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On the measure of sea ice area from sea ice concentration data sets

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ABSTRACT

The measure of sea ice surface variability provides a fundamental information on the climatology of the Arctic region. Sea ice extension is conventionally measured by two parameters, i.e. Sea Ice Extent (SIE) and Sea Ice Area (SIA), both parameters being derived from Sea Ice Concentration (SIC) data sets. In this work a new parameter (CSIA) is introduced, which takes into account only the compact sea-ice, which is defined as the sea-ice having concentration at least equal the 70%. Aim of this study is to compare the performances of the two parameters, SIA and CSIA, in analyzing the trends of three monthly time-series of the whole Arctic region. The SIC data set used in this study was produced by the Institute of Environmental Physics of the University of Bremen and covers the period January 2003 – December 2014, i.e. the period in which the data set is built using the new AMSR passive microwave sensor.

Keywords: sea-ice, Arctic, AMSR-E, AMSR-2, SSMIS

1. INTRODUCTION

Arctic ice cover has been subject of many studies in the last 20 years, among them Parkinson et al.[1] , Comiso et al.[2] , Parkinson and Cavalieri[3] , Wang et al.[4] and Comiso[5] , may be quoted. All the studies show a rapid decline of the conventional sea ice cover indexes, Sea Ice Area (SIA) and Sea Ice Extent (SIE). Most of these studies made use of the Sea Ice Concentration (SIC) Arctic data set of the National Snow and Ice Data Set (NSIDC), dating back to the early eighties of last century; the present study, instead, uses the SIC data set provided by the Institute of Environmental Physics (IUP) of the University of Bremen even if it is limited to the period 2002-2014. To measure sea ice cover, a new parameter, Compact Sea Ice Area (CSIA), is introduced. CSIA is extracted from the SIC data set and computed by only considering the pixels whose SIC is above 70%. The monthly CSIA time series trends are then compared with SIA and SIE ones.

2. DATA AND METHODS

2.1. The Arctic data set

This study covers the period January 2003 – December 2014 and was carried out using the daily Arctic SIC data set produced by the Institute of Environmental Physics (IUP) of the University of Bremen. IUP SIC data are derived from the observations of AMSR-E, SSMIS and AMSR-2 passive microwave sensors and use the ARTIST Sea Ice (ASI) algorithm[6] , based on 89 GHz brightness temperature values distributed by NSIDC and JAXA. In particular, the following data sets were retrieved:

1. Daily AMSR-E SIC on a 6.25-km grid for the period 1.1.2003 - 5.10.2011;
2. Daily SSMIS SIC on a 6.25-km grid for the period 1.9.2010 - 31.12.2014.
3. Daily AMSR-2 SIC on a 6.25-km grid for the period 23.7.2012 - 31.12.2014.

SSMIS data set was necessary to fill the AMSR- data gap during the transition period (5.11.2011 – 22.7.2012) from AMSR-E to AMSR-2. As the sensors do not cover a small circular zone around the North Pole, for the whole Arctic region a constant value of 100% SIC was added to fill the hole.

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2.2. Sea ice cover indexes

Usually, two parameters are used for the sea ice cover, the Sea Ice Extent (SIE) and the Sea Ice Area (SIA). They are defined as follows:

1. SIA is the integrated sum of the products of the area of each pixel, with at least 15% ice concentration, and the corresponding ice concentration.
2. SIE is the integrated sum of the areas of pixels with at least 15% ice concentration. It gives an indication of the sea ice distribution, both thin and thick ice, at a certain time.

$$SIA = \sum_{\substack{i=1 \\ SIC_i \geq 15\%}}^{N} SIC_i \times A_i \tag{1a}$$

$$SIE = \sum_{\substack{i=1 \\ SIC_i \geq 15\%}}^{N} A_i \tag{1b}$$

where A_i and SIC_i are the i-th pixel area and the i-th SIC,respectively; N is the total number of pixels.

By a rule derived from studies of Antarctic polynyas,[7] a new sea ice cover index, hereafter referred to as Compact Sea Ice Area (CSIA), is introduced; this new index is defined as the integrated sum of the areas of pixels with at least 70% ice concentration (analogue to the SIE definition but with a 70% threshold instead of 15%).

$$CSIA = \sum_{\substack{i=1 \\ SIC_i \geq 70\%}}^{N} A_i \tag{2}$$

With regard to the 70% threshold value, we wish to stress that: i) it was used to discriminate between open water/thin ice and compact ice in studies of coastal polynyas by Parmiggiani[7] and by Markus and Burns[8] ; ii) it was recently confirmed by comparing SIC images from AMSR with MODIS thermal infrared images of Terra Nova Bay polynya[9]; and iii) it can distinguish the white ice (approximately thicker than 30 cm) from the younger ice.

