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SMOS SEA ICE THICKNESS DATA PRODUCT QUALITY CONTROL BY COMPARISON WITH THE REGIONAL SEA ICE EXTENT

Lars Kaleschke, Xiangshan Tian-Kunze

Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany

ABSTRACT

Brightness temperature data from wave Imaging Radiometer using Aperture Synthesis (MIRAS) on board the European Space Agency's (ESA) Soil Moisture and Ocean Salinity (SMOS) mission have been used to derive the thickness of thin sea ice for the Arctic freeze-up period. To control the long-term geophysical quality for level 3 SMOS sea ice thickness products we derive a regional extent parameter that can be compared to independent standard ice extent products such as the NSIDC sea ice index. This metric allows to identify first-order quality problems such as data gaps and to observe the evolution of the Arctic sea ice growth in key regions. The regionalized SMOS sea ice thickness extent corresponds in general well with the corresponding NSIDC Sea Ice Index. The occurrence of severe RFI problems has so far mainly been limited to the initial period of the SMOS measurements during the season 2010/2011. Otherwise the comparison does not reveal any significant quality problems of the SMOS sea ice thickness data.

Index Terms— Microwave radiometry, Sea ice, SMOS, SSMI

1. INTRODUCTION

Sea ice plays an important role in the global climate system. It indicates changes in the climate system and the couplings between sub-systems. Sea ice modulates fluxes of energy, momentum, salt, moisture, and (trace) gases as interface between the ocean and the atmosphere. The sea ice thickness is the most important parameter that describes the state of the sea ice. On the other hand, there is the difficulty of measuring the sea ice thickness accurately. Precise validation measurements are rare and if available very limited in space and time. Only spaceborne remote sensing allows to measure the sea ice thickness with a suitable temporal and spatial sampling rate. There are different methods to infer the sea ice thickness from altimetric measurements of the freeboard as well as from the emitted radiation in the low-frequency microwave range [1, 2]. Due to the complementarity of the methods and resulting data products it is not feasible to use one for the other for a continuous validation or quality control of a satellite sea ice thickness product.

Fig. 1. Regions of the Arctic according to the NSIDC Sea Ice Index binary mask [9].

With the aim to develop a quality control and monitoring method for the ESA/AWI SMOS level 3 sea ice thickness product [3] we demonstrate a metric that allows an evaluation of the data product using an independent data set, the regional NSIDC sea ice index based on SSM/I data (Fig. 1).

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The crux of the comparison are the different parameters sea ice concentration and sea ice thickness and their different physical units. Our main research question is therefore how can these two different parameters be compared in a meaningful way? To answer this question and to introduce a new comparison metric we take advantage of the correspondence between the sea ice concentration and the sea ice thickness through the concept of the thickness distribution.

The sea ice concentration is a general retrieval concept that describes the fraction (percentage) of sea ice on the ocean surface. Using coarse resolution passive mirowave measurements it is possible to estimate this parameter in a given resolution cell even with a resolution that does not resolve small scale sea ice features like leads [4]. One main assumption is that there are two principle surface components, ocean and sea ice, which have different emissivities. A large variety of sea ice concentration alogrithms exist that differ in the choice of microwave frequencies and technical details [5]. However, by definition, the sea ice concentration is always one minus the open water fraction for a given observed grid cell.

The thickness distribution describes the sea ice as a mixture of surfaces with different thicknesses [6]. The open water fraction is indicated by the first bin of the histogram of the statistical sea ice thickness distribution. Likewise in dynamic thermodynamic sea ice models a threshold thickness h_0 defines the transition from open water to thin sea ice [7]. Thus we can identify SMOS pixels that include a fraction of sea ice by applying a threshold thickness which is approximately the detection limit for thin sea ice in a given pixel. This concept can be extended for different ice thickness categories [8]. In the following we consider a threshold thickness that provides a good correspondence between SMOS sea ice thickness data and the sea ice extent derived from SSMIS sea ice concentration data.

2. METHODS AND DATA

The sea ice extent was calculated from the SMOS sea ice data by summming up the ice-covered pixels weighted by the grid-cell size in km^2. A binary mask from the NSIDC sea ice index given in 25 km grid-cell size resolution was used to derive the according regional values of the sea ice extent. The binary mask was upsampled to match the 12.5 km grid of the SMOS level 3 data. An optimal threshold value was derived to distinguish ice-covered and open water pixels in the SMOS sea ice level 3 product. For doing this we applied a range of different threshold values and evaluated the resulting linear regression of the independent sea ice extent data points.

