G2–P1

ARCTIC SEA ICE VARIABILITY DERIVED FROM AN EXPANDED SEA ICE DATASET, 1850-2012

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A synthesis of sea ice data from various sources has extended the post-1979 satellite record of sea ice coverage back to 1850. The primary inputs to the expanded digital database are historical charts from Norway, Denmark, Russia, Alaska and Canada, as well as whaling and other ship reports from the North Pacific sector. The primary variable is ice extent, although the passive microwave satellite-derived concentrations provide the basis for reconstructions of historical ice concentration fields. We summarize the data synthesis procedure as well as the trends and low-frequency variations in the extended record. The outstanding feature is the ongoing abrupt decrease of sea ice coverage, especially in the summer and autumn. This decrease is unique in the 160-year record, as is the increased amplitude of the seasonal cycle of ice coverage over the past five years. In addition, there are low-frequency variations, including a reduction of ice extent in the early 20th Century. The latter event was confined primarily to the Atlantic sector. The low-pass filtered record of Atlantic ice extent is also consistent with the Atlantic Multidecadal Oscillation, which has a cycle length of 70-90 years. This finding is supported by other recently published studies based on paleo reconstructions of Arctic sea ice coverage over the past millennium. The linkage to the Atlantic Multidecadal Oscillation appears to arise through the inflow of Atlantic Water to the Arctic Ocean. Less robust, and by all indications non-stationary, associations with atmospheric modes such as the North Atlantic Oscillation have also been documented, primarily in recent decades. One possible reason for the non-stationarity of such associations is that the centers of action of major atmospheric modes can change over the timescale of centuries or even less.

NUMERICAL SIMULATION OF THE ARCTIC SEA ICE VARIABILITY

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We here simulated the distribution and variation of sea-ice in the Arctic Sea using an ice-coupled Ocean General Circulation Model (OGCM). The OGCM used in this study is the Regional Ocean Model System (ROMS) version 3.4, which is a three dimensional, s-coordinate, primitive equation ocean model with a free surface. The model area covers the region 65° —90° N, 180W° —180° E with grid resolution of 14–21km in latitude and longitude. A total of 70 s-coordinate levels are adopted along the vertical direction with enhanced resolution near the surface. Daily ECMWF (European Center of Medium range Weather Forecasting) forcast data with 0.5° resolution during the period 2002-2012 are used to calculate heat and salt fluxes as well as wind stress at the sea surface. Temperature and salinity imposed at inflow open boundaries are from the HYCOM-NCODA (Navy Coupled Ocean Data Assimilation) Global 1/12° data.

G2–P3

THE ENERGY BUDGET OF ARCTIC FIRST-YEAR SEA ICE THROUGH THE MELT SEASON

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Over recent decades first-year ice is the dominant ice type in much of the Arctic Ocean. An improved understanding of the processes that affect this younger ice cover is needed as these can differ significantly from those on multi-year ice that was dominant in the past. To this end, we have carried out field campaigns to observe the energy fluxes and processes affecting the melt of different types of seasonal Arctic sea ice. We observed the spatial variability of the four components of the surface radiation budget* along with measurements of the sensible and latent heat fluxes to the surface from the atmosphere and the transmitted solar radiation below the ice, on relatively thick seasonal landfast ice (Barrow, Alaska) and thinner pack ice (Nansen Basin).

Before snow melt there is little spatial variability, however with onset of melt and meltpond formation, surface albedo drastically decreases and spatial variability increases. This is also important beneath the ice. As transmittance of photosynthetically active radiation varied from around 10% through thicker white ice up to over 60% through ponds overlying thin ice during melt. Previous studies, generally from multiyear ice, reported pond transmittances closer to the white thicker ice, and also showed less pond coverage overall.

Our results highlight how the changes towards thinner ice and higher pond coverage may alter the way solar radiation contributes to the melt of seasonal Arctic sea ice. The increasingly transparent Arctic ice should be better understood if we are to know how future changes to the ice and ecosystem will unfold.

*Hudson, S.R., M.A. Granskog, T. I. Karlsen., K. Fossan. 2012 An integrated platform for observing the radiation budget of sea ice at different spatial scales, *Cold Regions Science and Technology*, 82, 14-20.

