MEaSUREs Global Record of Daily Landscape Freeze/Thaw Status, Version 5

USER GUIDE

How to Cite These Data

As a condition of using these data, you must include the following citations:

Kim, Y., J. S. Kimball, J. Glassy, and K. C. McDonald. 2021. *MEaSUREs Global Record of Daily Landscape Freeze/Thaw Status, Version 5*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/LJ6SLXNJB2CQ [Date Accessed].

Kim, Y., J. S. Kimball, J. Glassy, and J. Du. 2017. An Extended Global Earth System Data Record on Daily Landscape Freeze-Thaw Determined from Satellite Passive Microwave Remote Sensing, Earth System Science Data. 9. 133–147. https://doi.org/10.5194/essd-9-133-2017

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National Snow and Ice Data Center

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1 DATA DESCRIPTION

This MEaSUREs[1] Earth System Data Record (ESDR) reports the freeze/thaw (F/T) status of the landscape, in the morning and afternoon, at 25 km on the original EASE-Grid. The algorithm identifies F/T state changes based on the dynamic relationship between vertically polarized brightness temperatures (T_bs) and changes in the aggregate landscape dielectric constant associated with transitions between predominantly frozen and non-frozen conditions.

The ESDR spans 1979 – 2021 by combining calibrated, overlapping T_b measurements from the following satellite-based sensors:

- Scanning Multichannel Microwave Radiometer (SMMR)
- Special Sensor Microwave Imager (SSM/I)
- Special Sensor Microwave Imager/Sounder (SSMIS)
- Advanced Microwave Scanning Radiometer 2 (AMSR2)

1.1 File Format

Data files are available in the following formats:

- HDF5 (.h5)
- GeoTIFF (.tif)
- GIF (.gif)

ⓘ Not all data are provided in all formats. For example, quality control (QC) and quality assurance (QA) data are provided as HDF5 formatted files only. Consult the following sections to determine which files will best suit your needs.

1.2 Parameters

F/T status is provided for both morning (AM) and afternoon (PM) overpasses and as a single, daily value (CO) that combines the two. QC, QA, and annual accuracy data are also available. The following sections describe each of these parameters.

[1] Making Earth System Data Records for Use in Research Environments

1.2.1 Daily F/T Status (HDF5, GeoTIFF)

Daily AM and PM F/T status indicates whether the cell was frozen (0) or thawed (1) during the corresponding morning or afternoon overpass. Daily CO F/T status reports a single, combined daily value for the cell using the following scheme:

- AM and PM frozen (0)
- AM and PM thawed (1)
- AM frozen, PM thawed (2)
- AM thawed, PM frozen (3)

1.2.2 Daily F/T Status QC (HDF5 only)

Daily AM, PM, and CO F/T status files contain a quality control (QC) data field that uses bit flags that indicate whether F/T status in a cell was interpolated (due to a data gap) or potentially affected by any of the following conditions that can impact algorithm performance: a large precipitation event; a large fraction of open water; and complex topography.

1.2.3 Annual F/T QA (HDF5 only)

Annual Quality Assurance (QA) attempts to quantify the negative impacts to mean annual F/T status as a result of the following factors: open water cover; terrain complexity; length of F/T transitional season; and uncertainty in F/T algorithm threshold.

1.2.4 Annual F/T Status Accuracy (HDF5 only)

Annual F/T accuracy reports the spatial accuracy for each cell, expressed as the proportion of World Meteorology Organization (WMO) weather stations with daily maximum and minimum air temperatures that are consistent with the daily F/T classifications.

