PREPARATIONS BY THE CANADIAN ICE SERVICE FOR FUTURE EARTH OBSERVATION MISSIONS

Matt Arkett [(1)], Tom Carrieres [(1)], Tom Zagon [(1)] , Vladimir Zabeline [(1)] , Mark Buehner [(2)] , Alain Caya [(2)], Lynn Pogson [(1)] and Yi Luo [(1)]

[(1)] *Canadian Ice Service, 373 Sussex Drive, Ottawa, ON, Canada, K1A 0H3, Email: matt.arkett@ec.gc.ca*
[(2)] *Canadian Meteorological Centre, Dorval, QC, Canada, H9P 1J3, Email: tom.carrieres@ec.gc.ca*

ABSTRACT

The Canadian Ice Service (CIS) is responsible for the daily monitoring and reporting of sea ice, lake ice, and iceberg conditions in Canadian coastal regions and adjacent international waters. The CIS is also responsible for the Integrated Satellite Tracking of Pollution (ISTOP) program, monitoring Canadian coastal waters for the illegal discharge of oil from ships. To fulfil these mandates, the CIS relies primarily on satellite SAR imagery to prepare manual analyses and associated products.

The transition to the Sentinel-1 and RADARSAT Constellation mission (RCM) represents unique opportunities, challenges and potential risks to the CIS operational programs. Transitioning existing SAR-based operations into the constellation era is paramount, while concurrently expanding existing automated data assimilation and image classification systems to prepare routine analyses over all areas of CIS responsibility. These data assimilation systems, coupled with other advanced remote sensing techniques, will be further developed to take advantage of the more frequent coverage.

This paper will identify the new application and product development CIS expects to achieve through the unique capabilities provided by these missions.

1. INTRODUCTION

The recent decline in Arctic sea ice has increased the marine community's need for timely and accurate ice information services. The retreat of the sea ice during the last two decades is facilitating a large increase in oil and gas and mineral development, accompanied by increased shipping activity. The Canadian Ice Service (CIS), who serves a varied marine clientele, recognizes the growing need for its current products, but also the increasing requirement for new and leading edge sea ice products. In particular, as the marine industry adapts to these longer operational seasons there is a growing demand for short and long term sea ice forecasts. As the primary sea ice information provider in Canada, CIS is also committing to the continued improvement of our services to meet the needs of expanding Arctic development.

Earth Observation (EO) satellites have revolutionized the provision of ice information services by our national ice services. The advent of synthetic aperture radar (SAR) technology removed the reliance on daytime observations and the impact of clouds and weather on the ability to monitor sea ice conditions. However, SAR cannot answer the whole question and there is a strong need for data from visible and infrared sensors, passive microwave sensors, and scatterometers. The number of EO satellites in orbit continues to grow, with approximately 30 planned for launch in the next 5 years identified as capable for sea ice monitoring. This coupled with continued advancements in satellite ground segment technologies, means images are being made available to expert ice analysts in tens of minutes.

An increased availability of EO data is timely as ice services' areas of responsibility increase into uncharted territories, under the new World Meteorological Organization (WMO) METAREAS responsibility mandate to Arctic nations. Canada is now responsible for providing weather and ice information for METAREA regions XVII & XVIII (Fig. 1). The expansion of ice and weather information into these Arctic waters means mariners can now receive vital information about navigational and meteorological hazards in the harsh Arctic environment.

