SMAP Enhanced L3 Radiometer Global and Northern Hemisphere Daily 9 km EASE-Grid Freeze/Thaw State, Version 4

USER GUIDE

How to Cite These Data

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

Xu, X., R. S. Dunbar, C. Derksen, A. Colliander, Y. Kim, and J. S. Kimball. 2020. *SMAP Enhanced L3 Radiometer Global and Northern Hemisphere Daily 9 km EASE-Grid Freeze/Thaw State, Version 4*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/NQLCDOZJYAKX. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/SPL3FTP_E

National Snow and Ice Data Center

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1 DATA DESCRIPTION

1.1 Parameters

Freeze/thaw (F/T) state and the direction of diurnal freeze/thaw transitions (frozen in the morning to thawed in the afternoon and vice versa) derived from brightness temperatures are output on two 9 km Earth-fixed, Equal-Area Scalable Earth Grids, Version 2.0 (EASE-Grid 2.0): a global cylindrical and a Northern Hemisphere azimuthal. Freeze/thaw state, the occurrence of freeze/thaw transitions, and the direction of transitions are expressed in Boolean values (0 or 1). For freeze/thaw state, 0 indicates thawed conditions and 1 indicates frozen. For freeze/thaw transition state, 0 indicates the a.m. and p.m. Freeze/thaw (FT) states are not in transition and 1 indicates they are in transition. The transition direction flag is only meaningful if there is a transition (transition state = 1), and is set to 0 for a.m. frozen/p.m. thawed and 1 for a.m. thawed/p.m. frozen. Transition direction flag is set to 0 if not in transition state.

Also included are brightness temperatures (TBs; given in K) for a 9 km EASE-Grid 2.0 cell.

Refer to the *Appendix – Data Fields* Section of this document for details on all parameters.

1.2 File Information

1.2.1 Format

Data are in HDF5 format. For software and more information, including an HDF5 tutorial, visit the HDF Group's HDF5 website.

1.2.2 File Contents

As shown in Figure 1, each HDF5 file is organized into the following main groups, which contain additional groups and/or data sets:

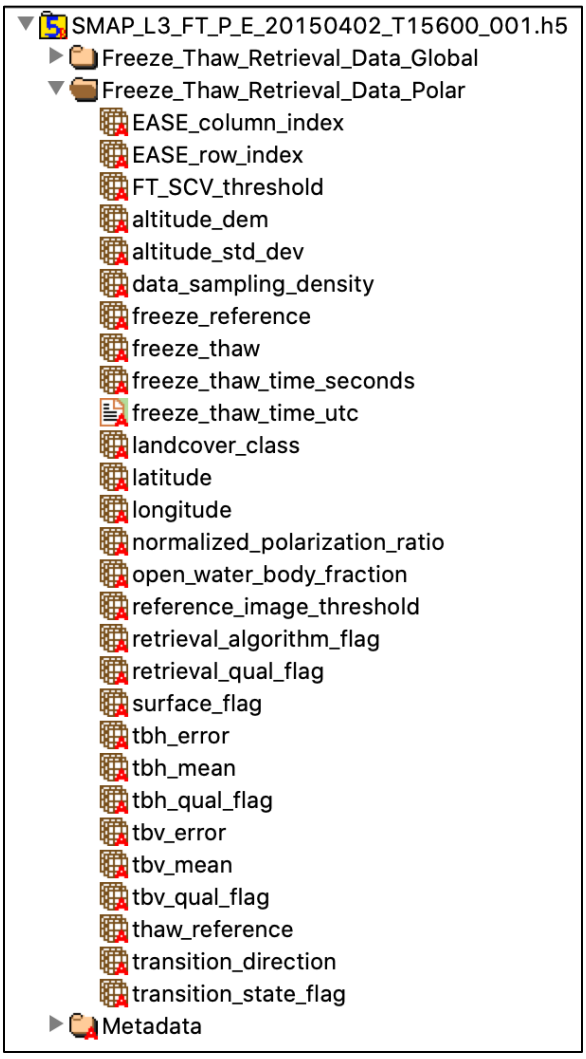

Figure 1. Subset of File Contents. For a complete list of file contents for the SMAP enhanced Level-3 radiometer freeze/thaw product, refer to the *Appendix – Data Fields* Section in this document.

1.2.3 Data Fields

Each file contains the main data groups summarized in this section. For a complete list and description of all data fields within these groups, refer to the *Appendix – Data Fields* Section of this document.

Data element arrays are three dimensional, with the exception of *transition_direction* and *transition_state_flag* arrays, which are two dimensional. Arrays in the Polar group have dimensions of 500 rows and 500 columns in each a.m. and p.m. layer; the Global group array dimensions are 406 rows x 964 columns. For the a.m./p.m. index of the array, the a.m. layer is assigned to the index value 0 and the p.m. layer is assigned to index value 1.

Freeze/Thaw Retrieval Data Global

Includes freeze/thaw data, latitude and longitude arrays, and associated quality assessment flags. Also includes all ancillary data, such as landcover classification and open water body fraction, and all radiometer data and associated quality assessment flags. Data are provided in the 9 km Global EASE-Grid 2.0 projection.

Freeze/Thaw Retrieval Data Polar

Contains the same data fields as the global projection group, but data are provided in the 9 km Northern Hemisphere azimuthal EASE-Grid 2.0 projection.

1.2.4 Metadata Fields

Includes all metadata that describe the full content of each file. For a description of all metadata fields for this product, refer to the Product Specification Document (Dunbar, 2018).

1.2.5 File Naming Convention

Files are named according to the following convention:

```
SMAP_L3_FT_P_E_yyyymmdd_RLVvvv_NNN.[ext]
```

For example:

```
SMAP_L3_FT_P_E_20170117_R14010_001.h5
```

Table 1 describes the variables within a file name:

Table 1. File Naming Convention

Variable	Description
SMAP	Indicates SMAP mission data
L3_FT_P_E	Indicates specific product (L3: Level-3; FT: Freeze/Thaw; P: Passive; E: Enhanced)
yyyymmdd	4-digit year, 2-digit month, 2-digit day of the first data element that appears in the product.
RLVvvv	Composite Release ID, where: R: Release L: Launch Indicator (1: post-launch standard data) V: 1-Digit CRID Major Version Number (Note: the data set's major version does not necessarily coincide with the CRID major version) vvv: 3-Digit CRID Minor Version Number Example: R13242 indicates a post-launch data product with a version of 3.242. Refer to the SMAP Data Versions page for version information.
NNN	Number of times the file was generated under the same version for a particular date/time interval (002: 2nd time)
.[ext]	File extensions include: .h5: HDF5 data file .qa: Quality Assurance file .xml: XML Metadata file

1.3 Spatial Information

1.3.1 Coverage

Coverage for the Northern Hemisphere EASE-Grid 2.0 projection extends to all land regions north of 45°N latitude, and from 180°W to 180°E. For the global EASE-Grid 2.0 projection, coverage spans from 180°W to 180°E, and from approximately 85.044°N and 85.044°S.

1.3.2 Resolution

9 km

1.3.3 Geolocation

These data are provided on the global cylindrical and Northern Hemisphere azimuthal EASE-Grid 2.0 projections. Each grid cell has a nominal area of approximately 9 x 9 km^2 regardless of longitude and latitude. The following tables provide information for geolocating this data set. For more on EASE-Grid 2.0, refer to the EASE Grids website.