1.3 File Contents

1.3.1 HDF5

1.3.1.1 Daily F/T Status

Daily F/T status files (AM, PM, and CO) contain the data fields described in the following table:

Table 1. Daily F/T Status File Data Fields

Name	Description	Dimensions (r × c)	Data Type
ft_status	F/T status indicated as follows: AM, PM 0 = frozen 1 = thawed CO 0 = AM/PM frozen 1 = AM/PM thawed 2 = AM frozen, PM thawed (transitional) 3 = AM thawed, PM frozen (inverse transitional) Additional Values 252 = no data 253 = non-cold constraint area 254 = 100% open water 255 = fill	586 × 1383	8-bit unsigned integer
ft_qc	Daily QC bit flags. Flags are initialized to zero and set as follows (bits 4-7 are unused): Bit 0: interpolated T_b Bit 1: open water fraction >20% Bit 2: elevation gradient >300 m Bit 3: large precipitation event on this day	586 × 1383	8-bit unsigned integer
cell_lat	Latitude, center of cell	586 × 1383	32-bit floating point
cell_lon	Longitude, center of cell	586 × 1383	32-bit floating point

1.3.1.2 Annual F/T Accuracy

Annual accuracy files are available for both AM and PM overpasses. Accuracy is expressed as the percentage of daily F/T retrievals per year that are consistent with daily, in situ maximum and minimum air temperatures measured by stations in the global WMO weather network.

Percentages range from 0.0 to 100.0. A value of -9999 indicates no data. Annual F/T accuracy files contain the data fields described in Table 2:

Table 2. Annual F/T Accuracy File Data Fields

Name	Description	Dimensions (r × c)	Data Type
ft_annual_accuracy	Accuracy: 0–100 Fill: -9999	586 × 1383	32-bit floating point
cell_lat	Latitude, center of cell	586 × 1383	32-bit floating point
cell_lon	Longitude, center of cell	586 × 1383	32-bit floating point

1.3.1.3 Annual F/T Status Quality Assurance

Annual F/T Status Quality Assurance (QA) represents a relative index of data quality for each grid cell, based on the potential negative impacts from data gaps, open water, terrain complexity, length of F/T transitional season, and uncertainty in the F/T algorithm threshold.

QA values range from 0.0 to 1.0 and should be interpreted as follows:

- QA < 0.70 (low)
- 0.70 ≤ QA ≤ 0.85 (moderate)
- 0.85 ≤ QA ≤ 0.95 (good)
- QA > 0.95 (best)

Separate files are available for each year and contain the following data fields:

Table 3. Annual F/T Status QA File Data Fields

Field	Description	Dimension r x c	Data Type
ft_annual_qa	QA: 0.0–1.0	586 × 1383	32-bit floating point
cell_lat	Latitude, center of cell	586 × 1383	32-bit floating point
cell_lon	Longitude, center of cell	586 × 1383	32-bit floating point

1.3.2 GeoTIFF

AM, PM, and CO F/T statuses are also available as GeoTIFFs, which report F/T status using the approach described in Table 1. Note that GeoTIFFs do not contain the daily QC bit flags.

1.3.3 GIF

GIF browse images are available for daily AM, PM, and CO F/T status. These images utilize the RGB color scheme shown in Table 4 to indicate F/T status:

Table 4. Browse Image F/T Codes and RGB Color Scheme

F/T Classification	F/T Code	Color Scheme (R,G,B)
AM/PM frozen	FR	(0,0,255)
AM/PM thawed	NF	(255,0,0)
AM frozen, PM thawed (transitional)	TF	(168,168,0)
AM thawed, PM frozen (inverse transitional)	INV-TF	(76,230,0)
Non-cold constraint area	—	(200,0,0)
No data, 100% open water, fill	—	(255,255,255)

1.4 File Naming Convention

1.4.1 Daily F/T Status (HDF5, GeoTIFF, GIF)

Naming Convention

[InstrumentLabel]_[Channel][Polarization]_[OverpassCode]_FT_[Year]_day[DOY]_v##.#.[Ext]

Example

SSMI_37V_CO_FT_1993_day001_v05.1.h5

The following table describes the variables used in daily F/T status file names:

Table 5. Variables Used in Daily F/T Status File Names

Variable	Description
InstrumentLabel	Sensor: SMMR, SSMI, or AMSR[2]
Channel	Frequency in GHz
Polarization	V = vertical (i.e., 37V = 37 GHz, vertical polarization)
OverpassCode	Morning (AM), afternoon (PM), or combined (CO)
Year	Observation year
DOY	Day of year
v##.#	Version number
Ext	.h5 (HDF5) .tif (GeoTIFF) .gif

[2] F/T statuses derived from AMSR-E observations are no longer included with this data set. Starting with Version 5.1, the instrument label “AMSR” in file names refers to AMSR2.