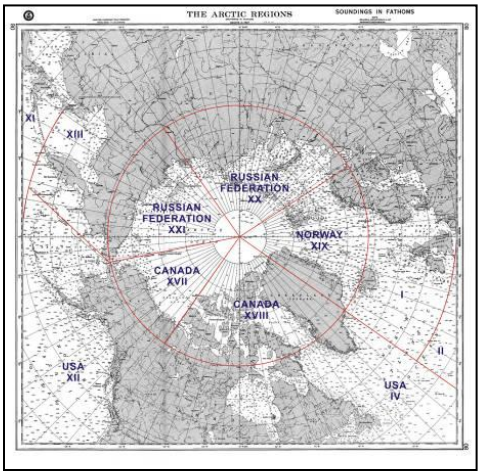

Figure 1. WMO/IMO Arctic METAREAS

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Although real time weather and ice observations are improving in the remote Arctic, they are difficult to obtain. There is a shortage of weather reporting stations in the Arctic and much of the real time atmosphere and ocean information is currently provided by ice and ocean buoys. EO satellites provide another valuable source of this information and are becoming an integral input to automated data assimilation systems. These data assimilation systems will provide an environment whereby imagery from numerous satellite sensors will be optimally combined with a numerical ice model to prepare objective sea ice analyses. The ice model will also use the high resolution analyses to produce more accurate ice forecasts.

2. UPCOMING SATELLITES FOR SEA ICE

The CIS uses a mixture of EO satellites to produce its ice information products. The upcoming SAR satellite constellations Sentinel-1 and the RCM will form the backbone of CIS' EO data for the future. Sentinel-1 is a two-satellite C-Band SAR constellation and is the first mission of the European Union (EU)-European Space Agency's (ESA) operational EO observation programme called Global Monitoring for Environment and Security (GMES). Sentinel-1 is the first of five new Sentinel missions and will provide radar imaging for ocean, land and emergency services. The Sentinel-1 series can operate in four exclusive imaging modes with different resolution and coverage capabilities: Extra Wide Swath (EWS), Interferometric Wide Swath (IWS), Stripmap Mode (SM), and Wave Mode (WM). IWS and EWS will be the preferred modes over oceans. These will benefit marine services with reduced revisit times, geographical coverage and rapid data dissemination over the marine domain [1].

The RCM is the third mission in the Canadian RADARSAT series. At full complement, RCM will have three C-Band satellites in orbit, providing near daily SAR coverage in all Canadian waters. The primary objective of the mission is to support the operational requirements of Canadian government departments in the following priority areas: maritime surveillance, disaster management, natural resources management, and northern development. RCM has ten available beam modes with three primarily identified for wide area ice monitoring: Low resolution, Medium Resolution and Low Noise modes. Of particular interest is the availability of compact polarimetry (CP) on the RCM. CIS' current research in CP is discussed in Section 4.2.

Although SAR imagery is the primary data set used at CIS, cloud free VIS/IR, passive microwave, and scatterometer data are all important data sources when creating ice information products. MODIS data is extensively used by CIS ice analysts and forecasters, and therefore the recent launch of SUOMI-VIIRS is of particular interest. VIIRs will provide valuable information for both visual analysis and as input into data assimilation routines. AMSR-2 and ASCAT data on board GCOM-W and METOP-B respectively, will also provide valuable inputs to data assimilation.

3. DATA ASSIMILATION

Sea ice analyses are prepared for a variety of purposes including marine transportation planning, sea ice model initialization, specifying the boundary conditions for numerical weather prediction (NWP) models, and climate monitoring. In Canada, analyses to assist the planning of marine transportation and other marine activities are currently produced by a highly manual and time consuming process involving expert analysis of a wide variety of satellite, aircraft and *in situ* observations [2]. Such manual analyses are produced operationally in near real-time by the CIS and include the ice concentration and thickness distribution [3].

A central ice modelling project currently under development at CIS is an automated sea ice analyses system called the Regional Ice Prediction System (RIPS). RIPS is primarily aimed at satisfying the requirements for planning of marine transportation and other marine operations in ice-infested waters around North America, including for Canada's two arctic METAREAs; regional sea ice model initialization, and for the needs of regional numerical weather prediction models [2]. The current system does not employ a sea ice model and instead persists the previous analysis as the background state. There are four analyses produced daily, valid at 0, 6, 12, and 18 UTC. The 6 UTC analyses has proven to be a useful update to the CIS daily ice charts that are produced for CIS clients at 18 UTC. Fig. 2 is an example of the North American RIPS output product.