Table 2. Geolocation details for the EASE-Grid 2.0 projections used in this product

	Global	Northern Hemisphere
Geographic coordinate system	WGS 84	WGS 84
Projected coordinate system	EASE-Grid 2.0 Global	EASE-Grid 2.0 North Azimuthal
Longitude of true origin	0	0
Standard Parallel	30° N	90° N
Scale factor at longitude of true origin	N/A	N/A
Datum	WGS 84	WGS 84
Ellipsoid / spheroid	WGS 84	WGS 84
Units	meter	meter
False easting	0	0
False northing	0	0
EPSG code	6933	6931
PROJ4 string	`+proj=cea +lon_0=0 +lat_ts=30 +x_0=0 +y_0=0 +ellps=WGS84 +towgs84=0,0,0,0,0,0,0 +units=m +no_defs`	`+proj=laea +lat_0=90 +lon_0=0 +x_0=0 +y_0=0 +ellps=WGS84 +towgs84=0,0,0,0,0,0,0 +units=m +no_defs`
Reference	http://epsg.io/6933	http://epsg.io/6931

Table 3. Grid details for the EASE-Grid 2.0 projections used in this product

	Global	Northern Hemisphere
Grid cell size (x, y pixel dimensions)	9,008.05 m (x) 9,008.05 m (y)	9,000 m (x) 9,000 m (y)
Number of columns	3,856	2,000
Number of rows	1,624	2,000
Geolocated lower left point in grid	85.044° S, 180.000° W	45.000° N, 180.000° W
Nominal gridded resolution	9 km by 9 km	9 km by 9 km
Grid rotation	N/A	N/A
ulxmap – x-axis map coordinate of the outer edge of the upper-left pixel	-17367530.45	-9000000.0
ulymap – y-axis map coordinate of the outer edge of the upper-left pixel	7314540.83	9000000.0

1.4 Temporal Information

1.4.1 Coverage

Coverage spans from 31 March 2015 to present.

1.4.2 Satellite and Processing Events

Due to instrument maneuvers, data downlink anomalies, data quality screening, and other factors, small gaps in the SMAP time series will occur. Details of these events are maintained on two master lists:

SMAP On-Orbit Events List for Instrument Data Users
Master List of Bad and Missing Data

Significant gaps in coverage occurred between 19 June and 23 July 2019 and between 6 August and 20 September 2022 after the SMAP satellite went into Safe Mode. A brief description of the 2019 event and its impact on data quality is available in the SMAP Post-Recovery Notice. The SMAP data acquired after the 2022 event were determined to be of high quality and consistent with the data acquired prior to the event.

1.4.3 Latencies

For further information, see What are the latencies for SMAP radiometer data sets? web page.

1.4.4 Resolution

Each Level-3 file is a daily composite of half-orbit files/swaths. To ensure complete coverage of the freeze/thaw domain in each daily file, a.m. and p.m. data for the current day are combined with a.m. and p.m. data from previous days. A maximum of three days of past data is used, and is necessary only near the southern margin of the freeze/thaw domain.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

The SPL3FTP_E product is derived using a temporal change detection approach that has been previously developed and successfully applied using time series satellite remote sensing radar backscatter and radiometric brightness temperature data from a variety of sensors and spectral wavelengths. The baseline approach is to identify the landscape F/T state via the temporal response of the normalized polarization ratio (FT-NPR) of the brightness temperature, which is sensitive to changes in the dielectric constant of the landscape that occur as the water within the components transitions between frozen and non-frozen conditions.

This approach assumes that the large changes in dielectric constant occurring between frozen and non-frozen conditions dominates the corresponding NPR temporal dynamics across the seasons,

rather than other potential sources of temporal variability such as changes in canopy structure and biomass, large precipitation events, or changes in soil moisture.

However, in lower-latitude areas where the seasonal difference of the NPR is too small to be effectively used to discriminate F/T state, the extended algorithm using the single-channel vertical-polarization (V-pol) brightness temperature has been introduced (FT-SCV). The V-pol TB is compared to a threshold value to retrieve the F/T state. At very low latitudes where no F/T transitions occur, no algorithm is applied. Figure 2 illustrates both freeze/thaw algorithm domains in the two projections provided.