2.1. NSIDC Regional Sea Ice Index

Passive microwave radiometer data from the Scanning Multichannel Microwave Radiometer (SMMR, 1978-1987), the Special Sensor Microwave Imager (SSM/I, 1987-2008) and the Special Sensor Microwave Imager/Sounder (SSMIS, 2000-present) form the basis of a consistent sea ice area and extent data record that is available at https://nsidc.org/data/g02135. The Sea Ice Index version 3 is a defacto standard for climate research. A regional version of the Sea Ice Index is based on a binary mask as presented in [9] (Fig. 1).

2.2. AWI/ESA SMOS sea ice thickness

The AWI/ESA SMOS sea ice thickness data are available at https://spaces.awi.de/display/CS2SMOS/SMOS+Sea+Ice+Thickness and https://earth.esa.int/eogateway/missions/smos/data. Here we use the product version 3.2 which is provided in the same polar stereographic projection used for the NSIDC Sea Ice Index but with 12.5 km grid resolution instead of 25 km. A 3-day running mean filter was applied to fill small data gaps that otherwise disturb the comparison with the daily sea ice extent.

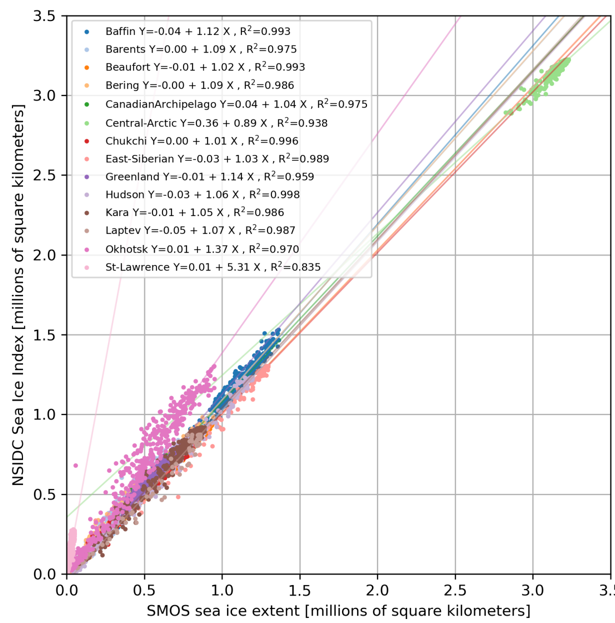

Fig. 2. Scatterplots and linear regression coefficients derived from regional sea ice extent time series for a threshold value of $h_0 = 3$ cm. Each data point represents a three day mean value.

3. RESULTS

Linear regression coefficients have been derived from regional sea ice extent time series for a range of different threshold values. A threshold value of $h_0 = 3$ cm was identified as an optimal choice to distinguish ice-covered and open water pixels in the SMOS sea ice product in correspondence with the NSIDC sea ice index (Fig. 2). The choice was based on a visual inspection of the resulting scatter plots with their regression lines. Two regions can be identified by their particular slopes, Okhotsk and St-Lawrence. These two regions are not fully covered by the SMOS sea ice data and are therefore excluded in further plots. The season 2010/2011 has been excluded from the regression analysis because of larger data gaps.

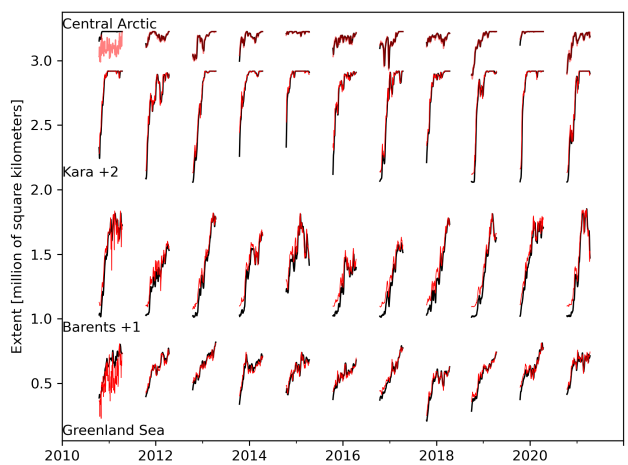

Fig. 3. Atlantic-Central-Arctic region ice extent time series. The NSIDC Sea Ice Index is shown in black and the SMOS sea ice extent in red. Region names and offsets (+1,+2) in million square km for better visibility are also indicated. Daily values for the SMOS sea ice thickness processing periods from October to April.

