Bootstrap Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS, Version 4

USER GUIDE

How to Cite These Data

As a condition of using these data, you must include a citation:

Comiso, J.C., Gersten, R.A. 2023. *Bootstrap Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS, Version 4*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/X5LG68MH013O. [Date Accessed].

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National Snow and Ice Data Center

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1 DATA DESCRIPTION

This sea ice concentration data set was derived using measurements from the Scanning Multichannel Microwave Radiometer (SMMR) on the Nimbus-7 satellite and from the Special Sensor Microwave/Imager (SSM/I) sensors on the Defense Meteorological Satellite Program (DMSP) -F8, -F11, and -F13 satellites. Measurements from the Special Sensor Microwave Imager/Sounder (SSMIS) aboard DMSP-F17 are also included. The data set has been generated using the Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E) Bootstrap Algorithm with daily varying tie-points. Daily (every other day prior to July 1987) and monthly data are available for both the north and south polar regions. Data are gridded on the SSM/I polar stereographic grid (25 x 25 km).

1.1 Parameters

The data set consists of sea ice concentration derived from gridded brightness temperatures. Historically – including previous versions of this data set – sea ice concentration was provided as “concentration” values ranging from 0 to 100 percent. Now the data are provided as the CF-compliant standard name “sea_ice_area_fraction” which ranges from 0 (meaning no sea ice) to 1 (meaning 100% sea ice cover). The data are encoded in the NetCDF file as short (2-byte) integers with a scaling factor of 0.001, so the sea ice concentration values range from 0 to 1000 and thus have a precision of one tenth of a percent.

Two sentinel values – data values in the sea ice concentration field which are not sea ice concentrations – are also used: A value of “1200” indicates that a pixel is primarily land or permanent ice-shelf (not water) and therefore would never have a sea ice concentration value. A value of “1100” indicates missing data, e.g. some pixels near the North Pole are never measured because of the path of the observing satellite.

1.2 File Information

1.2.1 Format

The data are in NetCDF (.nc) format, using CF 1.6 (Climate and Forecast) and ACDD 1.3 (Attribute Conventions for Dataset Discovery) metadata conventions.

1.2.2 File Contents

The NetCDF (`.nc`) files come with a granule-specific metadata file in Extensible Markup Language (`.xml`) format. CF metadata, and, when sea ice concentration is calculated, a concentration variable.

On days when concentration data are available, the NetCDF file contains the concentration field in a variable of the form <SENSOR>_ICECON where the sensor may be N07, F08, F11, F13, or F17; for example, "F17_ICECON".

On days when no sea ice concentration data are computed, the file exists but there is no ICECON variable in the file. For example, the SMMR instrument (N07) collected data only every other day, so there is a sea ice concentration field only every other day during the period which the SMMR was active (1978 to August 1987). A NetCDF file is generated each day during the SMMR era, but on days without data, the N07_ICECON variable will not be present in the file. This is also the case for all other days when sea ice concentrations are not computed, including a 6-week data gap from December 1987 to January 1988 when sea ice concentrations were computed using data from the F08 SSMI sensor.

The dimensions of the ICECON variable are (t, y, x) with time (t) as the "unlimited dimension." This allows the data to be concatenated along the time dimension using standard NetCDF tools.

Each data file also includes a coordinate reference system variable, "`crs`", and its associated x and y dimensions containing the center-of-grid cell locations in projected meters. This encoding allows the data to be properly georeferenced by software tools such as Panoply, QGIS, GDAL, and other geo-aware programs.

1.2.3 Naming Convention

Files are named according to the following convention and as described in Table 1.

Daily File Name Convention: `NSIDC0079_SEAICE_PS_HXXkm_YYYYMMDD_v4.0.ext`
Example Daily Data File Name: `NSIDC0079_SEAICE_PS_N25km_20220630_v4.0.nc`

Monthly File Name Convention: `NSIDC0079_SEAICE_PS_HXXkm_YYYYMM_v4.0_SSS.ext`
Example Monthly Data File Name: `NSIDC0079_SEAICE_PS_N25km_202206_v4.0.nc`

