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Characterization of Hazardous Ice using Spaceborne SAR and Ice Profiling Sonar: Preliminary Results

Kaan Ersahin, Leslie Brown, Anudeep Kanwar, Michael Henley, Ed Ross, David Fissel (ASL Environmental Sciences Inc.)

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Abstract

Ice can pose hazard for operations (e.g., transportation, shipping, offshore oil and gas exploration) and for infrastructure (e.g., ports, pipelines, offshore structures). There is an increasing need for fine scale characterization of hazardous ice conditions. This information is of interest to many stakeholders including government departments and agencies, and the oil and gas industry. Spaceborne Synthetic Aperture Radar (SAR) sensors have demonstrated the viability and cost-effectiveness of near-real-time monitoring of the regional ice conditions. Satellite derived ice information products typically rely on the interpretation of ice analysts or in some cases semi-automated techniques, and cover relatively large areas at coarse resolution. Development of improved data products using high spatial resolution polarimetric RADARSAT-2 datasets (e.g., Fine Quad) is desired for detailed characterization of potentially hazardous ice conditions. Although validation of ice data products is challenging due to limited *ground truth* data, there are numerous sites throughout the Arctic with many years of continuous measurements of ice conditions obtained using bottom mounted Upward Looking Sonar (ULS) instruments. Using ULS data we have recently developed analytical methods to characterize highly deformed sea ice features including large individual keels, segments of hummocky ice, multi-year ice, and episodes of internal ice stress, which can also serve as validation data for SAR-based analysis. This paper presents an overview of our ongoing work and very preliminary results on hazardous ice characterization using SAR and ULS data. ULS data *view from below* and SAR data *view from above* are complementary information sources, and utilizing both is expected to result in better characterization of the ice conditions. During this work, paired SAR and ULS datasets will be generated to allow calibration and validation of algorithms, and methodologies will be developed to utilize these complementary data sources. This project is expected to (1) develop improved methods for fine scale analysis of RADARSAT-2 data; (2) develop enhanced information products generated in the hindcast mode when ULS and RADARSAT-2 are both available; (3) demonstrate potential for RCM (compact polarimetry). Calibrated and validated information products of hazardous ice will be extremely valuable for users who require such information for engineering design, to make management and policy decisions, and to safely perform operations.

Introduction

The areal coverage of Arctic marine ice is now rapidly reducing in summer, changing the ecosystem of the region, altering the use of marine areas by indigenous peoples and greatly increasing shipping access to the area. In spite of the reductions of ice cover, navigation in Arctic areas is perilous, and there are important and dangerous ice hazards in the form of dense multi-year ice, large individual ice keels, fields of hummocky ice, and regions of high internal ice pressure. The changing Arctic ice regime will continue to evolve the likelihood and impact of interactions with these ice hazards. There is a critical need for improved understanding of the marine ice regime in the form of:

- Improved knowledge of the properties of marine ice for input to engineering design of coastal and offshore platforms and as inputs to Arctic ship design;
- Informing the development of government policies required for regulation of Arctic shipping, regulating energy development, marine uses of the area and others;
- Operational support for shipping and industry activities;
- Improved characterization of sea ice as an important part of ecosystem understanding required for environmental assessments and the regulatory approval process.

Upward-looking sonar (ULS) instruments have become the primary source of data for high resolution and long duration measurements of sea ice drafts to support engineering requirements for oil and gas exploration projects in Arctic and other ice-covered areas. ULS instruments, in the form of ASL's Ice Profiler, provide accurate measurements for ice draft on a continuous year-long basis and allow detailed characterization of keel shapes and other ice features (Fissel *et al*., 2008). When combined with a companion Acoustic Doppler Current Profiler (ADCP) to measure ice velocities, high resolution ice thicknesses and ice velocities can be obtained along thousands of kilometers of ice which move over moored ice profiler location. These measurements provide important data for establishing metocean design criteria related to oil and gas operations in areas with seasonal or year-round ice cover.

Spaceborne Synthetic Aperture Radar (SAR) sensors have proven to be ideal for sea ice monitoring because of their all-weather operation and sensitivity to surface roughness. Although routine operational requirements for ice monitoring programs typically rely on wide coverage (300-500km), there is also a need for fine scale characterization of potentially hazardous ice conditions. The information provided by polarimetric SAR (e.g., RADARSAT-2 quad-pol) datasets improves the ability to characterize targets through their scattering properties, at the expense of a reduced swath (25-50km).

ULS data *view from below* and SAR data *view from above* are complementary information sources where utilizing both is expected to result in better characterization of the ice conditions. This concept is shown in Figure 1. As a result, it is expected to enhance existing capabilities for detection and characterization of hazardous ice features, and to demonstrate value to various stakeholders including government departments and agencies, and the oil and gas industry.