G2–P4

MOORING MEASUREMENT OF SEA-ICE THICKNESS IN THE CHUKCHI SEA OFF BARROW ALASKA

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Recently, sea ice in summer has dramatically decreased in the Chukchi Sea. In August 2009, we started the direct sea-ice measurement off Barrow, Alaska. This is the first attempt to measure the sea-ice thickness by mooring in this region. Mooring observations were carried out at two stations. The nearshore site is occasionally covered with fast ice and the offshore one is in the Chukchi Sea polynya (Figure 1(a)). These two moorings have been replaced every summer to sustain the observations. Each mooring contained Ice Profiling Sonar (IPS), Acoustic Doppler Current Profiler (ADCP), temperature/conductivity and temperature/pressure recorders. Figure 1(b) shows an example of the time series of the sea-ice draft observed at the site B2. Time series contains periods of thin ice (polynya) and deep keels. Thin ice-thickness comparison with the satellite data obtained by the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) will be carried out focusing on the polynya events.

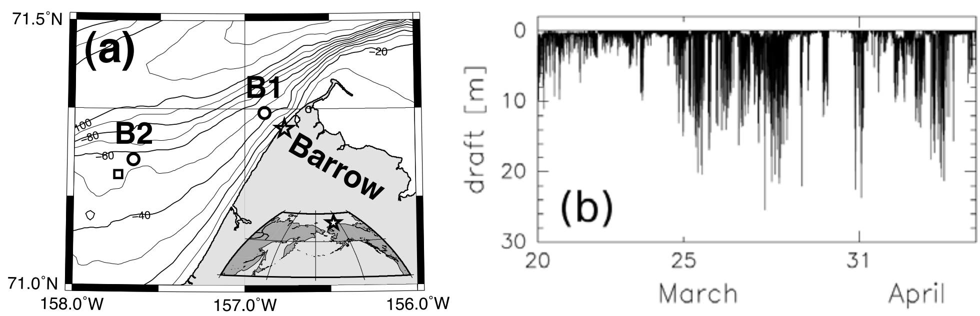

Figure 1: (a) Map of the observation site off Barrow with bottom topography. Circles denote the mooring sites. Square shows the nearby AMSR-E data point for comparison. Star shows the central Barrow. (b) Example of time series of the draft of the sea ice at site B2 in 2010.

G2–P5

Influence of ocean thermal condition on the wintertime sea ice extent variability in the Barents Sea

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The sea ice variability of the Barents Sea in early winter and its resultant atmospheric response is considered to be the triggers of downstream climate change such as Japan [Honda et al., 2009; Inoue et al., 2012]. In this study, we examined the ocean heat content, which is known to be a major factor for the sea ice extent variability [Arthun and Schrum, 2010; Arthun et al., 2012], based on the hydrographic and reanalysis data and explore the possibility for the long-term prediction of the sea ice extent variability. We found that the sea ice extent in December is highly correlated with

the ocean temperature of the North Atlantic Water in the sub-surface layer (50-200m), when the latter leads the former by about 2 years (Fig. 1). The Climate Forecast System Reanalysis data show the consistent result and reveal the slow advection of the ocean heat content from the North Atlantic to the Barents Sea. The sub-surface water variation is related with strength of the warm Norwegian Current along the Scandinavian Peninsula. The northward current is significantly correlated with the wind stress associated with the strength of the Iceland Low. Thus, the usage of the sub-surface water temperature probably improves the prediction skill of the sea ice variability.

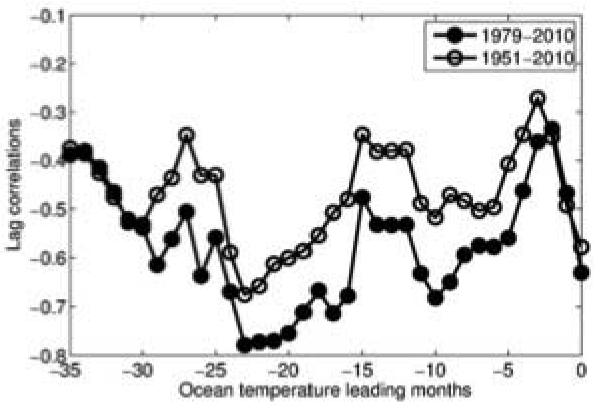

Figure 1. Lagged correlation coefficients between the sea ice extent in the Barents Sea and the monthly subsurface ocean temperature along the Kola Section (70°-73°N, 33.5°E) from 1979 to 2010 (closed circles) and 1951 to 2010 (open circles).

