphere) of air-sea interaction in the SIZ. The camp depends on the accomplishment of making an agreement with Russian government, which admits us to establish a research camp therein. Even if establishing a research camp in the Franz Josef Land is not viable, we will try to carry out experiments in this area by visiting and deploying autonomous observing systems (e.g., drifting buoys) if permission acquired from the Russian authority. We need to check the feasibility of this plan. The Svalbard archipelago is also an alternative. The KOPRI's Arctic research station, named "*Dasan* station", is located at Ny-Alesund, on the high Arctic island of Spitsbergen. Experiments in the offshore north and east of Svalbard can be conducted if the establishment plan of the research camp can be realized.

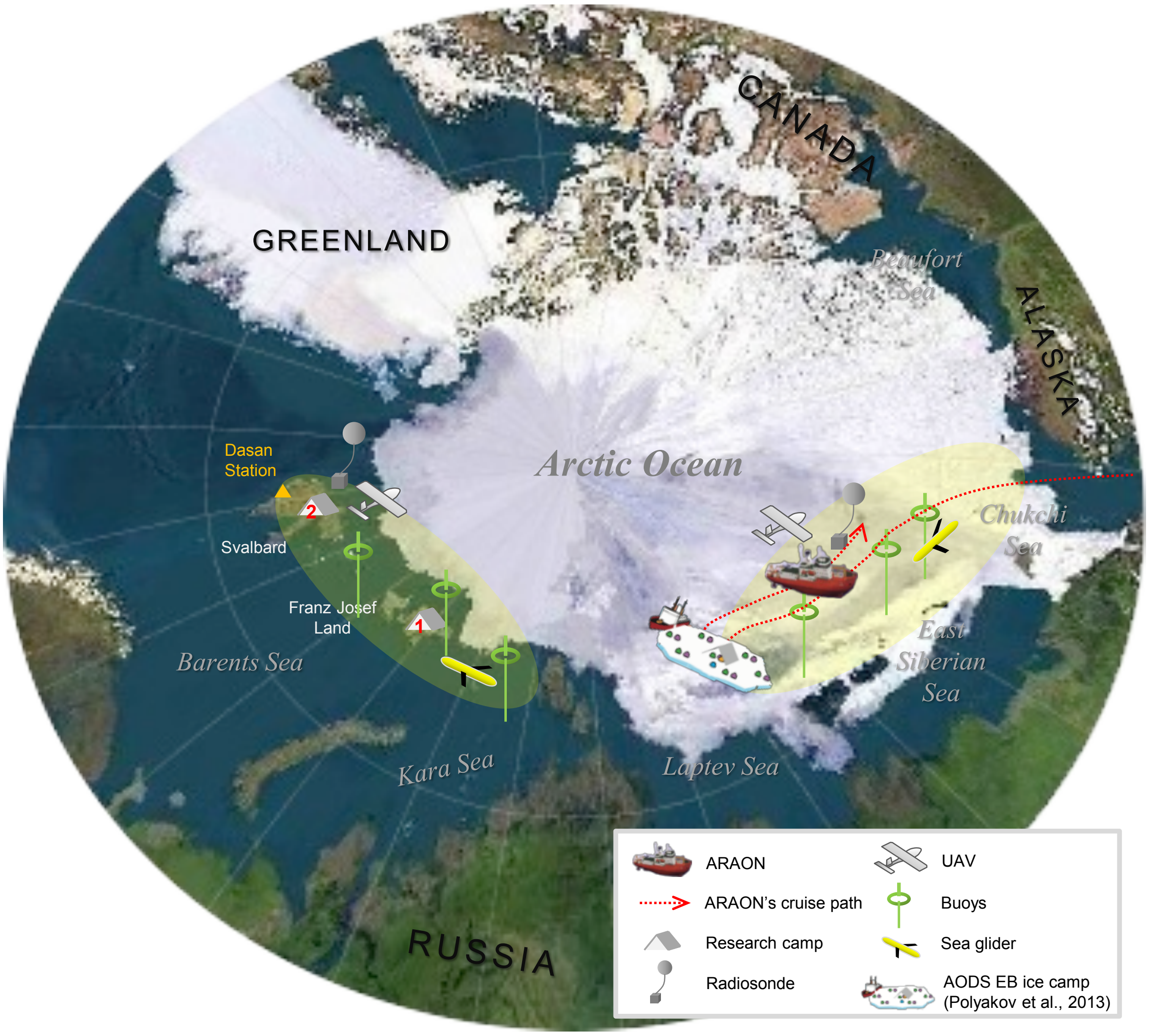

Figure 4. Illustration of areas of KOPRI's field experiments. Transparent yellow ovals are our major target SIZs. While the eastern area over the northern East Siberian and Chukchi Seas will be cover by the research vessel ARAON, the western area over the northern Barents/Kara Seas will be studied with the land-based research camp. One of the proposed locations (1: Franz Josef Land, 2: Svalbard) will be selected for the land-based research camp.

Ship-based field campaigns from the Korean icebreaker ARAON can be only realized during short periods of late summer and early autumn. This is because it is not feasible for ARAON to navigate the

Barents/Kara Seas, because the ARAON must return to South Korea no later than early October to prepare her long journey to Antarctica. Since 2010, the ARAON has repeatedly visited the Chukchi Borderland region through the Bering Strait during July-September, and this navigation plan will be likely to be maintained. Thus ship-borne observations will focus on the longitudinal sector east of 125°E (e.g., Chukchi Sea, East Siberian Sea), but, if ship time is allowed, the cruise can be extended to the eastern Eurasian Basin (EB) where the EB ice camp of the AODS will be established in September 2015 [the AODS white paper by *Polyakov et al.*, 2013]. Our provisional plan of the ARAON excursion is as follows. She will enter the Arctic Circle in August and navigate through the Chukchi Sea and its north, the northern fringe of the East Siberian Sea, and near the AODS EB ice camp during August and September. The cruise route will be carefully designed to increase the probability of encountering the Arctic storm initiating the HHFE in the SIZ.

Parameters to be observed and instruments to be used

The cruise route and the deploying locations of buoys should be properly designed, because the HHFEs occur intermittently and not on the pan-Arctic scale. The expected locations of experiments are depicted in Fig. 4. Prior to selecting locations, a preliminary meteorological study to find frequently occurring regions of HHFEs should be preceded during 2013-2014, using pre-existing datasets (e.g., reanalysis data, radiosonde sounding, satellite data, etc.). However, turbulent heat fluxes, the measure of air-sea interaction, from reanalysis data and satellite observations suffer from large uncertainties, especially in the high wind speed regime [*Brunke et al.*, 2011]. Therefore the flux measurements directly from buoys and ship-borne flux measuring instruments are instrumental for the quantification of heat extracted from the ocean to the atmosphere and associated changes in physical and bio-geochemical parameters. A preliminary study should be also extended to the investigation of biomass and production of under-ice phytoplankton and ice algae. It is highly likely that the preconditioned heating by biological feedback may enhance surface turbulent heat fluxes in the SIZ. Continuous ship-borne observations and collection of satellite data will reveal ice-edge blooms' scale and their timing. Completing the preliminary studies during 2013-2014, we will set off the intense observations of various meteorological, oceanic, and bio-geochemical parameters with combined measurements from the land-based camp, ship, buoys, airplane and satellites during the melting and freezing seasons of 2015.

A land-based camp will be established primarily for the purpose of meteorological observations at the sea front of the SIZ in the northern Barents/Kara Seas. It will be equipped with the ground-based meteorological instruments measuring basic physical parameters such as temperature, pressure, humidity, wind, radiation, and so on. For the vertical profile of those basic parameters, a radiosonde will be launched at 6-hourly intervals, and a tethersonde balloon will be used to simultaneously collect them at multiple levels in the atmospheric PBL. In addition, a Microwave Radiometer Profiler (MWRP) will also provide vertical profiles of temperature, humidity, and cloud liquid water content at much finer time intervals. An all-sky camera will help to quantify total cloud cover during the daytime. A LIDAR instrument will be operated to measure cloud properties including height, concentration and optical property. Additionally, an Unmanned Aerial Vehicle (UAV) will be operated to capture three-dimensional variation of the PBL in the SIZ. Above integrated observations will promote our understanding on air-sea interaction and atmospheric evolution with the HHFE.

Ship-borne observational instruments aboard ARAON will provide us with an opportunity to carry out various experiments ranging from the ocean to the atmosphere. The Conductivity-Temperature-Depth (CTD), salinometer, and the Acoustic Doppler Current Meter (ADCP) will measure the basic oceanic physical parameters including temperature, salinity, and ocean currents at various depth levels. The ARAON will be also heavily equipped with meteorological instruments which enable us to measure air temperature, humidity, wind, precipitation, 4-component radiation (upward and downward shortwave and longwave). Direct observations of turbulent fluxes of heat, moisture, momentum, carbon dioxide, and methane will be obtained using the eddy covariance method. While the met and flux tower measurements can provide continuous and rather accurate measurements of surface and atmospheric properties, the radiosonde and tethersonde sounding systems aboard the vessel will measure the atmospheric vertical structure at a point basis. In addition, cloud height and properties will be measured continuously using the onboard LIDAR. For detection of the bio-geochemical parameters (e.g., phytoplankton, sea-ice algae, etc.), either a Niskin sampler or electric submersible pump through the ice hole will be used to collect water sample under sea-ice. Sea-ice samples for ice algal biomass and production will also be collected using a manual ice corer (Mark II coring system).

Drifting buoys can offer continuous observation of location (GPS), sea-ice melt and growth rates, air, ice and upper ocean temperatures, and meteorological parameters (e.g., pressure, temperature, humidity, and wind at near-surface levels). GPS and meteorological data from drifting buoys can be used to locate the passage of cyclones and thus HHFEs. Divergence and convergence of sea-ice can be continuously monitored from DKPs (differential kinematic parameters), which is calculated from buoy GPS data. Barometric pressure data measured from the buoys can be also used to validate and confirm the occurrence and passage of the storms seen by reanalysis data. Sea-ice and temperature can be measured with a reasonable accuracy. From sea-ice buoy, water temperature can be measured up to a depth of a few tens of meters within mixed layer, while dedicated ocean temperature buoys can measure temperature up to 60-m depth (e.g. UpTempO). Small portable CTD sensors can be attached at the bottom of the buoys that allow us to measure salinity as well. Direct measurements of sensible heat flux can be also realised if sonic anemometer be installed and corrected for the motion and icing. This technology also provides independent measurement of air temperature (from sonic) that can be compared with the measurements from exposed thermistor chain. This technology still needs to be tested and verified to ensure its accuracy and implementation. Such buoy observation is critical if we are to observe the transitional processes occurring from melting summer through freezing autumn. In order to capture regional variability in large area, it is essential that large quantity of buoys are to be deployed on various surface types, e.g. open water, multi-year ice and first year ice.

Long-term mooring systems are essential to measure the change of sea-ice and associated heat and mass balance in the upper ocean. Because reduction of sea-ice is crucially related with warm water inflow from the Pacific and Atlantic Ocean, the heat exchange in the interfaces between air, sea-ice and sea surfaces, and thus the spatial and temporal variability of Pacific-origin Summer Water (PSW) and Atlantic Water (AW) will be investigated by a series of hydrographic observation using CTDs and ADCPs. Several long-term moorings including thermistors and current profiler will be deployed along the gateway of PSW and AW. The Chukchi shelf and Barents/Kara Seas are potential candidates for installing the mooring systems. As a part of international collaboration with Dr. Craig Lee at Applied Physics Lab/University of Washington (APL/UW), the cutting-edge platforms (e.g., sea gliders) are potentially deployed to measure the processes under the ice-covered and inaccessible SIZs. The sea gliders will visualize the structures of many oceanographic cross-sections by measuring the distribution of temperature, salinity, dissolved oxygen (DO) and turbulence.

