Passive Microwave Sea Ice Concentration Climate Data Record

1. Intent of This Document and POC

1a) This document is intended for users who wish to compare satellite derived observations with climate model output in the context of the CMIP/IPCC historical experiments. Users are not expected to be experts in satellite derived Earth system observational data. This document summarizes essential information needed for comparing this dataset to climate model output. References are provided at the end of this document to additional information.

Dataset File Name (as it appears on the ESGF):

--to be added once file is accepted-----

Sea Ice daily, northern hemisphere:

sic_SSMI-NH_L3_PMSIC-v2_YYYYMMDD_YYYYMMDD.nc

Sea Ice daily, southern hemisphere:

sic_SSMI-SH_L3_PMSIC-v2_YYYYMMDD_YYYYMMDD.nc

Sea Ice monthly, northern hemisphere:

sic_SSMI-NH_L3_PMSIC-v2_YYYYMM_YYYYMM.nc

Sea Ice monthly, southern hemisphere:

sic_SSMI-SH_L3_PMSIC-v2_YYYYMM_YYYYMM.nc

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2. Data Field Description

CF variable name, units:	*Sea ice area fraction*
Spatial resolution:	*25 km (nominal) polar stereographic projections*
Temporal resolution and extent:	*Daily and monthly average, 7/1987 – 12/2013*
Coverage:	*Arctic and Antarctic regions (latitude limits vary between 30° and 40° depending on longitude)*

3. Data Origin

Satellite swaths of passive microwave brightness temperatures from a series of U.S. Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave Imager (SSM/I) and Special Sensor Microwave Imager and Sounder (SSMIS) instruments (see Section 6), obtained from

Remote Sensing Systems, Inc. (http://www.remss.com), are gridded to daily averaged fields on a polar stereographic grid with a nominal resolution of 25 km using a drop-in-the-bucket method (Maslanik and Stroeve, 2004).

The Sea Ice Concentration Climate Data Record (CDR) is derived from the input gridded brightness temperatures via two empirically derived algorithms developed at the NASA Goddard Space Flight Center (GSFC), called NASA Team (Cavalieri et al., 1999) and Bootstrap (Comiso and Nishio, 2008) algorithms. These algorithms are processed and archived at the National Snow and Ice Data Center. For each algorithm, linear regression and adjustment of algorithm coefficients based on overlap between sensors, developed by Cavalieri et al. (1999) and Comiso and Nishio (2008), is used for intercalibration to provide consistency across each of the time series. These two concentration estimates form the input for constructing the Sea Ice Concentration Climate Data Record (CDR) described in this document.

The Sea Ice Concentration CDR is a merged product of the NASA Team and Bootstrap concentrations. The merging is performed on the daily maps as follows. First, the ice edge is defined from the Bootstrap algorithm, using a 10% concentration threshold. Within the interior of this ice edge, the Sea Ice Concentration CDR value is chosen as the higher value from the NASA Team and Bootstrap algorithms. This simple approach provides consistency while employing both widely used and validated GSFC algorithms and ameliorates the tendency of the algorithms to underestimate sea ice concentration in many conditions (see below). The Sea Ice Concentration CDR uses only automated methods to meet CDR requirements and there is no interpolation done to fill in missing data. Once the daily merged Sea Ice Concentration CDR is constructed, the monthly value is determined by averaging all daily concentration fields within the given month.

In addition to the Sea Ice Concentration CDR parameter, the product includes additional auxillary QA fields (Table 1). This includes a similar concentration estimate, using NASA Team and Bootstrap products processed at NASA GSFC, designated as a "Merged Goddard" concentration. One notable difference with the Sea Ice Concentration CDR is that the Merged Goddard field includes spatial and temporal interpolation to fill missing grid cells. Bilinear spatial interpolation is used to fill in isolated missing grid cells. For larger regions (e.g., from missing swaths), a temporal interpolation is used where cells in the missing region is filled in with the average of the values of those cells on the day before and the day after; regions with missing data for more than a day (for example between early December 1987 and mid-January 1988 when no data was collected) are not interpolated. Another notable difference with the Sea Ice Concentration CDR is that the Merged Goddard field includes manual corrections to remove erroneous sea ice estimates. These manual corrections consistent of removal of clearly spurious ice in the open water (due to atmospheric emission and/or wind roughening) and correction of erroneous artifacts due to errors in the swath brightness temperatures. Such erroneous regions are removed manually, marked missing, and then filled via the temporal interpolation described above.

