Remote Sensing of Environment 128 (2013) 315–332

Contents lists available at SciVerse ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Validation and potential applications of Environment Canada Ice Concentration Extractor (ECICE) algorithm to Arctic ice by combining AMSR-E and QuikSCAT observations

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ARTICLE INFO

Article history:
Received 27 June 2012
Received in revised form 25 September 2012
Accepted 21 October 2012
Available online 14 November 2012

Keywords:
Sea ice
Retrieval algorithms
Ice concentration
Arctic ice
QuikSCAT
AMSR-E
Multiyear ice

ABSTRACT

The Environment Canada's Ice Concentration Extractor (ECICE) combines observations from several different satellite sensors to resolve heterogeneous components of a given footprint. To validate the algorithm and demonstrate its applicability, results are presented from combining the enhanced AMSR-E 36.5 GHz passive microwave data with dual-polarization QuikSCAT active microwave scatterometer observations of Arctic ice during September to May; 2007/08. Validation is performed using comparison with results from other algorithms in addition to operational ice charts. Three ice types are resolved: young, first-year and multiyear. Total ice concentration from ECICE under cold Arctic winter conditions is in agreement with estimates from previous algorithms such as the enhanced NASA Team. Distribution of multiyear ice concentration from ECICE is presented along with evolution of daily concentration of each ice type. Events of melt-refreeze, which are common during seasonal transition periods, cause misidentification of multiyear ice as first-year ice in the fall. The reverse is observed in the spring. This is a limitation on ice type identification. ECICE is an optimal approach that minimizes the error between observations and predicted concentrations. It provides a confidence measure associated with each ice concentration estimate. It is a generic algorithm, i.e. its applications are not limited to AMSR-E and QuikSCAT.

1. Introduction

One of the primary indicators of a warmer Arctic climate is the recent rapid decrease in Arctic sea ice cover. Arctic sea ice declined at a rate of approximately 3% per decade in 1979–1996 and that rate has increased to about 10% per decade for the perennial ice extent in 1997–2007 (Comiso et al., 2008; Stroeve et al., 2007). Perennial ice is the ice cover that survives summer melt and consists mainly of thick multiyear ice (MYI) floes. The MYI in the central Arctic has decreased by more than 42% since 2005 (Kwok et al., 2009). This decrease has been accompanied by a reversal in the proportion of seasonal to multiyear ice types with seasonal sea ice now covering more than two thirds of the Arctic Ocean in late winter (Kwok et al., 2009). Seasonal ice refers to Young ice types (YI), which is <35 cm thick as well as first-year ice (FYI) which is >35 cm thick. With a changing climate, the composition of sea ice types in sub-regions within the Arctic is expected. For example, recent studies of Agnew et al. (2008) and Howell et al. (2009) have found evidence of increased influx of Arctic pack ice into the Canadian Arctic Archipelago. These observations point to the importance of developing algorithms which can better estimate not only total but also ice type concentrations. Better discrimination among different ice types is also important in operational ice services. This paper is an attempt to contribute to this goal.

The most popular sea ice algorithms rely on a single passive microwave sensor, mostly the Special Sensor Microwave Imager (SSM/I) (Hollinger et al., 1987) or the Advanced Microwave Scanning Radiometer for (AMSR-E) (Kawanishi et al., 2003). Identifying total ice concentration (i.e. ice versus open water) is relatively easy because the microwave radiation from open water (OW) is usually quite distinct from that of sea ice. Some algorithms are capable of identifying certain ice types and determining their partial concentration but the ice type estimates are generally less accurate than total ice concentration. The NASA Team (NT) algorithm (Cavalieri et al., 1984) is capable of discriminating between FYI and MYI and so is the ARTIST Sea Ice (ASI) (Kaleschke et al., 2001) algorithm when results are further processed using the Lomax algorithm (Lomax et al., 1995). The NASA Thin Ice (NT-Thin) algorithm (Cavalieri, 1994) identifies thin ice, and the enhanced NASA Team2 (NT2) algorithm (Markus & Cavalieri, 2000) identifies a surface type (called C-type) composed mainly of surface glaze and layering of the snow pack. The overlap of a given radiometric parameter from different ice types makes identification of those ice types difficult. Such overlap increases under complex surface conditions in response to meteorological forcing. This is particularly true during season transition; i.e. from late melt season to early freeze-up seasons when significant changes in the physical conditions of snow takes place (Agnew & Howell, 2003).

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http://dx.doi.org/10.1016/j.rse.2012.10.016