Table 1. File Naming Convention

Variable	Description
`SEAICE`	Identifies this as a file containing sea ice concentration
`PS`	Identifies the grid as Polar Stereographic spatial reference system
`H`	Hemisphere: Northern (N) or Southern (N)
`XXkm`	Grid cell size (example: 25 km)
`YYYY`	4-digit year
`MM`	2-digit month
`DD`	2-digit day (omitted for monthly files)

`vV`	Version number (example: v4.0)
`SSS`	3-character sensor name for browse images (`.png`) files only: `N07` for Nimbus-7 SMMR `F08, F11,` or `F13` for DMSP SSM/I sensors `F17` for the DMSP SSMIS sensor
`.ext`	File extension: NetCDF (`.nc`)

1.3 Spatial Information

1.3.1 Coverage

Data set coverage includes the polar regions, as defined by the Polar Stereographic Projection spatial coverage map.

Each of the three instruments provide global coverage except for a circular section centered over the North Pole. These sectors are never measured due to orbit inclination of the satellite.

Table 2 shows the sizes and latitudes of each of the pole holes.

NOTE: The SSMIS pole hole was implemented in March 2015 and applied to all data from January 2008 to present. Even though SSMIS data begin in January 2007, this product does not start using the SSMIS pole hole mask until January 2008 to allow for comparison analysis with SSM/I during the transition from SSM/I to SSMIS data in 2007.

Table 2. Pole Hole Sizes and Dates by Mask

Pole Hole Mask Name	Pole Hole Area (million km^2)	Pole Hole Radius (km)	Latitude	Dates Used
SMMR Pole Hole Mask	1.19	611	84.5° N	November 1978 to June 1987
SSM/I Pole Hole Mask	0.31	311	87.2° N	July 1987 to December 2007
SSMIS Pole Hole Mask	0.029	94	89.18° N	January 2008 to present

1.3.2 Resolution

The nominal spatial resolution for this data set is 25 km. However, because the polar grids are not equal area, the exact resolution varies by latitude.

1.3.3 Projection and Grid Description

The sea ice concentration data are displayed in polar stereographic projection. The Northern and Southern Hemisphere fields have different grid sizes and different grid definitions, as described in Table 4 and

Table 5. For more information, see Polar Stereographic Projections and Grids.

Table 3. Grid Dimensions

Region	Columns (x)	Rows (y)
North	304	448
South	316	332

The following tables provide information for geolocating this data set.

Table 4. Geolocation Details

Geographic Coverage	Northern Hemisphere	Southern Hemisphere
Geographic coordinate system	Hughes 1980	Hughes 1980
Projected coordinate system	NSIDC Sea Ice Polar Stereographic North	NSIDC Sea Ice Polar Stereographic South
Longitude of origin	-45°	0°
Latitude of true scale	70°	-70°
Scale factor at latitude of true scale	1	1
Datum	Hughes 1980	Hughes 1980
Ellipsoid/spheroid	Hughes 1980	Hughes 1980
Units	meters	meters
False easting	0	0
False northing	0	0
EPSG code	3411	3412
PROJ4 string	`+proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +a=6378273 +b=6356889.449 +units=m +no_defs`	`+proj=stere +lat_0=-90 +lat_ts=-70 +lon_0=0 +k=1 +x_0=0 +y_0=0 +a=6378273 +b=6356889.449 +units=m +no_defs`
Reference	https://epsg.io/3411	https://epsg.io/3412

Table 5. Grid Details based on Hemisphere.

Grid	North Polar	South Polar
Grid cell size (km)	25 × 25	25 × 25
Grid size (rows × columns)	448 × 304	332 × 316

Geolocated lower left point in grid (km)	(-3850, -5350)	(-3950, -3950)
Nominal gridded resolution	25 km	25 km
Grid rotation (degrees)	-45	0
ulxmap: x-axis coord, center of upper left pixel (XLLCORNER) (km)	-3,837.5 km	-3,937.5 km
ulymap: y-axis coord, center of upper left pixel (YLLCORNER) (km)	5,837.5 km	4,337.5 km

1.4 Temporal Information

1.4.1 Coverage

Bootstrap sea ice concentration data coverage began on 01 November 1978 and is ongoing through the most current processing.

1.4.2 Resolution

SMMR data were collected every other day. (The scanner operated only on alternate days, due to spacecraft power limitations). Major data gaps occurred in August 1982 (4, 8, and 16 August) and 1984 (13 through 23 August) for both polar regions. Data were interpolated where missing pixels were present so that no areas of missing data remained.

