DMSP SSM/I-SSMIS Pathfinder Daily EASE-Grid Brightness Temperatures, Version 2

USER GUIDE

How to Cite These Data

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

Armstrong, R., K. Knowles, M. J. Brodzik, and M. A. Hardman. 1994. *DMSP SSM/I-SSMIS Pathfinder Daily EASE-Grid Brightness Temperatures, Version 2*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/3EX2U1DV3434. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/NSIDC-0032

National Snow and Ice Data Center

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1 DATA DESCRIPTION

1.1 Parameters

The parameter of this data set is brightness temperature.

1.1.1 Parameter Description

Theoretically, brightness temperature is the effective temperature of a blackbody radiating the same amount of energy per unit area at the same wavelengths as the observed body. Empirically, brightness temperature is the apparent radiant temperature of a non-blackbody determined by measurement with an optical pyrometer or radiometer. The brightness temperature (T_b) at a given wavelength (λ) is the product of the physical temperature (T_p) and the emissivity (ε) at the given wavelength of the surface viewed by the radiometer. Refer to Equation 1.

$T_b(\lambda) = \varepsilon(\lambda)T_p$ **(Equation 1)**

Equation 1 is the Rayleigh-Jean approximation of Plank's law for the passive microwave region of the electromagnetic spectrum. It is an approximation and does not take into account effects of the atmosphere on the microwave radiation.

1.1.2 Parameter Range

Brightness temperature data values are scaled by 10; divide the stored values by 10 to get kelvins. Values range from 550 (representing 55.0 K) to 3200 (representing 320.0 K); missing data are indicated by the value 0.

Time values range from 0 (representing 0000 UTC or midnight) to 239 hours (representing 23:54 UTC or 23.9 hours); missing data are indicated by the value 255. Beginning with F17 time files, the missing data value is the minimum 2-byte integer, or -32768. The legitimate, non-missing value of 0 is midnight of the enclosing day, and a non-missing value of 1439 is one minute prior to midnight the following day.

Latitude and longitude values vary depending upon the grid used. Values are in decimal degrees scaled by 100000; divide the stored values by 100000 to get actual values. Latitude values range from -9000000 to 9000000, and longitude values range from -18000000 to 18000000. Missing data values are indicated by the value 1431655765.

Table 1 summarizes these data ranges.

Table 1. Data Value Range

Parameter	Unit of Measurement	Data Range	Missing Data Value
Brightness Temperatures (T_b)	Tenths of kelvins	550 (representing 55.0 K) to 3200 (representing 320.0 K)	0
Time	Tenths of hours since midnight of the date of the enclosing file	0 (representing 00:00 UTC or midnight) to 239 (representing 23:54 UTC or 23.9 hours)	255
Time (F17 files only)	Minutes since midnight of the date of the enclosing file	0 (representing 00:00 UTC or midnight) to 1439 (representing 23:59 UTC	-32768
Latitude/Longitude	Hundred thousandths of degrees (1 meter precision)	Latitude values range from -9000000 to 9000000 (representing -90 to 90)) Longitude values range from -18000000 to 18000000 (representing -180 to 180)	1431655765

1.2 File Information

1.2.1 Format

1.2.1.1 Brightness Temperature Files

Brightness temperature data are contained in flat binary files (little-endian) with one grid per file consisting of 2-byte integer arrays (721x721) of brightness temperatures in tenths of kelvins.

Each brightness temperature file represents gridded data for a single channel and polarization; they are derived from either ascending or descending orbits (for example, 37 GHz, horizontal, ascending) for one day. There are 18 brightness temperature files per day for each projection.

1.2.1.2 Time Series Files

Time series data are contained in 1-byte, unsigned integer arrays consisting of Coordinated Universal Time (UTC) in tenths of hours. Each time series file represents the corresponding time of the swath sample used for the interpolation of the given grid cell, for either ascending or descending orbits for that day. There are two time files per day (ascending and descending passes) for a given projection, both at a 25 km resolution.

Beginning with F17 files, time data are contained in 2-byte, signed integer arrays (721x721). Time data are minutes since 00:00 Coordinated Universal Time (UTC), or midnight, of the date of the enclosing file. Each time file represents the corresponding time of the swath sample used for the interpolation of the given grid cell, for either ascending or descending orbits for that day. There are two time files per day (ascending and descending passes) for a given projection, both at 25 km resolution.