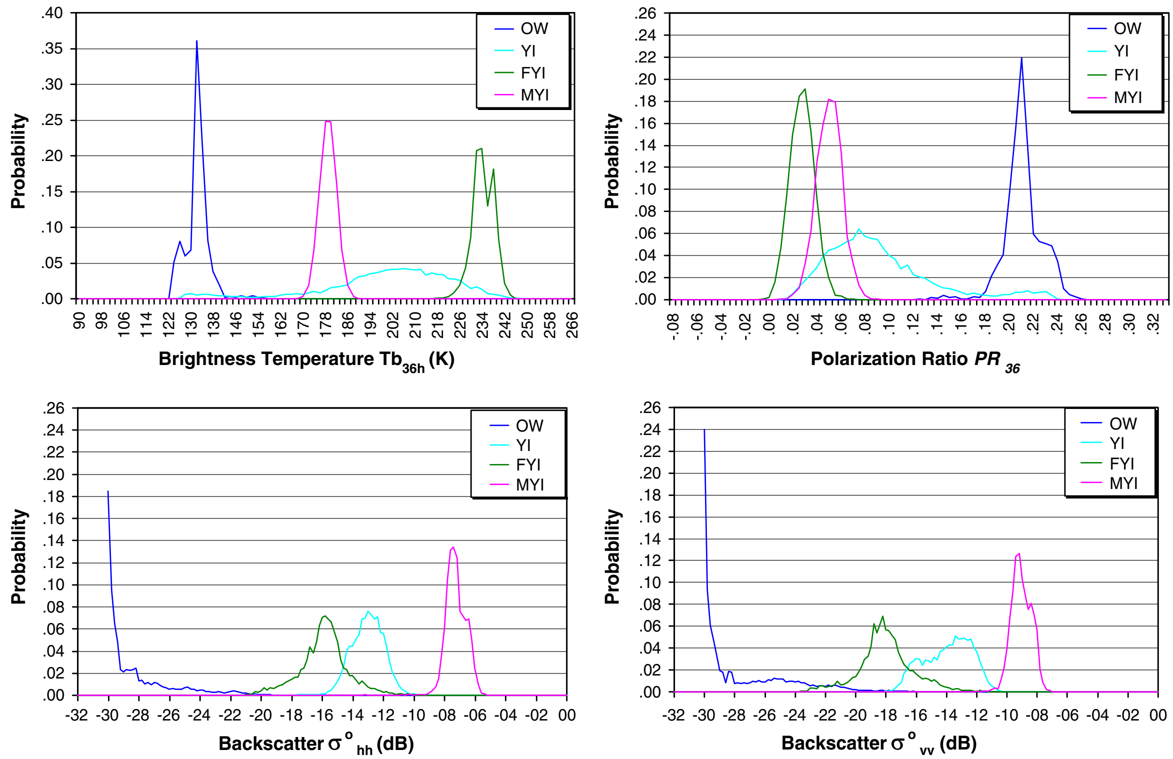

Fig. 1. Probability distributions of each radiometric parameter for each ice surface plus OW. Brightness temperatures were obtained from AMSR-E and backscatter from QuikSCAT. Noise floor of backscatter is −36 dB. Data for OW are obtained from pixels with up to 4 m/s wind speed.

The added information from combining data of different satellite sensors has been used by several authors to improve the retrieval of partial ice concentrations. In a previous study by Beaven and Parra (2000) the authors used a least-squares solution to a linear mixture model within a hybrid fusion algorithm to estimate ice type concentration from Synthetic Aperture Radar (SAR) and passive microwave observations. In another study (McNutt et al., 2001) SAR and Advanced Very High Resolution Radiometer (AVHRR) were combined to further understand the behavior of seasonal and marginal ice zones (MIZ) in the Beaufort Sea and its implication on modeling ice dynamics. QuikSCAT radar and SSM/I radiometer data were also combined in Tonboe and Toudal (2005) to classify new ice off Greenland and in Walker et al. (2006) to identify a separate kind of multiyear ice which was incorrectly classified as first-year ice by passive microwave SSM/I data alone. In a more recent study Yu et al. (2009) AMSR-E and QuikSCAT imagery were combined using a supervised sea ice classification scheme to better identify ice types and their concentrations. It was found that QuikSCAT data contain additional information that augments the passive microwave observations. Nevertheless, trend analysis of the sea-ice concentration time series that are calculated with the various existing sea-ice concentration retrieval algorithms (Anderson et al., 2007) has shown substantially different results from different algorithms.

This paper is an application of an algorithm called Environment Canada's Ice Concentration Extractor (ECICE), which can combine observations from different satellite sensors to estimate concentrations of specified ice types (Shokr et al., 2008). The algorithm is applied to a combination of spatially enhanced AMSR-E and QuikSCAT data in an attempt to improve on single sensor algorithm estimates of ice type concentration. It should be emphasized that the algorithm is quite generic; i.e. not designed specifically for AMSR-E, QuikSCAT or their combination. It can take other radar, visible or infrared observations. The data set covers the entire Arctic basin from September 1st 2007 to May 31st 2008. The three ice types presented in this study are; young ice (YI), first-year ice (FYI), and multiyear ice (MYI), in addition to open water (OW). The overall purpose of the study is to highlight the potential and limitations of the passive/active microwave combination in identifying ice types and consequently their concentration using ECICE. This will also reveal the potentials and limitations of the algorithm. The information should furnish a background for future studies that use longer records of passive/active microwave combination to identify spatial and temporal patterns of Arctic ice types and conditions. A recent study on the spatial and temporal distributions of young ice in the Arctic from 2002 to 2009 using ECICE can be found in Shokr and Dabboor, in press.

Sections 2 and 3 describe the data sets and the algorithm; respectively. Section 4 addresses the probability distributions of the radiometric parameters that are used in ECICE for each one of the given ice types in addition to OW. Section 5 presents the results. It starts with comparison of results from ECICE against corresponding results from NT2 and ASI algorithms. It then proceeds to present case studies that show the potential and limitations of this application. Even when the algorithm fails to identify FYI and MYI correctly, it points out the meteorological conditions that lead to the misidentification. The new information that can be revealed using the algorithm with the aforementioned combinations is highlighted in this section.

Table 1
Brightness temperature from passive microwave 36 GHz channel and backscatter from the Ku band modeled data. Numbers between brackets indicate the standard deviation.

	Tb (36 h)		Ku σ^o_{hh}
	Eppler et al. (1992)	NT2 tie points	Kim (1984)
OW	130	134.8	–
YI	–	183.5	−13.0 (−5.1)
FYI	232	223.8	−17.9 (−8.1)
MYI	175	–	−7.5 (−5.8)

2. Data sets

In addition to QuikSCAT and AMSR-E data, two other data sources were used to support interpretation of the ice concentration results: