Project Title: Improved Sea Ice Forecasts Through Classification and Assimilation of SAR Imagery

Context:

As global temperatures rise, exploration is increasing for oil, gas, and minerals in areas previously considered inaccessible due to ice cover. The ice conditions on the east coast of Canada are also becoming less predictable due to global warming. Safe operations in ice-infested waters are critically dependent on an accurate estimate of the ice state.

Currently, forecasts of the sea ice state for navigation are prepared through visual inspection by trained analysts of high-resolution satellite imagery from synthetic aperture radar (SAR) sensors. This is very time consuming, and for this reason automated tools are being developed. Ideally, these automated tools would be used both for ship routing and for improved weather forecasts in ice-covered regions.

Two methods are currently being investigated at the Canadian Ice Service (CIS) to generate automated sea ice analyses. These are:

1) Automated classification of sea ice types using SAR imagery
2) Assimilation of SAR imagery within a sea ice data assimilation system.

The objective of the proposed research is to develop a method to incorporate the classification output from 1) into the data assimilation system of 2).

The automated classification of sea ice types using SAR imagery is the "holy grail" of remote sensing problems, identified when SAR first captured sea ice imagery, and an unsolved problem to this day. A solution to this problem has been accelerated via the HV-polarization data (horizontal - transmit, vertical - receive) now available from RADARSAT-II to complement the HH-pol data RADARSAT-I provided. The HV-pol is not as sensitive to incidence angle changes in backscatter as the HH-pol. However, the HV-pol does not effectively discriminate new ice and open water. RADARSAT-II is a satellite owned and operated by a Canadian company, MDA Corporation, and its data is used extensively (5000+ scenes each year) by CIS to map all ice-infested waters in and around Canada. Over the last year, through an advanced computer vision algorithm, significant progress has been made solving the CIS-defined problem of identifying ice and open water uniquely given any SAR sea ice scene (Fig 1).

Fig. 1 SAR scene captured June 23 2010 in Beaufort Sea. *Left*: HH-pol. *Middle*: HV-pol. *Right*: Scene segmented into ice (aqua) and water (blue) using MAGIC software package developed by Prof. Clausi at the University of Waterloo. Processed scenes are 2.5k x 2.5k pixels and are reduced in size here for presentation. Land in bottom right corner.

Sea ice classification data is critical for ship routing and operations in ice-infested waters. However, discrete data of this nature cannot be used directly in operational data assimilation systems, which are designed for continuous fields (e.g., sea ice concentration). This means that classification data cannot be used at the present time in the Regional Ice Prediction System (RIPS) being developed jointly by CIS and the Meteorological Service of Canada (MSC) [1]. RIPS is an operational system currently providing forecasts of sea ice concentration every six hours. The sea ice forecasts are based on the assimilation of coarse-resolution passive microwave data and ice charts (which are treated approximately as continuous fields). Coarse-resolution data cannot represent open water areas within the ice (e.g., leads) or the details of the marginal ice zone. Sea ice models also suffer considerable shortcomings in these respects [2]. Assimilating high-resolution classification data would provide significant improvements. The assimilation of SAR data would provide an even more significant positive impact relative to VIS/IR data [3] because there is a greater quantity of data due to the insensitivity of microwave data to cloud cover and illumination conditions.

Accurate representation of the sea ice state is critical for weather forecasts in ice-covered regions [4]. The transfer of heat and moisture from the ocean to the atmosphere is dependent on the sea ice thickness and the presence of open water in the ice pack [5]. Canada has a new responsibility to provide weather forecasts to the international community over two areas of the Arctic Ocean (METNAV areas XVII and XVIII), which the RIPS system has been designed to include. The assimilation of high-resolution SAR data in should have a positive impact on weather forecasts.

Research approach and desired outcomes

An ice classification algorithm has been implemented within the software package MAGIC (MAp-Guided Ice Classification) developed by Prof. Clausi at the University of Waterloo [6]. MAGIC encompasses years of scene classification research and its key algorithm, IRGS [7-9], is able to take large SAR scenes (2.5k x 2.5k pixels) and robustly break them into homogeneous regions using the HV-pol. The current research effort involves the automatic assignment of ice or water labels to each of the regions using a support vector machine (SVM) classifier with texture features. The algorithm has been tested on 60 dual-pol scenes with an overall accuracy of 95%.

The ice classification algorithm will grow according to two objectives. First, the ice/no ice algorithm will be improved by dedicated training by region and by time-of-year. The second objective, which can be done in parallel, is to break down the ice into standardized World Meteorological Organization (WMO) ice types [10], such as multi-year ice, grey ice, grey-white ice, etc.