SSM/I and SSMIS data are collected daily. Monthly mean files are calculated by averaging all available daily files for each individual month, excluding pixels of missing data. Ice concentrations are provided for each day of data and as monthly means. Due to satellite data outage, a major data gap in the SSM/I data occurs from 03 December 1987 to 13 January 1988.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

The SMMR, SSM/I, and SSMIS instruments are microwave radiometers that sense emitted microwave radiation. This radiation is affected by surface and atmospheric conditions, and thus provides a range of geophysical information. The emitted energy of the surface measured by the passive microwave frequencies on the SMMR, SSMI, SSMIS instruments is dependent on the phase state of water – i.e., whether it is liquid or solid. Thus, the passive microwave sensors can distinguish between ice and water. The Bootstrap sea ice concentration algorithm employs multiple frequencies and polarizations to limit the effects of the atmosphere and ocean emission, reduce ambiguity in the ice-water discrimination, and provide a retrieval of concentration in each grid cell.

2.2 Acquisition

Five sets of satellite sensors are used to create the Bootstrap sea ice data product:

- Nimbus-7 SMMR, data range: 01 November 1978 through 31 July 1987
- DMSP-F08 SSM/I, data range: 01 August 1987 through 17 December 1991
- DMSP-F11 SSM/I, data range: 18 December 1991 through 09 May 1995
- DMSP-F13 SSM/I, data range: 10 May 1995 through 31 December 2007
- DMSP-F17 SSMIS, data range: 01 January 2008 through the most current processing

2.2.1 SMMR

Sea ice concentrations were processed by GSFC using SMMR brightness temperatures. The SMMR brightness temperatures were processed and quality checked at GSFC (Gloersen et al. 1992).

2.2.2 SSM/I-SSMIS

Bootstrap sea ice concentrations were processed at GSFC using DMSP SSM/I-SSMIS Daily Polar Gridded Brightness Temperatures from NSIDC. Processing of DMSP-F17 brightness temperatures is ongoing. For more information on the brightness temperatures, see the DMSP SSM/I-SSMIS Daily Polar Gridded Brightness Temperatures documentation.

2.3 Processing

Sea ice concentrations for this data set were derived from the NASA Goddard Bootstrap algorithm. For more information about the algorithm and its background, please see the Enhanced Sea Ice Concentrations from Passive Microwave Data document (Comiso and Nishio 2008).

2.3.1 Interpolation

Data were interpolated in areas with missing pixels according to the following steps. First, data were spatially interpolated only for isolated empty pixels. An empty pixel was replaced by the average of four good surrounding pixels, or if four good pixels were not available, then a smaller number of pixels was selected. Second, a time interpolation was applied to the spatially interpolated map. Time interpolation was based on a weighting scheme; the closer the good data were in time, the higher the weighted value. For each empty pixel, the algorithm searched forward in time for a good pixel, and backward in time for a second good pixel. The algorithm determined how many days ahead and behind the two good pixels occurred and calculated the weight of each pixel. A weighted average of the two good pixels was then calculated, and the result was used for the empty pixel. During the SSM/I period, most temporal interpolations were conducted using only adjacent days. During the SMMR period, particularly in 1986 when larger gaps were present, temporal interpolations had separations of more days.

2.4 Quality, Errors, and Limitations

2.4.1 Assessment of Version Differences

NSIDC DAAC staff review the entire set of data files, including file structure, comparisons to existing SMMR- and SSM/I-derived sea ice concentration grids, and information files and examination of data quality.

2.4.2 Errors and Limitations

Sensitivity analysis of potential errors associated with the retrieval of sea ice products were discussed previously. For example, see Comiso et al. 1997 and other references associated with the NASA Team Algorithm sea ice products. Sea ice concentration errors are difficult to quantify because sea ice is an evolving ice cover and does not have uniform physical and radiative characteristics throughout the ice pack. The emissivity of sea ice is known to change as the ice cover develops from grease ice to nilas, pancake to young ice, or first year ice to multiyear ice. The algorithm is calibrated to a maximum concentration of 100% thick ice (e.g., >~50 cm). Areas with 100 percent of thinner ice types are often estimated to have lower ice concentrations – as low as 80 percent due to lower emissivities (Comiso et al. 1992). In the summer, retrievals in the Arctic could have biases caused by meltponding effects (Comiso and Kwok 1996).