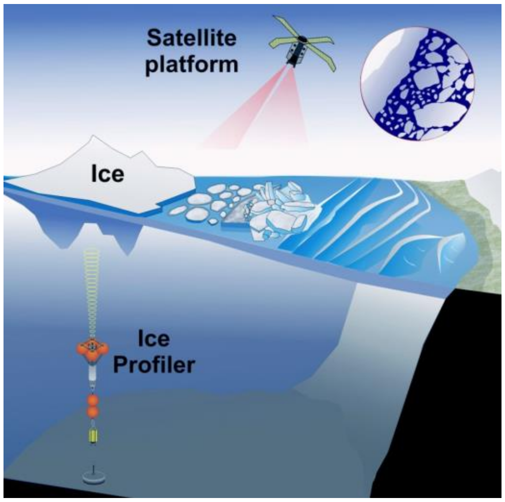


Figure 1. Concept for combining the view from above (satellite) and the view from below (ULS)

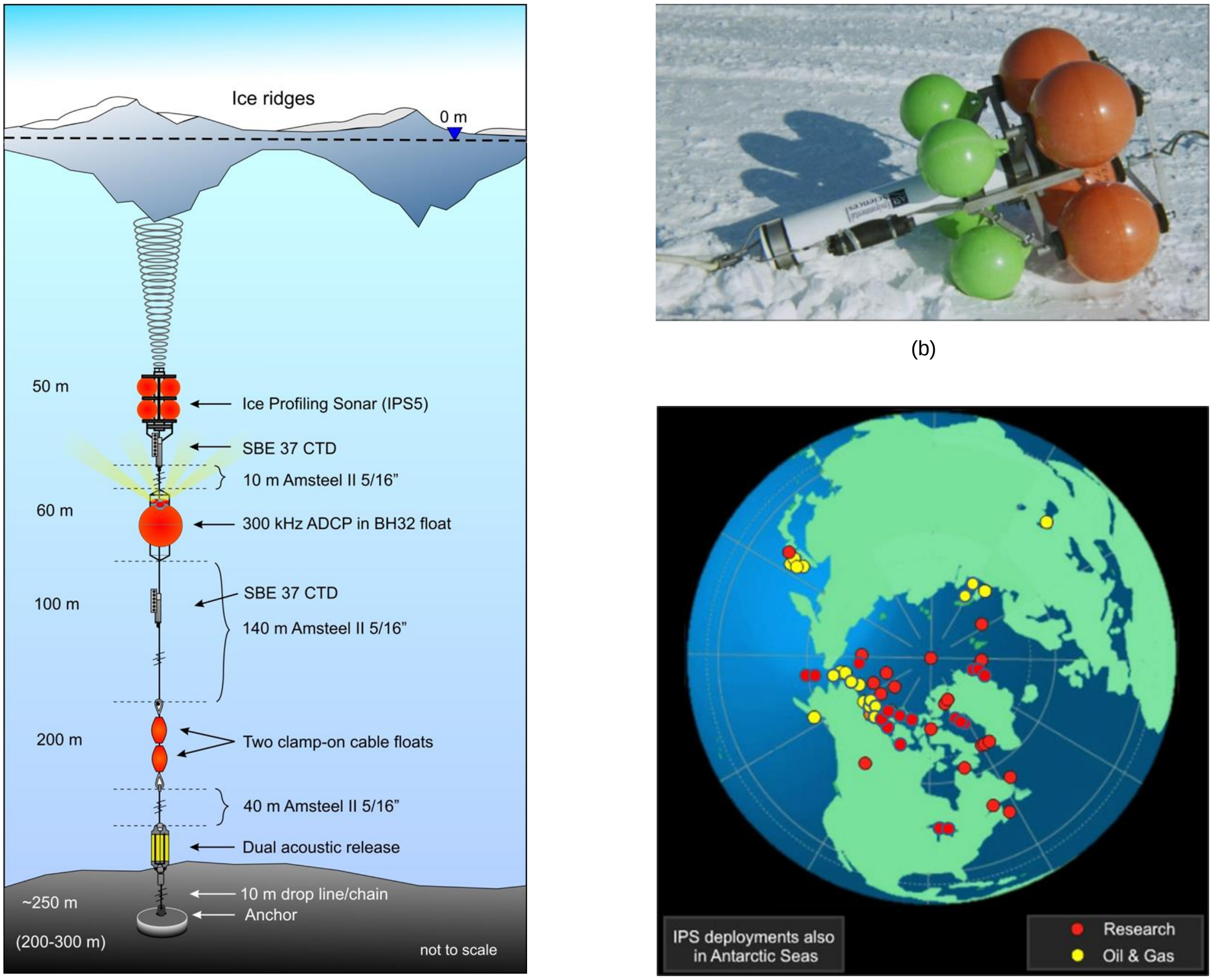
Data sources for characterization of hazardous sea ice

A. Upward Looking Sonar (ULS) Instruments

Measurements of ice draft (the underwater thickness of ice) obtained using moored Upward Looking Sonar (ULS) instruments have a horizontal resolution and vertical thickness accuracy which exceed the performance of other advanced ice measurement methods (Fissel and Marko, 2011). ULS measurement methods have been widely used since the mid-1990s to provide accurate and very high resolution measurements of sea ice drafts and ice velocities in support of oil and gas exploration programs in the Arctic Ocean and marginal ice zones.

