Operational Evaluation of a Knowledge-Based Sea Ice Classification System

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ABSTRACT

ARKTOS (Advanced Reasoning Using Knowledge for Typing of Sea Ice) is a fully automated intelligent sea ice classification system. ARKTOS is in use at the U.S. National Ice Center (NIC) for daily operations related to the NIC'S task of mapping the ice covered oceans. ARKTOS incorporates image processing, input from ancillary data, and artificial intelligence (AI) to analyze and classify RADARSAT Synthetic Aperture Radar (SAR) imagery. The NIC and Naval Research Laboratory (NRL/ERIM) have been testing and evaluating ARKTOS through the freeze-up, winter, melt-out and summer seasons of the Beaufort Sea. In this paper we outline the development and evolution of ARKTOS, evaluate current output, and discuss future implementation.

Introduction

The U.S. National Ice Center (NIC), under sponsorship of the U.S. Navy, U.S. Coast Guard, and National Oceanic and Atmospheric Administration (NOAA), is tasked with mapping the ice covered oceans of the world using both remotely sensed and in situ observations. Synthetic Aperture Radar (SAR) data became a major input to the program after the November, 1995 launch of the Canadian RADARSAT Satellite [1]. The NIC acquires RADARSAT data primarily from the Alaska SAR Facility (ASF) at Fairbanks, but also acquires a limited amount of imagery under contract from Tromso, Norway, and West Freugh, Scotland, and from the Gatineau station mask through a bilateral data exchange agreement with the Canadian Ice Service (CIS). Almost 1 GB of RADARSAT data per day is currently received at the NIC. In order to make efficient use of this large volume of data, the NIC has been actively involved in the development of algorithms that can assist in the analysis of sea ice using SAR.

The University of Kansas (KU) began to study the use of expert systems in sea ice classification from SAR under a NASA graduate student fellowship in 1990. The work continued in 1992 and 1993 under a NASA Mission to Planet Earth grant, and produced various techniques to measure and identify sea ice features in SAR imagery [2,3]. Of particular interest to the NIC was a system that classified winter sea ice into three major classes using dynamic thresholding and expert rule-based systems. It is this system that has evolved into the versions of ARKTOS that are currently in operational use at NIC and in research use at NRL.

System Description

ARKTOS (Advanced Reasoning using Knowledge for Typing Of Sea Ice) is a sea ice classification system that incorporates image processing, ancillary data, and knowledge based rules to interpret RADARSAT SAR images. Figure 1 displays a flow chart of the ARKTOS system as it is currently implemented.

ARKTOS first segments the input image using a Watershed region-growing technique based on image gradients into an initial set of regions. These initial regions are then merged based on area, average intensity, and strength of common boundaries [4] into contiguous regions call features. For each feature, ARKTOS computes a series of measurable descriptors, or attributes, such as area, average intensity, texture, and measures of shape (roundness, jaggedness, etc.). Facts regarding each feature are generated by quantizing the calculated attribute values into symbols based on a thresholding of the descriptor values [5]. For example, if a feature has an average intensity less than 25.0, then intensity (feature) = 'black'.

During the classification phase, the Dempster-Shafer rule-base engine reads the facts generated for each feature and matches the facts to rules in the rule-base by looking for satisfied conditions. After matched rules are fired, the engine combines the evidence and gives the belief and plausibility values for a feature to be in one of five ice surface classifications: multi-year ice, first-year ice, fast ice, open water/new ice, and unknown. ARKTOS then assigns the feature to the ice surface classification with the highest product of the plausibility and belief values.

The rule-base was originally generated from a series of knowledge engineering experiments, in which sea ice geophysicists from the NIC and the Canadian Ice Service (CIS) were interviewed and asked, in a variety of ways, to describe sea ice [6]. The collective 'experience' of these geophysicists was then transcribed and converted into the measurable descriptors used in the analysis of each feature. The rule-base has been fine tuned over the course of the system evaluation to correct misinterpretations introduced by the knowledge engineering process. Ancillary data, such as the NASA Team ice concentration from the Special Sensor Microwave/Imager (SSM/I) and a land mask, were also added to the system, and additional rules were developed to exploit these new information sources.

Current Status

One of the distinguishing features of the ARKTOS classification system is that it provides the user with a variety of graphical tools that allow for easy fine-tuning of its rule base. This feature gives the user great flexibility in the application of ARKTOS to varying ice regions and seasons. Initially, the rule base of ARKTOS was tuned to operate in the Beaufort Sea in the winter season. Initial quantitative results have indicated that the system performs well in areas of first year and multiyear ice during this time. ARKTOS classifications were compared to manual classifications performed by ice analysts at NIC for six winter Beaufort RADARSAT images. The average percent error between the ARKTOS classifications and the manual classifications was 12%.