1.2.2 File Contents

Figure 1 shows a sample browse image for 01 January 2008 for the Northern Hemisphere at 25 km, 37 GHz.

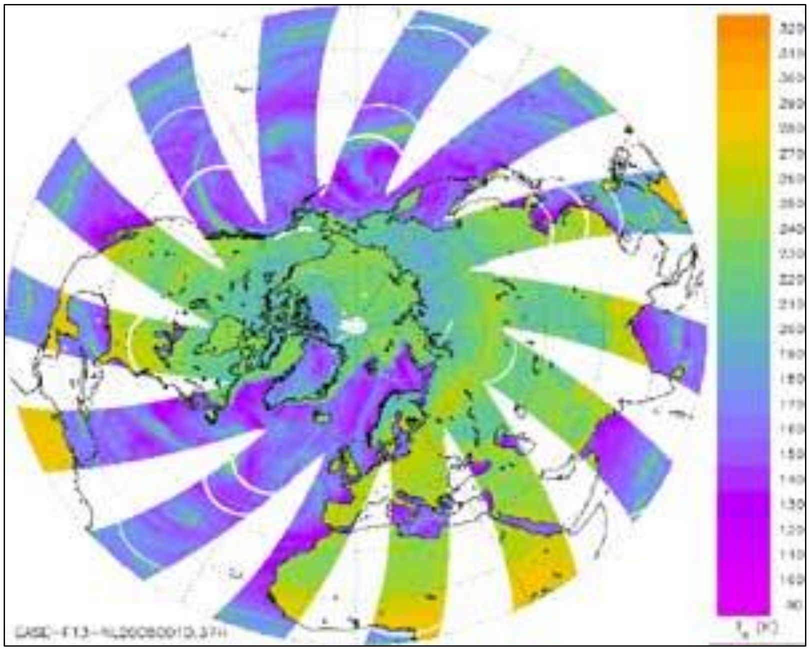

Figure 1. 25 km, 37 GHz Sample Browse Image for 01 January 2008 for the Northern Hemisphere

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

Brightness temperature files are named according to the following convention and as described in Table 2.

`EASE-Fxx-zzyyyydddp-vV.ccc.gz`

Example File: `EASE-F17-NH2014001A-V2.91H.gz`

Table 2. Naming Convention for Brightness Temperature Files

Variable	Description
EASE	Indicates EASE-Grid
xx	DMSP platform ID (`08, 11, 13,` or `17`)
zz	EASE-Grid ID (`NL, NH, SL, SH, ML, MH`) `N`: Northern Hemisphere `S`: Southern Hemisphere `M`: full global `L`: 25 km resolution `H`: 12.5 km resolution, for 85 and 91 GHz only
yyyy	4-digit year
ddd	3-digit day of year
p	Direction of pass (`A`: ascending, `D`: descending)
vV	Data version number (example: `v2`). Note: If the file name does not have a version number, it is version 1.
ccc	Channel (GHz) and polarization (`19H, 19V, 22V, 37H, 37V, 85H, 85V, 91H, or 91V`)
gz	Identifies this as a gzipped file

Time series files are named according to the following convention and as described in Table 3.

`EASE-Fxx-zzyyyydddp-vV.TIM.gz`

Example file: `EASE-F17-ML2014365D-V2.TIM.gz`

Table 3. Naming Convention for Time Files

Variable	Description
EASE	Indicates EASE-Grid
xx	DMSP platform ID (08, 11, 13, or 17)
zz	EASE-Grid ID (`NL, SL,` or `ML`) `N`: Northern Hemisphere `S`: Southern Hemisphere `M`: full global `L`: 25 km resolution
yyyy	4-digit year
ddd	3-digit day of year
p	Direction of passes (`A`: ascending, `D`: descending)
vV	Data version number (example: `v2`). Note: If the file name does not have a version number, it is version 1.
TIM	indicates the contents are time data
gz	Identifies this as a gzipped file

1.2.5 File Size

Gzipped brightness temperature data files range in size from 25 KB to 3.4 MB, and gzipped time files range in size from 1.1 KB to 36 KB.

1.3 Spatial Information

1.3.1 Coverage

These data files are provided in three different equal-area, spatial coverages: Northern Hemisphere azimuthal, Southern Hemisphere azimuthal, and Global cylindrical. Refer to Figures 2, 3, and 4 for maps showing the three different coverages.

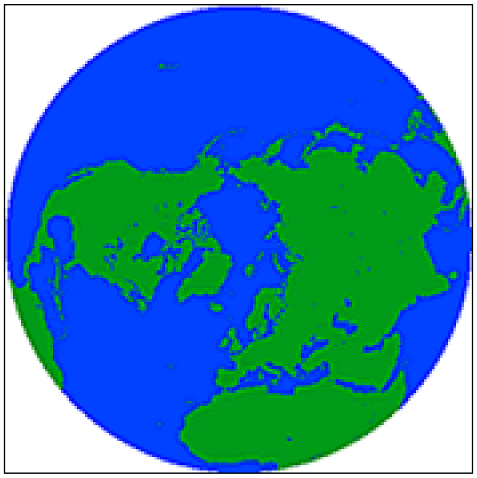

Figure 2. Coverage of the Northern Hemispheres Based on Lambert's Equal-area, Azimuthal Projection

Figure 3. Coverage of the Southern Hemispheres Based on Lambert's Equal-area, Azimuthal Projection

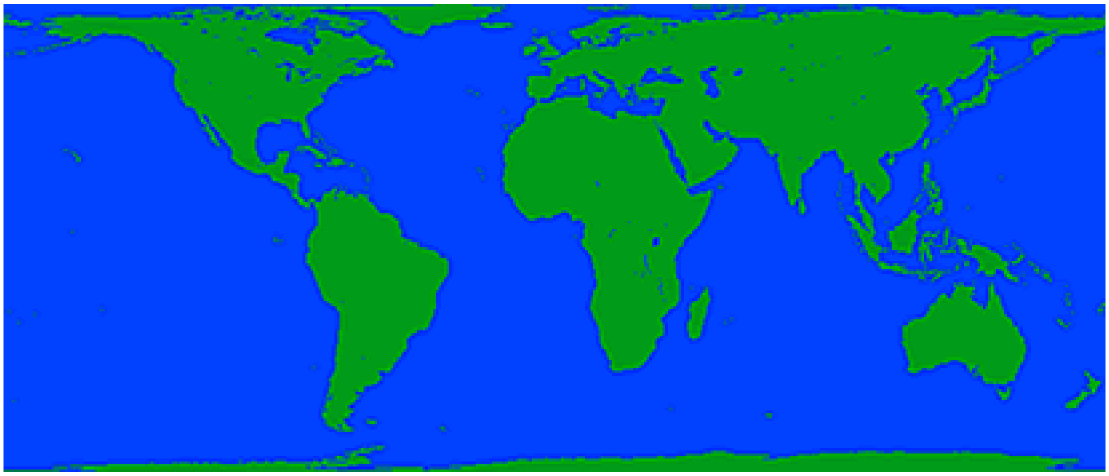

Figure 4. Global Coverage Based on Cylindrical, Equal-area Projection

1.3.2 Resolution

The spatial resolution for the 19 GHz, 22 GHz, and 37 GHz channels is 25 km. There are two different spatial resolutions for the 85 GHz and 91 GHz channels: 25 km and 12.5 km.

1.3.3 Projection and Grid Description

The SSM/I EASE-Grids are a set of three equal-area projections: two azimuthal equal-area projections, one for the Northern and one for the Southern Hemisphere; and a Global cylindrical equal-area projection. The EASE-Grid dimensions are 721 columns by 721 rows. For more details on the EASE-Grid, please refer to the EASE Grids web page.

1.4 Temporal Information

1.4.1 Coverage

Coverage begins 09 July 1987 and is ongoing.

The goal of the SSM/I Pathfinder product team is to produce a continuous time series of SSM/I data using a single consistent processing and interpolation scheme. Data are made available as processing is completed. A brief list of some of the larger gaps in the data are explained in Table 3.