The Merged Goddard field also encompasses data from an earlier sensor, the NASA Nimbus-7 Scanning Multichannel Microwave Radiometer, which operated from October 1978 to July 1987. Thus, the Merged Goddard fields is more complete, has fewer artifacts of erroneous data, and encompasses a longer period than the Sea Ice Concentration CDR. However, because of the interpolation and manual corrections, the fields do not meet CDR requirements for full documentation and reproducibility. The manual corrections and interpolation generally amounts to a minor difference between the Sea Ice Concentration CDR and Merged Goddard, and otherwise processing is nearly identical. Thus, the Merged Goddard is largely interchangeable with the Sea Ice Concentration CDR and is intended for users who desired a longer record, with missing data filled by interpolation, and who are less concerned with satisfying all CDR criteria such as full reproducibility.

4. Validation and Uncertainty Estimate

The NASA Team and Bootstrap algorithm sea ice concentrations estimates have been validated via numerous comparisons with other satellite and airborne data (primarily visible/IR or SAR) (e.g., Meier, 2005; Comiso et al., 1997). The Sea Ice Concentration CDR parameter has been validated by assessing the consistency with sea ice concentration products processed at GSFC (Peng et al., 2013; Meier et al., 2014). The Sea Ice Concentration CDR have only small differences from the GSFC estimates, with most differences attributable to the interpolation and manual corrections done by Goddard. Comparison of the Sea Ice Concentration CDR estimates with Merged Goddard concentration for non-missing regions indicate an RMS difference of <100,000 square kilometers (~0.5-2.0% depending on time of year) (Peng et al., 2013).

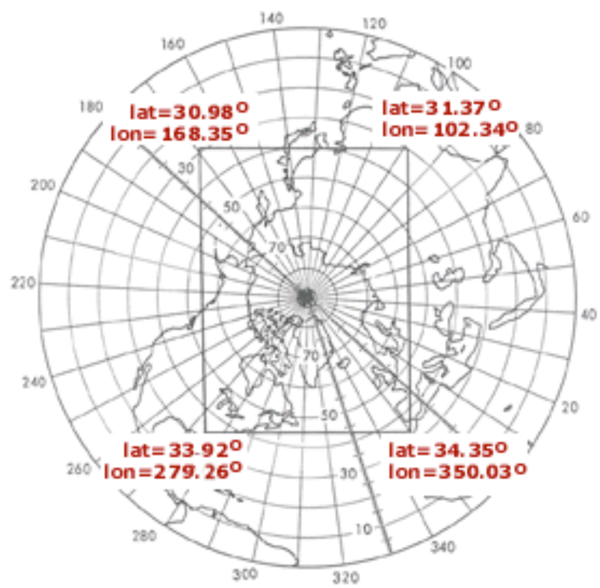
Table 1. Summary of differences of the two primary gridded sea ice concentration fields.

	Sea Ice Concentration CDR	**Merged Goddard**
Source input	TBs gridded from RSS swath data	TBs gridded from RSS swath data
Processing location	NSIDC	NASA GSFC
Years available	1987 – 2013	1978 – 2013
Quality control	Automated filtering only, with full reproducibility	Automated and manual (hand corrections) filtering
Interpolation for missing values	None	Spatial (bilinear) for isolated grid cells; temporal (surrounding days) for larger missing regions (e.g., missing swaths)
Associated Quality Assessment (QA) parameters	1. Melt onset day of year 2. QA flag field* 3. Spatial NT/BT standard deviation (see Section 4)	None
Satisfies NOAA CDR criteria	Yes	No

*The QA flag field is a bit-coded field that indicates several conditions: (1) whether the Bootstrap or NASA Team concentration value is used at a given grid cells, (2) cells where no sea ice is allowed by an applied SST climatology mask, (3) cells near the coast that are susceptible to land contamination (mixed ocean/land cells that may be detected by the algorithms as sea ice, (4) cells that have a concentration lower than 50% (indicating the possibility of thin ice or melt, both of which are underestimated by the algorithms [see Section 4]), and (5) cells where melt onset has been detected.

In terms of absolute uncertainty of the algorithms, daily concentration errors of 5-10% are found within the ice pack during cold winter conditions. However, errors can be much higher in non-optimal conditions, such as near the ice edge and during surface melt conditions, and vary both spatially and temporally due to local conditions. Because of the low spatial resolution of the passive microwave sensors (footprints as large as 70 km for some frequencies), daily concentrations near ice edge may have errors of 50% or more; the low spatial resolution essentially limits the precision of the ice edge determination to ~25-50 km. Near the ice edge, concentration may be overestimated or underestimated depending on the sensor footprint location relative to the edge and the character of the ice at the edge (thin vs. thick, consolidated vs. loose). Within the ice pack, the passive microwave algorithms tend to underestimate concentration, especially in regions of thin ice and melting ice. Under strong surface melt conditions (including melt pond formation), concentrations may be underestimated by 20-30%. Extreme cold surface temperatures and atmospheric emission (primarily from thick clouds) tend to result in less extreme underestimations.

Wind roughening of the ocean and/or other atmospheric effects over the open ocean can lead to an incorrect detection of ice by the algorithms. Automated filters, based on brightness temperature ratios, remove most of this effect, but some false ice may linger. Removal of this ice is a substantial component of the manual corrections done by NASA GSFC.



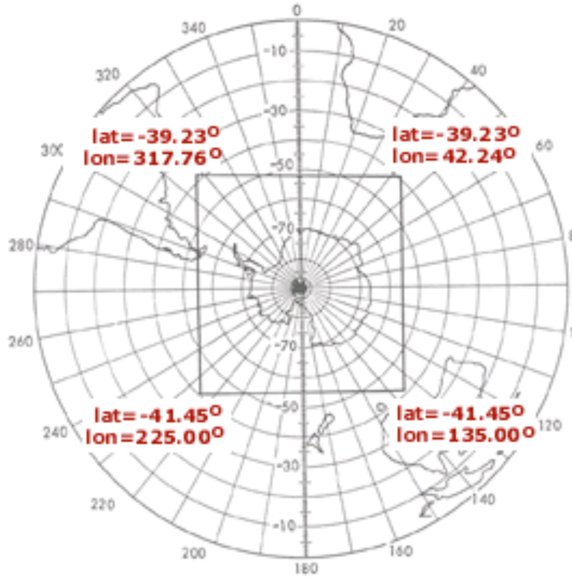


Figure 1. *Coverage map of polar stereographic grid (outlined in box) for Arctic (top) and Antarctic (bottom) regions with latitude and longitude of corner points.*

A final effect is erroneous ice found along ice-free coastlines. This results due to the large sensor footprint obtaining emission from both land and open ocean. These “mixed pixels” often have a signature that is detected as ice by the algorithms. Automated coastal filters remove some of these artifacts, but some often remain, particularly during summer. The result is a one or two grid cell border of ice along some coastlines.

Estimating quantitative grid cell level uncertainty estimates is difficult because there are no in situ measurements readily available and the surface is highly spatially variable. The CDR has developed a quantitative indicator of data quality based on a spatial standard deviation. Standard deviation for each grid cell is computed from the both the Bootstrap and NASA Team algorithm (as processed for the Concentration CDR at NSIDC) at that grid and the eight surrounding cells. Thus, the value calculated from 18 total estimates is a function of the difference between NASA Team and Bootstrap and the spatial variability of the neighboring grid cells. High standard deviation values correspond to greater uncertainty because higher uncertainty tends to occur in regions with large spatial variability: thin ice regions, melting ice, near the ice edge, and near the coast (especially where false ice occurs due to mixed land-ocean grid cells). Also the NASA Team and Bootstrap algorithms use different microwave frequencies and have different sensitivities to thin ice and surface melt; so greater difference between the algorithm estimates (which contributes to higher standard deviation) also indicates higher uncertainty.

In addition, a melt onset field is included as an ancillary parameter (melt onset day of year in Table 1 above). Melt onset is detected based on thresholds of microwave frequencies. Activation of the melt flag indicates that melt has likely occurred and concentration estimates have higher uncertainty. In addition to the melt onset field, a melt onset indicator (melt/no-melt) is included in a Quality Assessment (QA) field, along with other relevant quality indicators, as noted in Table 1.

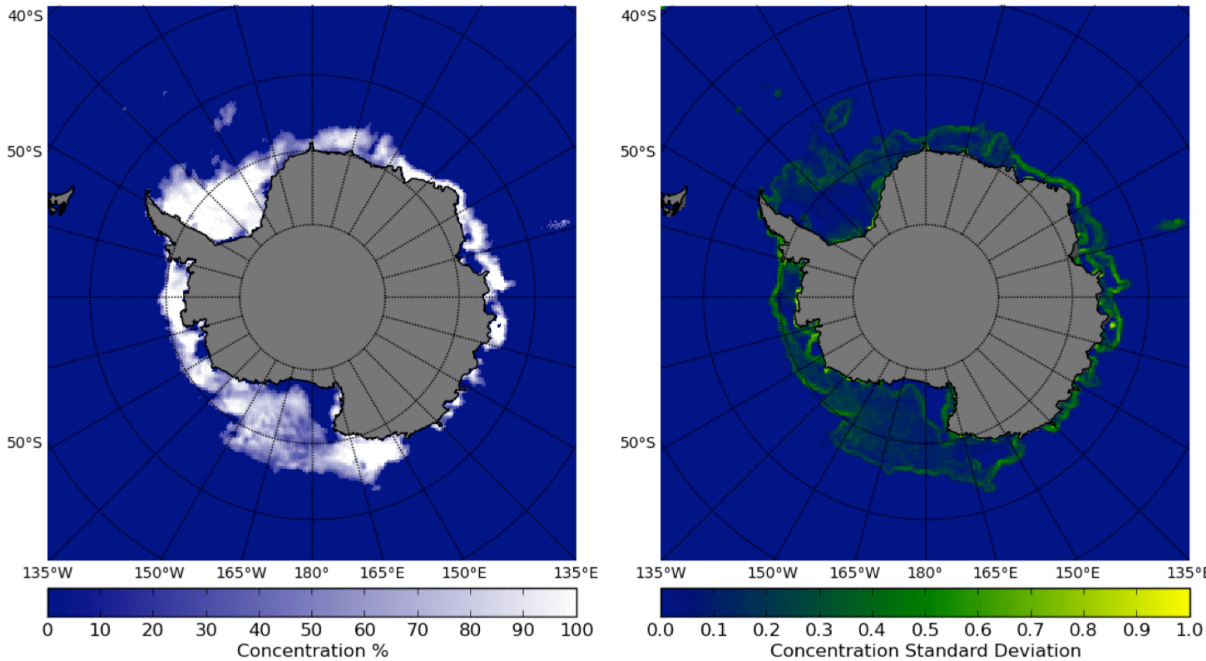


Figure 2. *Sea ice CDR concentration parameter (left) and standard deviation quality indicator (right) for Antarctic region, 1 January 2007.*

5. Considerations for Model-Observation Comparisons

The sea ice concentration fields are derived from gridded daily-average brightness temperatures using a drop-in-the-bucket method. This means that changes in concentration through dynamics (ice motion) or ice growth/melt are "smeared" by the daily average. Due to varying coverage at different latitudes, the number and timing of sensor observations varies between grid cells. A given grid cell may be a daily average of between one and five sensor observations. This leads to an average over different times of the day, which can average out diurnal variations. Because of the different number of looks per day, diurnal effects will vary. Because there are more swath overlaps at high latitudes, such effects are more notable at lower latitudes. Nearer to the poles, away from the ice edge where conditions are more stable, daily variations are 1-2%. At lower latitudes, particularly near the ice edge, daily variations of 15-20% are common (e.g., Brucker et al., submitted). The sensors are all in sun-synchronous orbit, so there is reasonable consistency in the regions where these effects occur, though they do vary with time due to orbit precession; because of the low spatial resolution and the relatively slow rate of change of the ice cover, the inconsistencies are thought to be relatively small.

The sensor footprint issue is another important consideration. While the nominal grid spacing is 25 km, as mentioned above, the input sensor data have footprints as low as 45 x 70 km. This means that the gridded product is oversampled and the effective resolution is less than 25 km. One of the most significant effects of the low resolution is the imprecision and ambiguity of the location of the ice edge. For example, a grid cell that indicates even moderate concentration (50%) may be at an ice-free location with the signal corresponding to ice coming from a neighboring cell. Thus, care should be taken at the ice edge and in general, cells near the ice edge should be considered to have lower confidence.

Intercalibration using sensor overlaps has been done to minimize differences between the various sensors (see Section 6 below) and provide a consistent long-term record. However, intercalibration periods were often short (as little as two weeks) and may not capture the effects of high seasonal variability, leading to less than optimal consistency. However, this effect appears to be negligible and overall, the sea ice time series exhibits good consistency.

As mentioned above, thin ice, melt, near-coast, and strong atmospheric emission lead to errors and are not explicitly accounted for. Particularly during summer during the melt season, concentration is underestimated. Generally, using ice extent (ice/no-ice with a 15% concentration threshold) may provide a better, more consistent, parameter for comparison with models.