Inside the ice pack, observations from helicopter and aircraft flights typically show very high sea ice concentrations with some 5 to 10 percent of the leads covered by nilas or pancake ice. The frequency distribution of sea ice concentration in highly consolidated ice areas has a standard deviation of about 3 percent, which includes sea ice cover with concentrations of less than 100 percent. Overall, retrieval accuracy is estimated to be approximately 5 to 10 percent except in some unusual cases, such as the presence of a large fraction of thin ice or meltponding within the pixel and the presence of stormy weather conditions, especially near the ice edge. Limited comparative analysis with high resolution instruments and other measurements confirm this, but more extensive validation in a greater number of places over all of the seasons would provide more accurate error assessments. More recent studies by Kern et al. (2019, 2020) confirm these characteristics and provide comparisons with other algorithms.

For information describing the rough error/differences between each sensor (F8, F11, F13, F17) during the sensor overlap time period, refer to the following documentation: Comiso et al. 2008, Comiso et al. 2009, and Comiso et al. 2010.

Basic limitations arise from the sensor resolution, temporal coverage, and algorithm assumptions and characteristics. Users should review the information provided on fields of view, temporal sampling, and algorithm characteristics.

Particular care is needed in interpreting the sea ice concentrations during summer when melt is underway and in regions where new sea ice makes up a substantial part of the sea ice cover. As noted, some residual errors remain due to sensor differences and to weather effects along with mixing of ocean and land area within the sensor field of view.

No data coverage is available for regions poleward of 84.5° N for SMMR and 87.2° N for SSM/I or SSMIS due to the inclination of the orbits. SMMR data were acquired every other day, while SSM/I and SSMIS data were acquired daily.

2.5 Instrumentation

For a detailed description of the SMAP instrument, visit the SMMR, SSM/I, and SSMIS Sensors Summary website.

3 SOFTWARE AND TOOLS

The data are provided in NetCDF format and can be read and viewed using software capable of interpreting this standard format. NASA's Panoply visualization software (https://www.giss.nasa.gov/tools/panoply/) and the NetCDF Operators (NCO) suite of command line tools (http://nco.sourceforge.net/) have been used extensively at NSIDC to work with these data. A GitHub repository (https://github.com/nsidc/polarstereo-reformat/) contains scripts that convert the NetCDF back to the original binary format used in previous versions of this data set.

4 VERSION HISTORY

Table 6 outlines the processing and algorithm history for this product.

Table 6. Version History Summary

Version	Date	Description of Changes
V1	January 1996	Original version of data. For information regarding Version 1 data processing, see the Bootstrap Sea Ice Concentrations Version 1 Processing Steps web page.

V2	September 2007	Changes to this version include: • Adjusted tie points to be consistent with the AMSR-E Bootstrap algorithm • Adjusted Southern Hemisphere land mask to account for changes in extent and positions of ice shelves • Reprocessed entire SMMR-SSM/I time series Due to the updates outlined in this version summary, we ask that you acquire the entire Version 3 data set in order to update your time series.
V3	November 2017	Changes to this version include: • Intercalibration techniques between SMMR and F08, as well as F08 and F11, were changed to match sea ice area rather than sea ice extent • Ocean tie points now change each day (similar to the ice tie points) based on brightness temperatures for that day. • The threshold for the lower limit for ice was relaxed to allow retrieval of ice at 10 percent ice concentration
V3.1	July 2018	Version 3.1 of the Bootstrap ice concentrations computes sea ice concentration with an open water identifier that is calculated daily in May and October; in version 3.0, this value was calculated using a single monthly value for May and a single monthly value for October.
V4	November 2023	The NSIDC DAAC repackaged the data fields provided by GSFC in CF-compliant NetCDF files.

5 RELATED DATA SETS

- Sea Ice Trends and Climatologies from SMMR and SSM/I-SSMIS
- DMSP SSM/I-SSMIS Daily Polar Gridded Brightness Temperatures
- Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data
- Sea Ice Index
- Sea Ice Data

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7 DOCUMENT INFORMATION

7.1 Publication Date

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7.2 Date Last Updated

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