Operated from subsurface moorings located safely below the sea ice canopy, the ULS instrumentation, consisting of the Ice Profiler Sonar (IPS) and the Acoustic Doppler Current Profiler (ADCP) are designed to be deployed 25 to 60 m below the air-water interface from seafloor-based moorings, or in shallower water, at near-bottom moorings. Figure 2(a) shows a typical deployment arrangement of IPS and ADCP instrumentation on a single subsurface mooring. In shallow waters, these instruments are operated from separate moorings located within 100 m of one another. A photograph of the IPS instrument is shown in Figure 2(b).

The ASL IPS [1] is an upward looking sonar device that was purpose-designed for sea ice draft measurements by the Institute of Ocean Sciences (IOS) of the Fisheries and Oceans Canada (Melling *et al*., 1995) and has been upgraded by ASL Environmental Sciences Inc. through improved instrument design based on more capable microprocessors and more advanced on-board firmware (Fissel *et al*., 2007).



(a) (b) (c)

Figure 2. (a) A typical deployment arrangement of IPS and ADCP instrumentation on a single subsurface mooring; (b) photograph of IPS mooring; (c) IPS deployments in the Northern Hemisphere since 1996.

The IPS instrument operates by emitting and detecting surface returns from frequent short pulses (pings) of acoustic energy concentrated in narrow beams (less than 2°). Precise measurements of the delay times between ping emission and reception are converted into distances separating the instrument's transducer and the ice undersurface. Contemporary data from the instrument's on-board pressure sensor are then combined with atmospheric surface pressure data and estimates of the mean sound speed in the upper water column (obtained from observations of open water above the instrument) to derive estimates of ice draft from each emitted ping. The IPS provides fine resolution of approximately 1 m horizontal and 0.05 m vertical of the underside of the sea ice (Fissel *et al*., 2008a).

Acoustic Doppler Current Profiler (ADCP), manufactured by Teledyne RDI, provides accurate direct measurements of ice velocities. The ADCP information is used in conjunction with the IPS to provide information about feature widths and ice floe position at a sub-hour time interval. The capabilities of the ULS instrumentation for detailed and accurate representation of the thousands of kilometers of sea ice passing over the moored measurement sites are well established (Fissel *et al*., 2008a). Since the first development in 1996, more than 180 IPS instruments have been manufactured, and well over 100 year-long ULS deployments have been conducted around the world as shown in Figure 2(c).

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[1] ASL IPS: http://www.aslenv.com/IPS.html

The processing and analysis of IPS data is routinely undertaken including the continuous improvements to the instrumentation, analysis methodologies and software. ASL has developed a library of over 200 software programs to analyze the data sets in the form of the IPS MATLAB Toolbox[2]. The methods developed in detailed processing and analysis of many dozens of year-long ULS data sets have led to quantitative characterizations of potentially hazardous ice features (Fissel *et al.*, 2012), in the form of large individual ice keels, segments of large hummocky (rubbled) ice, multi-year ice features, episodes of large internal ice pressures, and glacial ice features. Techniques for characterization of potentially hazardous ice features are constantly being improved. Recently, an additional category, i.e., massive ice features, has been introduced (Fissel *et al*., 2014).

B. Spaceborne Synthetic Aperture Radar (SAR) Sensors

Spaceborne Synthetic Aperture Radar (SAR) sensors have proven to be ideal for sea ice monitoring because of their all-weather operation, sensitivity to surface roughness and wide coverage. SAR satellites have traditionally operated in single polarization mode defined by both transmit and receive polarizations (i.e., linear horizontal or linear vertical). The user requirements dictated the choice of polarization. For example, ERS-1 and ERS-2 sensors were built using vertical transmit and receive (i.e., VV) that allowed strong response from the ocean surface. On the other hand, RADARSAT-1 was designed primarily for sea ice monitoring and used horizontal transmit and receive (HH) polarization which is known to result in lower response to the rough ocean surface, thus provides enhanced contrast between open water and sea ice. RADARSAT-1 met most of the operational requirements of the sea ice community and demonstrated the viability and cost-effectiveness of near-real-time monitoring of ice conditions.