6. Instrument Overview

The input data for the sea ice product are passive microwave brightness temperatures from a series of instruments, beginning with the Scanning Multichannel Microwave Radiometer (SMMR) on the NASA Nimbus-7 platform. This was followed by a series of Special Sensor Microwave Imager (SSM/I) and Special Sensor Microwave Imager and Sounder (SSMIS) on Defense Meteorological Satellite Program (DMSP) platforms. The passive microwave sensors are conically scanning multichannel radiometers. The sensors, platforms, date ranges, frequencies used by the sea ice algorithm, and footprint size are provided in Table 2.

Platform and Instrument	Time Period	Frequency, in GHZ, (footprint resolution in km) of channels for sea ice
Nimbus-7 SMMR	10/26/1978 – 07/08/1987	18.0 (54x35), 21.0 (44x29), 37.0 (28x18)
DMSP-F8 SSM/I	07/09/1987 – 12/02/1991	19.3 (70x45), 22.0 (60x40), 37.0 (38x30)
DMSP-F11 SSM/I	12/03/1991 – 09/30/1995	19.3 (70x45), 22.0 (60x40), 37.0 (38x30)
DMSP-F13 SSM/I	10/01/1995 – 12/31/2007	19.3 (70x45), 22.0 (60x40), 37.0 (38x30)
DMSP-F17 SSMIS	01/01/2008 – 12/31/2011	19.3 (70x45), 22.0 (60x40), 37.0 (38x30)

Table 2. *Sensor, date, and time period for input brightness temperatures used in the sea ice algorithm. All frequencies have both horizontal and vertical polarization channels except the 21/22 GHz frequencies, which are only vertically polarized.*

7. References

Primary CDR references:

Meier, W., F. Fetterer, M. Savoie, S. Mallory, R. Duerr, and J. Stroeve. 2013. *NOAA/NSIDC Climate Data Record of Passive Microwave Sea Ice Concentration, Version 2*. Boulder, Colorado USA: National Snow and Ice Data Center. http://dx.doi.org/10.7265/N55M63M1

Meier, W. N., M. Savoie, and S. Mallory. 2011. CDR Climate Algorithm and Theoretical Basis Document: Passive Microwave Sea Ice Concentration. NOAA NCDC CDR Program.

Peng, G., W. N. Meier, D. J. Scott, and M. H. Savoie. 2013. A long-term and reproducible passive microwave sea ice concentration data record for climate studies and monitoring. Earth Syst. Sci. Data 5: 311-318. doi: 10.5194/essd-5-311-2013.

Meier, W. N., G. Peng, D. J. Scott, and M. Savoie, 2014: Verification of a new sea ice concentration climate data record. Polar Research. doi:http://dx.doi.org/10.3402/polar.v33.21004.

Background and related references:

Brucker, L., D.J. Cavalieri, T. Markus, and A. Ivanoff, 2014. NASA Team 2 sea ice concentration algorithm retrieval uncertainty, submitted to *IEEE Trans. Geosci. Rem. Sens.*

Cavalieri, D. J., C. L. Parkinson, P. Gloersen, and H. Zwally. 1996, updated yearly. *Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data*. Boulder, Colorado USA: NASA DAAC at the National Snow and Ice Data Center. http://nsidc.org/data/nsidc-0051.html.

Cavalieri, D. J., C. l. Parkinson, P. Gloersen, J. C. Comiso, and H. J. Zwally. 1999. Deriving Long-term Time Series of Sea Ice Cover from Satellite Passive-Microwave Multisensor Data Sets. *Journal of Geophysical Research* 104(7): 15,803-15,814.

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Comiso, J. C., and F. Nishio. 2008. Trends in the Sea Ice Cover Using Enhanced and Compatible AMSR-E, SSM/I, and SMMR Data. *J. of Geophys. Res.*, 113, C02S07, doi:10.1029/2007JC0043257.

Maslanik, J. and J. Stroeve. 2004, updated 2012. *DMSP SSM/I-SSMIS Daily Polar Gridded Brightness Temperatures*. Version 4. Boulder, Colorado USA: NASA DAAC at the National Snow and Ice Data Center. http://nsidc.org/data/nsidc-0001.html.

Meier, W. N. 2005. Comparison of Passive Microwave Ice Concentration Algorithm Retrievals with AVHRR Imagery in Arctic Peripheral Seas. *IEEE Trans. Geosci. Remote Sens.*, 43(6): 1324-1337.

8. Dataset and Document Revision History

Rev 0 – 6 March 2015 - This is a new document/dataset, referring to Version 2 of the NOAA/NSIDC Sea Ice Concentration CDR data set.