CHARACTERIZATION OF A SATELLITE-BASED PASSIVE MICROWAVE SEA ICE CONCENTRATION CLIMATE DATA RECORD

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ABSTRACT

A long-term, consistent, and reproducible satellite-based passive microwave sea ice concentration climate data record (CDR) is available for climate studies, monitoring, and model validation with an initial operation capability (IOC). The daily and monthly sea ice concentrations are on the National Snow and Ice Data Center (NSIDC) polar stereographic grid with nominal 25 x 25 km grid cells in both the Southern and Northern Hemispheres from 09 July 1987 to 31 December 2007 with an update through 2012 underway. The NetCDF data files along with detailed data processing steps and error source information can be found at http://dx.doi.org/10.7265/N5B56GN3. The dataset is archived by the National Oceanic and Atmospheric Administration (NOAA)'s National Climatic Data Center (NCDC) under the satellite climate data record program (http://www.ncdc.noaa.gov/cdr/operationalcdrs.html).

The description and basic statistical characteristics of the CDR are presented here. Our analysis results have shown that while the Northern Hemisphere experiences diminishing sea ice extent for the two decades from January 1988 to December 2007 with a faster reduction rate for the annual minimum sea ice extent, the Southern Hemisphere has experienced slightly increase in its sea ice extent for the same period, especially for the annual maximum.

Index Terms— Sea Ice, Arctic and Antarctic Oceans, Remote Sensing, Climate Data Record

1. INTRODUCTION

The depletion of the Arctic sea ice coverage is occurring faster than most of the climate model predictions [1]. In September 2012, a record low Arctic sea ice extent minimum was reached, well below the previous Arctic sea ice extent minimum record set in September 2007 (http://nsidc.org/arcticseaicenews/). While numerous sea ice products are available, with the substantial changes in the Arctic sea ice and the associated impacts of the change in weather and climate systems, ecosystems, and coastal communities, it is valuable to have a climate data record (CDR) quality sea ice concentration product.

A long-term, satellite-based sea ice concentration product has been transitioned from research to operations (R2O), based on the recommendations from the National Research Council (NRC) [2], through collaboration between the National Oceanic and Atmospheric Administration (NOAA)'s National Climatic Data Center (NCDC) satellite Climate Data Record (CDR) Program and the National Snow and Ice Data Center (NSIDC). The purpose of this R2O process is to produce and preserve consistent climate data records derived from satellite measurements based on mature research algorithms and provide a consistent long-term, sustainable, transparent, and reproducible sea ice time series for climate variability and change studies, monitoring, and model validation. It is currently available with an initial operation capability (IOC). IOC is the first iteration of the public released CDR which has met all the source code, product validation, documentation, and data archive and access requirement [3].

Here, we present a description of the NOAA/NSIDC sea ice concentration CDR and basic statistical characteristics of the CDR such as long-term mean and trend to provide a baseline for users.

2. DATASET DESCIPTION

The NOAA/NSIDC CDR sea ice concentrations are daily and monthly estimates of the fraction of ocean area covered by sea ice. They are derived from the brightness temperature from the Defense Meteorological Satellite Program (DMSP) series of Special Sensor Microwave Imager (SSM/I) passive microwave radiometers: F-8, F-11, and F-13 [4] (see also Table I for an outline of passive microwave sensor sources for the CDR). The CDR leverages two well-established and well-validated passive microwave sea ice concentration algorithms developed at the NASA Goddard Space Flight Center (GSFC): the NASA Team (NT) algorithm [5] and the Bootstrap (BT) algorithm [6]. The algorithms use adjusted coefficients, based on overlap of sensor operations, to assure consistency through the series of sensors. The input DMSP SSM/I brightness temperatures are daily gridded fields archived at NSIDC [7], derived from swath fields generated by Remote Sensing Systems, Inc. (RSS) [8].

Table I: Sources and attributes of passive microwave sensors for NOAA/NSIDC sea ice concentration CDR

Satellite	Sensor	Data Period*
DMSP F-8	SSM/I	7/9/87 – 12/30/91
DMSP F-11	SSM/I	12/3/91 – 9/30/95
DMSP F-13	SSM/I	5/3/95 – 12/31/07

*Data periods in this table are for sensor data used in generating the CDR, which may not span the full data available periods for the sensors.

The sea ice concentrations are gridded on the NSIDC polar stereographic grid with nominal 25 x 25 km grid size. The dataset covers the ocean surface area from 31.1°N to 89.84°N in the Northern Hemisphere and 39.36°S to 89.84°S in the Southern Hemisphere. Fig.1 shows spatial distributions of ice concentrations in September from daily data files for year 1987, 1997, and 2007, which provides snapshots of the decadal variability (i.e., shrinking) of Arctic sea ice extent.

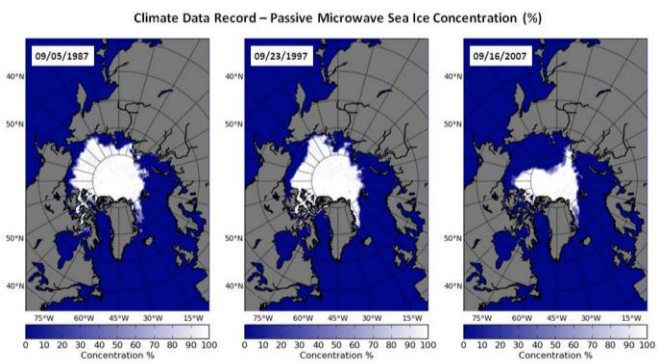

Figure 1: Spatial distribution of sea ice concentration from daily CDR data on the minimum sea ice extent day (based on a 5-day average) in year 1987, 1997, and 2007. The area not measured by the satellite sensor over the North Pole is assumed to be entirely covered by ice.

The data files are available in the NetCDF data format which is self-describing and machine-independent. The file-level metadata conform to the guidelines recommended by the NCDC CDR program [9]. The guideline utilizes the existing metadata conventions such as Climate and Forecast (CF) Metadata Convention and Unidata Attribute Convention for Dataset Discovery (ACDD) for easy dataset search and discovery, subsetting and other down-stream applications. Each file includes three CDR related variables: the primary CDR sea ice concentration field from 09 July 1987 to 31 December 2007, local spatial standard deviation of the algorithm concentrations, and a quality flag field. The standard deviation and quality flags for each grid-cell provide indications of uncertainty/error. Three additional sea ice concentration variables, two created by GSFC using the NT and BT algorithms, respectively, and one created at NSIDC that merges these two GSFC concentrations using the same methodology that generates the CDR sea ice concentrations, are also included in the data files. They provide easy access to heritage variables in the same format and grid to user communities and a benchmark for evaluating the CDR. Including the GSFC variables in the data files also extends the sea ice concentration record back in time from July 9, 1987 to October 26, 1978 (albeit without meeting the traceability and reproducibility requirements). A detailed description of the climate algorithm for the CDR and algorithm validation and error assessment can be found [4]. The CDR well captures the seasonal and inter-annual variability when compared with other satellite-based sea ice products [10].

Hereafter, we will refer NOAA/NSIDC CDR sea ice concentrations as CDR and merged Goddard sea ice concentrations as GSFC. CDR and GSFC are produced using the same methodology and based on the same algorithms – the main differences are additional manual quality control in input brightness temperature and output sea ice concentration fields and gap-filling in both time and space for GSFC. Because of the interpolation and manual corrections, GSFC represents a higher quality research product that can be used as a benchmark for evaluating and characterizing model or other satellite-based sea ice products, such as we have done in this analysis for CDR; however, the higher quality comes at the expense of traceability and data latency (about 12 months). CDR, on the other hand, aims to ensure traceability, consistency and sustainability of the sea ice time series with planned updates on a quarterly basis (monthly in the future and effort is also underway to extend the time series through year 2012) and offers transparency with availability of source code and detailed algorithm and processing description.

3. CHARACTERIZATION OF THE CDR

The characterization of the CDR is provided here using monthly sea ice extent for a period of 20 years (January 1988 – December 2007) in terms of long-term mean and trend to provide a baseline for users. The sea ice extent is computed by summing the grid cell area of all cells that have 15 percent or greater sea ice concentrations, assuming the area not measured by the sensor around the North Pole is entirely covered by at least 15% ice.