1.4.2 Missing Data

1.4.2.1 85 GHZ Channel April 2008 to Present

Beginning with data in the late spring of 2008, the 85 GHz horizontal data and some Southern Hemisphere 85 GHz vertical data files contain zeros for the brightness temperatures. This means that either no brightness temperatures were measured or the brightness temperatures failed quality control procedures from Remote Sensing Systems that NSIDC uses in our preprocessing. The affected periods of 85 GHz horizontal files are shown in Table 4.

Table 4. 85 GHz 2008 Missing Data

Region	Pass	Polarization	Day of Year (ddd)
Northern	Ascending	Horizontal	128
Northern	Descending	Horizontal	118 - 128
Southern	Ascending	Horizontal	123 - 127
Southern	Descending	Horizontal	114 - 116, 118, 120, 123 - 182
Southern	Descending	Vertical	117, 121
Global	Ascending	Horizontal	128 - 182
Global	Descending	Horizontal	117 - 127, 129 - 182
Global	Descending	Vertical	173, 175, 176, 179-182

1.4.2.2 Alaska and Canadian Prairies, 1994 to May 1995

Substantial amounts of swath data over Alaska and the Canadian Prairies are missing beginning early in 1994 until May 1995. During this period, the data tape recorder on the DMSP-F11 failed. As a result, it was necessary to download data to ground stations more frequently than usual. Data download and acquisition could not occur simultaneously, consequently data gaps exist in the EASE-Grid data for Alaska and the Canadian Prairies from early 1994 until data acquisition by the DMSP-F13 SSM/I began in May 1995.

1.4.2.3 85 GHZ Channel, 01 February 1989 to 31 December 1991

There are usually 18 brightness temperature files per day for a given projection, except from 01 February 1989 through 31 December 1991. For this period, no data exist for the 85 GHz channel due to degradation of this channel after heating cycles during Northern Hemisphere winters that resulted in increased solar illumination on the SSM/I instrument (Wentz 1992). Only 10 brightness temperature files are available per day during these dates, and all files are in the 25 km resolution grid.

1.4.3 Resolution

The data are daily, separated by ascending and descending passes.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

The SSM/I and SSMIS instruments measure passive microwave radiances. For more information about these instruments, please see the SMMR, SSM/I, and SSMIS Sensors Summary. For a detailed discussion of the theory behind the acquisition methods used here, please refer to the following articles:

Poe, G. A. 1990. Optimum Interpolation of Imaging Microwave Radiometer Data. IEEE Transactions on Geoscience and Remote Sensing 28(5):800-810.

Galantowicz, J. F. and A. W. England. 1991. The Michigan Earth Grid: Description, Registration Method for SSM/I Data and Derivative Map Projections. Technical Report 027396-2-T. Radiation Laboratory Dept. of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor.

2.2 Acquisition

The source for the raw antenna temperature and brightness temperature data for this data set is Remote Sensing Systems (RSS), Santa Rosa, California (Wentz 1993). The input orbital brightness temperature data for this product was ingested via the RSS software programs DECODE and QUAL1 (Wentz 1993). Switches were used to include the following options:

1. Along-scan bias corrections were turned on.
2. Sensor intercalibrations (adjusting non-F8 SSM/I antenna temperatures to correspond to F8 SSM/I antenna temperatures) were turned off.
3. Data values during times that RSS has determined to be "periods of erroneous data," and identified in RSS files BADLOC.D08, BADLOC.D11, BADLOC.D13, were discarded prior to gridding and interpolation.
4. Groups of scans that RSS identified as corrupted by calibration error problems between 09 October 1990 and 29 August 1992 and identified in RSS files BADCAL.D08 and BADCAL.D11, were discarded prior to gridding and interpolation.
5. After 29 August 1992 calibration errors detected in the RSS DECODE processing were discarded prior to gridding and interpolation.

Over the course of a day, points at mid-to-high latitudes will be observed from multiple orbits. For a given grid cell location, only observations from a single orbit were used in the Backus-Gilbert interpolation. In order to ensure the most consistent local observation time at each location, we chose the sample from the orbit whose local time was closest to the equatorial crossing times shown in Table 5. Actual equatorial crossing times do change slowly over the life of sunsynchronous satellites such as the DMSPs. The choice of these particular times was based on nominal crossing times at launch.