Research on radar polarimetry - based on airborne data - has shown that multiple polarizations allow better characterization of the target of interest in many applications. Since 2002, selectable multi-polarization SAR systems were operationalized (e.g., ENVISAT – ASAR, ALOS – PALSAR, RADARSAT-2, TerraSAR-X, Cosmo SkyMed). RADARSAT-2, launched in late 2007, offers a suite of beams at various spatial resolutions (3 – 100 m), modes of operation (Spotlight, Stripmap, and ScanSAR) and polarizations (single, dual-, and quad-pol) with varying swath widths and incidence angles shown in Figure 3.

The information provided in quad-pol datasets improves the ability to characterize the physical properties of targets through their scattering properties. However, RADARSAT-2 quad-polarized beams with high spatial resolution are available for relatively narrow swaths (i.e., Fine Quad – 25km or Wide Fine Quad – 50km) in comparison to ScanSAR beams (i.e., 300-500 km). Despite the improved information content and spatial resolution, their potential is not being fully utilized due to the limited coverage area that does not meet the routine operational requirements for the ice monitoring program of the Canadian Ice Service (CIS). Thus, ScanSAR beam modes of RADARSAT-2 (single- and dual-pol) are the primary data sources for the CIS and for other service providers with similar mandates for near real time monitoring (e.g., Danish Meteorological Institute – Ice Service).

The next generation Canadian space-borne radar system, i.e., RADARSAT Constellation Mission (RCM), will increase the number of available platforms and also introduce a new mode of operation, i.e., compact polarization. This mode transmits circular polarization and receives linear, thus allows increased information content over the wide swath coverage of RADARSAT-2 dual-pol beams. This advancement combined with the planned constellation of three platforms will allow more frequent wide area coverage for surveillance and enhanced operational monitoring of sea ice in near real time.

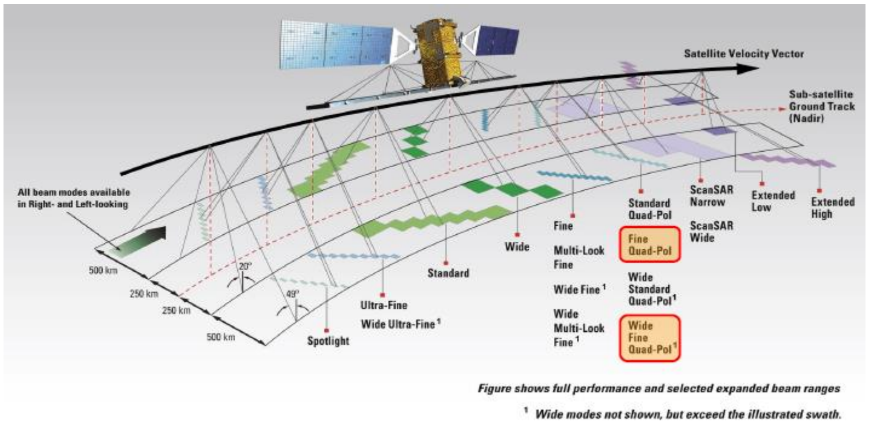

Figure shows full performance and selected expanded beam ranges

¹ *Wide modes not shown, but exceed the illustrated swath.*

Figure 3. RADARSAT-2 beam modes (courtesy of MDA Geospatial Services)

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[2] IPS MATLAB Toolbox: http://www.aslenv.com/toolbox.html

Engineering design studies require detailed characterization of potentially hazardous ice conditions over specific and relatively small areas of interest. In this case, quad-pol datasets with high spatial resolution will typically provide sufficient coverage to describe local conditions while ScanSAR data could be used to provide context.

Over the past three decades, multi-frequency, multi-polarized synthetic aperture radar (SAR) data have extensively been applied to sea ice classification using a variety of approaches. Some of the successful applications of SAR have focused on classification of ice types; thin ice and open water discrimination; and sea ice thickness estimation. Both polarimetric intensity and texture have been exploited for classification purposes, several techniques including neural networks, image segmentation, wavelet transformation, backscatter inversion, integration of SAR with ice models and lookup tables have been developed and tested to utilize SAR data for sea ice classification. Although most studies have successfully inverted single and dual co-polarized HH and VV backscatter to retrieve sea ice geophysical information, many others have highlighted the shortcomings of single polarized data. Multi and fully polarimetric backscatter have been more strongly related to sea ice characteristics and have yielded better classification results (Gill and Yackel, 2012). Most commonly used polarimetric parameters are derived from Claude-Pottier (Claude and Pottier, 1997) eigenvalue decomposition (Ferro-Famil *et al*., 2001; Scheuchl *et al*., 2001; Rodrigues *et al*., 2003; Scheuchl *et al*., 2003b) and Freeman-Durden (Freeman and Durden, 1998) three-component scattering decomposition (Scheuchl *et al*., 2002). An evaluation of the classification potential of some of these polarimetric parameters was performed by relating them to three pre-identified sea ice types, i.e., smooth first year ice, rough first year ice, deformed first year ice and wind-roughened open water (Gill and Yackel, 2012). Another recent study estimated sea ice thickness using RADARSAT-2 quad-pol data and reported a strong correlation between *in situ* sea ice thickness and the SAR-derived depolarization factors (Kim *et al*., 2012).

