Bootstrap Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS, Version 3

USER GUIDE

How to Cite These Data

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

Comiso, J. C. 2017. *Bootstrap Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS, Version 3*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/7Q8HCCWS4I0R. [Date Accessed].

FOR QUESTIONS ABOUT THESE DATA, CONTACT NSIDC@NSIDC.ORG

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/NSIDC-0079

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's (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) and provided in two-byte integer format.

NOTE: Users should acquire the entire Version 3 data set in order to update their time series. For more information, refer to the Version History section of this document.

1.1 Parameters

The data set consists of sea ice concentration derived from gridded brightness temperatures. Sea ice concentrations range from 0 to 100 percent.

Data are stored as two-byte integers representing sea ice concentration values. The sea ice concentration data values are packed into integer format by multiplying the original sea ice concentration values by 10 (divide stored value by 10 to get the percent). The sea ice concentration values range from 0 to 1000. Land is registered as 1200 and the Northern Hemisphere hole (a region of the North Pole that is not measured due to orbit inclination) is registered as 1100. Refer to the Spatial Coverage section of this document.

1.2 File Information

1.2.1 Format

Data files are stored in the original Goddard Space Flight Center (GSFC) flat binary two-byte integer format, use the little-endian byte order convention, and are scaled by a factor of 10. An individual image of daily or monthly averaged data constitutes a granule in the Bootstrap sea ice concentration time series.

1.2.2 File Contents

The following is a sample data record from the Northern Hemisphere monthly data.

```
837  887  924 971  971 992 980 975 974 964 980 965 936 972 968 986
982  987  978 984  988 965 980 972 981 985 992 988 989 983 993 986
985  984  982 983  982 981 974 990 982 983 978 977 983 987 981 992
985  979  978 982  981 969 966 972 977 984 973 976 980 970 972 977
980  984  980 982  977 973 973 969 968 972 980 951 887 877 928 936
1200 1200 1200 969 1200 951 956 980 980 980 975 982 982 961 937 863
791  710  706 706  678
```

1.2.3 Directory Structure

Data are available via HTTPS, the link for which can be found on the "Download Data" tab. Within the file directory, data are sorted by date.

1.2.4 Naming Convention

NOTE: For Version 3.1, file names were changed from v03 to v3.1, such as bt_20060901_f13_v3.1_n.bin.

Daily data files are named according to the following convention and as described in Table 1.

`bt_YYYYMMDD_SSS_vV.V_H.bin`

Table 1. Daily Files Naming Convention

Variable	Description
bt	indicates that this file was created using the bootstrap algorithm
YYYY	4-digit year
MM	2-digit month
DD	2-digit day
SSS	3-character sensor name: `n07` for Nimbus-7 SMMR `f08`, `f11`, or `f13` for DMSP SSM/I sensors `f17` for the DMSP SSMIS sensor
vV.V	2-digit version number (for example, v3.1)
H	Hemisphere: `n` for Northern `s` for Southern
.bin	Indicates that this file is in binary format

Example: `bt_20060901_f13_v3.1_n.bin`

Monthly data files are named according to the following convention and as described in Table 2.

`bt_YYYYMM_SSS_vV.V_H.bin`

Table 2. Monthly Files Naming Convention

Variable	Description
bt	indicates that this file was created using the bootstrap algorithm
YYYY	4-digit year
MM	2-digit month
SSS	3-character sensor name: `n07` for Nimbus-7 SMMR `f08, f11,` or `f13` for DMSP SSM/I sensors `f17` for the DMSP SSMIS sensor
vV.V	2-digit version number (for example, v3.1)
H	Hemisphere: `n` for Northern `s` for Southern
.bin	indicates that this file is in binary format

Example File Name: `bt_200609_f13_v3.1_n.bin`

1.2.5 File Size

Northern Hemisphere files are approximately 266 KB. Southern Hemisphere files are approximately 205 KB.

1.3 Spatial Information

1.3.1 Coverage

Data set coverage includes the northern and southern polar regions. For a detailed description, see the SSM/I Polar Spatial Coverage Maps section of the Polar Stereo website.