Table 5. Ascending and Descending Nodes by Platform

Platform	Ascending Node (Decimal Hours)	Descending Node (Decimal Hours)
F08	6.20	18.20
F11	17.17	5.17
F13	17.58	5.58
F17	17.31	5.31

The antenna pattern coefficients used in the Backus-Gilbert interpolation were provided to NSIDC by John Galantowicz (1995, Appendix C). The interpolated brightness temperatures represent optimally filtered data, that is, they represent what the sensor would have measured had it been directed at the center of the fixed grid cell. Depending on one's purposes, the Backus-Gilbert method can be tuned to enhance resolution, or reduce noise, but both cannot be achieved simultaneously. Galantowicz chose to generate coefficients that would minimize noise (ones that produced a pattern with lowest relative side-lobes). Refer to Figures 5 and 6.

The 19 GHz pattern has the largest footprint of the four SSM/I frequencies, and the interpolated patterns of the other channels are able to fit it without high side-lobes. If the 19 GHz pattern were interpolated to a significantly smaller desired pattern--that is, either the 37 GHz or 85 GHz pattern--then the best achievable interpolated pattern would be distorted and have high side-lobe levels (Galantowicz 1995).

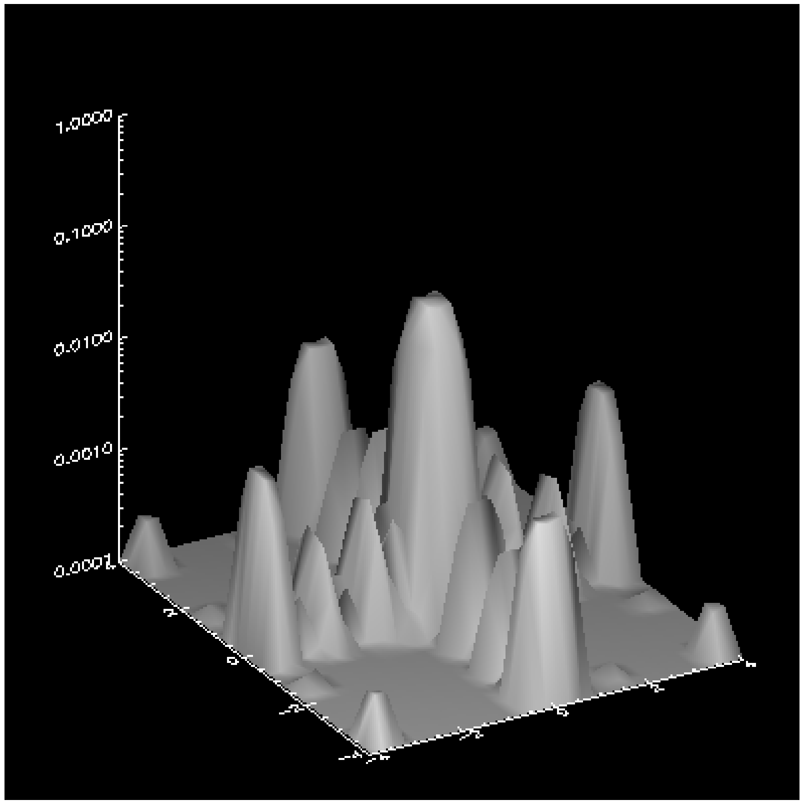

Figure 5. Example Frequency Response of Backus-Gilbert Interpolation, as 3-D Shaded Relief. Image courtesy of K. Knowles, NSIDC.

