"Applying High Resolution Imagery to Understand the Role of Dynamics in the Diminishing Arctic Sea Ice Cover"

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LONG-TERM GOALS

The proposed research aims to derive geophysical information and process understanding from declassified, high-resolution visible band satellite imagery. We will assess the available satellite imagery and extract parameters, including lead and ridge characteristics, that describe the state of the sea ice pack during of the last decade. Assessment of the satellite imagery database will help to improve our understanding of the physical environment of the Arctic Ocean, and the processes that define it.

OBJECTIVES

Our goal is to assess changes in the characteristics of the Arctic sea ice pack, during the last decade, in terms of (i) lead and ridge deformation features, (ii) ice type, (iii) ice thickness and (iv) ice strength, establishing linkages to the yearly sea ice minimum extent. We will compare the rates of change in the seasonal ice pack in the Beaufort and Chukchi Seas with the multi-year ice of the Canada Basin and high Arctic (North Pole region).

The specific objectives are:

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- To obtain, process and carefully assess the declassified, high-resolution visible-band imagery that is available from the Global Fiducials Library (GFL) at the U.S. Geological Survey (USGS), as described by *Kwok and Untersteiner* (2011) and *Kwok* (2014).
- To scale-up our analyses by incorporating additional data from IceBridge (airborne imagery and laser altimetry), ICESat and CryoSat-2 (satellite altimetry) that describe contemporary ice pack thickness, MODIS, AVHRR, RadarSat-2 (satellite imagery) that describe ice pack deformation features on large scales, as well as other relevant, publicly available data.
- To describe the role of sea ice dynamics in the transition of the Arctic ice pack from a predominantly multi-year ice pack to a seasonal cover. The combined data products will form a new database of geophysical parameters that describe the present-day Arctic ice cover, enabling the improvement of models used to forecast ice drift.

APPROACH

Our research is centered on the application of declassified, high-resolution visible band imagery that is available from the Global Fiducials Library (GFL) at the U.S. Geological Survey (USGS) (http://gfl.usgs.gov/ArcticSeaIce.shtml), for improved understanding of the nature of the Arctic ice pack. We will process and interpret the GFL imagery and combine the results with complementary products derived from high-resolution airborne digital imagery (from NASA's Operation IceBridge mission), satellite swath imagery, ice thickness from satellite and airborne altimetry (ICESat, CryoSat-2, IceBridge), and GPS ice drifters, to understand the dynamic signature of change over the last decade in the BC region. We will assess changes in sea ice mechanical properties (type, thickness, concentration, volume) and dynamics (lead, ice floe and ridge characteristics, ice drift).

We will test the hypothesis that sea ice in the Beaufort and Chukchi Seas is currently being preconditioned for future loss through changes to sea ice dynamics, in a way that irreversibly impacts the recoverability of the Arctic pack ice. In particular, we anticipate that lead spacing has decreased and lead width increased over the last decade in response to increased ice drift and deformation in the BC region. As a result, sea ice conditions in the BC region can negatively impact replenishment of multi-year ice across the entire Arctic, and a thinner pack, with increased lead fraction, will enhance the seasonal marginal ice zone formation and albedo feedback in summer.

WORK COMPLETED

This is a new project, getting underway in Summer 2014, and thus research progress is in an exploratory stage and many of our latest results are in preparation for publication. In terms of project personnel, all three project PIs (Farrell, Hutchings and Richter-Menge) have successfully received Year 1 funding. The teams at University of Maryland (UMD) and Oregon State University (OSU) are currently seeking two undergraduate students to provide immediate assistance with data acquisition and processing. The UMD team has also identified a potential Faculty Research Assistant (FRA) to join this project in January 2015. Dr. Farrell will supervise and mentor the FRA, who will be responsible for processing, analyzing, and interpreting the observational datasets for the extraction of statistical products that will characterize the sea ice cover within the study region, particularly sea ice leads and deformation features.

In addition to conducting an assessment of the available wintertime declassified, high-resolution visible band imagery available at the GFL, USGS, we plan to leverage new data available via the NASA Operation IceBridge (OIB) project. This includes six years of high-resolution sea ice thickness, snow depth, and visible imagery along IceBridge flight lines in the Western Arctic between 2009-

present. Environment Canada (EC) furnished the UMD team with RadarSat-2 imagery in the Western Arctic during IceBridge campaign periods, under a special licensing agreement between NASA OIB and EC. We intend to incorporate results derived from these new and unique OIB data with the GFL declassified imagery to assess rates of change in the seasonal ice pack in the Beaufort and Chukchi Seas and in the multi-year ice of the Canada Basin and central Arctic.