The monthly CDR sea ice extent values are in good agreement with estimates from GSFC (Fig. 2). As expected, the sea ice extent undergoes distinct seasonal cycles in both hemispheres. In the Northern Hemisphere, it peaks in March and reaches the minimum in September but it peaks in September and reaches the minimum in February in the Southern Hemisphere (Fig. 3). The 20-year average of annual CDR sea ice extent is about 12 million (mil) km^2 for both hemispheres with mean bias relative to GSFC of 0.1 and -0.05 mil km^2 for the Northern and Southern

Hemisphere, respectively (Table II). The standard deviation (SD), which is mainly associated with seasonal variability, is nearly twice as large in the Southern Hemisphere (compared 5.64 to 2.92 mil km^2). However, the inter-annual variability, represented by the range of the shaded area for each month in Fig. 3, tends to be smaller in the Southern than that in the Northern.

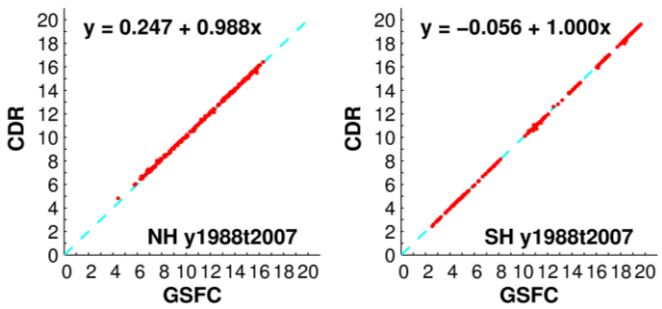

Figure 2: The scatter-diagram of CDR and GSFC monthly sea ice extents (mil km^2) (20 years from January 1988 to December 2007) for the Northern Hemisphere (left) and the Southern Hemisphere (right).

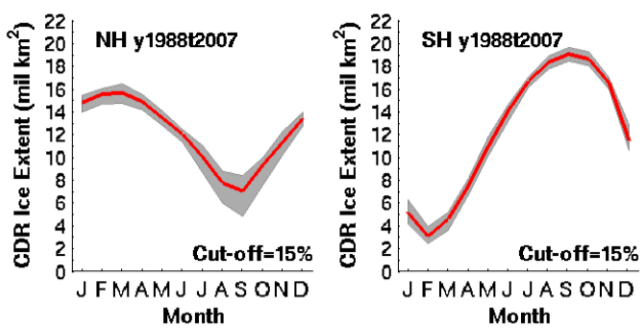

Figure 3: 20-year average of monthly CDR sea ice extent (solid line) for the Northern Hemisphere (left) and Southern Hemisphere (right). The shaded areas are bounded by the minimum and maximum extent values for each month.

Table II: Statistics of monthly sea ice extents (mil km^2)

	N. Hemisphere		S. Hemisphere	
	CDR	GSFC	CDR	GSFC
Mean	12.076	11.975	12.179	12.225
SD	2.92	2.96	5.64	5.64
Bias	0.100		-0.0458	
RMS	0.085		0.050	
Correlation	0.9997		1.000	

With the predominant seasonal cycle, the cross-correlation coefficients between the CDR and GSFC sea ice extents are very close to 1 for both hemispheres with very small bias and root-mean-square (RMS) error (Table II), largely reflecting the spatial homogeneity of the concentrations over much of the field . A lot of variability does occur near the ice edge, but that is a small portion of the grid cells.

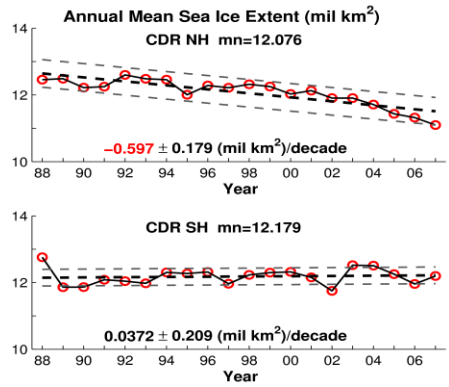

Figure 4: Annual mean CDR sea ice extent from 1988 to 2007 (red circles), with the linear regression ±1 standard deviation of the annual mean sea ice extent (black and grey dashed lines, respectively) for the Northern Hemisphere (top) and Southern Hemisphere (bottom) with the decadal trend and its margin of error - trend in red is statistically significant at the 95% confidence level.

