MEaSUREs Global Record of Daily Landscape Freeze/Thaw Status, Version 3

USER GUIDE

How to Cite These Data

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

Kim, Y., J. S. Kimball, J. Glassy, and K. C. McDonald. 2014. *MEaSUREs Global Record of Daily Landscape Freeze/Thaw Status, Version 3.* [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center https://doi.org/10.5067/MEASURES/CRYOSPHERE/nsidc-0477.003. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/NSIDC-0477

National Snow and Ice Data Center

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1 DETAILED DATA DESCRIPTION

The combined SMMR-SSM/I-SSMIS freeze/thaw record was derived from daily brightness temperature measurements at 37 GHz (vertical polarization) from the Scanning Multichannel Microwave Radiometer (1979-1986), Special Sensor Microwave Imager (1987-2008), and Special Sensor Microwave Imager/Sounder (2009-2012) sensor series. The AMSR-E (Advanced Microwave Scanning Radiometer for EOS) record was derived from daily (AM and PM overpass) 36.5 GHz (vertical polarization) brightness temperature retrievals encompassing the AMSR-E operational record. Separate AM (morning), PM (afternoon), and CO (combined AM and PM) freeze/thaw status files are available as well as daily and annual quality assurance (QA) and accuracy metrics.

1.1 Format

Data are provided in several formats:

- HDF5
- GeoTIFF
- GIF

The sections below describe each format type and the parameters stored in that format.

1.1.1 HDF5

Freeze/Thaw Status

The following freeze/thaw status parameters are provided in HDF5 v1.8 formatted files.

- Daily AM Freeze/Thaw status
- Daily PM Freeze/Thaw status
- Daily Composite (combined AM and PM) Freeze/Thaw status
- Daily Transitional Freeze/Thaw status
- Daily Inverse Transitional Freeze/Thaw status

HDF5 daily freeze/thaw status files for both the SMMR-SSM/I-SSMIS and AMSR-E records contain the data fields listed in Table 1:

Table 1. Freeze/Thaw Status Data Fields

FT_status	**Daily global freeze/thaw status**	**1383 columns; 586 rows**	**8-bit unsigned integer**
cell_lat	Latitude	1383 columns; 586 rows	32-bit floating point
cell_lon	Longitude	1383 columns; 586 rows	32-bit floating point

The cell_lat and cell_lon fields are included for CF v1.4 compliance, allowing users of common free software packages such as HDFView and Panoply to immediately view the data sets projected in a global geographic grid. In addition, the metadata for AM and PM HDF5 files includes an aggregate daily accuracy metric (Accuracy_Daily_Metric).

Quality Assurance

Annual F/T Status Quality Assurance (QA) maps are provided in an HDF5 file, one each for the SMMR-SSM/I-SSMIS and AMSR-E records, that contain one data field per year for each year in the corresponding instrument record. QA values are reported in a range from 0.0 (low, accuracy <70 percent) to 1.0 (best, accuracy >90 percent) and represent a relative index of data quality for each grid cell based on ancillary terrain and land cover heterogeneity, satellite data gaps, and daily F/T accuracy assessments. See Kim et al. 2011for details.

QA files contain the data fields listed in Table 2:

Table 2. QA File Data Fields (HDF5)

Field	**Description**	**Dimension**	**Data Type**
`FT_Annual_QA_[Year]`	QA	1383 columns; 586 rows	32-bit floating point
`cell_lat`	Latitude	1383 columns; 586 rows	32-bit floating point
`cell_lon`	Longitude	1383 columns; 586 rows	32-bit floating point

F/T Accuracy

Annual F/T accuracy data are provided in HDF5-formatted files for both the SMMR-SSM/I-SSMIS and AMSR-E records. These files consist of two data fields (AM and PM) per year for each year in the corresponding instrument record. Accuracy was assessed in relation to daily maximum and minimum air temperature measurements from the global WMO weather station network and calculated as the percent of daily F/T retrievals per year that are consistent with in situ air temperature measurements. Refer to Kim et al. 2011 for further details. Values are reported in the range of 0.0 to 100.0.

HDF5 accuracy files contain the data fields listed in Table 3:

Table 3. Accuracy File Data Fields (HDF5)

Field	Description	Dimension	Data Type
FT_Accuracy_[AM/PM]_[Year]	F/T accuracy value	1383 columns; 586 rows	32-bit floating point
cell_lat	Latitude	1383 columns; 586 rows	32-bit floating point
cell_lon	Longitude	1383 columns; 586 rows	32-bit floating point

1.1.2 GeoTIFF

Daily F/T status is also available for both the SMMR-SSM/I-SSMIS and AMSR-E records in GeoTIFF format.

1.1.3 GIF

Annual F/T accuracy data for both the SMMR-SSM/I-SSMIS and AMSR-E records, derived from the PM overpass, are available as GIF image files. Browse images of the daily CO F/T status are also available to quickly evaluate the data visually.

1.2 File and Directory Structure

Data are available on the HTTPS site in the https://n5eil01u.ecs.nsidc.org/MEASURES/NSIDC-0477.003/ directory. This directory contains one folder for each date from and within each folder are daily F/T status files are stored within /AMSRE/ and /SMMR_SSMI/ subdirectories in folders labeled by year. HDF5 QA and accuracy files are located at the top level of the /AMSRE/ and /SMMR_SSMI/ subdirectories within the QA and accuracy folder. Annual QA maps can be found in the folders labeled GIF.

Table 4 describes the contents of the four folders at the top of the HTTPS directory:

Table 4. HTTPS Directory Description

Directory	Description
`DAILY_FT_GEOTIFF`	Global daily F/T status in GeoTIFF (`.tif`) file format.
`DAILY_FT_BROWSE`	Global daily browse images of F/T status in GIF (`.gif`) file format
`DAILY_FT_HDF5`	Global daily F/T status in HDF5 (`.h5`) file format
`QA_ACCURACY`	Annual QA maps and accuracy metrics in GIF and HDF5 formats. Also contains MD5 files (`.md5`) with checksum hash signatures.

1.3 File Naming Convention

The following sections explain the file naming conventions for this data set.

1.3.1 Daily F/T Status HDF5 and GeoTIFF Files

Each daily F/T status product comprises three separate files—morning overpass (AM), afternoon overpass (PM), and a combined daily AM and PM (CO) file.

Directory
/DAILY_FT_HDF5/[instrument]/
/DAILY_FT_GEOTIFF/[instrument]/

Example File Name: SSMI_37V_CO_FT_1993_day001.h5
Naming Convention:
[InstrumentLabel]_[Channel][Polarization]_[OverpassCode]_FT_[Year]_day[DOY].[FileExt] The following table describes the variables listed above:

Table 5. Variables and Descriptions for Daily F/T Status Files

Variable	Description
`InstrumentLabel`	Sensor
`Channel`	Frequency, GHz
`Polarization`	V (Vertical)
`OverpassCode`	Morning (AM), Afternoon (PM), or Combined AM and PM (CO)
`Year`	Observation year
`DOY`	Day of Year
`FileExt`	.h5 (HDF5) or .tif (GeoTIFF)

1.3.2 Daily F/T Status GIF Browse Images

Directory
/DAILY_FT_BROWSE/[instrument]/

Example File Name: SSMI_37V_CO_FT_1993_day001.gif
Naming Convention: [InstrumentLabel]_[Channel][Polarization]_CO_FT_[Year]_day[DOY].gif

The following table describes the variables listed above.

Table 6. Variables and Descriptions for F/T Status Browse Images

Variable	Description
InstrumentLabel	Sensor
Channel	Frequency, GHz
Polarization	V (Vertical)
OverpassCode	CO (combined AM and PM)
Year	Observation year
DOY	Day of Year

1.3.3 QA and Accuracy Files

Directory

/QA_ACCURACY/[instrument]/

Example File Name: FT3_SMMR_SSMI_global_1979_2012_accuracy.h5

Naming Convention: [InstrumentLabel]_[Channel][Polarization]_CO_FT_[Year]_day[DOY].gif

The following table describes the file name variables listed above.

Table 7. Variables and Descriptions for Annual QA and Accuracy Files

Variable	Description
`ProductVersion`	Freeze/Thaw Status, Version 3 (FT3)
`InstrumentLabel`	Sensor
`StartYear`	First year of data record
`EndYear`	Last year of data record
`FileType`	QA or accuracy

1.3.4 QA Maps

Directory

/QA_ACCURACY/[instrument]/GIF/

Example File Name: SMMR_global_QA_1979_PM.gif

Naming Convention: [InstrumentLabel]_global_QA_[Year]_[OverpassCode].gif

The following table describes the file name variables listed above.

Table 8. Variables and Descriptions for Annual QA Maps

Variable	Description
InstrumentLabel	Sensor
Year	Year of data record
OverpassCode	PM (afternoon)

1.4 Volume

Coverage is global:

- Southernmost Latitude: -86.7167° S
- Northernmost Latitude: 86.7167° N
- Westernmost Longitude: -179.9999° W
- Easternmost Longitude: 179.9999° E

1.4.1 Spatial Resolution

25 km

1.4.2 Projection and Grid Description

Each grid cell is projected in a global EASE-Grid format (Armstrong and Brodzik, 1995; Brodzik and Armstrong 2002) at 25km spatial resolution, with 1383 columns and 586 rows for a total of 810438 pixels per daily data product.

1.5 Temporal Coverage

SMMR-SSM/I-SSMIS

01 January 1979 to 31 December 2012

AMSR-E

19 June 2002 to 27 September 2011

1.5.1 Temporal Resolution

Daily

1.6 Parameter or Variable

1.6.1 Parameter Description

Daily AM F/T status

Freeze/thaw status for the morning satellite overpass

Daily PM F/T Status

Freeze/thaw status for the afternoon satellite overpass

Daily Composite F/T Status

Combined freeze/thaw status for the morning and afternoon satellite overpasses

Daily Transitional F/T Status

AM frozen, PM thawed

Daily Inverse Transitional F/T Status

AM thawed, PM frozen

Daily F/T Status Accuracy Metric

Accuracy_Daily_Metric, stored as a metadata object in HDF5-formatted AM and PM files, provides an aggregate daily accuracy metric.

Annual F/T Status Quality Assurance (QA) Maps

Annual QA maps that provide a relative index of data quality derived from ancillary terrain and land cover heterogeneity information, satellite data gaps, and daily F/T accuracy assessments.

1.7 Parameter Range

1.7.1 F/T Status

The following table describes the values used to classify F/T status in data files and images:

Table 9. F/T Classification Values

Classification		Browse Image Color Table		
	Value	R	G	B
Frozen (AM/PM frozen)	0	000	000	255
Thawed (AM/PM thawed)	1	255	000	000
Transitional (AM frozen and PM thawed)	2	168	168	000
Inverse Transitional (PM frozen and AM thawed)	3	076	230	000
No data	251	255	255	255
Non-cold constraint area, but unmasked	252	255	255	255
Masked (permanent ice, non-vegetated, and urban area)	253	255	255	255
100 percent open water	254	255	255	255
Fill value	255	255	255	255

1.7.2 F/T Accuracy

Accuracy values are reported as a percent in the range 0.0 to 100.0. Missing values are indicated by -9999.

1.7.3 Sample Data Record

Figure 1 shows the SMMR-SSM/I-SSMIS daily combined AM/PM (CO) F/T status for 9 April 2004. Areas colored in gray lie outside of the F/T data set domain.

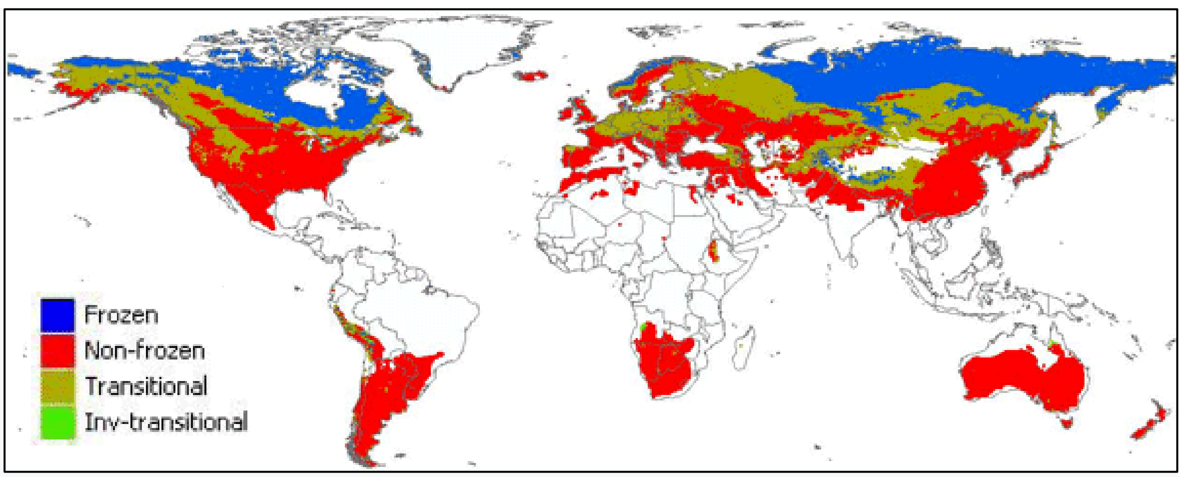

Figure 1. Daily CO SMMR-SSM/I-SSMIS F/T Status for 9 April 2004

2 SOFTWARE AND TOOLS

Software and Tools

HDF5 data files may be accessed with HDFView, Panoply, or similar HDF5-compatible applications. GeoTIFF files may be viewed with ESRI ArcMap or similar Geographical Information System (GIS) software.

3 DATA ACQUISITION AND PROCESSING

3.1 Theory of Measurements

The MEaSUREs Global Record of Daily Landscape Freeze/Thaw Status product, Version 3 allows F/T state dynamics to be quantified over vegetated land within a global domain where seasonally frozen temperatures are a major constraint to ecological processes. Satellite microwave remote sensing is well suited for monitoring global F/T status due to its relative insensitivity to atmospheric contamination, independence from solar illumination, and strong sensitivity to changes in landscape dielectric properties between frozen and thawed states. This freeze/thaw Earth System Data Record (F/T ESDR) is derived using daily radiometric brightness temperature measurement time series from two sources: overlapping SMMR-SSM/I-SSMIS time series and the AMSR-E operational record. The SMMR-SSM/I-SSMIS derived data represent a consistent, daily F/T global record that extends from 1979 to 2010, ensuring cross-sensor consistency through pixel-wise adjustment of the SMMR brightness temperature time series based on empirical analyses of overlapping SMMR, SSM/I, and SSMIS measurements. Refer to Kim et al. 2011 for a detailed description of this data set's methods and validation scheme.

3.2 Data Acquisition Methods

The SMMR-SSM/I-SSMIS record was developed by merging the Scanning Multichannel Microwave Radiometer (SMMR), Special Sensor Microwave Imager (SSM/I), and Special Sensor Microwave Imager/Sounder (SSMIS) 37 GHz frequency (vertical polarization) brightness temperature records . Refer to 4.1 belowRelated Data Collectionsfor more information, and apply the same algorithms and protocols used to construct previous versions of this product. The record extends from 1979 to 2012 and encompasses large climate variations and longer-term trends in terrestrial F/T cycles which have been verified against global weather station air temperature records and other biophysical data, including satellite vegetation greenness and tower CO2 flux measurement networks (Kim et al. 2011, Kim et al. 2012). This data set also includes a freeze/thaw data record derived from 36V GHz daily (1:30 AM/PM equatorial crossing) brightness temperature records from the AMSR-E sensor on board NASA's Aqua space vehicle, for the years 2002 to 2011 inclusive.