According to the rules expressed above, the original SIC data set was converted to three data sets to be used in the successive analysis. Consistency between the different satellite daily data sets (AMSR-2 and SSMIS) was achieved by making SSMIS data as close to those of AMSR-2 as possible, using parameters derived from a linear regression of the data of three sensors during the overlap period (24.7.2012 – 31.12.2013):

$$INDEX_{AMSR-2} = c_0 + c_1 \cdot INDEX_{SSMIS} \tag{3}$$

where $INDEX$ stands for SIA, SIE and CSIA. The estimated slope coefficients c_1 for each index are 1.22, 1.21 and 1.24 respectively. Equation 3 was applied to SSMIS data of the period 5.11.2011 – 22.7.2012; after this adjusting operation, the analysis was carried out on the averaged monthly data.

A plot, describing the 3 rules of Equations 1a, 1b and 2, is shown in Fig. 1.

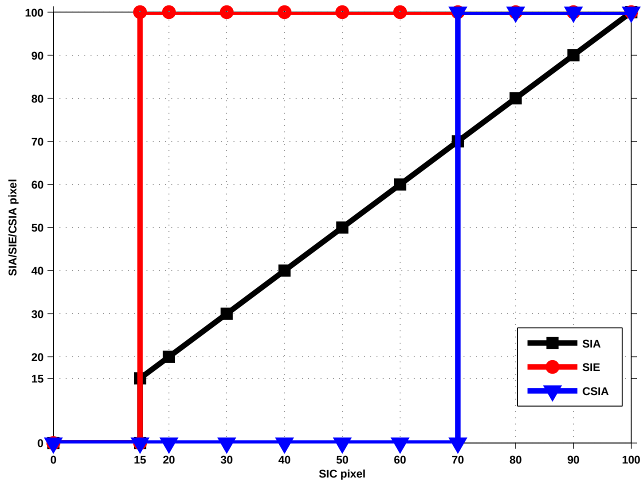

Figure 1. Conversion rules from SIC to SIA, CSIA and SIE

Table 1. CSIA, SIA and SIE maximum (MAX) and minimum (MIN) annual values trends (in $10^6 km^2/dec$) with 95% confidence intervals. Bold faced numbers are significant at the 95% level.

	MIN ($10^6 km^2/dec$)	MAX ($10^6 km^2/dec$)
CSIA	$\mathbf{-1.11 \pm 1.07}$	-0.23 ± 0.71
SIA	$\mathbf{-1.07 \pm 1.04}$	-0.24 ± 0.81
SIE	-1.07 ± 1.08	-0.21 ± 0.75

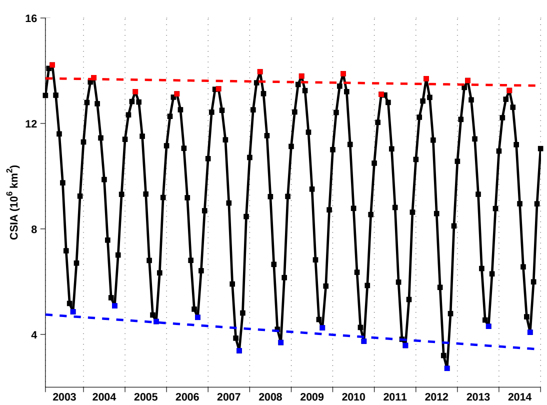

Figure 2. CSIA monthly averages for the period January 2003 – December 2014; regression lines for maximum and minimum values are the dashed red and blu lines, respectively.

Table 2. CSIA, SIA and SIE monthly anomalies trends. Trends are given in $10^6 km^2/dec$ with 95% confidence intervals.

	ANOM ($10^6 km^2/dec$)
CSIA	-0.59 ± 0.18
SIA	-0.59 ± 0.18
SIE	-0.54 ± 0.18

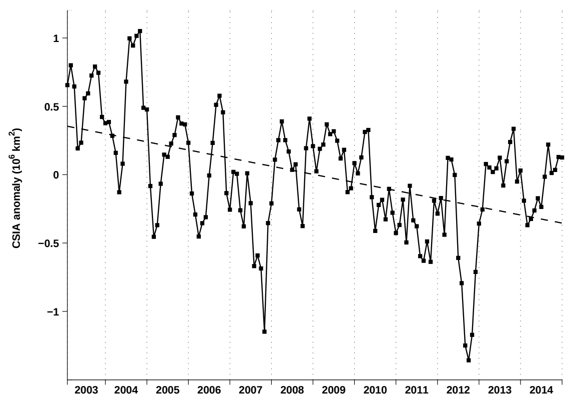

Figure 3. CSIA monthly anomalies for the period January 2003 – December 2014.

3. RESULTS

The linear trends of CSIA, SIA and SIE, for both maximum and minimum annual values derived from monthly averages, are shown in Table 1; as can be seen, the differences between trend values are minimal. All maximum and minimum values trends are not statistically significant at the 95% level, CSIA minimum trend is stronger, even if only slightly, than those of SIA and SIE. Figure 2 shows the monthly CSIA together with its regression line.

