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TECHNICAL REPORT

Pre-processing of satellite-derived Sea Ice Data for its use in the coupled NCUM data assimilation

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March 2024

National Centre for Medium Range Weather Forecasting
Ministry of Earth Sciences, Government of India
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10	Abstract	In Polar Regions, the sea ice plays a crucial role in the understanding and prediction of the earth's system due to its high reflectivity, which is an important component in the surface energy budget. The National Centre for Medium-Range Weather Forecasting (NCMRWF) receives a large number of ocean and sea ice observations from various sources and agencies. For the use of observed Sea Ice Concentration (SIC) data in the sea ice analysis, we have used the satellite-derived SIC products from the Special Sensor Microwave Imagers/Sounders (SSMIS) and Advanced Microwave Scanning Radiometer 2 (AMSR2). Both microwave radiometer products are developed based on the Ocean and Sea Ice Satellite Application Facility (OSI SAF) Hybrid Dynamical algorithm (linear combination of Bootstrap and Bristol algorithms). The inter-comparison was performed for sea ice data on the observed satellite data from SSMIS onboard DMSP-16, 17 and 18 satellites and AMSR-2 onboard GCOM-W1 satellite sea ice over the poles (Arctic and Antarctica) during the period of Dec-2022 to Apr-2023. The equal-weighted ensemble mean was also generated for the different satellite derived SIC products. This equal-weighted ensemble mean is also used SIC data assimilation system at NCMRWF.
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सारांश: ध्रुवीय क्षेत्रों में, समुद्री बर्फ अपनी उच्च परावर्तनशीलता के कारण पृथ्वी की प्रणाली को समझने और भविष्यवाणी करने में महत्वपूर्ण भूमिका निभाती है, जो सतह ऊर्जा बजट में एक महत्वपूर्ण घटक है। राष्ट्रीय मध्यम अवधि मौसम पूर्वानुमान केन्द्र (एनसीएमआरडब्ल्यूएफ) को विभिन्न स्रोतों और एजेंसियों से बड़ी संख्या में समुद्र और समुद्रीबर्फ के अवलोकन प्राप्त होते हैं। समुद्री बर्फ विश्लेषण में देखे गए समुद्रीबर्फ सांद्रण (एसआईसी) डेटा के उपयोग के लिए, हमने विशेष सेंसर माइक्रोवेव इमेजर्स/साउंडर्स (एसएसएमआईएस) और उन्नत माइक्रोवेव स्कैनिंग रेडियोमीटर-2 (एएमएसआर2) से उपग्रह-व्युत्पन्न एसआईसी उत्पादों का उपयोग किया है। दोनों माइक्रोवेव रेडियोमीटर उत्पाद महासागर और समुद्री बर्फ उपग्रह अनुप्रयोग सुविधा (ओएसआईएसएएफ) हाइब्रिड डायनामिक एल्गोरिदम (बूट स्ट्रैप और ब्रिस्टल एल्गोरिदम का रैखिक संयोजन) के आधार पर विकसित किए गए हैं। दिसम्बर-2022 से अप्रैल-2023 तक की अवधि के दौरान ध्रुवों (आर्कटिक और अंटार्कटिका) पर एसएसएमआईएस ऑन बोर्ड डीएमएसपी-16, 17 और 18 उपग्रहों और एएमएसआर-2 ऑन बोर्ड जीसीओएम-डब्ल्यू 1 उपग्रह से प्राप्त समुद्री बर्फ डेटा की अंतर-तुलना की गई थी। विभिन्न उपग्रह व्युत्पन्न एसआईसी उत्पादों के लिए समान-भारित समुच्चय माध्यभी उत्पन्न किया गया था। इस समान-भारित समुच्चय माध्यका उपयोग एनसीएमआरडब्ल्यूएफ में एसआईसी डेटा एसिमिलेशन सिस्टम में भी किया जाता है।