A method will be developed to assimilate the ice/no ice classification data in a continuous background state (ice concentration). The focus at this early stage will be on the forward model (the model that maps the continuous background state to the discrete observation space) and the error distribution associated with the observations. Experiments will be carried out first in a twin experiment setting (where the truth is known and observations are selected from the truth and perturbed before assimilation), and then using real observational data (classification results from MAGIC). Results from the assimilation of the classification data will be compared with a related initiative, which is the assimilation of texture features from SAR [11]. Knowledge gained will be shared with the data assimilation group at Environment Canada through regular monthly online or in person meetings. The desired outcome at this stage is a prototype system for ice/no ice data that could be transferred to RIPS.

User Involvement and External Partnerships

This project will involve a close collaboration between academic researchers at the University of Waterloo, the Data Assimilation Research Group at Environment Canada, and the Canadian Ice Service at Environment Canada. The project will be supported by data and in-kind contributions by MDA Corporation.

Relationship with MEOPAR strategic objectives

This project is directly aligned with several of MEOPAR's goals, such as promoting an operational network for marine observation, improve sharing of information and knowledge between academia and government, and contributing fundamental research on the development of an improved ability to predict risk. The project would contribute to the development of new tools that could be used to provide forecasts during marine environmental emergencies. It is complementary to the existing MEOPAR project 1.1 – A Relocatable Coupled Atmosphere-Ocean Prediction System.

We will work directly with CIS and directly support their mandate "At the Canadian Ice Service (CIS), our mission is to provide the most accurate and timely information about ice in Canada's navigable waters. We work to promote safe and efficient maritime operations and to help protect Canada's environment" (http://www.ec.gc.ca/glaces-ice) which directly supports MEOPAR strategic objectives.

Long Term Vision of Project

The funds requested at this stage are for a one-year project, with the funds being allocated for the training and support of HQP who are PhD students at the University of Waterloo. The nature of the data assimilation work at this stage is fundamental. If the method is successful for the assimilation of binary data, it will be extended to assimilate discrete data, namely the ice type category classification results being proposed by Prof. Clausi. In sea ice analyses, ice type categories are mapped to ice thickness values. Ice thickness is one of the most critical parameters needed to guide a ship safely through ice, and is one of important for weather forecasts in ice-covered regions, but it is very difficult to estimate from remote sensing data using current operational sensors.

The proposed project will lead to improvements in the automated classification of sea ice from SAR imagery, and the development of a new method to assimilate this data in an operational sea ice data assimilation system to provide information both to CIS and MSC. This is a timely proposal, as the recently approved Constellation mission will involve four satellites each carrying a SAR sensor, leading to improved response time and much greater quantities of SAR data. Building algorithms to ingest and analyze this data will allow optimal return on the investment Canada is making in the Constellation mission.

Budget

Category	**Year 1**
Personnel (2 full-time PhD students)	42K
Materials, Supplies, Dissemination	3K
Travel	7K
Equipment	0K
Totals	52K

Research Team

Andrea Scott (Assistant Professor University of Waterloo – UW) specializes in the assimilation of passive microwave, AVHRR and SAR data to improve short-term forecasts of sea ice concentration and thickness. She is currently an assistant professor in the Department of Systems Design Engineering at the University of Waterloo. Prior to her appointment at the University of Waterloo she was a postdoctoral researcher in the Data Assimilation and Satellite Meteorology Research Section at Environment Canada.

David Clausi (Professor, University of Waterloo - UW) specialized in the field of computer vision. He started his academic career in 1997 as an assistant professor in Geomatics Engineering at the University of Calgary. In 1999, he became a faculty member at UW and is now a professor specializing in the fields of Intelligent and Environmental Systems. Prof. Clausi is an active researcher with an extensive publication record, publishing over 50 refereed journal and over 70 refereed conference papers in diverse fields. His research efforts have led to successful commercial implementations including creating, building, and selling his own company. His key research project is the automated interpretation of sea-ice in SAR imagery in support of Canadian Ice Service operations. He was the Co-chair of IAPR Technical Committee 7 – Remote Sensing during 2004-2006. He has received numerous scholarships, paper awards, and two Teaching Excellence Awards. As examples, he received the 2010 award for "Research Excellence and Service to the Research Community" by the Canadian Image Processing and Pattern Recognition Society (CIPPRS) and he was awarded the 2012 Engineering Research Excellence Award in the Faculty of Engineering at UW.