More recently, ancillary data, in the form of NASA Team algorithm ice concentration fields from the Special Sensor Microwave/Imager (SSM/I) and a land mask, were added to the system. The addition of the SSM/I input, and the development and application of appropriate SSM/I rules in the rule base, has greatly enhanced the ability of ARKTOS to correctly classify areas of water with unusually high backscatter return. An example of this improvement is presented in Figure 2. The addition of a land mask to the system, and of appropriate coast oriented rules, has also improved ARKTOS' segmentation and classification of ice features adjacent to landmasses.

In preparation for the upcoming Arctic summer season, work has just been completed on the fine-tuning of a rule base for summer in the Beaufort Sea. The summer season represents a unique set of classification difficulties, due to intermittent backscatter inversion and the loss of floe boundary definition in the ice pack and at the ice edge. Figure 3 represents an example of ARKTOS' classification prior to and after the addition of a fine-tuned set of summer rules to the rule base.

Future Implementation

In the near future, work will begin on the separation of the new ice and open water classes. Examination of the segmented imagery over time has indicated definition between the two surface types, so a new rule base will be generated which exploits these differences. Further improvements in classification will also result from the integration of NIC historical climatology into ARKTOS. The area of ARKTOS operation will also be extended to other regions of NIC interest in the Arctic, and to other sensors, such as the Japanese ALOS and Europe's ENVISAT, when data from these sensors become available.

References

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Acknowledgements

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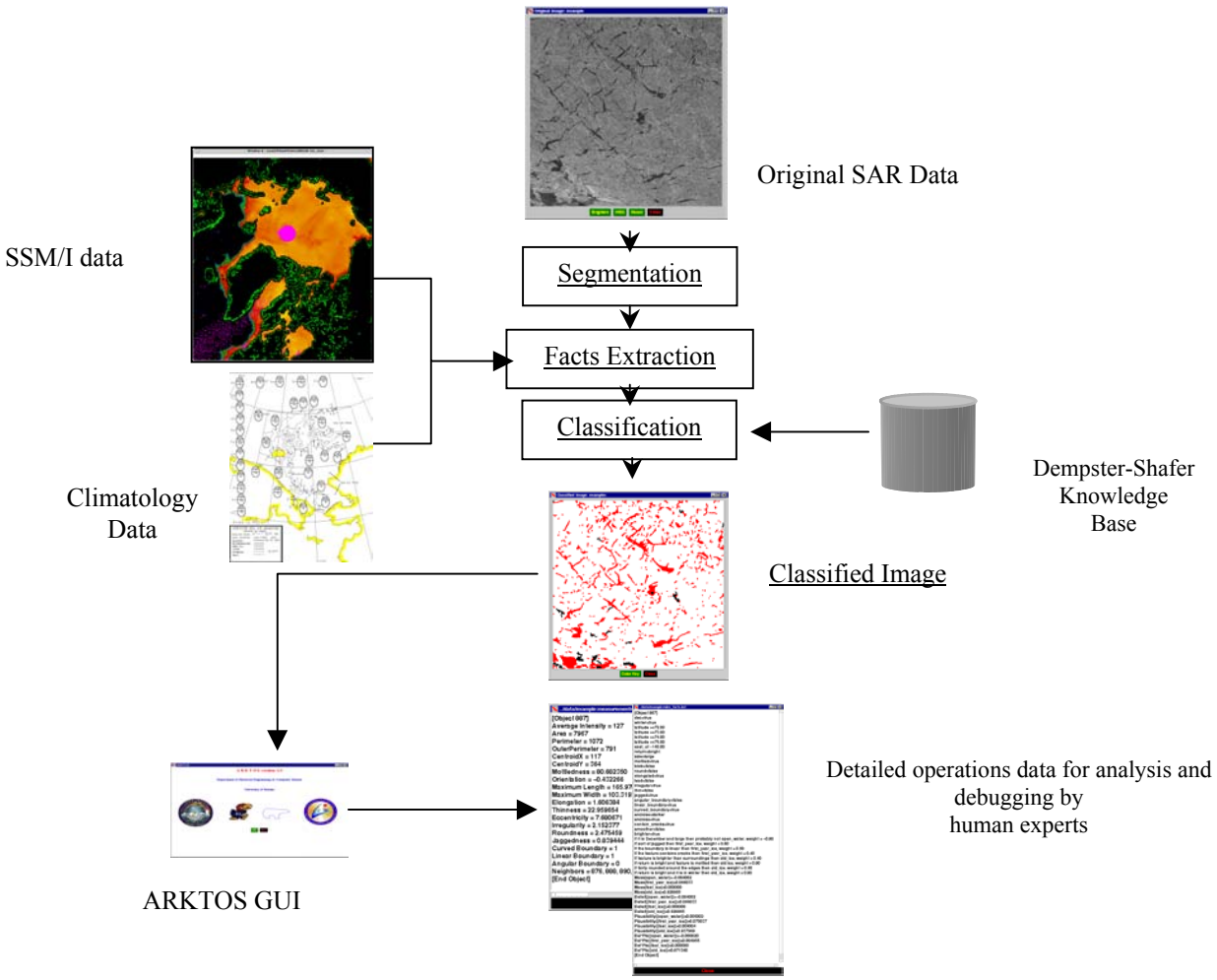
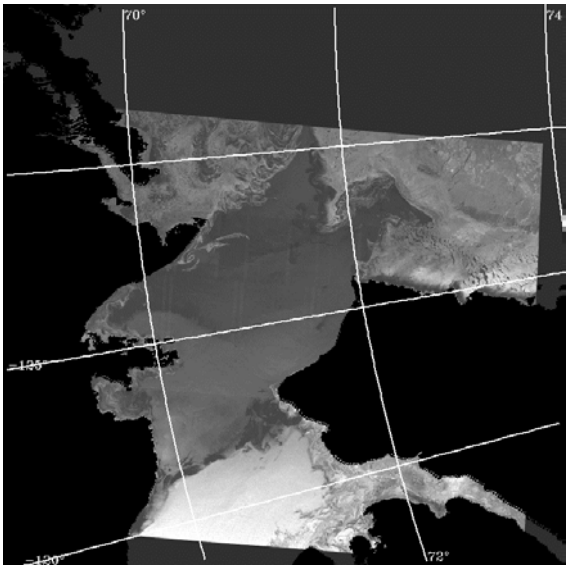