The F/T parameter derivation for AMSR-E is consistent with the SMMR-SSM/I-SSMIS methodology.

3.3 Derivation Techniques and Algorithms

The F/T ESDR was designed to have sufficient accuracy, resolution, and coverage to resolve physical processes that link Earth's water, energy, and carbon cycles. In addition, the data can resolve the F/T status of the composite landscape vegetation-snow-soil medium to a sufficient level to characterize the frozen temperature constraints to surface water mobility, vegetation productivity, ecosystem respiration, and land-atmosphere CO2 fluxes.

The F/T classification algorithm utilizes a seasonal threshold approach (STA); radiometric brightness temperature time-series are used to identify F/T transition sequences by exploiting the dynamic brightness temperature temporal response to differences in the aggregate landscape dielectric constant that occur as the landscape transitions between predominantly frozen and non-frozen conditions. These techniques are well-suited for resolving daily F/T state dynamics rather than single events or seasonally dominant transitions (Kim et al. 2011). F/T classification is further refined by using a modified single brightness temperature reference state STA algorithm for anomalous areas where the annual brightness temperature frozen reference state exceeds the brightness temperature non-frozen reference state; these areas, which include portions of northern Africa, Ethiopia and central Mexico, represent less than one percent of the F/T ESDR domain, and in general encompass dry climate areas where other environmental factors such as seasonal wetting events result in large brightness temperature changes similar to F/T transitions. Although these areas are still assigned a low QA value, the alternative single STA reference state F/T classification was found to markedly improve accuracy.

Satellite ascending and descending orbital data time series are processed separately to produce AM, PM, and composite daily (CO) F/T conditions. The F/T ESDR also identifies transitional (AM frozen and PM thawed) and inverse transitional (AM thawed and PM frozen) conditions. The global F/T ESDR domain encompasses unmasked vegetated land areas where low temperatures significantly constrain annual vegetation productivity as defined from climatological reanalysis data. Masked areas include permanent ice and snow, barren land, open water, and regions unconstrained by freezing temperatures. The F/T ESDR is projected in a global cylindrical Equal-Area Scalable Earth (EASE) grid (Brodzik and Armstrong 2002).

3.3.1 Quality Assessment

F/T accuracy is primarily assessed in relation to daily maximum and minimum air temperature measurements from the global World Meteorological Organization (WMO) weather station network (3,160 ±487 stations); mean annual F/T spatial classification accuracies are approximately 91.8

±1.03 and 84.2 ±1.00 percent for respective F/T ESDR PM and AM retrievals over the global domain and long-term record. The AMSR-E portion of the F/T ESDR has similar spatial classification accuracy.

The F/T ESDR accuracy shows strong seasonal and annual variability and is reduced during active F/T transition periods when spatial heterogeneity in landscape F/T processes is maximized in relation to the relatively coarse (~25 km) satellite footprint (Kim et al. 2011). A daily F/T spatial classification accuracy data quality (QA) metric is included with each daily F/T global grid, defined from pixel-wise comparisons of F/T classification accuracy in relation to co-located global weather station network daily air temperature (minimum and maximum) measurements (Kim et al. 2011, Kim et al. 2012); spatial classification accuracy is defined as the proportion of global stations where the daily F/T classification is consistent with station air temperature measurement based F/T estimates. Additional data quality (QA/QC) metrics are included that provide more spatially explicit information on algorithm performance, including potential negative impacts of temporal gaps in sensor data time series, precipitation, open water and dry soil effects, terrain and land cover heterogeneity, and uncertainty associated with use of global reanalysis temperature data to define per grid-cell frozen and non-frozen reference state thresholds for the seasonal threshold algorithm (STA) based F/T classifications. The resulting F/T ESDR database provides a consistent and continuous multiyear record of daily (AM and PM) F/T dynamics for the global biosphere.