Mark Buehner (Research Scientist, Canadian Meteorological Center - CMC) specializes in data assimilation for both atmospheric and sea-ice applications. He is the scientific lead for the development of sea-ice data assimilation systems at Environment Canada as part of the CONCEPTS and METAREAS operational forecasting systems. He is also internationally recognized for his research in variational data assimilation for numerical weather prediction. M. Buehner is currently a Research Scientist at Environment Canada in the Data Assimilation and Satellite Meteorology Research Section.

Tom Carrieres (Ice Modelling Manager, Canadian Ice Service – CIS) has extensive experience in sea ice modelling and operations, having worked at the Canadian Ice Service since 1986 in a variety of roles. He leads a team of physical scientists involved in: sea ice modelling and data assimilation; iceberg drift and deterioration models; and, extended range ice forecast models. He has managed a variety of externally funded ice modelling research projects over the past 15 or so years, averaging about $1 M/year

Matt Arkett (Acting Remote Sensing Manager, Canadian Ice Service) is responsible for providing technical, analytical and/or strategic advice on remote sensing issues related to CIS operations. Mr. Arkett graduated from the University of Waterloo with a BES in Geography in 1998. Upon graduation, Mr. Arkett accepted a position with the CIS in the Applied Science group. He has extensive experience in the analysis of SAR data, in particular C- and L-Band. He has also worked in the Forecast/Operations group at CIS, primarily responsible for satellite ordering related activities.

Christian Nadeau (Engineering Manager - Research & Development, MDA). has 15 years of R&D experience (remote sensing, requirements analyst, software life cycle), over 10 years experience as technical team lead, and was the project engineer for MDA sea ice mapping R&D.

References

1) M. Buehner, A. Caya, L. Pogson, T. Carrieres and P. Pestieau, "A new Environment Canada regional ice analysis system", Atmosphere-Ocean, DOI: 10.1080/07055900.2012.747171, 2012.
2) Johnson, M. Proshutinsky, A., Aksenove, Y. Nguyen, A.T., Lindsay, R., Haas, C., Zhang, J., Diansky, N., Kwok, R. Maslowski, W., Hakkinen, S., Ashik, I. and de Cuevas, B., "Evaluation of Arctic sea ice thickness simulated by Arctic Ocean Model Intercomparison Project model", Journal of Geophysical Research, 117, C00D13, doi:10.1029/2011JC007257, 2012.
3) Scott, K.A., M. Buehner, A. Caya and T. Carrieres, "A preliminary evaluation of the impact of assimilating AVHRR data on sea ice concentration analyses", Remote Sensing of Environment, in press.
4) Drusch, M., "Sea ice concentration analyses for the Baltic Sea and their impact on numerical weather prediction", Journal of Applied Meteorology and Climatology, 45, 982-994, 2006.
5) Maykut, G.A., "Energy exchange over young sea ice in the central Arctic", Journal of Geophysical Research, 83, C7, 3646-3658, 1978.
6) Clausi, D.A., Qin, K., Chowdhury, M.S., Yu, P. Maillard, P. (2010) MAGIC: MAp-Guided Ice Classification, *Canadian Journal of Remote Sensing*, 36(S1), pp. S13-S25.
7) Qin, K. and Clausi, D.A. Multivariate image segmentation using semantic region growing with adaptive edge penalty, *IEEE Transactions Image Processing*, 19(8), pp. 2157-2170, 2010.
8) Yu, Q. and Clausi, D.A. IRGS: MRF based image segmentation using edge penalties and region growing. *IEEE Transaction Pattern Analysis and Machine Intelligence*, 30(12), pp. 2126-2139, 2008.
9) Yu, Q. and Clausi, D.A. SAR sea-ice image analysis based on iterative region growing using semantics, *IEEE Transactions on Geoscience and Remote Sensing*, 45(12), Part I, pp. 3919-3931, 2007.
10) MANICE - Manual of Standard Procedures for Observing and Reporting Ice Conditions. https://www.ec.gc.ca/glaces-ice/4FF82CBD-6D9E-45CB-8A55-C951F0563C35/MANICE.pdf. Issued by the Meteorological Service of Canada, pp. 146.
11) Scott, K.A., Z. Ashouri, M. Buehner, L. Pogson, and T. Carrieres, "Assimilation of SAR data in the marginal ice zone" To be presented at the 2013 IEEE Radar Conference, Ottawa, Canada.

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