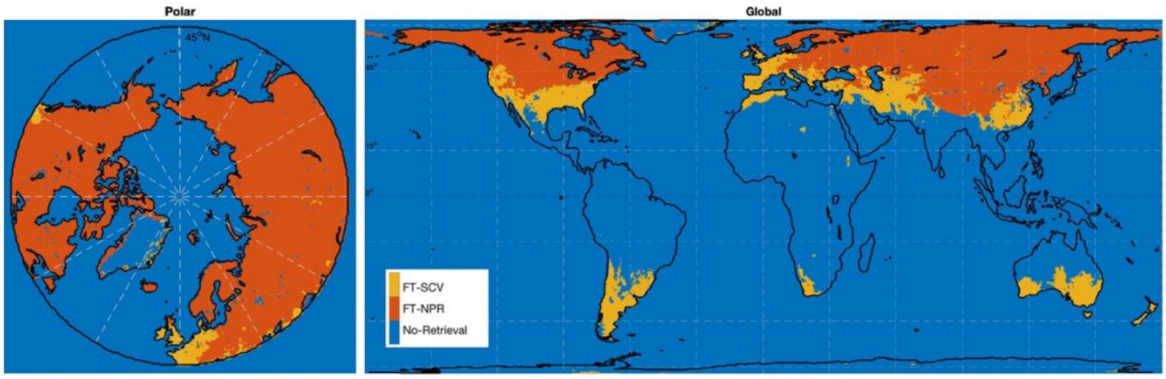

Figure 2. Freeze/thaw algorithm domain in polar grid (left) and global grid (right)

2.2 Instrumentation

For a detailed description of the SMAP instrument, visit the SMAP Instrument page at Jet Propulsion Laboratory (JPL) SMAP website.

2.3 Acquisition

SMAP enhanced Level-3 radiometer freeze/thaw data (SPL3FTP_E) are derived from SMAP Enhanced L1C Radiometer Half-Orbit 9 km EASE-Grid Brightness Temperatures, Version 4 (SPL1CTB_E).

2.4 Derivation Techniques and Algorithms

This product (SPL3FTP_E) is an enhanced version of the SMAP L3 Radiometer Northern Hemisphere Daily 36 km EASE-Grid Freeze/Thaw State (SPL3FTP), Version 4 product. Both products are derived using the same techniques and algorithms; refer to the SPL3FTP User Guide for an overview of those and information on ancillary data, and to the Algorithm Theoretical Basis Document (or ATBD; Dunbar et al., 2020) for details. For information regarding the Backus-Gilbert

optimal interpolation algorithm used to enhance the input data for this product, refer to the SPL1CTB_E User Guide.

2.5 Processing

The derivation of freeze/thaw from SMAP brightness temperature measurements occurs during an intermediate Level-2 processing step of the input enhanced Level-1C brightness temperature data. During the Level-2 processing step, the freeze/thaw algorithm utilizes a seasonal threshold approach to convert SMAP brightness temperature measurements to freeze/thaw state. This product is generated the same way as SPL3FTP. Refer to that User Guide for an overview of the processing steps and to the ATBD (Dunbar et al., 2020) for details.

2.6 Quality, Errors, and Limitations

2.6.1 Error Sources

Anthropogenic Radio Frequency Interference (RFI), principally from ground-based surveillance radars, can contaminate both radar and radiometer measurements low microwave frequencies (long wavelengths), which is otherwise also known as L-band or at approximately 1 GHz (20-30 cm). The SMAP radar and radiometer electronics and algorithms include design features to mitigate the effects of RFI. The SMAP radiometer utilizes selective filters and an adjustable carrier frequency to tune to predetermined RFI-free portions of the spectrum while on orbit.

The landscape freeze/thaw state retrieval represented by the SPL3FTP_E algorithm and products characterizes the predominant frozen or non-frozen state of the land surface within the sensor Field of View (FOV) and does not distinguish freeze/thaw characteristics among different landscape elements, including surface snow, soil, open water, or vegetation. The lower frequency L-band retrievals from SMAP are expected to have greater sensitivity to surface soil freeze/thaw conditions under low to moderate vegetation cover. Microwave freeze/thaw sensitivity is strongly constrained by intervening vegetation biomass, soil moisture levels, and snow wetness. Ambiguity in relating changes in the radiometer signal to these specific landscape components is a challenge to validation of the freeze/thaw product. In northern boreal and tundra landscapes, L-band penetration depth is greater under frozen conditions when land surface liquid water levels are low, and markedly reduced under thawed conditions due to characteristically moist surface organic layer and soil active layer conditions, even under relatively low tundra vegetation biomass levels.

Note that spatial classification error is expected to be larger in regions with small differences between frozen and thawed NPR references, particularly at lower latitudes. This includes areas where freeze/thaw is ephemeral and densely vegetated areas due to vegetation scattering effects

on microwave emissivity. Small differences in TB V- and H-polarization and lower dynamic range of NPR both increase the uncertainty in the retrievals using the NPR algorithm. In regions of complex terrain, freeze/thaw heterogeneity is greater which also adversely impacts retrieval performance. In arid regions, the small amount of water present in the thawed state makes the soil permittivity close to the frozen state, which can cause false freeze retrieval errors. These are largely mitigated through additional screening.

To address spatial classification errors at lower latitudes, the SCV algorithm assigns a V-pol brightness temperature (TBv) threshold and applies it on a pixel-by-pixel basis to determine freeze/thaw state using a computed value of the correlation between the TBv and physical surface temperature at each pixel. Additional mitigation steps for this version include brightness temperature screening and the use of a ‘never frozen’ mask based on AMSR-E climatology and GEOS-FP (NASA's Global Modeling and Assimilation Office-Forward Processing) surface temperature.

Finally, a major assumption of the NPR seasonal threshold-based temporal change freeze/thaw classification is that the major temporal shifts in brightness temperature are caused by land surface dielectric changes from temporal freeze/thaw transitions. This assumption generally holds for higher latitudes and elevations where seasonal frozen temperatures are a significant part of the annual cycle and a large constraint to land surface water mobility and ecosystem processes. However, freeze/thaw classification accuracy is expected to be reduced where other environmental factors may cause large temporal shifts in brightness temperature, including large rainfall events and surface inundation, and changes in vegetation biomass (e.g. phenology, disturbance and land cover change). Winter season false thaw in areas of complex terrain are due to uncertainty in the references due to sub-grid heterogeneity. While there is a strong NPR response to freeze/thaw transitions, NPR is not stable during summer due to the influence of vegetation, soil moisture, etc. Depolarization of summer season measurements leads to false freeze retrievals that must be mitigated.

For an assessment of algorithm performance and sources of uncertainty using in situ observations and other satellite data sets, refer to the Assessment Report for this product (Xu et al., 2020).

2.6.2 Quality Assessment

For in-depth details regarding the quality of these data, refer to the Assessment Report (Xu et al., 2020).

2.6.3 Quality Overview

The SPL3FTP_E product has sufficient fidelity and accuracy to identify the primary seasonal freeze and thaw transitions, and distinguish diurnal freeze/thaw state changes common during seasonal transitions.

SMAP products provide multiple means to assess quality. Each product contains bit flags, uncertainty measures, and file-level metadata that provide quality information. For information regarding the specific bit flags, uncertainty measures, and file-level metadata contained in this product, refer to the Product Specification Document (Dunbar, 2018) and the *Appendix – Data Fields* Section of this document.

Each HDF5 file contains metadata with Quality Assessment (QA) metadata flags that are set by the SDS at the JPL prior to delivery to the National Snow and Ice Data Center Distributed Active Archive Center (NSIDC DAAC). A separate metadata file with an .xml file extension is also delivered to NSIDC DAAC with the HDF5 file; it contains the same information as the HDF5 file-level metadata.