Annual QA maps represent a discrete metric for relative data quality ranging from low (estimated spatial classification accuracy < 70 percent) to best (accuracy > 90 percent. To produce the QA maps, stepwise linear regression was applied to a set of independent variables to estimate FT classification accuracy in relation to global temperature validation sites, where independent variables examined include temporal gaps in sensor brightness temperature data time series, identified active precipitation events, sub-grid (within each 25-km grid cell) open water inundation, and terrain and land cover heterogeneity. Mean annual QA maps are derived for each year of record. Refer to Kim et al. 2014 for a complete description of the methodology,

The QA metrics provide an indicator of data quality for each grid cell within the global product domain. Refer to Figure 2. The dynamic QA information includes uncertainty associated with using reanalysis temperature data to define STA F/T thresholds; this metric was defined from the annual pixel-wise standard deviation of classified non-frozen periods derived from four global reanalysis based air temperature records: NCEP/NCAR, NCEP2, ERA-Interim, and MERRA. The dynamic QA information also includes the number of days per year with SMMR and SSM/I (and AMSR-E) brightness temperature data gaps and flagged precipitation events (Ferraro et al. 1996) and the average number of days per year with reanalysis air temperatures within ±3°C of 0.0°C. The static QA information integrates the potential effects of fractional open water cover defined from the finer scale (1 km resolution) MODIS 17-class IGBP global land cover product (Friedl et al. 2002); the static QA metric also accounts for complex topography (GLOBE, 1999) and heterogeneous land cover conditions defined from the 1 km resolution global land cover classification and digital elevation model.

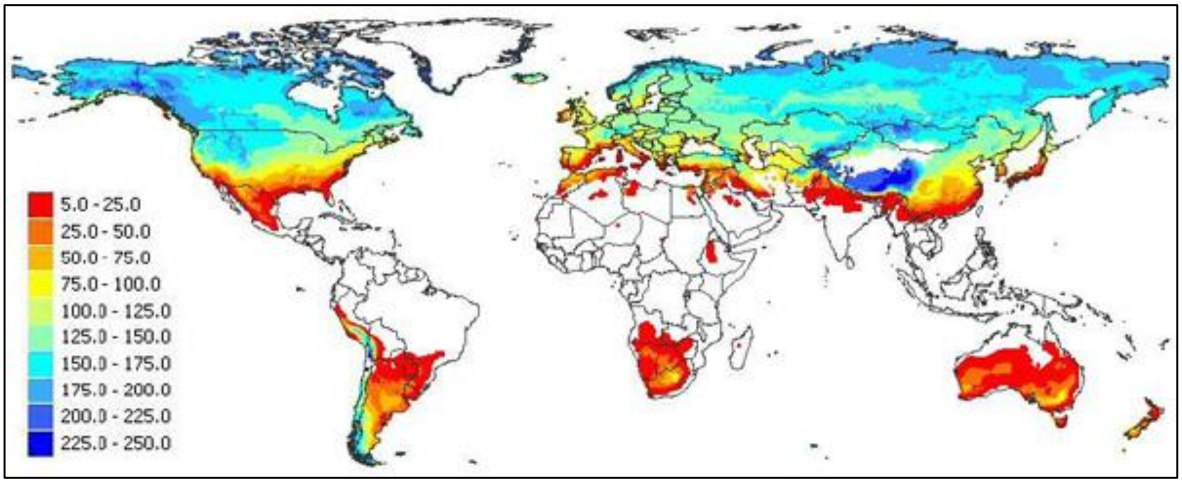

Figure 2. Global F/T ESDR domain defined from a Cold Temperature Constraints Index (CCI, days per year) and GMAO model reanalysis-based daily Tmn over a 7-year (2000-2006) Period. The F/T ESDR domain includes all vegetated land areas where the CCI ≥ 5 days per year.