SSM/I and SSMIS instrument coverage is global, except for circular sectors centered over the North Pole, 311 km in radius, located poleward of 87.2°. These sectors are never measured due to orbit inclination. The 50° scan pattern provided a swath width of 780 km at the Earth's surface. The spatial resolutions at the various frequencies ranged from approximately 27 km at 37 GHz to 148 km at 6.6 GHz. For more details, please refer to the SMMR, SSM/I, and SSMIS Sensors Summary. The measurement footprint size or effective field of view (FOV) varies by frequency, as shown in the following table.

Table 3. SSM/I-SSMIS

Frequency	Footprint Size
19.3 GHz	70 x 45 km
22.2 GHz	60 x 40 km
37.0 GHz>	38 x 30 km

SMMR instrument coverage is global, except for circular sectors centered over the North Pole, approximately 611 km in radius, located poleward of 84.5°. These sectors are never measured due to orbit inclination. The 50° scan pattern provided a swath width of 780 km at the Earth's surface. The spatial resolutions at the various frequencies ranged from approximately 27 km at 37 GHz to 148 km at 6.6 GHz. For more details, please refer to the SMMR, SSM/I, and SSMIS Sensors Summary. The measurement footprint size varies by frequency, as shown in the following table.

Table 4. SMMR

Frequency	Footprint Size
6.6 GHz	148 x 95 km
10.7 GHz	91 x 59 km
18.0 GHz	55 x 41 km
21.0 GHz	46 x 30 km
37.0 GHz	27 x 18 km

1.3.2 Resolution

Sea ice concentrations are provided at a resolution of 25 km.

1.3.3 Projection and Grid Description

For more information, see Polar Stereo. The grid size varies depending on the region, as shown in the following table.

Table 5. Grid Size

Region	Columns	Rows
North	304	448
South	316	332

1.4 Temporal Information

1.4.1 Coverage

Bootstrap sea ice concentration data are available for 26 October 1978 through 31 December 2020.

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. Monthly means are generated by averaging all available files for each individual month, excluding pixels of missing data. Data were interpolated where missing pixels were present so that no areas of missing data remained.

SSM/I and SSMIS data are collected daily. Ice concentrations are provided for each day of data and as monthly means. Monthly mean files are generated by averaging all available daily files for each individual month, excluding pixels of missing data. 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 and SSM/I instruments are dual-polarized and multi-frequency microwave radiometers that sense emitted microwave radiation at an incidence angle of about 53° and an altitude of about 800 km. At microwave frequencies, the observed radiance varies linearly with the temperature of the emitting material, according to the Rayleigh-Jeans law, and is usually expressed in terms of brightness temperature. The constant of proportionality in the linear relationship is the emissivity, which provides information about the electrical and physical properties of the material itself. The observed brightness temperatures come primarily from the Earth's surface with some contributions from the atmosphere and outer space. Depending on frequency and polarization, the brightness temperature is affected by changing surface, subsurface, and atmospheric conditions. The multichannel capability allows for the discrimination of different surfaces and atmospheric effects and allows for the development of algorithms that provide a range of geophysical information about the surface.

2.2 Acquisition

Four sets of satellite data are used to create the Bootstrap sea ice data stream:

- 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 a revised Bootstrap algorithm which uses a different set of tie-points and adjustments. For algorithm background, please see the Enhanced Sea Ice Concentrations from Passive Microwave Data document (Comiso and Nishio 2008). For changes made to this Version 3 data set, see the Positive Trend in the Antarctic Sea Ice Cover and Associated Changes in Surface Temperature document (Comiso, et al. 2017).

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

NOTE: A large fraction of the text in this document was supplied by the data provider. It may include qualitative judgments and statements by the provider and does not necessarily represent endorsements or imply that independent assessments have been performed by NSIDC staff.

2.4.1 Assessment of Version Differences

For Version 3.1 data, the differences in total Arctic sea ice area and sea ice extent are usually small (less than ± 0.5%), except in the second half of May when daily sea ice areas are often 0.5-1.5% higher and extents are 1-3% higher in V3.1 than in V3.0.

The staff at the NSIDC DAAC performed an evaluation between Version 2 and Version 3 data to verify any difference between the two versions. Here are their findings:

- The changes introduced in Version 3 have some effect on the total ice covered area and extent. These differences have some seasonality and appear to be largely due to the use of dynamic open water tie points.
- The majority of pixels show no change in concentration value or less than one percent, although a small fraction have larger differences. Roughly two percent of pixels show concentration changes of more than 10 percent.