Figure 1: ARKTOS system flow chart.

(a)



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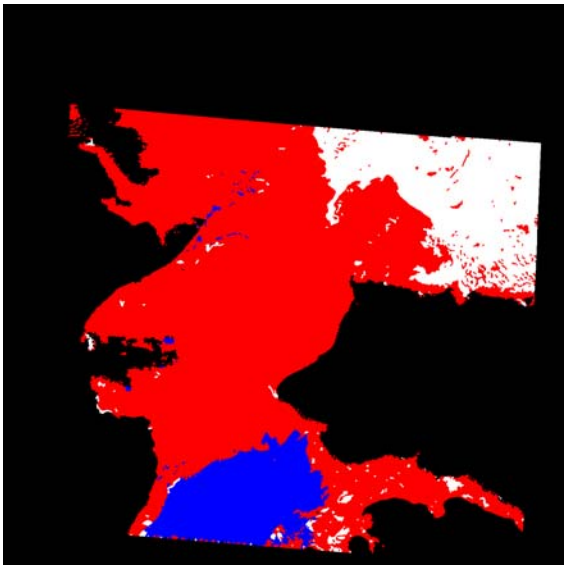

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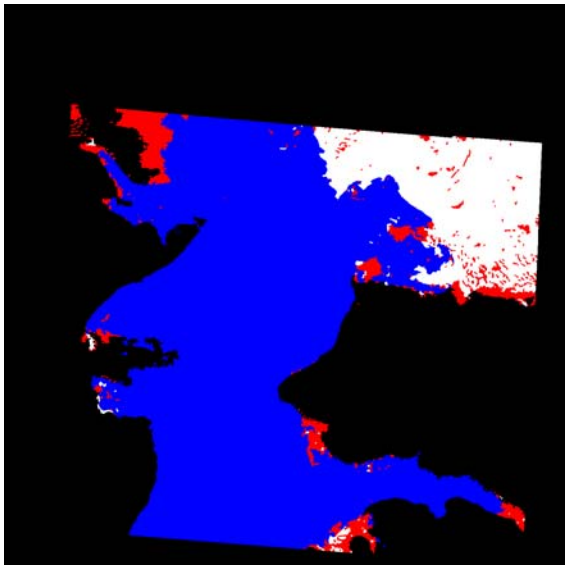

Figure 2: ARKTOS performance with inclusion of SSM/I ice concentrations.

(a) Radarsat image of the Amundsen Gulf, October 28, 1999. (b) ARKTOS classification map (without SSM/I input) incorrectly classifying open water as FY ice. (c) ARKTOS classification map after inclusion of SSM/I data, correctly classifying the open water areas. White areas are areas classified by ARKTOS to be MY ice, red areas - FY ice, and blue areas - new ice or open water.