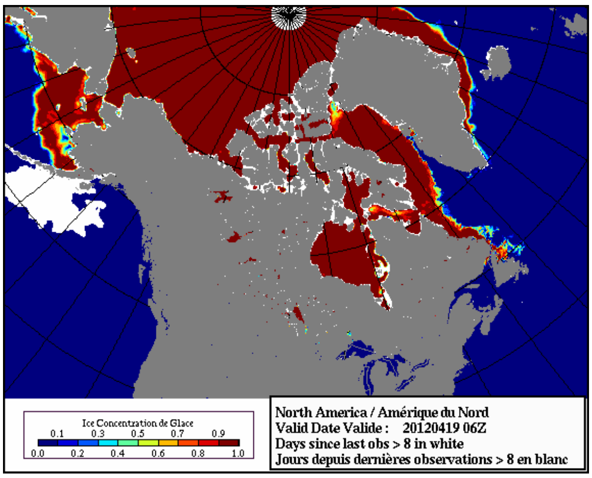

Figure 2. North American RIPS product

Presently, RIPS uses a three-dimensional variational approach to assimilate observations from two passive microwave sensors; AMSR-E aboard the Aqua satellite and SSM/I onboard the DMSP satellite F15. Ice concentration values from CIS daily ice charts and RADARSAT image analyses are also assimilated in the system.

Recent collaborative efforts of CIS and its MSC partners has focused on the state of the art sea ice model CICE 4, and its use in coupled modelling of the Arctic, boundary conditions for NWP, and in sea ice data assimilation. The CICE 4 model will be included as the forecasting component of RIPS in winter 2012-13. In addition to forecasts, RIPS 2.0 will include the assimilation of SSM/IS and ASCAT data. Later in 2013, RIPS will incorporate the model into the analysis cycle, thereby improving the analyses.

Research for the assimilation of other sensor data is underway for future versions of RIPS, including SAR data assimilation. The method being employed to convert the imagery into ice/water classes is called Grey Level Co-Occurence Matrix, which uses not only the individual backscatter values, but hte pattern of hte surrounding area as well. A large amount of RADARSAT-2 data (September 2010-2011) is being analysed to determine the ice and water signatures for varying conditions, including geographic influence, environmental conditions, and instrument effects. The addition of SAR data into RIPS is expected to mark a significant improvement in the RIPS output, with benefits in resolution and coverage.

4. REMOTE SENSING RESEARCH

The following section describes the current remote sensing research initiatives underway at CIS, in anticipation of the upcoming SAR constellations and other current and future EO missions relevant to sea ice monitoring.

The assimilation of remote sensing data will be a valuable advancement in sea ice analysis for CIS. The development of advanced remote sensing techniques is also a strong research thrust at CIS, in particular the exploitation of SAR data. The Sentinel-1 and RCM constellations will significantly increase the amount of imagery available to CIS in the Canadian marine domain on a yearly basis.

4.1. Automated SAR Classification

The automated classification of SAR imagery is an ongoing research problem in the sea ice domain. It is a complex and challenging task, but it is hoped that once successful, it will permit for better use of the analyst's skill and time by allowing them to concentrate on quality control and on operationally important areas.

There are two different methodologies being presently examined for automated or semi-automated classification. One methodology, being developed in conjunction with MDA Systems Ltd, derives sea ice information from co- and cross-polarized (HH and HV) ScanSAR Wide RADARSAT-2 images using a multichannel data fusion algorithm. This method is designed for sea ice-water separation and sea ice type classification using spectral and textural information from both the HH and HV channel.