Although most bad data are easily identifiable and removed with little ambiguity, human judgments must be made and applied consistently to the time series data. While efforts were made to minimize errors in judgment and inconsistencies, the resulting data set is not perfect. Nevertheless, the data provider feels that these maps are suitable for some types of research studies, such as basin-scale trend analysis, model inputs, and some regional studies. They are less useful in evaluating conditions on a specific day in a localized region.

NSIDC staff visually checked 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 line AD in the scatter plot that provides the sea ice tie-point in the Bootstrap Algorithm corresponds to 100 percent ice for the relatively thick ice types such as first year or multiyear ice. Areas with 100 percent of thinner ice types are often estimated to have 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.

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 data were acquired daily. SSMIS data are also acquired daily.

2.5 Instrumentation

2.5.1 Description

Please refer to the SMMR, SSM/I, and SSMIS Sensors Summary for details regarding the following sensors and platforms:

2.5.2 Sensors

Scanning Multi-channel Microwave Radiometer (SMMR)
Special Sensor Microwave Imager (SSM/I)
Special Sensor Microwave Imager (SSMIS)

2.5.3 Platforms

Nimbus 7 Spacecraft System
Defense Meteorological Satellite Program (DMSP) Satellite F8
Defense Meteorological Satellite Program (DMSP) Satellite F11
Defense Meteorological Satellite Program (DMSP) Satellite F13

3 SOFTWARE AND TOOLS

Table 6 lists the tools that can be used with this data set. For a comprehensive list of all polar stereographic tools, see the Polar Stereo web page.

Table 6. Tools for this Data Set

Tool Type	Tool File Name(s)
Data Extraction	extract_ice.pro
Geocoordinate	locate.for
	mapll.for and mapxy.for
	psn25lats_v3.dat and pss25lats_v3.dat
	psn25lons_v3.dat and pss25lons_v3.dat
Pixel-Area	psn25area_v3.dat and pss25area_v3.dat
Land Masks	gsfc_25n.msk and gsfc_25s.msk
	coast_25n.msk and coast_25s.msk
	ltln_25n.msk and ltln_25s.msk
	pole_n.msk
Region Masks	region_n.msk and region_s.msk

4 VERSION HISTORY

Table 7 outlines the processing and algorithm history for this product.

Table 7. Version History Summary

Version	Date	Description
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.
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
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.
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.

5 RELATED DATA SETS

- Sea Ice Trends and Climatologies from SMMR and SSM/I-SSMIS
  NSIDC provides a suite of value-added products to aid in investigations of the variability and trends of sea ice cover. These products provide users with information about sea ice extent, total ice covered area, ice persistence, monthly climatologies of sea ice concentrations, and ocean masks.
- DMSP SSM/I-SSMIS Daily Polar Gridded Brightness Temperatures
  NSIDC produces daily gridded brightness temperature data from orbital (swath) data generated by SSM/I mounted on the DMSP F8, F11, and F13 platforms. The gridded brightness temperatures are distributed in polar stereographic projection.
- Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data

This data set is generated from brightness temperature data derived from the Nimbus-7 SMMR and DMSP F8, F11, and F13 SSM/I radiances at a grid cell size of 25 x 25 km. The data are provided in the polar stereographic projection.

- Sea Ice Index
  The images in the Sea Ice Index data set depict average ice conditions, estimated using satellite passive microwave data for the most recent month available, as well as snapshots of trends and anomalies that compare these recent conditions with the mean for the month.
- Sea Ice Data
  This site offers a summary of sea ice data derived from passive microwave sensors and other sources and is useful for users who want to compare characteristics of various sea ice products to understand their similarities and differences. This site also provides links to tools for passive microwave data and a list of other sea ice resources.

6 RELATED WEBSITES

- Descriptions of and Differences between the NASA Team and Bootstrap Algorithms
- Polar Stereographic Projections and Grids
- SMMR, SSM/I, and SSMIS Sensors Summary

7 CONTACTS AND ACKNOWLEDGMENTS

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8 REFERENCES

Cho, K., N. Sasaki, H. Shimoda, T. Sakata, and F. Nishio. 1996. Evaluation and Improvement of SSM/I Sea Ice Concentration Algorithms for the Sea of Okhotsk. *Journal Remote Sensing of Japan* 16(2):47-58.