1.4.2 Annual F/T Accuracy

Naming Convention

[InstrumentLabel]_[Channel][Polarization]_FT_[Year]_[OverpassCode]_accuracy_[v##.#].h5

Example

SMMR_37V_FT_1979_AM_accuracy_v05.1.h5

The following table describes the variables used in annual F/T accuracy file names.

Table 6. Variables Used in Annual F/T Accuracy File Names

Variable	Description
InstrumentLabel	Sensor: SMMR, SSMI, AMSR[3]
Channel	Frequency in GHz
Polarization	V = vertical (i.e., 37V = 37 GHz, vertical polarization)
OverpassCode	Morning (AM) or Afternoon (PM)
Year	Observation year
v##.#	Version number

1.4.3 Annual QA

Naming Convention

[InstrumentLabel]_global_QA_[Year]_[OverpassCode]_v##.h5

Example

SMMR_global_QA_1979_PM_v05.h5

The following table describes the variables in annual QA file names.

Table 7. Variables Used in Annual QA File Names

Variable	Description
InstrumentLabel	Sensor: SMMR, SSMI, or AMSR
Year	Observation year
OverpassCode	PM (afternoon)
v##.#	Version number

[3] F/T statuses derived from AMSR-E observations are no longer included with this data set. Starting with Version 5.1, the instrument label “AMSR” in file names always refers to AMSR2.

1.5 Spatial Coverage

This data set encompasses all land areas with seasonal freezing temperatures equatorward of 86.7167° N/S latitude, including urban, barren, snow and ice, and open-water-body dominated grid cells.

1.5.1 Spatial Resolution

25 km

1.5.2 Projection and Grid Description

This data set is provided in the original 25 km EASE-Grid projection. The following table provides information for geolocating the data:

Table 8. EASE-Grid Geolocation Details

Geographic coordinate system	Unspecified datum based upon the International 1924 Authalic Sphere
Projected coordinate system	Cylindrical Equal Area
Longitude of true origin	0
Latitude of true origin	90
Scale factor at longitude of true origin	1
Datum	Not specified (based on International 1924 Authalic Sphere)
Ellipsoid/spheroid	International 1924 Authalic Sphere
Units	meter
False easting	0
False northing	0
EPSG code	3410
PROJ4 string	proj4.defs("EPSG:3410","+proj=cea +lon_0=0 +lat_ts=30 +x_0=0 +y_0=0 +a=6371228 +b=6371228 +units=m +no_defs");
Reference	https://epsg.io/3410

1.6 Temporal Coverage

1 January 1979 – 31 December 2021

The following table specifies the date ranges for each sensor and satellite:

Table 9. SMMR, SSM/I, SSMIS Temporal Coverages

Sensor	Satellite	Start Date	End Date
SMMR	Nimbus-7	01/01/1979	07/08/1987
SSM/I	DMSP[4] F08	07/09/1987	12/11/1991
SSM/I	DMSP F11	12/12/1991	05/02/1995
SSM/I	DMSP F13	05/03/1995	12/31/2007
SSMIS	DMSP F17	01/01/2008	12/31/2020
AMSR2	GCOM-W1	01/01/2021	Ongoing

1.6.1 Temporal Resolution

Daily

1.7 Sample Data

Figure 1 shows the SMMR-SSM/I-SSMIS CO F/T status for four days in 2016. Daily CO F/T status combines AM and PM T_b retrievals to output four discrete F/T states: AM and PM frozen (FR, blue); AM and PM non-frozen (NF, red); AM frozen, PM non-frozen, or “transitional” (TR, gold); and AM non-frozen, PM frozen, or “inverse-transitional” (INV-TR, green). Open water and land areas outside the F/T domain are shaded white and grey, respectively.