Time series of the regional sea ice extent derived from SMOS and the corresponding independent SSMIS-based Sea Ice Index are presented in Figs. 3-4. The time period spans the SMOS observation period from 2010 up to April 2021. The SMOS time series only covers the freezing periods from October to April because the SMOS sea ice thickness retrieval is not applicable during the melting seasons [3]. Both independent datasets agree in general well with correlation coefficients higher than 0.97 and small biases.

A large deviation of both data sets highlights the periods where persistent data gaps are present, which is mainly during the first year of SMOS measurements due to RFI. This is evident in the Central Arctic and Greenland Sea (Fig. 3) where the strongest and persistent data loss occurred in the season 2010/2011 [3].

4. CONCLUSIONS

The regionalized SMOS sea ice thickness extent corresponds in general well with the corresponding NSIDC Sea Ice Index,

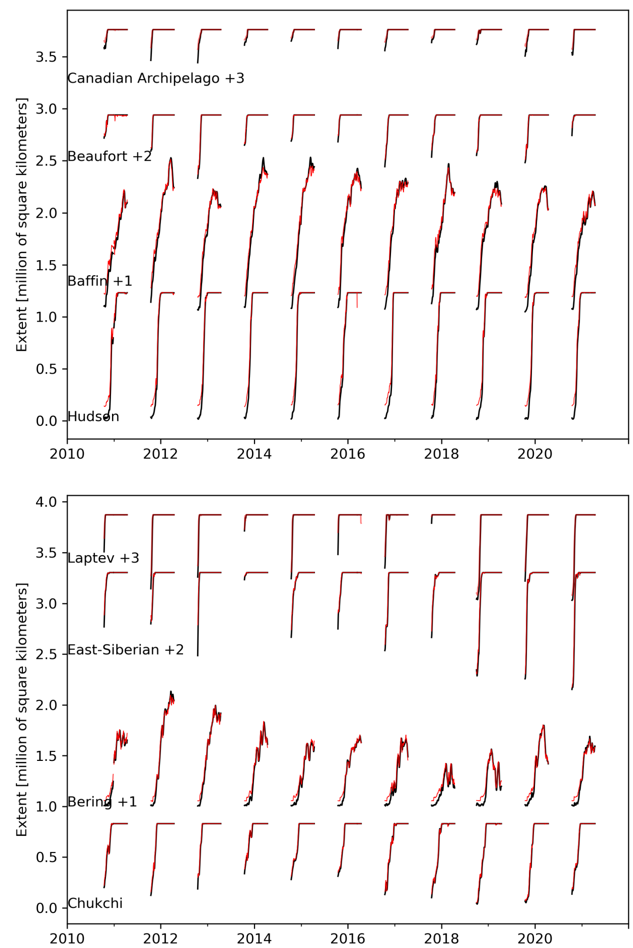

Fig. 4. US-Canadian-Arctic (top) and Pacific-Central-Arctic (bottom) Sea ice extent time series. Description same as Fig. 3.

which is based on independent SSMIS measurements. Thus, we can use the method for comparison and quality control to identify periods and regions with first-order quality problems, i.e. serious data gaps. The occurrence of such problems has so far mainly been limited to the initial period of the SMOS measurements. Small biases are likely caused by the different resolutions of the sensors and the products. The 25 km resolution NSIDC Sea Ice Index regional binary mask causes difficulties along the coastlines and is therefore not the best choice. This is in particular the case for the Canadian Archipelago with its relatively narrow channels. Otherwise the comparison does not reveal any significant quality problems of the SMOS sea ice thickness data and is therefore of limited use for the purpose of quality control.

However, the regional ice extents are suitable climate variables and are therefore worth to be further analysed. More insights about the sea ice growth evolution can be gained by using different and larger thresholds but this is beyond the scope of the present exercise. A regional mask with the SMOS sea ice data grid cell resolution should be generated for this purpose.

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