Satellite data can provide information on surface and atmospheric conditions, which help us to fill the gap between the limited ground-based observations and much larger scales. Even though satellite-derived estimates suffer from either uncertainty or spatiotemporal gaps, the usefulness of such data cannot be overemphasized. Large-scale surface turbulent heat fluxes can be derived from combined information of radiometers (both microwave and infrared) and scatterometer as first approximation. Identifying HFFE-induced cloud formation may be a key to bridge between AA and ASIA because clouds warm the atmosphere through increasing downward longwave radiation. For the detection of clouds, high-resolution vertical profiles from CALIPSO can be also utilized, provided that the satellite passes over the location of field observations. High-resolution Synthetic Aperture Radar (SAR) and visible images [*Kwok and Untersteiner*, 2011] can offer much better spatial resolution (up to 1-m resolution). These images can be used to identify openings within sea-ice (leads, cracks and polynyas) and newly formed ice where heat exchange is significantly higher than surrounding thicker ice [*Alam and Curry*, 1998]. High-resolution images can also be used to monitor sea-ice divergence and convergence caused by storm events at potentially sub-daily temporal resolution (e.g. COSMO-SkyMed, TerraSAR-X) and at spatial resolution of tens of meters.

Aircraft measurements (piloted either directly or remotely) can provide a “slap shot” of atmospheric status in a large area. Light Remotely Piloted Aircraft (LRPA) (under 150 kg, e.g., CryoWing and Sumo) can be used to measure small-scale variability (e.g. active leads) of turbulent heat fluxes in an area of about 50 km from a launching platform (ship, sea-ice or shore). Wide range of sensor capabilities are available, e.g. aerosol and cloud physics, turbulent fluxes, atmospheric profiling, and sea-ice and ocean mapping (e.g. camera, multispectral), but all the sensors cannot be deployed simultaneously on a LRPA due to limited payload capacity [*AMAP*, 2012]. Pilot (manned) aircrafts includes a variety of range from Twin Otters (CIRPAS in US, MASIN in UK) to C-130 'Hercules' (US Coast Guard) and BAe 146-301 (Facility for Airborne Atmospheric Measurements (FAAN), UK). They can accommodate the same or much wider range of sensors, and repeated long-range observations can be also realized. The operation of both LRPA and manned aircrafts requires careful flight planning and access permits from designated airspace regulators [*AMAP*, 2012].

5. Expected Outcomes and Influences

Some fruitful outcomes will be expected from integrated efforts of targeted observations and international collaborations. Straightforward outcome is the accurately measured data of physical and bio-geochemical parameters on various surface types in the Arctic Ocean: 1) turbulent heat fluxes (both sensible and latent); 2) basic met parameters (temperature, humidity, pressure, and wind), radiative fluxes (both longwave and shortwave) and clouds (cover and height); 3) ocean physical parameters (temperature, salinity, and currents) and their vertical profiles; 4) bio-geochemical parameters (e.g., phytoplankton, ice algae, fluxes of CO_2 and methane, etc.); 5) sea-ice properties (melting and growing rates, ice temperature and thickness, motion, etc.). Those parameters will be collected under various surface conditions (open water, multi-year ice, and first-year ice). A desired primary scientific outcome through these integrated efforts is an identification of the linkage between ASIA and AA synthesizing the processes from the ocean to the atmosphere. A secondary (but instrumental) outcome is the improvement of the KOPRI’s observational technology in the Arctic Ocean. Both the scientific and technological advancement will encourage Korean scientists to join the international collaboration network for the Arctic researches.

The modelers will benefit by the invaluable data and scientific perspective obtained from this project. The observed data will help to improve the physical parameterizations of the state-of-the-art earth system model. First, in the perspective of atmospheric modeling, more realistic simulation of cloud-PBL interactions in the Arctic Ocean will be expected if it should help to improve the model’s atmospheric processes. Undoubtedly this may be one of the most significance influences of this field observation project for atmospheric modeling. Second, in the perspective of ocean (including sea-ice) modeling, the physical processes at the ocean-ice interface influencing growth/ablation of the bottom of sea-ice will be more reasonably modeled if both the ice melting and freezing rates at the sea-ice bottom and the heat gain of ice from the upper ocean should be accurately quantified. Furthermore, ocean modelers will be able to improve the feedback processes involving the bio-geochemical effects that effectively control the upper ocean heat content. All of these prospective improvements of the earth system model components would eventually reduce uncertainty in the future projection of Arctic climate.

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