[4] Defense Meteorological Satellite Program

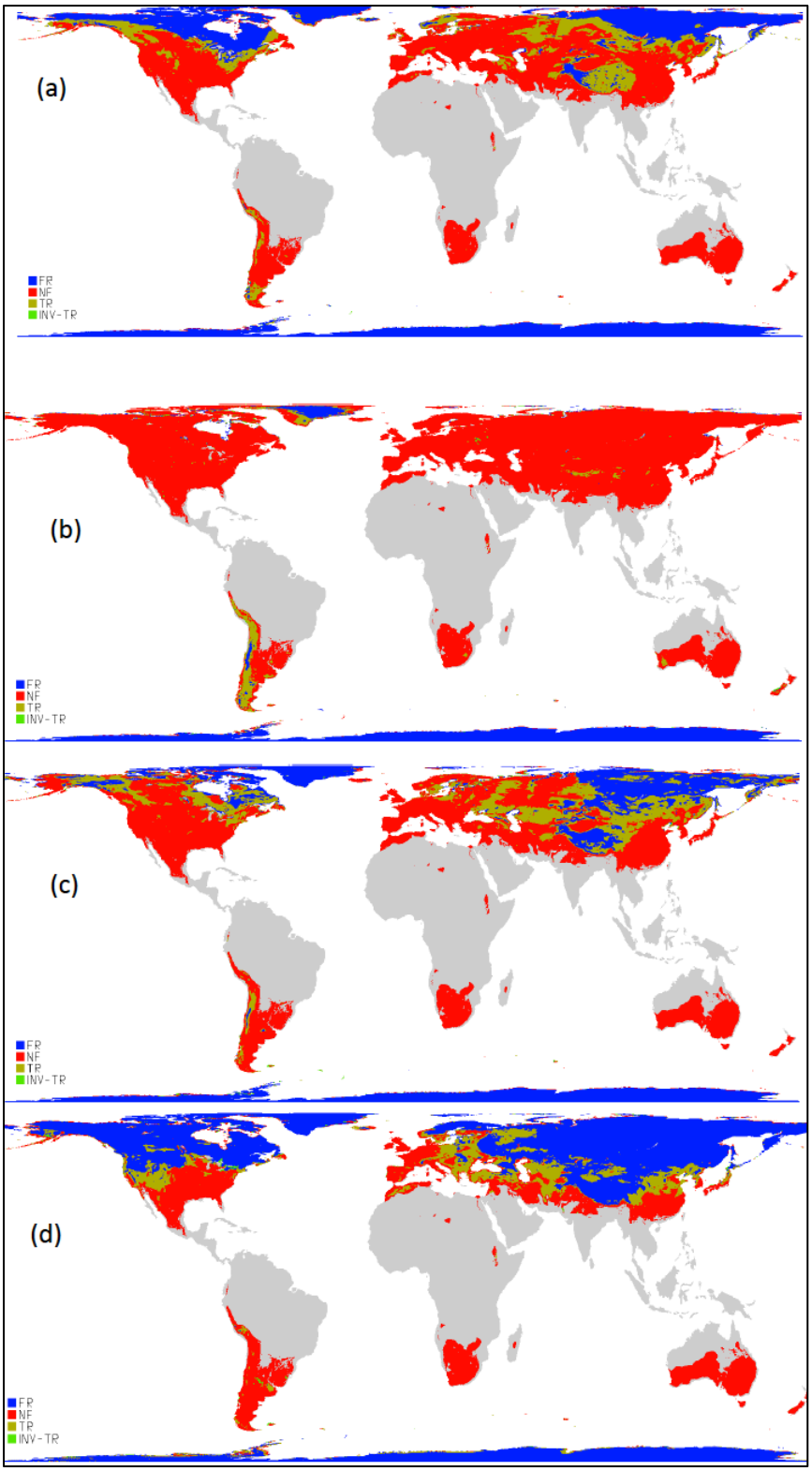

Figure 1. Daily CO F/T status for four days in 2016: day of the year 100 (a), 200 (b), 300 (c), and 360 (d).