The second methodology being examined uses the MAp-Guided Ice Classification (MAGIC) software system has been designed and built by Prof. David Clausi at the University of Waterloo. MAGIC is the development platform used to implement the necessary computer vision algorithms to solve the current ice/water classification problem using RADARSAT-2 SAR imagery. The software uses a scene classification algorithm to segment an image into homogeneous regions and assigns each region to an unlabeled finite number of classes [4]. To classify a full SAR scene, classification is first performed on each polygon separately, then the polygons are 'glued' together to create a full classified scene. The gluing is performed by changing the polygon boundaries to region boundaries and then running the algorithm on the full scene to merge regions across the new boundaries. Given the local nature of the custom polygon classification followed by the global classification ("gluing"), this technique is referred to as the 'glocal' approach [5]. Fig. 3 illustrates the improvement in the segmentation result when both image channels are used.

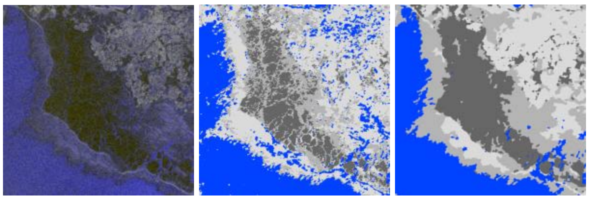

Figure 3. HH/HV Composite image on far left; HH Segmentation result in middle; HH/HV Segmentation result on far right

Fully automated classification is a challenging problem that requires a multi-faceted solution. Whichever method (or combination of methods) proves to be most effective, it will need to consistently work for many different ice types and in different seasons.

4.2. Compact Polarimetry

The availability of a compact polarimetry mode aboard the RCM provides an exciting alternative to current single- and dual-polarization SAR modes. With compact polarimetry, or coherent dual-polarimetric SAR, only one polarization is transmitted and two orthogonal polarizations are received. Compact polarimetric radars require that the relative phase between the two receive polarizations be retained [6], in distinct contrast to conventional ‘‘dual-polarized’’ SARs in which the relative phase is not available. The major motivation for compact polarimetry is to strive for quantitative backscatter classifications of the same finesse as those from a fully polarized system while avoiding the disadvantages associated with a quadrature-polarimetric (quadpol) SAR. The fundamental data product from a compact polarimetric radar is a complex target vector of the backscattered field, which in turn may be transformed into the Stokes vector. Either form captures all of the information contained in the observed electromagnetic (EM) field [7].

The Canada Centre for Remote Sensing (CCRS) has developed specialized software which utilizes fully polarimetric R-2 data and simulates the compact polarimetry mode to resemble the pixel size, number of looks, and noise floor values of proposed RCM ScanSAR modes. In order to characterize all of the different ice types found in Canadian waters, CIS is acquiring R-2 polarimetric imagery in different ice regimes at different times of the year.

The Stokes parameters are based on right-circular transmit linear receive, providing horizontal (RH) and vertical (RV) linear representations (Eq. 1). Second-order parameters are also known as child parameters.

$$
\begin{aligned}
S_1 &= \left\langle |E_H|^2 + |E_V|^2 \right\rangle \\
S_2 &= \left\langle |E_H|^2 - |E_V|^2 \right\rangle \\
S_3 &= 2\,\mathrm{Re}\left\langle E_H E_V^* \right\rangle \\
S_4 &= -2\,\mathrm{Im}\left\langle E_H E_V^* \right\rangle
\end{aligned}
\qquad (1)
$$

The following CP parameters are derived from the polarimetric data: Stokes vectors, the horizontal (RH) and vertical (RV) backscatter, the right (RR) and left (RL) polarized waves, the relative phase of RH and RV (also known as the *delta* (δ) parameter, the degree of polarization (m), the circular polarization ratio, the ellipticity, RV/RH, RR/RH, RL/RH and RR/RL. Decomposition products (eg. m-delta and CPSeaIce) are also created and contain child parameters.

Early results show that each CP parameter has separation potential for sea ice types and open water but incidence angle is a strong determinant [8]. Detailed statistical evaluation for defined incidence angle ranges is being performed and will provide robust quantitative measures as well as identifying the best incidence angle ranges within which to employ a particular CP parameter. Fig. 4 shows a comparison between a single-polarization HH image versus the CPSeaIce decomposition product.