A separate QA file with a `.qa` file extension is also associated with each data file. QA files are ASCII text files that contain statistical information in order to help users better assess the quality of the associated data file. If a product does not fail QA, it is ready to be used for higher-level processing, browse generation, active science QA, archive, and distribution. If a product fails QA, it is never delivered to NSIDC DAAC.

3 SOFTWARE AND TOOLS

For tools that work with SMAP data, refer to the Tools web page.

4 VERSION HISTORY

Table 4. Version History

Version	Release Date	Description of Changes
V1	December 2016	First public data release
V2	June 2018	Changes to this version include: • Implementation of a supplementary single-channel V-pol (SCV) algorithm for areas of lower latitudes where the seasonal difference of the NPR algorithm is too small to be effectively used to discriminate freeze/thaw state; results are captured in the *retrieval_quality_flag*. This change provides stronger flag agreement between Tair and Tsoil, and for ascending/p.m. versus descending/a.m. overpasses due to physics (e.g. the NPR algorithm response to wet snow over frozen soil in spring). It also addresses an artifact of the validation approach (e.g. soils remain thawed for weeks after freeze onset in fall due to insulation from snow). • With the addition of the new SCV algorithm to the NPR baseline algorithm, spatial coverage of freeze/thaw data was extended to global. Data are output on a fixed global 9 km EASE-Grid 2.0 and are provided in the *Freeze_Thaw_Retrieval_Data_Global* group. • Updated *retrieval_quality_flag* for water contamination/permanent ice. • Implementation of false flag mitigation using TB screening and AMSR-E weekly climatology maps, resulting in significantly fewer false flags.

V3	August 2020	Changes to this version include:
		• Adjusted the freeze/thaw reference states for the normalized polarization ratio (NPR) algorithm per the improved Level-1 brightness temperature recalibration. The freezing reference averages from 2016-2020 and the thaw reference averages from 2015-2019.
		• Adjusted the reference states for the Single-Channel Vertical-polarization (SCV) algorithm per the update of the GEOS-FP surface and soil temperature profiles.
		• Improved the never frozen/never thawed masks for false-flag mitigation by:
		  ○ extending the temporal extent of the AMSR-E source data to include data through 2019
		  ○ blending in a GEOS-FP temperature climatology for 2015-2020 using a loose ±10 ºC criterion for fully-frozen or fully-thawed conditions.
		• The product data structure, content, and processor code are otherwise unchanged from the previous version.

Version	Release Date	Description of Changes
V4	November 2023	Changes to this version include: • Minor bug fix to correct the indexing of bits in the AMSER-E never-frozen never-thawed maps • An improved processing methodology was applied to the input enhanced Level-1C radiometer brightness temperatures. • The data algorithms, structure, content, or processor code are otherwise unchanged from the previous version.

5 RELATED DATA SETS

SMAP Data at NSIDC | Overview

SMAP Radar Data at the ASF DAAC

6 RELATED WEBSITES

SMAP at NASA JPL

7 REFERENCES

Dunbar, R. S., X. Xu, A. Colliander, C. Derksen, J. Kimball, and Y. Kim. 2020. Algorithm Theoretical Basis Document (ATBD): SMAP Level 3 Radiometer Freeze/Thaw Data Products (L3_FT_P and L3_FT_P_E). Revision C, SMAP Project, Jet Propulsion Laboratory, Pasadena, CA. (see PDF)

Dunbar, R. S. 2018. SMAP Enhanced Level 3 Freeze-Thaw Passive Product Specification Document, Release 2. SMAP Project, JPL D-56294. Jet Propulsion Laboratory, Pasadena, CA. (see or PDF)