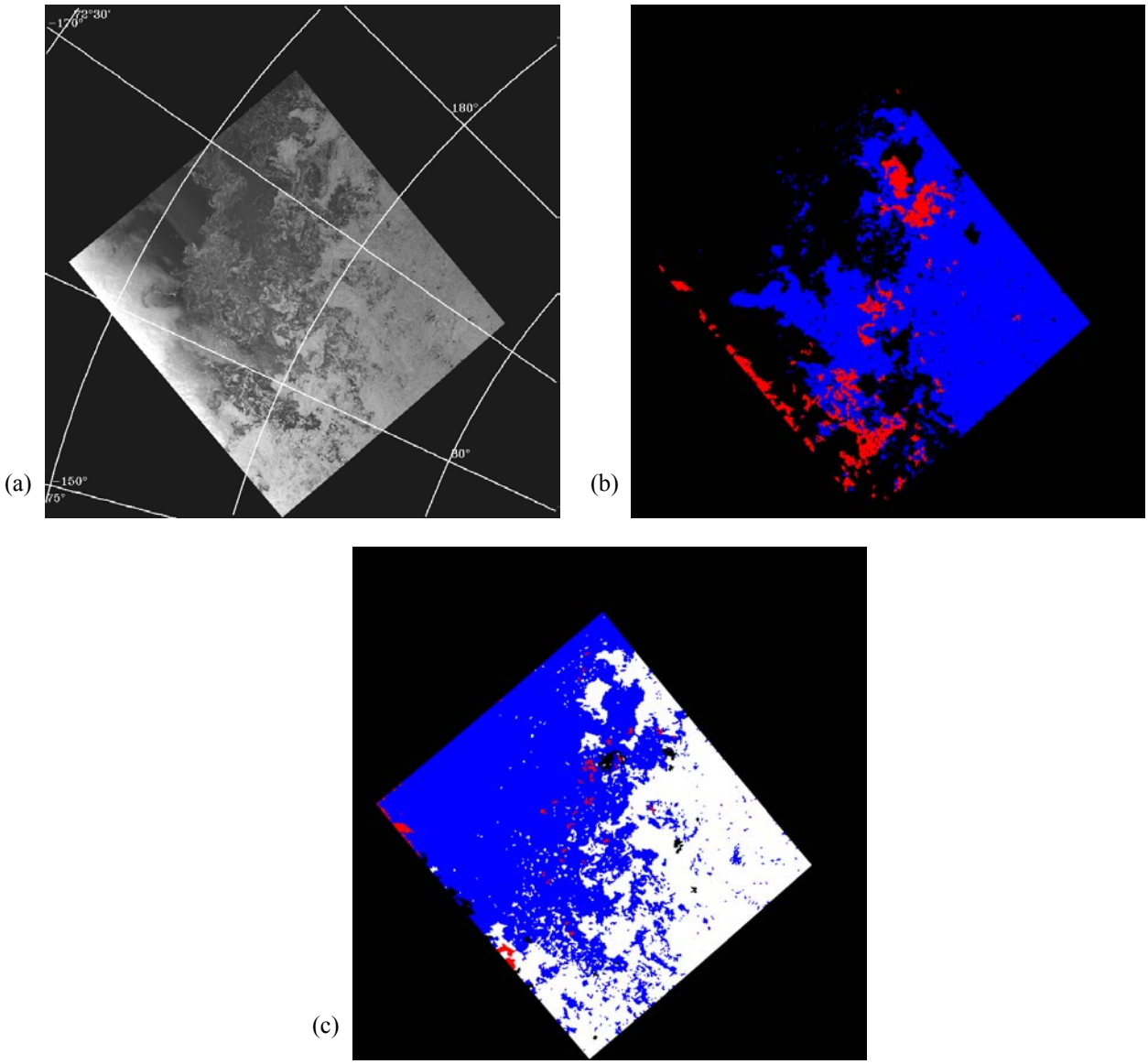

Figure 3: ARKTOS performance with improved summer rules.

(a) Radarsat image of the Arctic Ocean north of Pt. Barrow, September 12, 1998. (b) ARKTOS classification map, produced with initial rule base, incorrectly classifying MY ice at the ice edge as open water and some open water areas as unknown. (c) ARKTOS classification map, produced with improved summer rule base, correctly classifying both the MY ice and open water areas. White areas are areas classified by ARKTOS to be MY ice, red areas - FY ice, blue areas - new ice or open water, and black areas - unknown.