Abstract: In Polar Regions, the sea ice plays a crucial role in the understanding and prediction of the earth's system due to its high reflectivity, which is an important component in the surface energy budget. The National Centre for Medium-Range Weather Forecasting (NCMRWF) receives a large number of ocean and sea ice observations from various sources and agencies. For the use of observed Sea Ice Concentration (SIC) data in the sea ice analysis, we have used the satellite-derived SIC products from the Special Sensor Microwave Imagers/Sounders (SSMIS) and Advanced Microwave Scanning Radiometer-2 (AMSR2). Both microwave radiometer products are developed based on the Ocean and Sea Ice Satellite Application Facility (OSI SAF) Hybrid Dynamical algorithm (linear combination of Bootstrap and Bristol algorithms). The inter-comparison was performed for sea ice data on the observed satellite data from SSMIS onboard DMSP-16, 17 and 18 satellites and AMSR-2 onboard GCOM-W1 satellite sea ice over the poles (Arctic and Antarctica) during the period of Dec-2022 to Apr-2023. The equal-weighted ensemble mean was also generated for the different satellite derived SIC products. This equal-weighted ensemble mean is also used SIC data assimilation system at NCMRWF.

1. Introduction

Sea ice is a vital component of the Earth's system because of its role in the energy balance over the Polar Regions. Therefore, an accurate simulation of Sea Ice Concentration (SIC) is essential in the Los Alamos Sea Ice Model (CICE) model (Hunke & Lipscomb, 2010). NCMRWF receives different atmospheric and ocean observations in near-real time through Global Telecommunication System (GTS), EUMETSAT, NOAA, ISRO, IMD, etc., for their use in the NWP system. For the SIC data, we used the observed Special Sensor Microwave Imagers/Sounders (SSMIS) and Advanced Microwave Scanning Radiometer 2 (AMSR2) products. Both microwave radiometer products are developed based on the Ocean and Sea Ice Satellite Application Facility (OSI SAF) Hybrid Dynamic algorithm (linear combination of Bootstrap and Bristol algorithms). The OSI SAF Hybrid Dynamical algorithm utilizes the 19 GHz and 37 GHz channels. The Level 2 global SIC product (OSI-410-a) is derived from Level 1 passive microwave measurements from the SSMIS and AMSR2 instruments onboard the Defense Meteorological Satellite Program (DMSP) and JAXA'sGCOM-W1 polar-orbiting satellites, respectively.

NCMRWF operationally runs the NEMO-CICE model for sea ice data assimilation. Ocean Observation Pre-processing System (OOPpS) (Momin and Rani, 2023) was developed for the NEMOVAR-based global ocean data assimilation (Momin et al., 2020). The center also indigenously developed an Observation Pre-processing system (OPpS) for its Unified model (UM) based NWP systems (Prasad, 2014, Buddhi et al., 2019). The OOPpS converts different types of SSMIS and AMSR2 SIC data into the required format (SeaIce.Obstore) for its use in the NEMOVAR system. .

This report mainly describes various satellite-derived sea ice observations received at NCMRWF, the inter-comparison of different sea ice observations, preparation of equal-weighted ensemble-mean from the sea ice observations. Information about the observational data sets and methodology is presented in Section 2. Section 3 elaborates on the main results (inter-comparison). A summary and discussions are described in the last section.

2. Data, and Methods

2.1 AMSR2

The AMSR2 instrument, which has a 2m diameter antenna, a constant incident angle of 55^{o}, and a swath width of 1450 km, was launched in May 2012.The instrument has 14 channels covering microwave frequencies from 6.925 GHz to 89.0 GHz with horizontal and vertical polarizations. Characteristics of the AMSR2 channels used in the SIC algorithms are given in Table 1.The OSI SAF hybrid algorithm uses 3 channels (18.7 GHz V and 36.5 GHz V & H), while the Technical University of Denmark (TUD) algorithm employs 4 channels (18.7 and 36.5 GHz V, and 89.0 GHz V & H). For our study, we have used sea ice data based on the OSI SAF hybrid dynamic algorithm.

Table1: Characteristics of the AMSR2 channels used in the SIC algorithms

Centre freq. (nominal) (GHz)	Polarization	Bandwidth (MHz)	Footprint (km x km)	Sampling Interval (km
18.70 (19)	V	200	14 × 22	10
36.50 (37)	H & V	1.000	7 × 12	10
89.00 (89)	V	3.000	3 × 5	5

2.2 SSMIS

SSMIS is flown on board the United States Air Force DMSP series of satellites, F-16, F-17,F-18,andF-19,launchedrespectivelyin2003,2006,2009,and2014(however,F-19has not been operational since February 2016). SSMIS is the successor to the Special Sensor Microwave/Imager(SSM/I).TheSSMISinstrumenthasanantennawitha0.8mdiameter, a constant incidence angle of 53.1°, and a swath width of about 1700 km. The instrument has 24 channels covering microwave frequencies from 19 to 183 GHz. A summary of the SSMIS channels used in the sea ice concentration algorithm is provided in Table 2**.**

Table2: CharacteristicsoftheSSMISchannelsusedintheSICalgorithms

Centre freq. (nominal) (GHz)	Polarization	Bandwidth (MHz)	Footprint (km x km)	Sampling Interval (km
19.35 (19)	V	356	42.4 × 70.1	12.5
37 (37)	H & V	1.580	27.5 × 44.2	12.5

The Level 2 processing is triggered when a new Level 1 AMSR2 or SSMIS swath file is received at Danish Meteorological Institute (DMI) and in one day DMI receives approximately 29 (for AMSR2), 44 (for SSMIS) satellite swaths, considering F-16, F-17 and F-18. Both the data sets are received at NCMRWF from EUMETCast. Both files are available in compressed NetCDF format.

EUMETCast

- L2 AMSR2: S-OSI_-DMI_—AMSR2_L2-CONC__-<YYYYMMDDHHMM>.nc.gz
- L2 SSMIS:

  S-OSI_-DMI_-SSMIS16_L2-CONC__-<YYYYMMDDHHMM>.nc.gz

  S-OSI_-DMI_-SSMIS17_L2-CONC__-<YYYYMMDDHHMM>.nc.gz

  S-OSI_-DMI_-SSMIS18_L2-CONC__-<YYYYMMDDHHMM>.nc.gz

2.3 Pre-Processing of SIC data

The satellite SIC data sets (SSMI/S and AMSR2) are in NetCDF format and are converted into ASCII form at using the Climate Data Operators (CDO). All the sea ice products (ASCII files) of SIC data are further reprocessed into the required obstore format (SeaIce.obstore) using a collection of FORTRAN programs and modules developed in MIHIR HPC at NCMRWF (Prasad, 2014; Buddhi et al., 2019; Momin and Rani, 2023). The details of the pre-processing of SIC data are mentioned in the flow chat (Fig. 1).

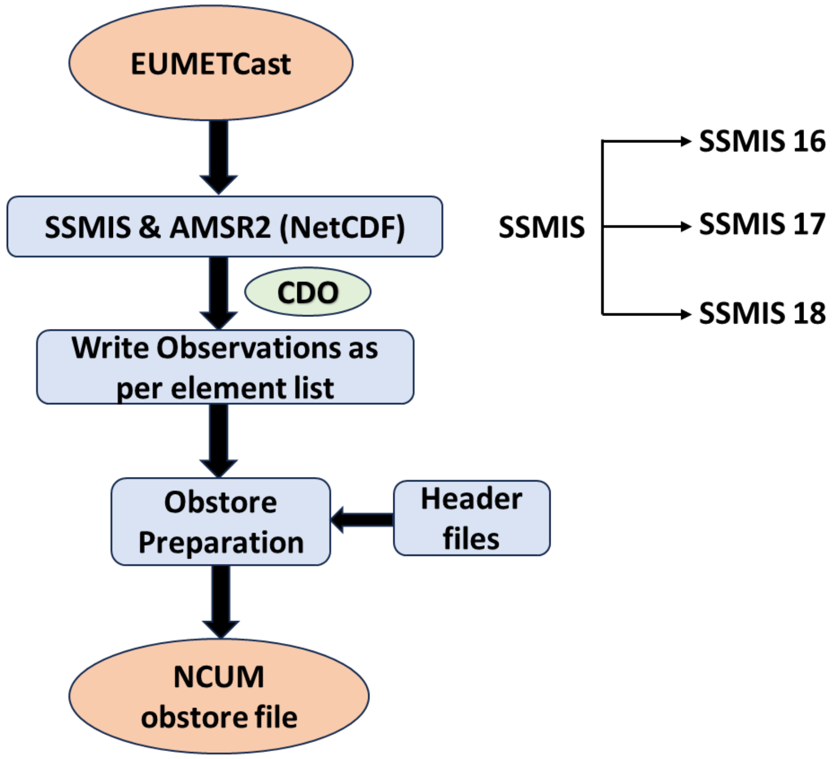

Fig. 1 Flow chart for the Pre-Processing of SIC data at NCMRWF.

3. Inter-comparison of SSMIS and AMSR2 SIC data.

The SIC data from the different satellite sensors (SSMIS16, SSMIS17, SSMIS18, and AMSR2) was received at NCMRWF through EUMETCast, which is based on the OSI SAF Hybrid Dynamic algorithm. To understand the variability of SIC data, we have compared both the satellite data from December 2022 to April 2023.The average number of satellite-observed points per day for the sensor SSMIS (individual) was approximately 1.8 and 1.4 lakhs for the Northern (NH: 60^oN to 90^oN) and Southern Hemisphere (SH: 60^oS to 90^oS), respectively. Similarly, for AMSR2, it was around 14 and 10 lakhs for the NH and SH, respectively, as presented in Fig.2. It can be concluded that a higher number of data points near the pole characterizes the sea ice products generated by AMSR2 observations (due to high spatial resolution of 10 km) as compared to SSMIS products which have a resolution of 25km.

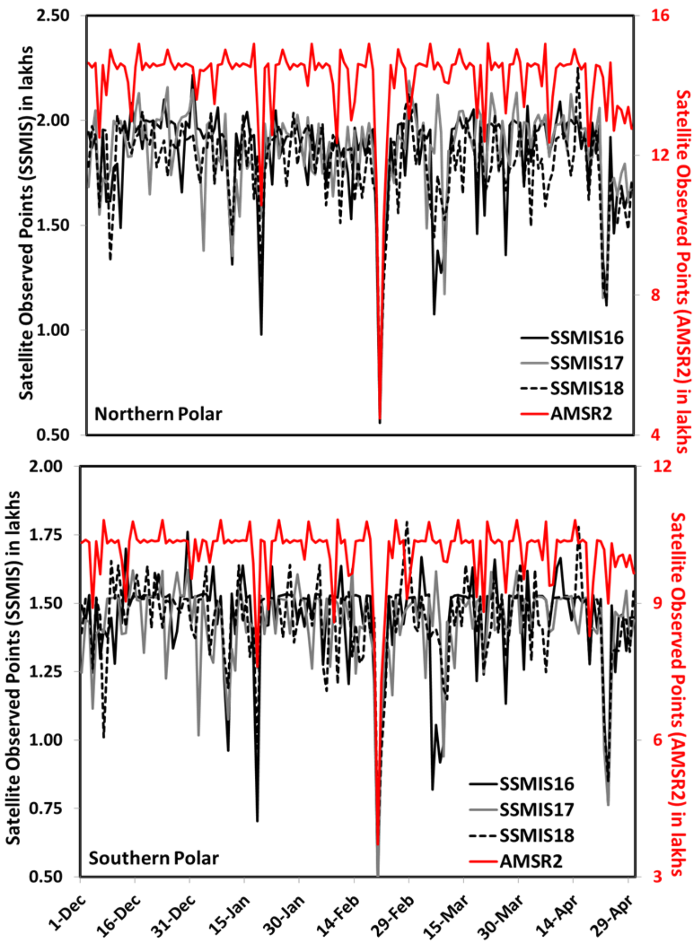

Fig. 2 Number of observation points received from satellite sensors (SSMIS and AMSR2) for SIC data from December 2022 to April 2023 over both Polar Regions.

The spatial distribution of mean SIC from December 2022 to April 2023 over the Polar Regions is presented in Fig.3. From this figure, it is clear that the SIC generated by AMSR2 observations are almost covered over the Northern Polar region (Arctic region) while SSMIS observations show the data gap near the poles. The data gap in SSMIS products is due to its spatial resolution of 25km, whereas AMSR2 has a horizontal resolution of 10km.

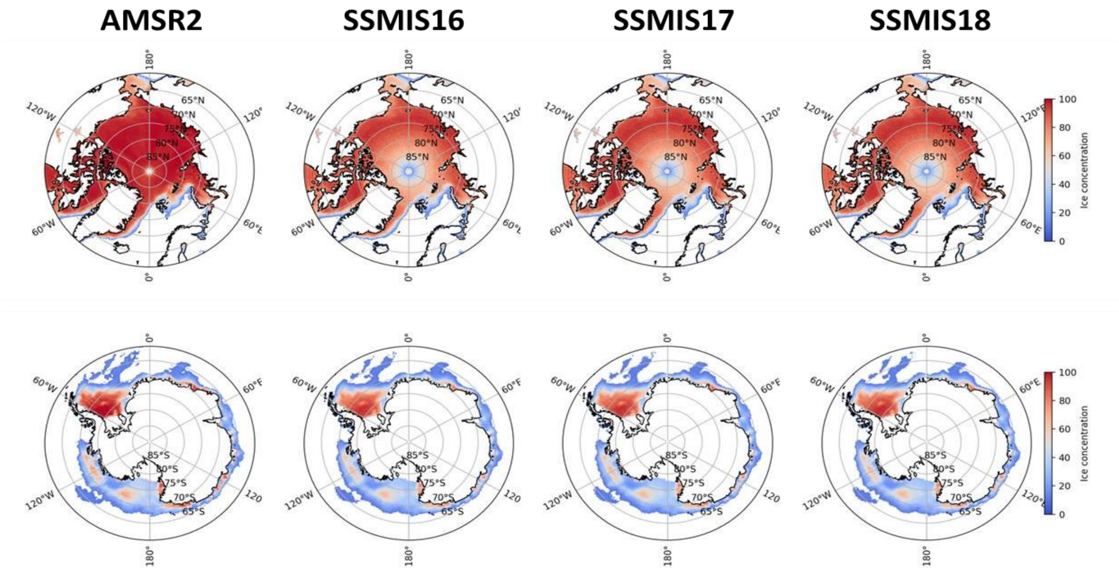

Fig. 3 Spatial distribution of the mean (Dec 2022-Apr 2023) SIC over the Arctic (top panel) and Antarctic (lower panel) from different satellite products.

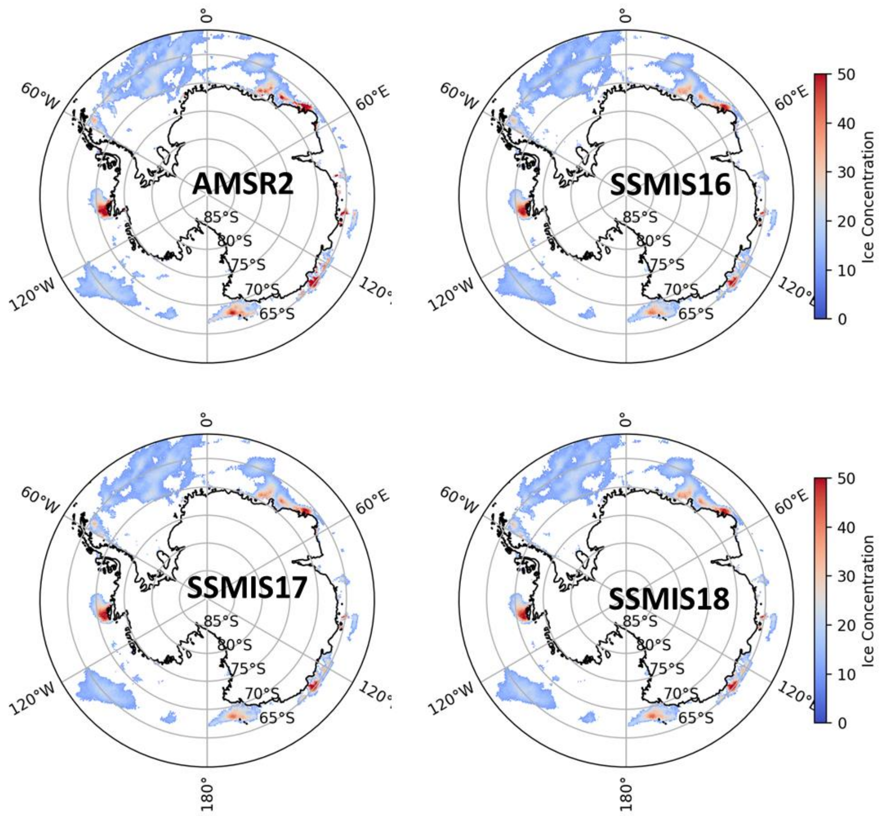

Fig.4 Spatial distribution of seasonal difference (DJF-MA) between different satellite sensors over Antarctica

The seasonal difference (DJF and MA) spatial distribution of SIC over the Antarctica and Arctic is shown in Fig. 4 and 5. These figures show that DJF over the Arctic is treated as a growing period of sea ice and vice versa for Antarctica. From March onwards, the SIC over the Arctic/Antarctic region starts melting/growing respectively. The spatial pattern of seasonal difference (DJF-MA) is similar over Antarctica & Arctic regions in terms of magnitude for the all SSMI products (SSMI 16, 17, and 18)

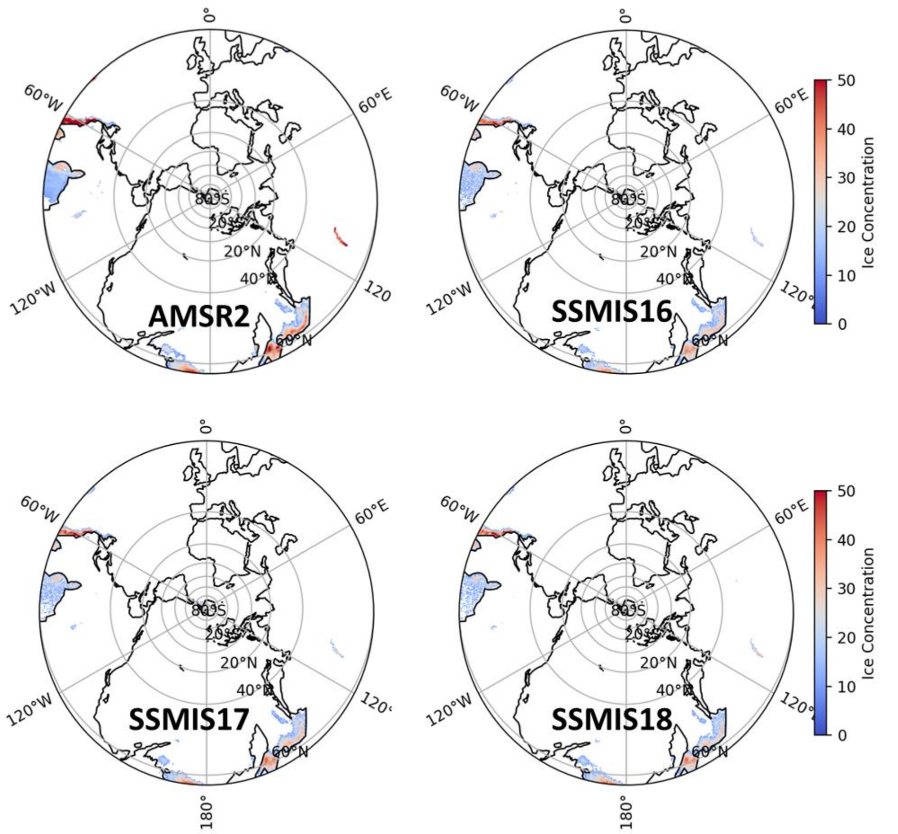

Fig.5 Spatial distribution of seasonal difference (MA-DJF) between different satellite sensors over Arctic