<u>Year 1 Work Plan:</u>

- Obtain, process and interpret available high-resolution satellite imagery from USGS GFL; extract lead width, frequency, distribution, floe size and ice concentration. [*underway*]
- Obtain, process and interpret available high-resolution airborne (DMS) imagery from the NASA IceBridge mission to extract lead width, frequency, distribution and floe size. [*underway*]
- Assess lead characteristics, contrasting results for seasonal and multi-year ice areas.
- Calculate inter-annual variability and trends in lead statistics, assessing potential impact of September 2012 sea ice minimum on ice pack characteristics.
- Collate mappings and trend analyses of related remote-sensing data sets including ice thickness, concentration, ice-pack drift, divergence and shear. [*completed*]
- Prepare results for presentation at national meetings and submit peer-reviewed publication. [*completed/underway*]

RESULTS

Six years of winter sea ice thickness estimates from the NASA IceBridge mission spanning March 2009 to April 2014 are now available and have been assessed. Following *Richter-Menge and Farrell* (2013), we divide the winter-time IceBridge sea ice thickness data into two regions: (i) the Central Arctic, which remains dominated by multiyear ice (> 90 %), and (ii) the BC region, where the ice pack is more seasonal in nature and is a mix of multi-year (~ 25 %) and first-year ice (~ 75 %). Ice thickness distributions for (a) the Central Arctic and (b) the Beaufort/Chukchi Seas are shown in Figure 1. Also provided in Figure 1 is a mapping of the IceBridge quick-look data indicating sea ice thickness in the Western Arctic in March/April 2014. Our analysis shows that mean ice thickness remains stable in the Central Arctic, at around 3.2 m, with interannual variability of ~ 0.6 m over the 6-year period. Average ice thickness in the BC region is significantly lower, at 2.0 m, with interannual variability of ~ 1 m. Some of the observed variability in ice thickness in the BC region may be explained by two factors: (i) the location and width of the multi-year sea ice tongue, and (ii) spatial sampling due to location of flight lines, particularly in the early part of the measurement period. It appears that ice thickness in the BC region declined after 2010 through 2013, with a marked change in the form of the ice thickness distribution. There was a slight increase in mean ice thickness in 2014 due to the presence of a wide band of multi-year ice throughout the northern Beaufort and Chukchi Seas. Thickness products (*Kurtz et al.,* 2012) are available at: nsidc.org/data/icebridge/.

Analysis of ice pack strain-rate from full resolution drifting buoy position data, between 2000 and 2010, has been completed and has identified a step change in both divergence and shear of the Arctic ice pack that occurred in 2006 to 2007. Divergence and shear variance, as well as shear magnitude, increased in response to ice transport from the Arctic between 2006 and 2007. An approximate doubling in strain-rate magnitude has resulted in increased ridging rate and leads throughout the Arctic. However in the Beaufort Sea we find a decrease in ridging (-12%) and an increase in lead opening (+170%). These results are presented in *Hutchings et al.* (2014).

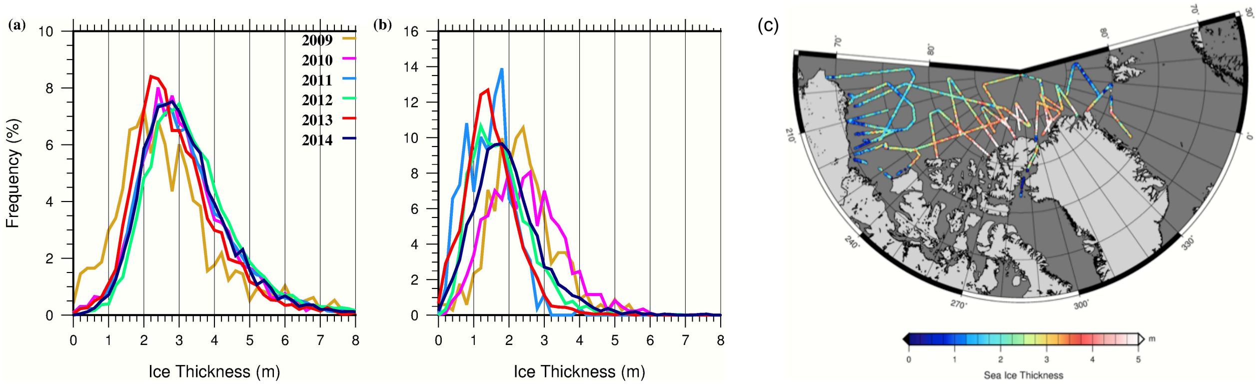
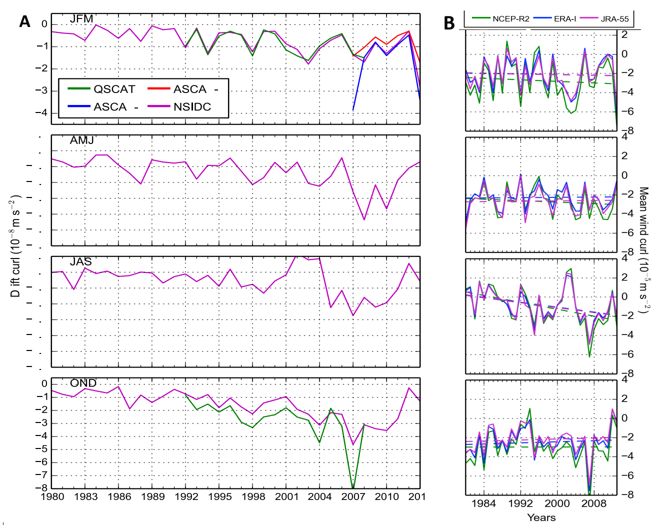