2 DATA ACQUISITION AND PROCESSING

2.1 Background

The frozen/non-frozen state of the landscape is closely linked to numerous components of the climate system, including changes in the surface energy budget and evapotranspiration, vegetation growth and phenology, snow-melt dynamics, permafrost extent and stability, terrestrial carbon budgets, and land-atmosphere trace gas exchanges. Satellite-borne passive microwave sensors are particularly well-suited to monitoring global F/T status of the landscape because they are strongly sensitive to changes in dielectric properties at the surface that correspond to frozen and thawed states, are relatively insensitive to atmospheric contamination, and do not require solar illumination. The following sections outline the approach used to infer F/T state changes from remotely sensed T_b. For a complete description, see Kim et al. (2011).

2.2 Acquisition

The SMMR-SSM/I-SSMIS record merges 37 GHz, vertically polarized T_b observations by applying the protocols in Kim et al. 2011, 2012, 2014c, 2017a, and 2017b.

AMSR2 T_b observations are first reprojected to the 25 km global original EASE-Grid (Armstrong 1995, Du 2014). The reprojected AMSR2 T_bs at 36.5 GHz are then calibrated to the SSM/I 37 GHz T_b baseline, to create a record of estimated AMSR2 T_bs at 37 GHz for F/T classification.

2.3 Processing

The freeze/thaw (F/T) state is determined using a modified seasonal threshold algorithm (MSTA) that identifies F/T transition sequences in radiometric T_b time series. This approach exploits how T_b responds dynamically through time to changes in the aggregate landscape dielectric constant, associated with transitions between predominantly frozen and non-frozen conditions (Kim et al. 2017a, 2017b). The MSTA was chosen over the seasonal threshold algorithm because the selection of the T_b threshold does not depend on frozen and non-frozen reference states that are derived from average T_b measurements for the respective winter and summer periods. As a result, F/T status is less sensitive to gaps in T_b data during the reference periods.

Starting with Version 5, ERA5 surface air temperature (SAT) records are used to calibrate the MSTA, instead of the ERA-Interim record. Using ERA5 SAT (and previously ERA-Interim SAT) to define reference states produces the most globally accurate results relative to other reanalysis data sets and satellite records (Kim et al., 2017a).

Annual F/T thresholds are defined using an empirical linear regression between satellite T_b retrievals and daily ERA5 SAT estimates. Separate AM and PM thresholds are derived using the corresponding daily SAT minimum (SAT_{min}) and SAT maximum (SAT_{max}) values. When selecting each grid cell's T_b-based F/T threshold, SAT values closer to 0° C are weighted more heavily using a cosine function within the temperature range of -60.0° C to 30.0° C. This range accounts for 99% of the SAT frequency distribution, as defined from the SAT global climatology (Kim et al., 2017a).

Over permanent snow and ice regions, when the correlation between ERA5 SAT and T_b is low ($|r| \leq 0.5$), F/T state is determined using a constant T_b threshold. Constant thresholds are computed as an annual mean threshold derived from values with higher correlations between SSM/I T_b and ERA5 SAT ($|r| > 0.5$). In grid cells with lower correlations — for the PM overpass only — the diurnal amplitude variation (DAV) of AM and PM overpass retrievals within the cell is used as a second criteria to confirm the thaw condition. In these cases, F/T state is confirmed as thawed when $|DAV| > 10$ K (Ramage et al. 2006; Mioduszewski et al. 2014).