The scatter plots with regression line of mean SIC (December 2022 to April 2023) over both the Polar Regions are presented in Fig.6. The scatter plots are generated over a point (79°N, 12°E) near Himadri over the Arctic and Miatri (71.75°S, 11.7°E) over the Antarctica region. In the scatter plots, the cluster of data points along the regression line (the slope is >0.6) represents consolidated 80% sea ice near the location Himadri over the Arctic, whereas more than 80% of sea ice near the location Maitri over the Antarctica for both SSMIS and AMSR2 observations. The correlation among SSMIS SIC datasets is 0.4-0.6, whereas the same between SSMIS and AMSR2 SIC products is more than0.6.This may be due to the number of observation points from SSMIS satellites being less than AMSR2 observations, which have high spatial resolution.

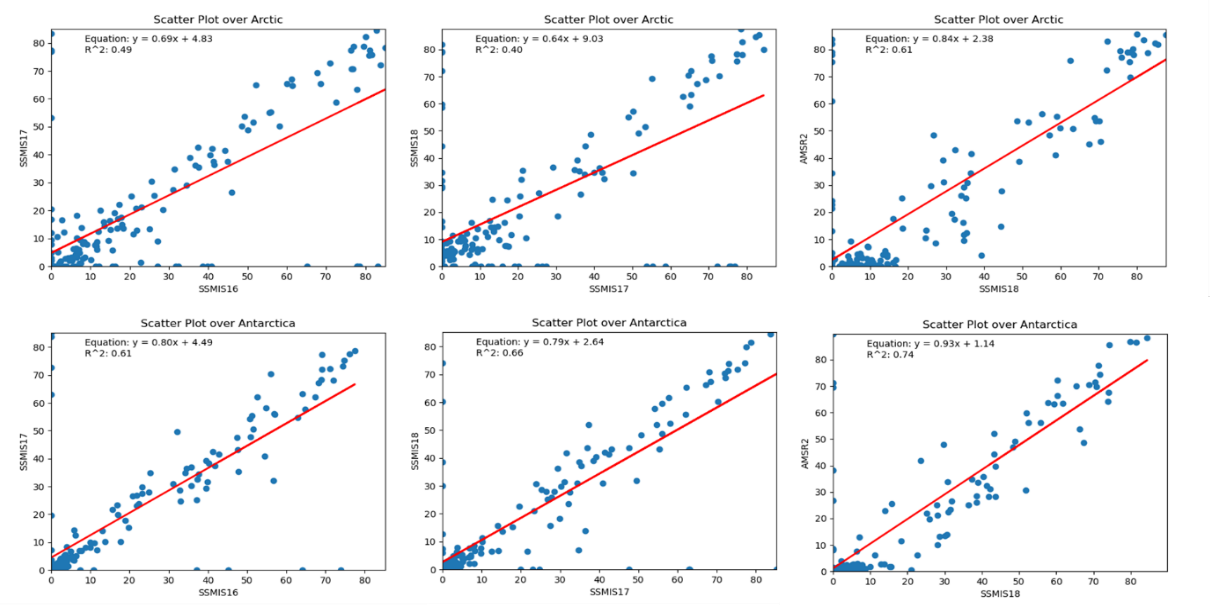

Fig. 6 Scatter plot of SIC over the Arctic (top panel) and over Antarctica (bottom panel) from SSMIS16, SSMIS17, SSMIS18, and AMSR2 satellite products near Himadri (79^{o}N, 12^{o}E) over the Arctic and Maitri (71.75^{o}S, 11.7^{o}E) over the Antarctica region.

4. Ensemble Mean of different satellite-derived SIC data

We aim to combine all the sea ice observations (SSMIS16, SSMIS17, SSMIS18, and AMSR2). However, the density of the observations is too high. High-density observations lead to two significant problems. First, high-density observations may violate the independent observations error, a data assimilation principle. Second, massive data increases the disk space requirement and computational costs. Liu and Rabier, (2002) reported that the high-density observations decrease the quality of the analysis using the theoretical study. However, the assumption is that the observational data is too large and error covariance is neglected. There are several methods to reduce the density of observations, such as data thinning, estimated error analysis, and ensemble mean. The ensemble mean method combines all the SSMIS and AMSR2 sea ice products with an equal weight. The equal-weighted ensemble mean is developed using the following formula.