Quality control (QC) metrics provide an indicator of F/T product quality for each grid cell within the F/T ESDR domain. Refer to Figure 3. The dynamic QC information includes the number of days per year with SSM/I radiometric brightness temperature data gaps and flagged precipitation events (Ferraro et al. 1996). The static QC information includes the potential effects of fractional open water cover (MODIS 17-class IGBP Global Land Cover Product, Friedl et al. 2002), complex topography (GLOBE, 1999) and heterogeneous land cover conditions defined from the 1 km resolution global land cover classification and Digital Elevation Model (DEM), and the average number of days (first year) with global model reanalysis air temperatures within ± 3 Celcius degrees of 0.0 Celcius degrees (Kim et al. 2011).

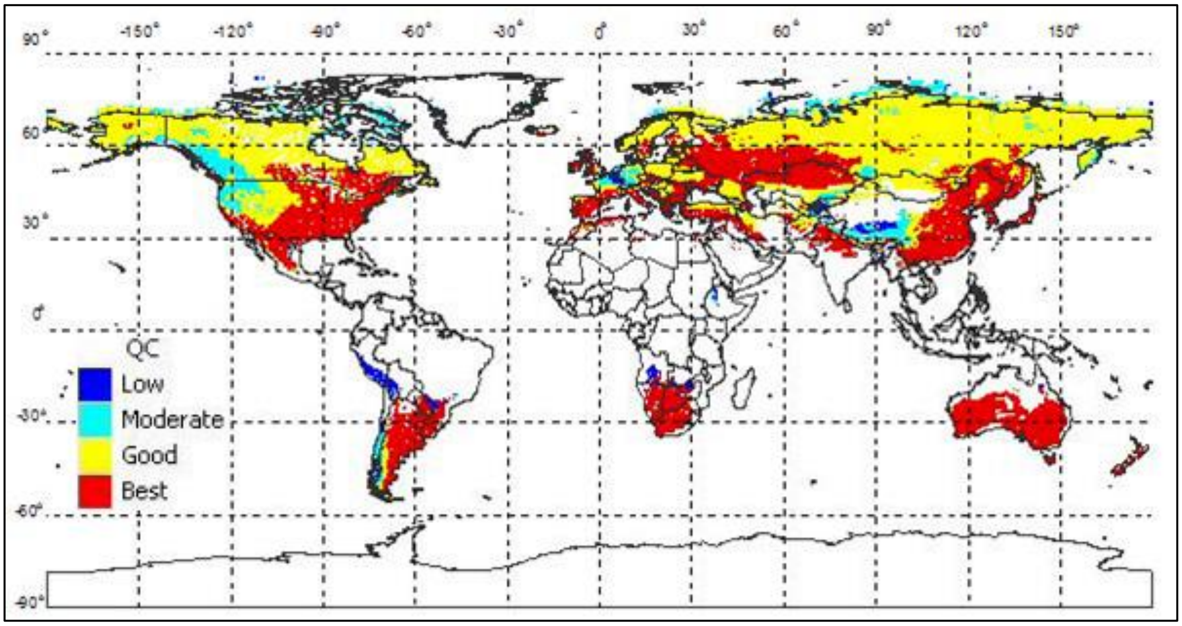

Figure 3. The QC scheme identifies regions of relative high to low quality F/T classification results, in relation to general climate and landscape features. The QC map pictured here ranges from low (estimated accuracy < 70 percent) to best (estimated accuracy > 70 percent) to best (estimated accuracy > 90 percent). Areas in white lie outside the F/T ESDR domain.

3.3.2 Version History

Table 11 summarizes the version history for this data set.