In addition to daily F/T state, ERA5 SAT data are used to define the global F/T ESDR domain (see Figure 2) using a simple SAT-driven bioclimatic index (Kim et al. 2011). The index identifies all land areas where seasonally frozen air temperatures represent a major constraint to ecosystem processes and water mobility on the land surface. The resulting global F/T 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.

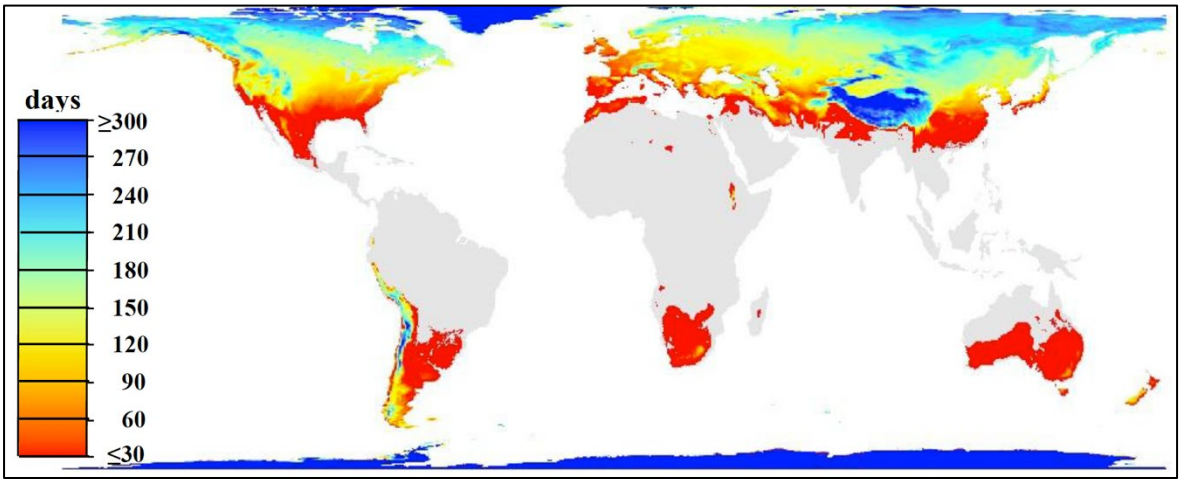

Figure 2. Mean annual frozen season (frozen and transitional) for 1979-2020. Open water bodies and land areas outside the F/T ESDR domain are shaded white and grey, respectively.

To create the daily composite F/T status, ascending and descending orbit time series are processed separately to determine the two additional states: transitional (AM frozen, PM thawed) and inverse transitional (AM thawed, PM frozen).

2.4 Quality, Errors, and Limitations

This F/T ESDR database provides a consistent and continuous multiyear record of daily, AM and PM F/T dynamics for the global biosphere. Data quality has been verified against a number of independent F/T metrics including weather station measurements and lake, river, and surface ice melt records (Kim et al. 2017a). F/T accuracy has been primarily assessed in relation to daily minimum and maximum air temperature measurements recorded by the global WMO weather station network (4268 ± 879 stations).

Daily SAT_{min} and SAT_{max} records for selected stations were used to define daily frozen (SAT ≤ 0 °C) and non-frozen (SAT > 0 °C) states and compared with the respective AM and PM F/T parameters. Agreement in F/T classification was assessed using grid-cell-to-point comparisons between WMO daily SAT measurements and overlying F/T results (Kim et al. 2017). Interannual spatial accuracies in mean annual F/T status are approximately 90.8% ±1.5σ and 85.1% ±1.8σ for corresponding F/T PM and AM retrievals over the global domain and long-term record.

F/T classification accuracy shows strong seasonal and annual variability and is degraded 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. 2017a).

Each daily F/T global grid includes a F/T accuracy metric defined by comparing F/T classifications in a pixel-wise manner to daily, minimum and maximum air temperatures recorded by nearby WMO weather stations (Kim et al. 2017a). F/T classification accuracy is defined as the proportion of global stations with air-temperature-based F/T estimates that match the T_b-based F/T classification.