$$\text{Ensemble Mean of SIC}=0.25\text{x}\ (SIC_{SSMIS16} + SIC_{SSMIS17} + SIC_{SSMIS18} + SIC_{AMSR2})$$

The spatial distribution of ensemble mean SIC over the Arctic and Antarctica are presented in Fig. 7. From this figure, it is clearly understood that the observation data points near the pole were increased compared to individual SSMIS and AMSR2 satellite data points in the Arctic region. This ensemble-mean of SIC data from different satellites will be used for the data assimilation.

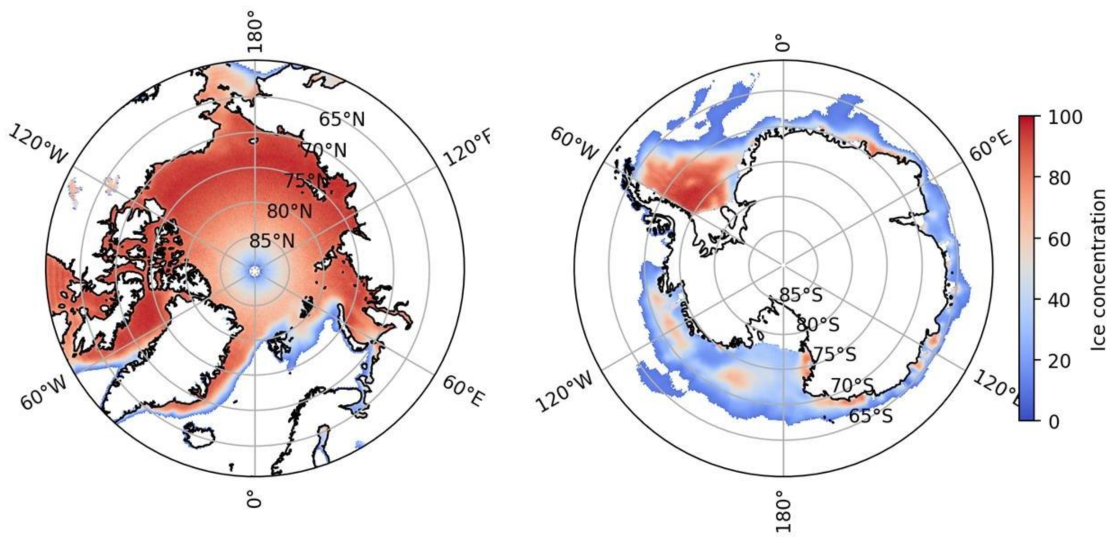

Fig. 7 Spatial distribution of ensemble mean SIC from SSMIS16, SSMIS17, and SSMIS18 satellite sensors over the Arctic (left) and Antarctica (right).

5. Summary and Conclusions

NCMRWF receives different SIC products such as SSMIS16, SSMIS17, SSMIS18, and AMSR2 from EUMETCast. These products are being processed and inter-compared from December 2022 to April 2023 to understand the variability in the different sea ice products. In the processing of SSMIS and AMSR2 datasets, it is observed that the AMSR2 has relatively good data coverage over the Northern Polar (near 90^{o} E) due to high spatial resolution compare to the SSMIS dataset. .The near real-time SIC retrievals generated by AMSR2 and SSMIS provide consistent temporal and spatial coverage over the Arctic and Antarctica regions. The total observations from all satellite data are more than10 lakhs per day. Pre-processing this massive datasets requires more computational time and delayed data assimilation. To reduce the size of the dataset, we first completed the inter-comparison study of the various sea ice products. The study brought out a good correlation among the various satellite data in inter-comparison, especially over Antarctica. The second step of the study is to produce the computationally efficient ensemble mean product from the all available sea ice products. Finally, this ensemble product is pre-processed using the set of programs to control SIC data quality for assimilation.

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Authors Contribution: The report was conceptualized and supervised by Dr. John. The report was reviewed and edited by Dr. Imran. Data Analysis, Methodology, and write up by SK Sahoo.

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