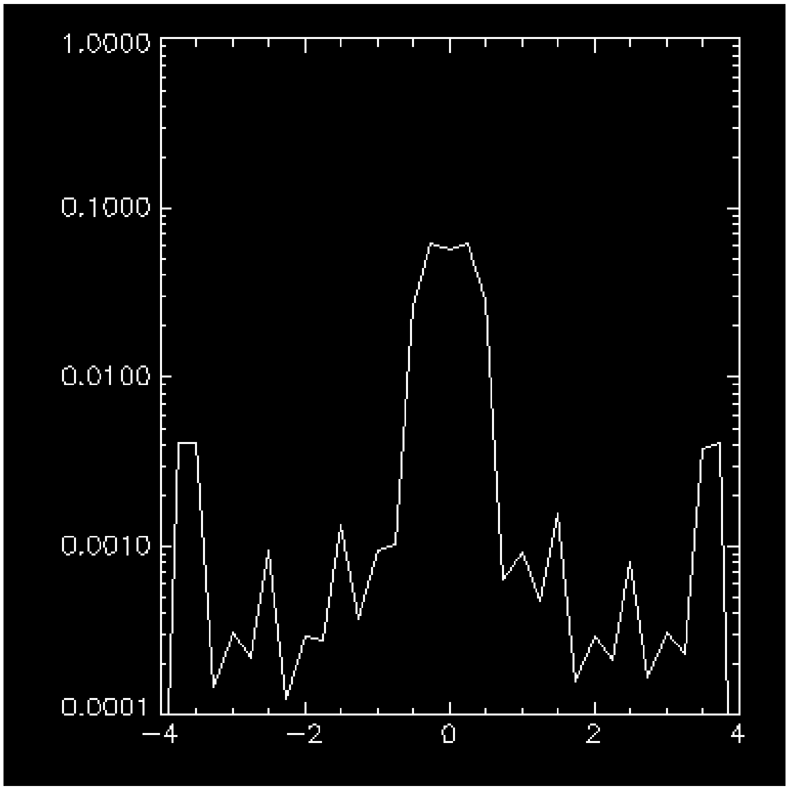

Figure 6. Example profile at y=0 (right). The side-lobes are the bumps outside the intervals x = ± 1/2 and y = ± 1/2. The decision to tune the EASE-Grid SSM/I brightness temperatures minimizes the side-lobes in the interpolation. Image courtesy of K. Knowles, NSIDC.

The resulting EASE-Grid brightness temperatures for all channels in the 25 km grids represent the Effective Field Of View (EFOV) at -3 db of the 19 GHz vertically polarized channel, and the EASE-Grid brightness temperatures for 85 GHz channels in the 12.5 km grids represent the EFOV of the 85 GHz vertically polarized channel. Users of the SSM/I EASE-Grid data can make inter-channel comparisons and develop geophysical algorithms based on the assumption that the gridded data represent the brightness of the same geographical area. For further details, refer to Galantowicz (1995), Galantowicz and England (1991), and Poe (1990).

2.3 Processing

The NOAA/NASA Pathfinder Program is designed to provide scientists with time series of global-scale remote sensing data ahead of the EOS satellite launches. The Pathfinder concept involves careful reprocessing of existing data sets and then making them readily available as high quality products for global change research. Since the polar regions hold special significance for global change research, the Polar Pathfinders have established a cooperation to maximize the scientific potential of polar data.

Binary data arrays contain spatially interpolated data. The data gridding technique maximizes the radiometric integrity of the original brightness temperature values, maintains high spatial and temporal precision, and involves no averaging of original swath data. Backus-Gilbert optimal interpolation is used to artificially increase, by 16 times, the density of brightness temperature measurements in the satellite swath reference frame with a sample interval of 25 km for 19, 22, and 37 GHz, and 12.5 km for 85 GHz. This process uses actual antenna patterns to create the over-sampled array, and the net effect is as if the additional samples had been made by the satellite radiometer itself because the beam patterns and spatial resolutions of the interpolated data approximate those of the original samples. This method is based on the earlier work of Galantowicz and England (1991) and Poe (1990). The brightness temperature for a given EASE-Grid cell is obtained from the over-sampled array by the nearest neighbor method.

The Backus-Gilbert technique also allows resolution enhancement but with a noise penalty. To avoid the noise penalty, the brightness temperatures for all channels in the 25 km grids were interpolated to the EFOV at -3 db of the 19 GHz vertically polarized channel. Brightness temperatures for 85 GHz channels in the 12.5 km grids were interpolated to the EFOV of the 85 GHz vertically polarized channel. However, beginning with the processing of the DMSP-F17 SSMIS sensor, EASE-Grid brightness temperature fields are gridded using an Inverse Distance Squared method instead of the Backus-Gilbert interpolation that had been used for the earlier sensors. Refer to the Processing Step Change for the DMSP-F17 SSMIS Sensor section of the document for additional information.