Table 10. Description of Version Changes

Version	Description of Changes
V3	Extended the SMMR-SSM/I-SSMIS F/T record through 2012; Corrected land/ocean mask and F/T misclassification errors over some ocean dominated grid cells; Revised the methodology used to produce data quality annual maps.
V2	Extended F/T record (1979 to 2010) by overlapping SMMR and SSM/I brightness temperature time series; Added new AMSR-E derived F/T record (2002 to 2011); Refined data quality annual maps; Added GeoTIFF format option and quick-look GIF browse images.
V1	Original version of data set.

3.4 Sensor or Instrument Description

The Special Sensor Microwave/Imager (SSM/I) instruments used for this product were deployed on the DMSP F-8, F-11, and F-13 satellites. The SSM/I is a seven-channel, four-frequency, orthogonally polarized passive microwave radiometric system. The system measures combined atmosphere and surface radiances at 19.3 GHz, 22.2 GHz, 37.0 GHz, and 85.5 GHz. Please see NSIDC's Special Sensor Microwave/Imager Instrument Description Web page for more details.

The Special Sensor Microwave/Imager (SSMIS) used for this product is currently deployed on DSMP F-17. The instrument is a 24-channel, passive microwave radiometer designed to obtain a variety of polarized atmospheric temperature, moisture, and land variables under most weather conditions. Channel frequencies range from 19 GHz to 183 GHz and are obtained over a swath width of approximately 1707 km. Please see NSIDC's Special Sensor Microwave Imager/Sounder Instrument Description Web page for more details.

The Scanning Multichannel Microwave Radiometer (SMMR) operated on NASA's Nimbus-7 satellite from 26 October 1978 to 20 August 1987. SMMR was a ten-channel instrument capable of receiving both horizontally and vertically polarized radiation. A parabolic antenna 79 cm in diameter reflected microwave emissions into a five-frequency feed horn. The antenna beam maintained a constant nadir angle of 42 degrees, resulting in an incidence angle of 50.3 degrees at Earth's surface. The antenna was forward viewing and rotated equally ± 25 degrees about the satellite subtrack. The 50 degree scan provided a 780 km swath of the Earth's surface. Scan period was 4.096 seconds. See NSIDC's Scanning Multi-channel Microwave Radiometer (SMMR) Instrument Description Web page for more information.

The Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E) is a twelve-channel, six-frequency, passive-microwave radiometer system on board the NASA Earth Oberserving System Aqua Satellite. The instrument measures horizontally and vertically polarized brightness temperatures at 6.9 GHz, 10.7 GHz, 18.7 GHz, 23.8 GHz, 36.5 GHz, and 89.0 GHz. Spatial resolution of the individual measurements varies from 5.4 km at 89 GHz to 56 km at 6.9 GHz. AMSR-E was developed and provided by the Japan Aerospace Exploration Agency (JAXA, Contractor: Mitsubishi Electric Corporation) with close cooperation of U.S. and Japanese scientists. The AMSR-E instrument onboard Aqua was modifed from the design used for AMSR, which flew on the Japanese ADEOS-2 satellite. See the AMSR-E Instrument Description document for more information.

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4.1 Related Data Collections

- Seasonal frost depths, midwestern USA
- Global Annual Freezing and Thawing Indices
- Modeled Daily Thaw Depth and Frozen Ground Depth
- Arctic Soil Freeze/Thaw Status from SMMR and SSM/I
- Circumpolar Active-Layer Permafrost System (CAPS)
- Near-Real-Time DMSP SSM/I-SSMIS Pathfinder Daily EASE-Grid Brightness Temperatures
- DMSP SSM/I-SSMIS Pathfinder Daily EASE-Grid Brightness Temperatures
- Daily Global Land Surface Parameters Derived from AMSR-E

4.2 Related Websites

- Freeze/Thaw Earth System Data Record

5 CONTACTS AND ACKNOWLEDGMENTS

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