G2–P6

FORMATION PROCESSES OF SEA ICE BAND FORMED BY CONVERGENCE OF SEA ICE MOTION IN THE PACIFIC SECTOR OF THE ARCTIC OCEAN - AVAILABILITY OF ARCTIC SEA ROUTES -

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A sea ice condition in the Arctic Ocean has already changed into a new state. In the southern Canada Basin and Makarov Basin, first-year ice (FYI) dominated the area instead of multi-year ice (MYI). Most of FYI cannot survive by the end of summer, huge sea ice retreat occurs in the Pacific Sector of the Arctic Ocean. However, heavy ice bands remain along the northern Chukchi and East Siberian Seas in some year. Presence, distribution, formation, and variation of this ice band have impacts on availability of the Arctic Sea Routes. In this study, we pay attention to a rafting process against the North American continent as one of candidates for the formation of the ice band. Here we evaluate convergence of sea ice motion that yields over 100% sea ice concentration.

In 2006 winter, large convergence of sea ice motion occurred along the Alaskan coast and formed the heavy sea ice band remained in the subsequent summer. In fact, in July of 2006 icebreakers, CCGS Laurier and USCG Healy, stacked in the Northern Chukchi Sea. Since the ice band was too heavy to melt by the end summer, as the result, an open ocean polynya-like feature was emerged around the Northwind Ridge where the FYI was dominated and warm Pacific Summer Water was delivered. On the other hand, in 2007, divergent motion of sea ice was dominant in the Pacific sector of the Arctic Ocean. Then the ice band was not formed. In 2008, 2012, the ice band was formed, but most of ice band did not survive by the end of summer. Thus, the growth of sea ice by the rafting associated with convergence motion of sea ice is a key process to predict the timing of disappearances of sea ice in the region of the Arctic Sea Routes near the coast. We plan to introduce results of back-tracing analysis for the ice band to understand the robustness, lifetime and formation history of the ice band.

Evidence of submarine mass wasting event in Molloy Hole, Fram Strait using multibeam backscatter

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The relatively deep channel of the Fram Strait between Svalbard and Eastern Greenland serves as the primary pathway for the mixing of the warmer Atlantic Ocean and the colder waters of the Arctic. Magnetic, tectonic and geological studies have shown that the Fram Strait was formed as a result of Svalbard breaking up from northeastern Greenland starting in the Late Mesozoic/Early Cenozoic era. The sea floor of the Fram Strait is characterized by an ultra-slow spreading ridge that is the northward continuum of the Mid-Atlantic Oceanic Ridge. It is also heavily influenced by changing ice cover from the adjacent islands which deposit their terrestrial sediments to the seabed. These tectonic and glacigenic processes have greatly influenced seafloor morphology of the Fram Strait producing a highly rugose seafloor that is riddled with complex submarine landforms with a spatially variable sedimentary cover. This paper focuses on one of these complex submarine landforms, the Molloy Hole, the deepest point in the Arctic Ocean. It is located adjacent (a few tens of kilometers) to the continental slope of Svalbard where considerable hydrate systems are found. These systems play an important role in slope stability and are sensitive to warming bottom water temperatures. Seafloor mapping surveys around the Molloy Hole area have been done using Swedish Icebreaker Oden's EM 122 Multibeam Echo Sounder (MBES). Seafloor characterization analysis using Geocoder algorithm was undertaken to produce maps of seafloor surface and sub-surface sediment types. High resolution (30 m grid) bathymetric maps were also produced by combining Oden's MBES data with other MBES data from German icebreaker *Polarstern* to produce a detailed bathymetry of the area. Results from the MBES data processing were used to identify and delineate geomorphological features of submarine mass wasting events. Slump features were identified at the Molloy Hole valley whose source could be traced to sediment areas in the upper slope (~2500 m depth) that are adjacent to areas where gas hydrate systems have been known to occur. Seismic activities is believed to have triggered the mass wasting event, however, the presence of gas hydrate system in the area could have initially caused the sediment weakening. This information will be useful for identifying potential submarine geohazards in the area and in studying methane gas release processes from marine sediments.