In addition, QC flags identify other factors that can potentially affect F/T classification accuracy. The QC flags are spatially and temporally dynamic and assigned on a per grid-cell basis. They indicate missing satellite T_b records that have been subsequently filled by temporal interpolation using adjacent, successful T_b retrievals obtained prior to the missing data. QC flags also indicate grid cells which contain more than 20% open water, elevation gradients that exceed 300 m, and days which saw a large precipitation event (Ferraro et al. 1996).

Global QA maps were constructed for each year of the record to provide a discrete, grid cell-wise indicator of the F/T ESDR's relative quality. These maps account for potential negative impacts from open water cover, terrain complexity, length of the F/T transitional season, and uncertainty in the MSTA F/T threshold that influences assessing mean annual F/T accuracy from WMO station comparisons.

For example, the annual QA map for 2012 shown in Figure 3 (below), shows regions of both relatively high and low quality. QA values have been stratified into a set of discrete categories

ranging from low quality (estimated mean annual F/T accuracy < 70%) to best (> 95%). Mean proportions of the four QA categories encompass 54.1% (best), 36.0% (good; 80-90% agreement), 6.6% (moderate; 70-80% agreement), and 3.3% (low<70% agreement)) of the global F/T domain.

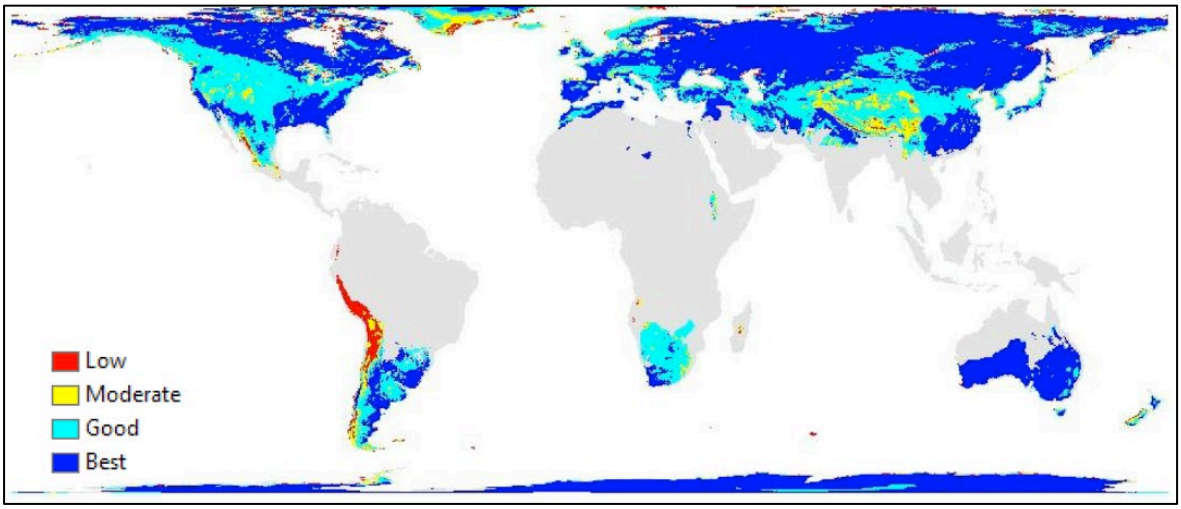

Figure 3. F/T ESDR annual quality assurance (QA) map for selected year of record 2012, aggregated into low (estimated mean annual spatial classification agreement < 70%), moderate (70-80%), good (80-90%) and best (>90%) relative quality categories. Land areas outside of the F/T ESDR domain are denoted by grey shading.