In this work, RADARSAT-2 quad-pol beam modes with high spatial resolution (i.e., Fine Quad, Wide Fine Quad) will be used as the primary source of spaceborne data sets for detailed characterization of sea ice. These datasets will also be used to simulate compact polarimetry beam modes of RCM. In this paper, an overview of our ongoing work and very preliminary results on a subset of the project tasks are presented.

Methodology

Our methodology follows the project work plan shown in Figure 4. Each work package (or major task group) is described in detail including data acquisition and assembly, ice characterization from ULS data, combining ULS and RADARSAT data, satellite-based sea ice characterization, and development of improved data products.

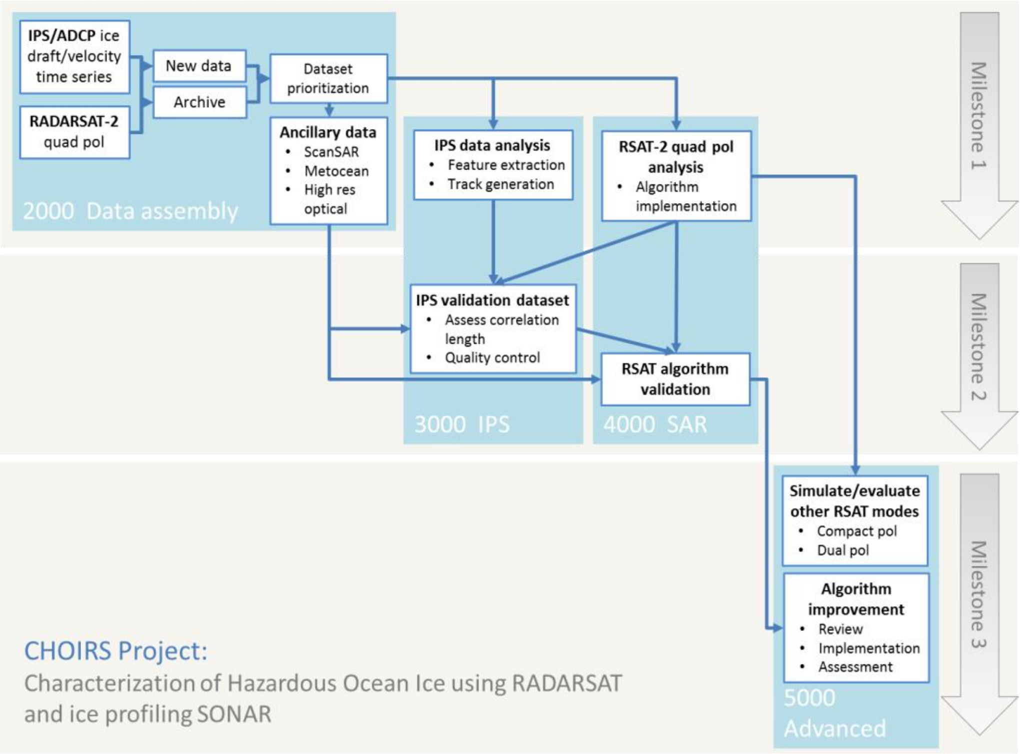


Figure 4. CHOIRS Project Work Plan

Data Acquisition and Assembly

Data acquisition and assembly involved two main data sources (i.e., ULS and space-borne SAR) as discussed in the previous section. Although, simultaneous collection of these datasets is necessary, the project scope does not include the planning and execution of field programs for ULS data collection. Instead, we take advantage of existing archive data and ongoing field programs planned by research organizations as well as the oil and gas industry. Thus, for the locations and times where ULS data is known or expected to be available, RADARSAT-2 data from FQ and FQW beam modes are obtained through the Canadian Space Agency (CSA) Order Desk via archive data orders and new data acquisition requests.

Ice Characterization from ULS data

The ULS datasets and other supporting data identified and retrieved during data acquisition and assembly are analyzed using the methodologies and tools previously developed for quantitative characterizations of potentially hazardous ice features (Fissel *et al*., 2012), in the form of

- large individual ice keels
- segments of large hummocky (rubbled) ice;
- multi-year ice features;
- episodes of large internal ice stress;
- glacial ice features.