G2–P8

DISTRIBUTION OF $CaCO_3$ UNDERSATURATED WATERS IN THE ARCTIC OCEAN, RECONSTRUCTED FROM HISTRICAL DATA

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Dissolution of anthropogenic CO_2 is making the ocean more acidic, making it difficult for marine biota to form their $CaCO_3$ shells and skeletons. It is known that surface and subsurface waters in the Canada Basin of the Arctic Ocean has already reached undersaturation with respect to aragonite-type $CaCO_3$. However, distribution of undersaturated water in the whole Arctic Ocean is not well known because carbonate chemistry data is limited. In this study, historical data of carbonate chemistry as well as other data such as temperature, salinity, nutrients and oxygen are used to reconstruct and draw a map of $CaCO_3$ saturation state throughout the Arctic Ocean. From this map, vulnerable regions to the ocean acidification in the Arctic ocean can be identified.

G2–P9

REDUCED SPACE 4DVAR TECHNIQUE AS A POTENTIAL TOOL FOR REANALYSIS AND OPERATIONAL HINDCAST IN THE ARCTIC OCEAN

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Reduced space four dimensional data assimilation (R4Dvar) is an efficient way to assimilate data without developing tangent linear and adjoint codes. The algorithm is based on interative minimization of the cost function in a sequence of low-dimensional subspaces, spanned by the leading EOFs of the ensembles derived from the model runs on each iteration. As it was shown before, the R4Dvar outperforms the conventional adjoint-based 4Dvar data assimilation technique in the case of assimilation into strongly non-linear models.
We illustrate performance of the R4Dvar in a series of twin-data assimilation experiments into diverse community models (MIT GCM, WAM, Canadian Ice, etc) and discuss potential advantages of the new data assimilation approach as a powerfull tool for reanalysis and operational hindcast.

G2–P10

SEDIMENTARY ORGANIC MATTER AND CARBONATE VARIATIONS IN THE CHUKCHI BORDERLAND IN ASSOCIATION WITH ICE SHEET AND OCEAN-ATMOSPHERE DYNAMICS OVER THE LAST 155 KYR

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Knowledge on past variability of sedimentary organic carbon in the Arctic Ocean is important to assess natural carbon cycling and transport processes related to global climate changes. However, the late Pleistocene oceanographic history of the Arctic is still poorly understood. In the present study we show sedimentary records of total organic carbon (TOC), $CaCO_3$, benthic foraminiferal $\delta^{18}O$ and the coarse grain size fraction from a piston core recovered from the northern Northwind Ridge in the far western Arctic Ocean. TOC shows orbital-scale increases and decreases during the past ~155 kyr that can be respectively correlated to the waxing and waning of large ice sheets dominating the Eurasian Arctic, suggesting advection of fine suspended matter derived from glacial erosion to the Northwind Ridge by eastward flowing intermediate water and/or surface water and sea ice during cold periods. At millennial scales, increases in TOC might correlate to a suite of Dansgaard-Oeschger Stadials between 120 and 45 ka BP indicating a possible response to abrupt northern hemispheric temperature changes. Between 70 and 45 ka BP, closures and openings of the Bering Strait could have additionally influenced TOC variability. $CaCO_3$ contents tend to anti-correlate with TOC on both orbital and millennial time scales, which we interpret in terms of enhanced sediment advection from the carbonate-rich Canadian Arctic via an extended Beaufort Gyre during warm periods and increased organic carbon advection from the Siberian Arctic during cold periods when the Beaufort Gyre contracted. We propose that this pattern may be related to orbital- and millennial-scale variations of dominant atmospheric surface pressure systems expressed in mode shifts of the Arctic Oscillation.