Figure 1*: Wintertime Arctic sea ice thickness distribution spanning six years (2009-2014) for the (a) central Arctic, and (b) the Beaufort/Chukchi Seas, derived from NASA IceBridge surveys of the ice pack. (c) Polarstereographic mapping of winter-time sea ice thickness in the Western Arctic in 2014. Updated from Richter-Menge and Farrell (2013).*



We have also conducted an initial assessment of sea ice drift curl in the BC region using drift products available at NSIDC and CERSAT and compared the results to wind curl extracted from a suite of reanalysis data sets. Figure 2 shows that while there has been a strong trend in ice drift curl throughout all seasons, a significant decline in wind curl is observable in summer only, with wind curl becoming more anti-cyclonic.

Figure 2*: Seasonal analysis of trends in (a) sea ice drift curl and (b) mean wind curl for the BC region over the last two decades. From Petty et al., 2014, (in prep.).*

IMPACT/APPLICATIONS

The project will result in the assessment of the utility of declassified, high-resolution visible band imagery for deriving geophysical information on the sea ice pack of the Arctic Ocean, and improve understanding of key processes driving change in the region. Much of the geophysical understanding that underpins the parameterizations in current sea ice models describes a thick, multi-year ice pack. The metrics derived under this project will describe the contemporaneous sea ice mechanical response to forcing, in both the seasonal and multi-year ice packs. This will facilitate improvement of ice drift models, including refinement of sea ice rheology required for improved ice drift forecasting, and will inform the next generation of high-resolution sea ice models.

RELATED PROJECTS

- **ONR**: Richter-Menge is funded under a separate ONR project that utilizes the high-resolution satellite imagery to track the evolution of sea ice floes in the Arctic. Working together with D.

Perovich the project, entitled "*The Seasonal Evolution of Sea Ice Floe Size Distribution*", will determine the evolution of floe size distribution and examine the role of winter preconditioning (i.e. refrozen cracks and leads) on summer floe breakup. Hutchings is collaborating with A. Mahoney, H. Eicken and C. Haas on an ONR-funded project "*Mass balance of multi-year sea ice in the southern Beaufort Sea*". This effort integrates in-situ, moored and aerial observations of ice thickness with sea ice drift from buoys and passive microwave to estimate the changing seasonality of ice thickness in the context of increasing multi-year ice melt in recent summers.

- **NASA IceBridge**: The NASA IceBridge project is closely related to this ONR work. The goal of IceBridge is to utilize a highly specialized fleet of instrumented research aircraft to characterize annual changes in the thickness of sea ice, glaciers, and ice sheets. These observations are critical for predicting the response of Earth's polar ice to climate change and sea-level rise. IceBridge will also bridge the gap in observations between NASA's ICESat satellite missions. Farrell and Richter-Menge currently serve as members of the IceBridge Science Team and can thus facilitate coordination of future IceBridge flights over specific sea ice targets where spatially and temporally coincident high-resolution satellite imagery may be obtained. Farrell is also a member of the NASA ICESat-2 Science Definition Team.
- **NASA**: Research project entitled "Sea Ice Dynamics and its Role in Understanding the Survivability of Arctic Sea Ice", funded through the NASA ROSES 2012 Cryospheric Science Program, aims to quantify how sea ice in the Beaufort-Chukchi Seas (BC) region has changed, and to understand the role of sea ice dynamics as a driving force for transformation in this area. The study will define the changes that have occurred in the BC region during the last decade, based on analysis of the following geophysical parameters: ice type, ice thickness distribution, ice age, ice volume transport and drift, melt and freeze onset dates.

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