Identification and characterization of large keels (i.e. deep and/or wide) is readily performed with an existing feature detection software tool operated on an equispaced ice draft series. An analogous tool is used to detect hummocky ice features. Individual large ice keels have the largest ice thickness of up to 20 m or more while large hummocky ice features have greater horizontal scales of 100 to several hundred meters with lesser ice thickness. Multi-year ice may also be detectable by analysis of thebackscatter profile at the ice-water interface (Fissel *et al*., 2012). The detection of likely episodes of high internal ice stress is based on the cessation of ice motion as revealed from the combined ice draft and ice velocity data sets, and the information on winds and near surface currents are used as a qualifier to distinguish between internal ice stress and the lack of driving force. Glacial ice features that in the ULS data sets are readily apparent due to their characteristic underwater morphology, in the form of very steep, nearly vertical sides and relatively featureless bottoms.

Combining ULS and RADARSAT Data

The spatial-temporal correspondence of the ULS and RADARSAT data need to be examined in detail before using these datasets as complementary sources of information to generate a validation dataset. Navigation accuracy for satellite datasets (especially offshore) is very important to co-locate with another data source. However, there are a number of other challenges that need to be addressed as well. These challenges are mainly due to the differences between the types of the data sets, their acquisition processes and timelines. The view from above (satellite) and the view from below (ULS) measure different physical parts of the target at different spatial and time scales.

The satellite data over a mooring site is acquired typically in a few seconds, thus it is considered a snapshot in time. However, ULS data is acquired at a single mooring position over a much longer period. Depending on the ice velocity and the scene size, this may be hours to days or longer. As a result, the two data sets inherently have temporal decorrelation except for the mooring location. However, the drifting ice over the mooring location which allows us to generate the spatial series and quantify the horizontal along track dimension of the ice pack, also allows us to overlay a segment of the ULS data over the satellite image data. Due to the temporal decorrelation between data sources, the overlay can only be achieved through a rigid body assumption, i.e., all the ice pack moves at the same speed and direction. Since the temporal decorrelation increases along the ULS track, any deviation from the rigid body assumption also results in spatial decorrelation manifesting itself as a positional error in the apparent IPS track where the cumulative error will increase over time.

Decorrelation in space and time limits the length of data segments that can be used for validation with relatively high confidence. Therefore, determination of the *correlation length* between data sets is required. Beyond this scale, the correspondence between ULS and SAR cannot be guaranteed, thus comparisons will no longer be valid. The correlation length will vary from scene to scene and one way to assess the correlation length is using the variability of ice drift vector field across the SAR scene, especially in the vicinity of the IPS track. This ice drift vector field can be estimated from consecutive scenes that were acquired within a relatively short period of time, e.g., 1-3 days. These scenes may be from different beam modes of RADARSAT-2 or even from different sensors (e.g., optical imagery). If multiple satellite scenes are not available, correlation length may be estimated from direct inspection of IPS track overlays on the satellite imagery. In this case, features that are easily recognized in both IPS and SAR datasets (such as floe edges) may be used as visual checkpoints on the coregistration of these data. Other ways to assess the correlation length or provide constraints are also considered.

If the rigid body assumption is valid, i.e., ice drift field is spatially not varying and is consistent with the ULS drift information, the confidence on the spatial correspondence is very high. However, the temporal decorrelation may still limit the correlation length, since for example the surface characteristics of the ice pack (as observed from above and from below) may have changed over time.

Satellite-based Sea Ice Characterization

There are a number of polarimetric parameters and a variety of techniques that were shown to be promising for classification of sea ice data. A selection of those, including polarimetric parameters derived from Cloude-Pottier eigenvalue decomposition (Claude and Pottier, 1997, Ferro-Famil *et al*., 2001; Scheuchl *et al*., 2001; Scheuchl *et al*., 2003b) and Freeman-Durden three-component scattering decomposition (Freeman and Durden, 1998; Scheuchl *et al*., 2002) will be used. In addition, Touzi decomposition (Touzi, 2007) and depolarization factors (Kim *et al*., 2012), polarimetric parameter (Gill and Yackel, 2012), and matrix distance measures (Dabboor *et al*., 2013) will also be investigated.

In order to use these techniques we will build on the capabilities of existing open source software tools for SAR polarimetry and commercial off-the-shelf (COTS) tools for remote sensing and image processing (e.g., PCI, ENVI), and custom software that was previously developed in-house. The pre-processing of the RADARSAT-2 quad-pol data will include speckle reduction, e.g., Refined Lee filter (Foucher and Lopez-Martinez, 2009). This will be followed by the analysis of the RADARSAT-2 data for detection and characterization of hazardous ice features. Validation data sets obtained through combining SAR, ULS and corresponding ice characterizations will then be used for the assessment of satellite-based techniques. The assessment will primarily be performed using hazardous ice characterizations, but may also include relationships to the SAR parameters.

Development of Improved Data Products

This project aims to develop improved algorithms for sea ice characterization that will lead to enhanced data products. This work will be based on the results obtained by the assessment of standard algorithms and may include improvements to existing algorithms, calibration, or new algorithm development.