Xu, X., R. S. Dunbar, A. Colliander, Y. Kim, J. Kimball, and C. Derksen. 2020. Soil Moisture Active Passive (SMAP) Project Calibration and Validation for the L3_FT_P and L3_FT_P_E Data Products (Version 3). SMAP Project, JPL D-56296. Jet Propulsion Laboratory, Pasadena, CA. (see or PDF)

8 DOCUMENT INFORMATION

8.1 Publication Date

September 2020

8.2 Date Last Updated

January 2024

APPENDIX – DATA FIELDS

This appendix provides a description of all data fields within the *SMAP Enhanced L3 Radiometer Global and Northern Hemisphere Daily 9 km EASE-Grid Freeze/Thaw State (SPL3FTP_E)* product. The data are grouped into two main HDF5 groups depending on the projection (global or polar):

- Freeze_Thaw_Retrival_Data_[Global | Polar]
- Metadata

For a description of metadata fields for this product, refer to the Product Specification Document (Dunbar, 2018). Table A - 1 describes the data fields of a typical SPL3FTP_E global cylindrical or north polar granule. Data element arrays are three dimensional, with the exception of *transition_direction* and *transition_state_flag* arrays, which are two dimensional with a size "N," (where N is the number of valid cells from the radiometer swath that appear on the grid).

Table A - 1. Data Fields for *Freeze_Thaw_Retrieval_Data_Global* and *Freeze_Thaw_Retrieval_Data_Polar*

Data Field Name	Shape	Concept	Byte	Signed	Unit	Min	Max	Fill/Gap Value
EASE_column_index	*AMPM_LatCell_LonCell_Array*	integer	uint16	2	N/A	0	65535	65534
EASE_row_index	*AMPM_LatCell_LonCell_Array*	integer	uint16	2	N/A	0	65535	65534
FT_SCV_threshold	*AMPM_LatCell_LonCell_Array*	string	float32	4	N/A	0	330	-9999.0
altitude_dem	*AMPM_LatCell_LonCell_Array*	real	float32	4	m	0.0	999999.9	-9999.0
altitude_std_dev	*AMPM_LatCell_LonCell_Array*	real	float32	4	m	0.0	1000.0	-9999.0
data_sampling_density	*AMPM_LatCell_LonCell_Array*	real	float32	4	km	0.0	2.0	-9999.0
freeze_reference	*AMPM_LatCell_LonCell_Array*	real	float32	4	dB	-5	5	-9999.0
freeze_thaw	*AMPM_LatCell_LonCell_Array*	boolean	uint8	1	N/A	0	1	254
freeze_thaw_time_seconds	*AMPM_LatCell_LonCell_Array*	real	float64	8	seconds	-999999.9	999999.9	-9999.0
freeze_thaw_time_utc	*AMPM_LatCell_LonCell_Array*	string	char	13	N/A	00:00:00.000Z	00:00:00.000Z	N/A
freeze_thaw_uncertainty	*AMPM_LatCell_LonCell_Array*	real	float32	4	N/A	-999999.9	999999.9	-9999.0
landcover_class	*AMPM_LatCell_LonCell_Array*	enum	uint8	1	n/a	0	16	254
latitude	*AMPM_LatCell_LonCell_Array*	real	float32	4	degrees	-90	90	N/A
longitude	*AMPM_LatCell_LonCell_Array*	real	float32	4	degrees	-180	180	N/A
normalized_polarization_ratio	*AMPM_LatCell_LonCell_Array*	string	float32	4	N/A	-5.0	5.0	-9999.0
open_water_body_fraction	*AMPM_LatCell_LonCell_Array*	real	float32	4	normalized	0.0	1.0	-9999.0
reference_image_threshold	*AMPM_LatCell_LonCell_Array*	real	float32	4	normalized	-999999.9	999999.9	-9999.0
retrieval_qual_flag	*AMPM_LatCell_LonCell_Array*	bit flag	uint32	4	N/A	N/A	N/A	65534
retrieval_algorithm_flag	*AMPM_LatCell_LonCell_Array*	bit flag	uint32	4	N/A	N/A	N/A	65534
surface_flag	*AMPM_LatCell_LonCell_Array*	bit flag	uint32	4	N/A	N/A	N/A	65534
tbh_error	*AMPM_LatCell_LonCell_Array*	real	Uint8	2	normalized	0	1	-9999.0
tbh_mean	*AMPM_LatCell_LonCell_Array*	real	float32	4	Kelvin	-999999.9	999999.9	-9999.0
tbh_qual_flag	*AMPM_LatCell_LonCell_Array*	bit flag	Uint16	2	N/A	N/A	N/A	65534
tbv_error	*AMPM_LatCell_LonCell_Array*	real	float32	4	Kelvin	-999999.9	999999.9	-9999.0
tbv_mean	*AMPM_LatCell_LonCell_Array*	real	float32	4	Kelvin	-999999.9	999999.9	-9999.0