Comiso, J.C., R.A. Gersten, L.V. Stock, J. Turner, G.J. Perez, and K. Cho. 2017. Positive Trend in the Antarctic Sea Ice Cover and Associated Changes in Surface Temperature. J. Climate, 30, 2251–2267, https://doi.org/10.1175/JCLI-D-16-0408.1

Comiso, J.C. 2010. Polar Oceans from Space, Springer Publishing, New York, doi 10.1007/978-0-387- 68300-3.

Comiso, J. C. 2009. Enhanced sea ice concentration and ice extent from AMSR-E Data, J. Remote Sensing Soc. of Japan, 29(1), 199-215.

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

Comiso, J. C., D. Cavalieri, C. Parkinson, and P. Gloersen. 1997. Passive Microwave Algorithms for Sea Ice Concentrations: A Comparison of Two Techniques. Remote Sensing of the Environment 60(3):357-84.

Comiso, J. C., and R. Kwok. 1996. The Summer Arctic Sea Ice Cover from Satellite Observations. Journal of Geophysical Research 101(C2):28,397-416.

Comiso, J. C. 1995. SSM/I Concentrations Using the Bootstrap Algorithm. NASA Reference Publication 1380. 40 pages.

Comiso, J. C, T. C. Grenfell, M. Lange, A. Lohanick, R. Moore, and P. Wadhams. 1992. Microwave Remote Sensing of the Southern Ocean Ice Cover. Microwave Remote Sensing of Sea Ice, ed. Frank Carsey. Washington D.C.: American Geophysical Union. 243-59.

Comiso, J. C. and C. W. Sullivan. 1986. Satellite Microwave and In-Situ Observations of the Weddell Sea ice Cover and its Marginal Ice Zone. Journal of Geophysical Research 91(C8):9,663-81.

Comiso, J. C. 1984. Characteristics of Winter Sea Ice from Satellite Multispectral Microwave Observations. Journal of Geophysical Research 91(C1):975-94.

Comiso, J. C., S. F. Ackley, and A. L. Gordon. 1984. Antarctic Sea Ice Microwave Signature and Their Correlation with In-Situ Ice Observations. Journal of Geophysical Research 89(C1):662-72.

Gloersen P., W. Campbell, D. Cavalieri, J. Comiso, C. Parkinson, H. J. Zwally. 1992. Arctic and Antarctic Sea Ice, 1978-1987: Satellite Passive Microwave Observations and Analysis. NASA Special Publication 511.

Maslanik, J. A. 1992. Effects of Weather on the Retrieval of Sea Ice Concentration and Ice Type from Passive Microwave Data. International Journal of Remote Sensing 13(1):37-54.

National Snow and Ice Data Center. 1992. DMSP SSM/I Brightness Temperature and Sea Ice Concentration Grids for the Polar Regions on CD-ROM - User's Guide. NSIDC Special Report - 1. 222 pp.

Parkinson, C. L., D. J. Cavalieri, P. Gloersen, H. J. Zwally, and J. C. Comiso, 1999. Arctic Sea Ice Extents, Areas, and Trends, 1978-1996. Journal of Geophysical Research 104(C9), 20,837-20,856.

Parkinson, C. L., J. C. Comiso, H. J. Zwally, D. J. Cavalieri, P. Gloersen, and W. J. Campbell. 1987. Arctic Sea Ice 1973-1976 from Satellite Passive Microwave Observations. NASA Special Publication 489.

Pearson, F. 1990. Map Projections: Theory and Applications. Boca Raton, FL:CRC Press. 372 pages.

Snyder, J. P. 1987. Map Projections - A Working Manual. U.S. Geological Survey Professional Paper 1395. Washington, D.C.:U.S. Government Printing Office. 383 pages.

Snyder, J. P. 1982. Map Projections used by the U.S. Geological Survey. U.S. Geological Survey Bulletin 1532.

Zwally, H. J., J. C. Comiso, C. L. Parkinson, W. J. Campbell, F. D. Carsey, and P. Gloersen. 1983. Antarctic Sea Ice 1973-1976 from Satellite Passive Microwave Observations. NASA Special Publication 459.

9 DOCUMENT INFORMATION

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