As the first step in the processing of Pathfinder data, a common Benchmark Period (April 1987 to November 1988) was chosen to facilitate the analysis and comparison of individual Pathfinder data products. Note that the SSM/I Benchmark Period is somewhat shorter (August 1987 to November 1988) than the Pathfinder Benchmark Period because the data record started with the launch of the DMSP-F8 satellite in July 1987.

Processing of the data has progressed over the course of several years. The goal of the product team has been to produce a consistent time series of continuous, gridded SSM/I data. However, over the course of the operational processing we have chosen at certain times to change some parts of the processing code. We have only made such changes after careful consideration of the consequences to the time series and then, only when the changes will result in an overall better quality time series. The following changes have been made.

1. We determined through visual inspections of processed data that some data for 28 June 1989 were mislocated. As a result, we added the following line to our BADLOC.D08 file in order to eliminate the erroneous orbital data:
   1989 179 8.0 1989 179 8.2
2. Due to an error in the processing code, time data files for the F8 data (August 1987 through December 1991) contain times that were inadvertently truncated to tenths of

hours, instead of rounded to the nearest tenth of an hour. This problem was corrected beginning with data for January 1992.

3. The treatment of out of bounds input data changed between the F8 and F11 data. For F8 data, input brightness temperatures that were out of bounds (defined to be less than 55.0 K or greater than 320. 0 K) were replaced with the average of the two closest in bound brightness temperatures along the same scan. Beginning with F11 data (January 1992), we eliminated this treatment and set the out of bounds value to an invalid brightness temperature. The Backus-Gilbert interpolation for any EASE-Grid pixel was only performed if both of the following conditions were true:
    a. The interpolation coefficient corresponding to any missing brightness temperature must have been smaller than a missing coefficient threshold of 0.0005.
    b. The sum of the interpolation coefficients corresponding to valid brightness temperatures must have been within 1.0000 ± 0.0005 (which is the sum of all 16 coefficients).
4. There are no 85 GHz data for 01 February 1989 through 31 December 1991. Refer to the Note in the Missing Data section of this document.

2.3.1 Processing Step Change for the DMSP-F17 SSMIS Sensor

Beginning with processing for the DMSP-F17 SSMIS sensor, EASE-Grid brightness temperature fields are gridded using an inverse distance squared method instead of the Backus-Gilbert interpolation that had been used for the earlier sensors. The Backus-Gilbert method requires analysis of the antenna pattern of the sensor to derive weighting coefficients, yet the required analysis has not yet been performed for SSMIS. Instead, the inverse distance squared method performs a weighted average of swath measurements whose center locations are less than a specified distance from the center of the grid cell. The distance is 1.5 times the nominal cell scale, or ~37.6 km (~18.8) for the 25 km (12.5 km) grids.

Since the two interpolation methods differ, there is a difference in the brightness temperature fields. NSIDC has investigated the difference and has found that most differences are within +/- 1 K, and the vast majority of grid cells have differences within 2 K. However, in regions with steep brightness temperature gradients, the differences can be upwards of 20 K. These regions include:

- coast lines,
- edges of swaths where overlap between swaths occurs, which is most noticeable near the poles (poleward of 60 degrees latitude), and,
- to a lesser degree, in mountainous regions.

These differences may be positive or negative and are one or two grid cells wide.

Users who make use of this extended EASE-Grid brightness temperature time series should be cautious using SSMIS data, particularly in the high difference regions noted above. NSIDC will investigate options for providing fully consistent EASE-Grid brightness temperatures as resources allow.

2.4 Quality, Errors, and Limitations

2.4.1 Quality Assessment

Each brightness temperature and time file is visually inspected by data center operators before being archived and distributed.

2.4.2 Intercomparison of F13 and F17 Data

NSIDC conducted an intercomparison of F13 with F17 data during the 01 January 2007 through 31 December 2007 period. The vast majority of differences are between 0.5 K and 2 K. Some larger differences, up to 10 K, are found primarily in regions of sharp gradients of brightness temperatures, along coasts and the ice edge, likely due to the changes in geolocation. Smaller biases of 0.5 K to 2 K in some channels, such as 19V, 19H, 22V, and 37H, are likely due to the cross-sensor calibration.