An extension of the quad-pol data analysis to other beam modes (i.e., dual-pol and/or compact-pol) will also be performed. Simulated compact polarization (CP) data will be generated from RADARSAT-2 quad-pol data using the Canada Center for Remote Sensing (CCRS) software (Charbonneau et al., 2009). We will then use the analysis techniques for compact polarimetry such as m-delta decomposition, degree of polarization, and circular polarization ratio (Raney, 2007). The assessment of the CP modes will be performed with respect to the quad-pol analysis.

Preliminary Results

Regions of Interest and Data sets

ASL has access to ULS data owned by various parties including the Oil and gas industry (i.e., Shell, ConocoPhillips, ExxonMobil, IOL, Statoil), the Canadian government (e.g., DFO), and international research institutes and universities (e.g., NOAA, ArcticNet, BREA, Norwegian Polar Institute, WHOI, etc.). For data acquisition planning, the availability of these data sets and the ice conditions they represent were taken into account. Hazardous ice types (e.g., large keels, hummocky ice, multi-year floes, and internal ice stress) typically present in these datasets vary by geographical region and the corresponding ice regime. Table 1, shows the expected hazardous ice types for ULS sites in different regions of interest.

Since spatial-temporal match-ups of ULS and RADARSAT-2 datasets are required, for each site the RADARSAT-2 archive was searched for FQ and FQW scenes. Resulting list of available scenes were then subject to an initial screening to remove any scene that corresponds to long episodes of open water. As a result, more than 60 archive acquisitions over 6 different ULS sites were obtained in the Chukchi and Beaufort Seas.

In addition to the archive data, RADARSAT-2 was tasked for new acquisitions (FQ and FQW beams) between June and November of 2013 over a selection of the ULS sites, where the instruments had been deployed previously (typically in Fall 2012) and were collecting data. These sites were selected based on the ice conditions and the satellite was tasked until the expected ice break-up or instrument recovery dates. However, conflicts with commercial users reduced the number of successful acquisitions especially for the sites owned by the industry. More than 60 acquisitions were completed over 15 sites in the Chukchi and Beaufort Seas, Byam Martin Channel, and NE Greenland. Most of the ULS instruments at these sites have recently been recovered (Fall 2013) and the data processing for this period is ongoing. These data will be available for analysis subject to permission from the owners.

Table 1. Expected hazardous ice types grouped by region of interest

Region	**Owner(s)**	**Expected Hazardous Ice Type**					**ULS Data archive (since 2007)**	**RADARSAT-2**	
		Large Keels	**Hummocky Ice**	**Multi Year Ice**	**Internal ice stress**	**Icebergs**		**archive (2011)**	**new acqusitions (2013)**
N. Chukchi - deep water	NOAA/DFO-IOS	x	x	x			2007-2013	33	12
Chukchi - shelf	Shell , CPAI, Statoil	x	x				2008-2013	7	-
Alaska Beaufort - shelf	Shell	x	x		x		2007-2013	12	-
Canadian Beaufort - shelf	DFO-IOS	x	x				2007-2013	10	6
Canadian Beaufort - slope	BREA	x	x	x			2011-2013	-	13
Byam Martin Channel	DFO-IOS	x	x	x	x		2012-2013	-	23
NE Baffin Bay	Shell	x				x	2011-2013	-	-
NE Greenland	NTNU/Statoil	x	x	x	x	x	2012-2013	-	5
NE Greenland	NPI	x	x	x			2012-2013	-	10
Nares Strait	DFO-IOS	x	x	x	x	x	2007-2012	-	-