The monthly anomaly trends, after a minimization of the intra-annual seasonal variations obtained by subtracting the monthly climatological averages from each monthly average, are shown in Table 2; it is interesting to note the same values for SIA and CSIA: $-0.59 \times 10^6 km^2/dec$; all the values are statistically significant at the 95% level. CSIA anomalies are shown in Figure 3.

The mean differences between monthly CSIA and monthly SIA and SIE are respectively $-0.22 \times 10^6 km^2$ and $-1.15 \times 10^6 km^2$. In terms of relative differences, $|(CSIA - SIA)/CSIA|$ is always less than 15% apart for the Arctic summer months (Aug–Oct), while $|(CSIA - SIE)/CSIA|$ is always less than 15% apart for the months July–Oct. In Fig. 4, the relative differences of the summer months are shown. For the winter months, the relative differences between SIA and CSIA are absolutely negligible.

Figure 4, together with the trend parameters reported in the tables, clearly demonstrates that CSIA and SIA, give very similar results. The only difference between the two methods is in the minimum values in the summer months; this difference, being due to low concentration ice, is considered not affecting the use of SIA in climatological studies. It is interesting to observe how the minimum values have, in general, a much larger fluctuation than the maximum ones. As an example, according to the definitions of the three indexes given above, Figs. 5 to 7 show the monthly ice cover maps for August 2012, a month in which a particular large sea-ice

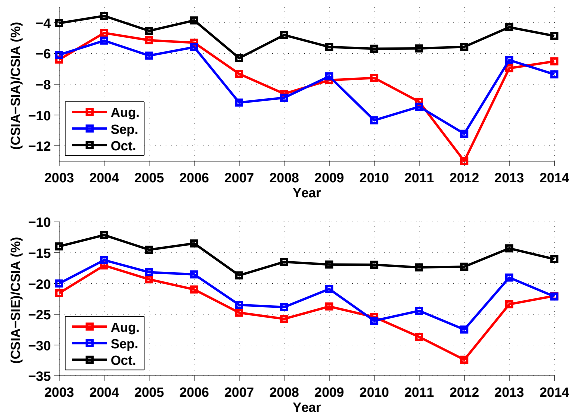

Figure 4. Relative differences (%) of monthly anomalies between CSIA and SIA, and between CSIA and SIE, for the arctic summer months.

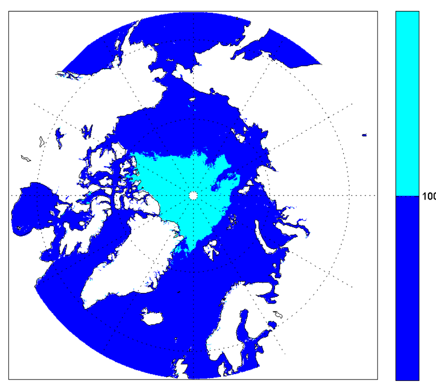

Figure 5. Sea ice cover on August 2012. Grid points having $SIC \geq 70\%$ were set to 100% while grid points $SIC \leq 70\%$ were set to 0%

thawing was observed. In Figs. 5 and 7 all grid points having $SIC \geq 70\%$ (or CSIA) and having $SIC \geq 15\%$ (or SIE) were set to 100% SIC, with the other values set to 0. In Fig. 6, only the grid points having $SIC \leq 15\%$ were set to 0, while values of the other points remain the same (or SIA).

4. CONCLUSIONS

The results presented in the previous section bring to conclude that the high compatibility between SIA and CSIA, suggests that the latter parameter could be preferred in future climatological studies as it gives a clear description of compact sea ice extent. Besides, by applying a binary decision (ice/no ice) to the data, it provides a sharp border between ice and open sea.

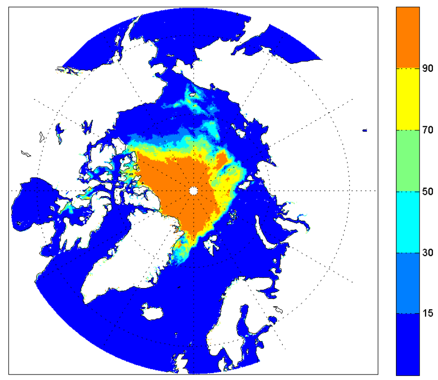

Figure 6. Sea ice cover on August 2012. Grid points having $SIC \leq 15\%$ were set to 0%

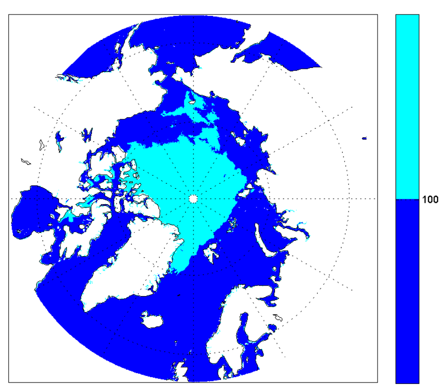

Figure 7. Sea ice cover on August 2012. Grid points having $SIC \geq 15\%$ were set to 100% while grid points $SIC \leq 15\%$ were set to 0%

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