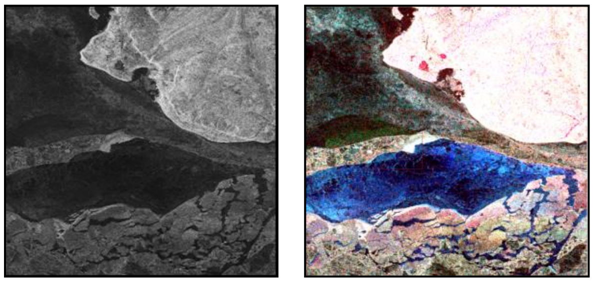

Figure 4. Comparative example of single-pol HH image on left with CPSeaIce decomposition product on right.

4.3. SAR Ice Motion

The CIS’ Automated Sea Ice Tracking System (CIS-ASITS) computes the two main components of ice movement (translation and rotation) from two overlapping SAR images that are sequential in time (Fig. 5). The CIS-ASITS employs a phase-correlation approach to estimate both the translational and rotational components of any sea ice motion [9]. The original algorithm has recently been ported to a new language in an effort to increase the computational speed and make it ready for full operational implementation. CIS hopes to run this algorithm on many or all incoming SAR images.

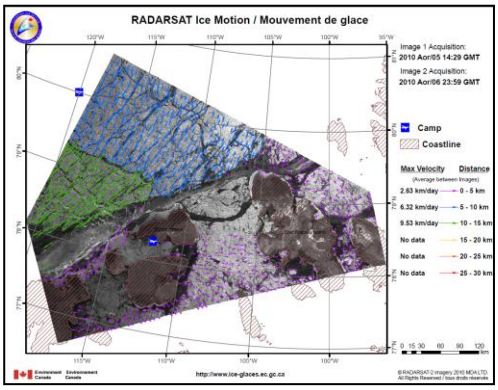

Figure 5. Sample CIS-ASITS product

4.4. Data Fusion

Two critical issues are related to this increase in data: How to fully exploit the data from different sensors and how to efficiently automate data processing and produce useful products. Research is underway at CIS looking at the fusion of MODIS and AMSR-E data (Fig. 6) using a regression based method; and an IHS based method to fuse RADARSAT-2 and MODIS. These methods will be transferable to future sensors.

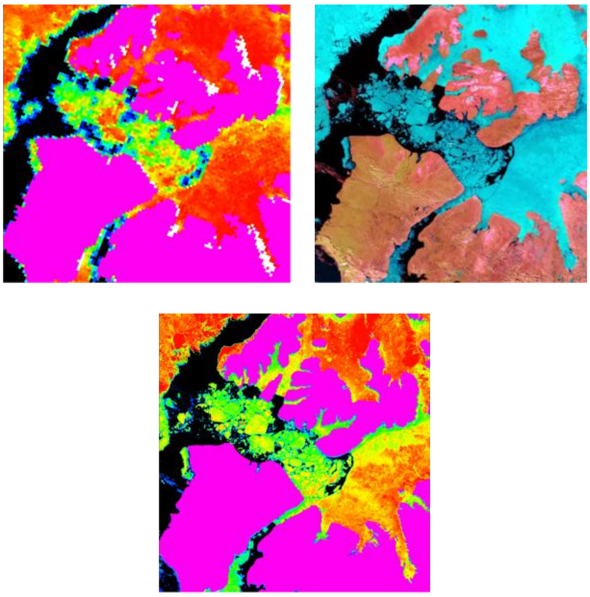

Figure 6. Bottom image represents fusion result from AMSR-E and MODIS data from the same day.

5. CONCLUSION

The upcoming increase in the availability of EO data to national ice services will present unique opportunities and challenges to sea ice monitoring. The goal will be to exploit these data to their fullest and extract as much relevant information as possible. The use of automated methods is key to achieving this goal and will require development in both data assimilation and advanced remote sensing methods. The CIS acknowledges this need for automation and as such is developing several different approaches with its key government, academic and private industry partners.

6. REFERENCES

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