2.4.3 F17 Solar Panel Position Shift

On 5 April 2016, the solar panel on the F17 Satellite shifted position compromising the integrity of Channel 16 (37Ghz vertical polarization). On 25 May 2016, a fix was implemented, however, the long term quality of the data is still unknown. NSIDC continues to monitor the quality of the data.

2.4.4 Measurement Error for Parameters

Geolocation errors in input Remote Sensing Systems (RSS) swath data are no more than 10 km, "although there may be exceptions" (Sharon Tremble, RSS, e-mail to M. J. Brodzik, 18 January 1996). Additional error introduced by nearest-neighbor interpolation from the over-sampled array is approximately 6 km for the 25 km grids and 3 km for the 12.5 km grids.

2.5 Instrumentation

2.5.1 Description

These data were acquired using the SSM/I instrument on the DMSP-F08, -F11, and -F13 platforms, as well as the SSMIS instrument on the DMSP-F17 platform. Refer to the SMMR, SSM/I, and SSMIS Sensors Summary for more information about the SSM/I and SSMIS instruments.

3 SOFTWARE AND TOOLS

Geolocation tools for this data set are available via the EASE Grids web page.

4 VERSION HISTORY

Table 6 outlines the processing and version history for this product. Note: Currently there is an overlap in the data for V1 and V2 from 14 December 2006 through 29 April 2009.

Table 6. Description of Processing Changes

Data Version	Platform	Temporal Range	Source Data Version	Description of Changes
V2	F17	14 Dec 2006 — 02 October 2018	RSS V7	• Updated version to reflect the beginning of the F17 data record • The source for this data set, RSS, changed from their version from V4 to V7 • RSS V7 cross-calibrates between all SSM/I and SSMIS sensors as well as AMSR-E and WindSat, providing interconsistency of brightness temperatures from the sensors
V1	F13	03 May 1995 — 31 Dec 2007	RSS V4	N/A
V1	F11	03 Dec 1991 — 30 Sep 1995	RSS V3	N/A
V1	F8	09 Jul 1987 — 31 Dec 1991	RSS V3	N/A
V1	F8	Not available	N/A	Original version of data. Note: V1 was not indicated in Version 1 file names.

5 RELATED DATA SETS

The following related data collections are available from NSIDC:

- TOVS Pathfinder Path-P Daily and Monthly Polar Atmospheric Grids
- DMSP SSM/I-SSMIS Daily Polar Gridded Brightness Temperatures
- Global Monthly EASE-Grid Snow Water Equivalent Climatology
- Nimbus-7 SMMR Pathfinder Daily EASE-Grid Brightness Temperatures
- Northern Hemisphere EASE-Grid Weekly Snow Cover and Sea Ice Extent
- Near-Real-Time DMSP SSM/I-SSMIS Pathfinder Daily EASE-Grid Brightness Temperatures

To access Level 2 SSM/I brightness temperatures, please visit the Remote Sensing Systems data Web pages.

6 CONTACTS AND ACKNOWLEDGMENTS

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Annette Varani for documentation support, developing the EASE-Grid Sampler area of the Equinox Sampler, and much patience involved in the packaging artwork.

7 REFERENCES

Based on the recommendations of the SSM/I Products Working Team (SPWT), the point of departure for the EASE-Grid interpolation from swath coordinates to earth-gridded coordinates is the methodology of Galantowicz and England (1991) which is based on earlier work by Stogryn (1978) and by Poe (1990). Those interested in the details of the interpolation method used in the EASE-Grid should consult the references listed below.

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Galantowicz, J. F., A. W. England. 1991. The Michigan Earth Grid: Description, Registration Method for SSM/I Data, and Derivative Map Projections. Radiation Laboratory, Department of Electrical Engineering and Computer Science, Technical Report 027396-2-T. University of Michigan, Ann Arbor, Michigan USA.

Galantowicz, J. F. 1995. Microwave Radiometry of Snow-Covered Grasslands for the Estimation of Land-Atmosphere Energy and Moisture Fluxes. PhD Thesis, Department of Electrical Engineering and Computer Science and Department of Atmospheric, Oceanic, and Space Sciences. University of Michigan, Ann Arbor, Michigan USA.

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8 DOCUMENT INFORMATION

8.1 Publication Date

4 April 2019

8.2 Date Last Updated

9 December 2020