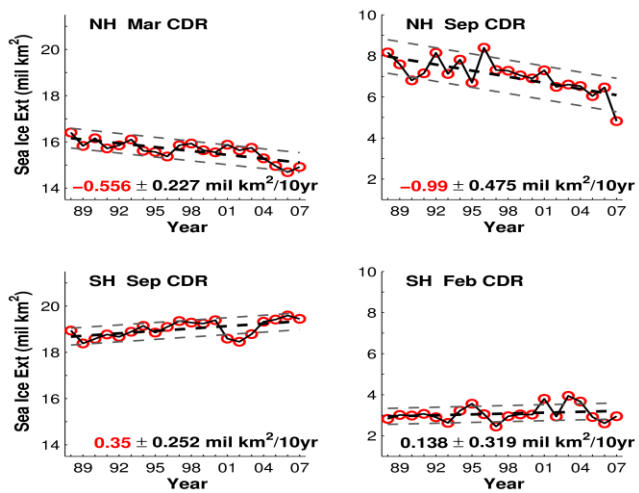

Figure 5: Same as Figure 4 but for the annual maximum sea ice extent (left panels) and minimum (right panel) for the Northern Hemisphere (top panels) and Southern Hemisphere (bottom panels). The decadal trend in red is statistically significant at the 95% confidence level.

Least-square linear regression of this twenty-year annual mean CDR sea ice extent time series indicates a sea ice coverage decrease of 0.597 mil km^2 per decade in the North Hemisphere, which is statistically significant at the 95% confidence level (Fig. 4). This decadal trend is about 4.94% per decade of the 20-year annual mean sea ice extent of 12.076 mil km^2. The margin of error is about 0.18 mil km^2 per decade. On the other hand, an almost zero but slightly positive trend (0.04 ± 0.21 mil km^2 per decade) is found in the South Hemisphere (Fig. 4). This trend represents an increase of about 0.3% per decade relative to the 20-year annual mean sea ice extent of 12.179 mil km^2 and is not significant at 95% confidence level. For the Northern Hemisphere, while the annual maximum sea ice extent decreases at a rate that is similar to the annual mean sea ice

extent rate, i.e., 0.556 ± 0.23 mil km^2 per decade, the annual minimum sea ice extent decreases at a faster rate, 0.99 ± 0.48 mil km^2 per decade (Fig. 5), indicative of the effect of enhanced summer melt [11], thinning of the ice cover and loss of older ice types [12]. Both annual maximum and minimum sea ice extent decadal trends are significant at the 95% confidence level. On the other hand, both annual maximum and minimum sea ice extents in the Southern Hemisphere experience a slightly increase, with a rate of more than double for the annual maximum sea ice extent (0.35 mil km^2 per decade, which is significant at the 95% confidence level) than that of the annual minimum sea ice extent (0.138 mil km^2 per decade, which is not significant at the 95% confidence level). This difference in magnitudes is in part due to the large difference in absolute mean extent at the minimum and maximum, as well as climate factors such as atmospheric and oceanic circulation. Therefore, while the Northern Hemisphere experienced diminishing sea ice coverage for the two decades, with a faster reduction rate for the annual minimum sea ice coverage, the Southern Hemisphere, as whole, has experienced a slight increase in its sea ice coverage for the same period with a noticeable increase of its annual maximum sea ice coverage, significant at the 95% confidence level.

4. SUMMARY

A long-term satellite-based sea ice concentration climate data record derived from passive microwave brightness temperatures is available for climate studies, monitoring, and model validation. The CDR sea ice extent compares well with that computed from GSFC with distinct seasonal cycles in both Northern and Southern Hemispheres. The mean CDR sea ice extent is about 12 mil km^2 for both regions with mean bias of 0.1 and -0.05 mil km^2 for the Northern and Southern Hemispheres, respectively.

With the predominant seasonal cycle, the cross-correlation coefficients between the CDR and GSFC sea ice extents are very close to 1 for both hemispheres with very small root-mean-square (RMS) error. The standard deviation (SD), which is mainly associated with seasonal variability, is nearly doubled in the Southern Hemisphere. However, the inter-annual variability tends to be smaller in the Southern Hemisphere than that in the Northern Hemisphere.

The results have shown that the Arctic region experienced diminishing sea ice coverage over the two decades of the CDR, with a faster reduction rate for the annual minimum sea ice coverage. The Antarctic region, on the other hand, has experienced slightly increased sea ice coverage with a more significant increase rate for the annual maximum, although spatial variability of sea ice extent trend in the Antarctic can be large as pointed out by [13].

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