Ice Characterization from ULS data

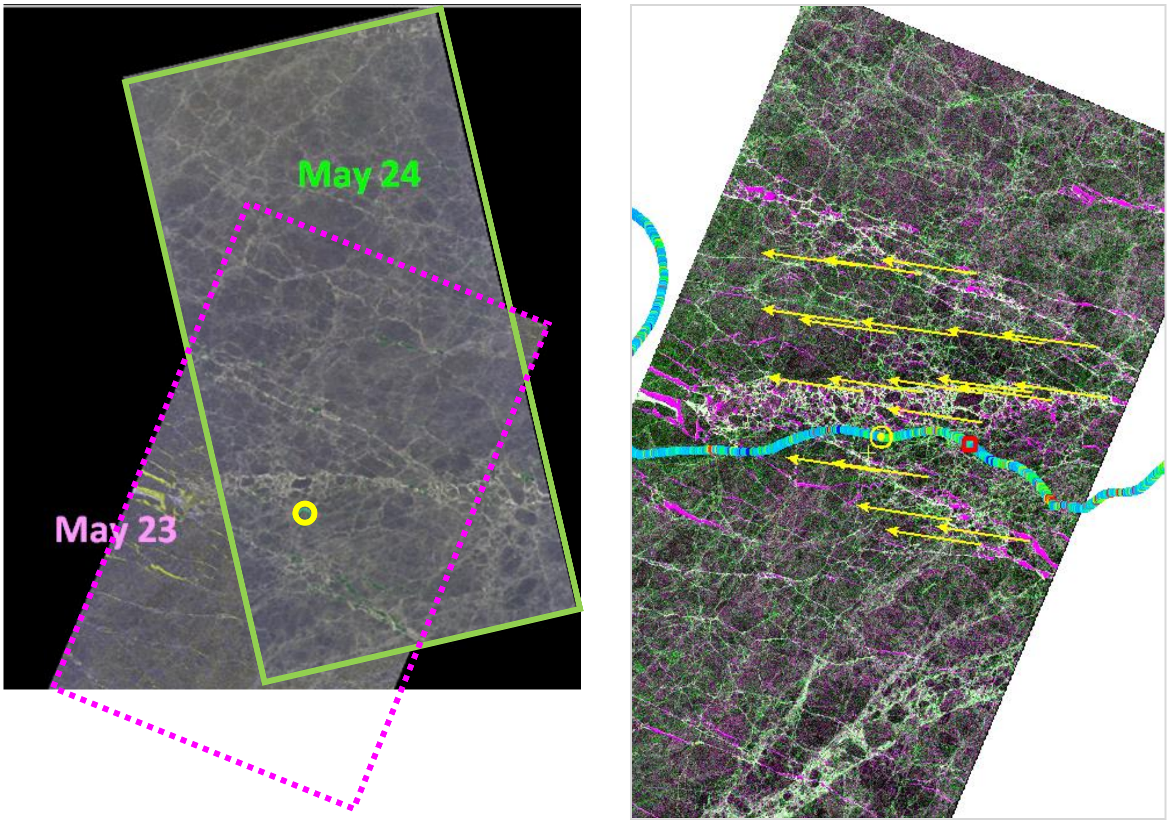
Previously processed ULS data were retrieved from the ASL archive with supporting data (e.g., currents, winds). The archive ULS datasets were then analyzed to characterize potentially hazardous ice features using the methodologies discussed above. The characterizations are reported for the period of interest where SAR data is available for each site. Based on the spatial extents and the acquisition time of the image, only a small subset of the ULS time series may correspond to each scene. A segment of the ice draft spatial series that correspond to each scene is extracted and reformatted. This allows the ice draft spatial series (i.e., IPS track) and characterization results to be overlaid on the image data.

Combining ULS and RADARSAT data: An Example

As discussed before combining two different data sources (i.e., ULS and satellite) is challenging and requires careful consideration due to spatial and temporal decorrelation between the data sets. Although, this task is work in progress, we present an example to showcase one of the scenarios where two consecutive satellite acquisitions are available.

In this case, two RADARSAT-2 FQ datasets were acquired over a ULS site in the Chukchi Sea (NOAA/IOS). The time difference between two acquisitions (May 23, 2011 and May 24, 2011) is about 10 hrs. The footprints for both scenes, the overlap area and the the position of ULS mooring (yellow) are shown in Figure 5(a). May-23 scene is chosen as the reference scene and the IPS track overlay is shown in Figure 5(b), where the ULS mooring position is marked yellow, and the relative position for May-24 is represented with the red marker.

The overlap between two acquisitions allowed us to generate an image-based drift vector field by identifying the same features (e.g., floes, ridges) in two consecutive scenes and their displacement. The drift vector field is shown in Figure 5(b) by yellow arrows near the ULS track. The statistics computed for this drift field presents a mean speed of 15.48 cm/s with a standard deviation of 0.05; and a mean direction of 278.4 degrees with a standard deviation of 0.31. Thus, it is concluded that the ice pack near the IPS track presents a coherent motion. This information is also consistent with the ice drift measured during this period using the ULS instruments. Thus, the rigid body assumption required for accurate spatial correspondence of the two datasets is valid for at least 10 hours, and the corresponding segment of the IPS track and the image data can be used for further analysis and validation purposes.



(a) (b)

Figure 5. An example for assessment of the correlation length (a) May-23 and May-24 data sets; (b) IPS track overlay on May-23 data and image based ice drift vector field (yellow)

Conclusions

In this paper, we presented an overview of an R&D project on characterization of hazardous ice conditions using Upward Looking Sonar and satellite SAR data. It is aimed to enhance information products by combining the “view from above” with the “view from below”. To date, archive and new data acquisitions from RADARSAT-2 have been completed and ULS moorings are underway including sites owned by government research organizations and the oil and gas industry. The project is still in early stages and the progress towards the stated goals is presented. This project is expected to (1) develop improved methods for fine scale analysis of RADARSAT-2 data; (2) develop enhanced information products generated in the hindcast mode when ULS and RADARSAT-2 are both available; (3) demonstrate potential for RCM (compact polarimetry).

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