3 SOFTWARE AND TOOLS

HDF5 data files may be accessed with The HDF Group's HDFView, NASA Goddard's Panoply, or similar HDF5-compatible applications. GeoTIFF files may be viewed with QGIS (free, open Source), ESRI ArcGIS, or similar geographical information systems.

4 INSTRUMENT DESCRIPTION

The Scanning Multichannel Microwave Radiometer (SMMR) flew on NASA's Nimbus-7 satellite from 26 October 1978 to 20 August 1987. A ten-channel instrument that received both horizontally and vertically polarized radiation, SMMR's 79 cm parabolic antenna reflected microwave emissions into a five-frequency feed horn. The antenna beam's constant nadir angle of 42° resulted in an incidence angle of 50.3° at Earth's surface. The antenna was forward viewing and rotated ±25° about the satellite subtrack. The 50° scan produced a 780 km swath along Earth's surface with a scan period of 4.096 seconds. For detailed information, see "User's guide for the Nimbus 7 Scanning Multichannel Microwave Radiometer (SMMR)" on the NASA Technical Reports Server.

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 was a seven-channel, four-frequency,

orthogonally polarized passive microwave radiometric system that measured combined atmosphere and surface radiances at 19.3 GHz, 22.2 GHz, 37.0 GHz, and 85.5 GHz.

The Special Sensor Microwave/Imager (SSMIS), a 24-channel, passive microwave radiometer, currently flies on the DMSP F-17 satellite. It was 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 observe a swath width of approximately 1707 km. For more information, see the NOAA's Office of Satellite and Product Operations maintains a Defense Meteorological Satellite Program web page.

The Advanced Microwave Scanning Radiometer 2 (AMSR2) instrument was deployed on May 17, 2012 on board GCOM-W1 — the water observation component of JAXA's Global Change Observation Mission. The AMSR2 antenna rotates once every 1.5 seconds and obtains data over a 1450 km swath. This configuration acquires a set of daytime and nighttime observations every two days that covers more than 99% of Earth.

5 VERSION HISTORY

Table 10. History of Changes for Each Version

Version	Description of Changes
V5.1	• The separate AMSR-E–AMSR2 data record (2002 - 2020) has been discontinued. • Starting with V5.1, F/T status is provided as a single ESDR derived from SMMR, SSM/I, and SSMIS (1979 through 2020) and AMSR2 (2021 to present). • Temporal coverage extended through 2021 using AMSR2 (see preceding bullet). • GeoTIFF and HDF file metadata enhanced. • GIFs added for AM and PM F/T statuses. • Inaccurate SMMR pixel counts in annual QA files, inadvertently carried over from V4 to V5.0, have been corrected in V5.1. • File names updated with "v05.1"
V5	Changes for this version include: • ESDR coverage extended through the end of 2020. • ERA5 used to calibrate MSTA (replacing ERA-interim) • When the correlation between ERA5 SAT and T_b is low ($r < 0.5$) over permanent snow/ice regions, a constant threshold is used to determine F/T state. • No-data fill value changed from NaN to -9999. • GIF browse images for AM and PM overpasses are *not* included with Version 5 (as with previous versions). CO browse images *only* are provided. Browse images for AM and PM overpasses may be added at a later date.

Version	Description of Changes
V4	• Extended F/T record to 2017 • F/T domain expanded to all land areas affected by seasonal freezing, including urban, snow-ice dominant, open water body dominant, and barren land. • Added a modified seasonal threshold algorithm (MSTA) and pixel-wise, annual MSTA calibration using daily surface air temperature records. • Added bit flags to identify cells (and days) with missing/interpolated T_b, large open water bodies, complex terrain, and large precipitation events.
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	Initial release

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7 RELATED DATA COLLECTIONS

- Seasonal frost depths, midwestern USA
- Global Annual Freezing and Thawing Indices
- Arctic EASE-Grid Freeze and Thaw Depths, 1901 - 2002
- 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

8 RELATED WEBSITES

- Freeze/Thaw Earth System Data Record

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10 DOCUMENT INFORMATION

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