Data Field Name	Shape	Concept	Byte	Signed	Unit	Min	Max	Fill/Gap Value
tbv_qual_flag	*AMPM_LatCell_LonCell_Array*	bit flag	uint32	4	N/A	N/A	N/A	N/A
thaw_reference	*AMPM_LatCell_LonCell_Array*	real	float32	4	dB	-5	5	-9999.0
transition_direction	*LatCell_LonCell_Array*	boolean	uint8	1	N/A	0	2	254
transition_state_flag	*LatCell_LonCell_Array*	boolean	uint8	1	N/A	1	2	254

Data Field Definitions

altitude_dem

The Earth surface elevation within the grid cell. The AM (dimension AMPM:0) and PM (AMPM:1) observations are stored separately in the array.

altitude_std_dev

The standard deviation of the Earth surface elevation within the grid cell. This element provides a surface roughness measure. The AM (dimension AMPM:0) and PM (AMPM:1) observations are stored separately in the array.

FT_SCV_threshold

Threshold for the SCV algorithm based on reference V-pol TB to differentiate between freeze and thaw conditions. The AM (dimension AMPM:0) and PM (AMPM:1) observations are stored separately in the array.

landcover_class

An enumerated type that specifies the predominant surface vegetation found in the grid cell. The AM (dimension AMPM:0) and PM (AMPM:1) observations are stored separately in the array. See Table A - 2 for a description of landcover classes.

open_water_body_fraction

Fraction of the area of the grid cell surface covered by open water. Open water areas do not have vegetation at or on the water surface. The AM (dimension AMPM:0) and PM (AMPM:1) observations are stored separately in the array.

EASE_column_index

The column index of the 9 km EASE-Grid 2.0 cell that contains the associated data. The AM (dimension AMPM:0) and PM (AMPM:1) observations are stored separately in the array.

EASE_row_index

The row index of the 9 km EASE-Grid 2.0 cell that contains the associated data. The AM (dimension AMPM:0) and PM (AMPM:1) observations are stored separately in the array.

Table A - 2. Landcover Classification Values

Value	Description
0	Water
1	Evergreen needleleaf forest
2	Evergreen broadleaf forest
3	Deciduous needleleaf forest
4	Deciduous broadleaf forest
5	Mixed forest
6	Closed shrubland
7	Open shrubland
8	Woody savanna
9	Savanna
10	Grassland
11	Permanent wetland
12	Croplands
13	Urban and built-up
14	Cropland/natural vegetation mosaic
15	Permanent snow and ice
16	Barren or sparsely vegetated
>16	TBD

data_sampling_density

Total number of radiometer data samples in the grid cell. The AM (dimension AMPM:0)

and PM (AMPM:1) observations are stored separately in the array.

freeze_reference
Reference normalized polarization ratio value used as a basis to indicate frozen conditions. The AM (dimension AMPM:0) and PM (AMPM:1) observations are stored separately in the array.

freeze_thaw
Boolean that indicates whether soil within cell is frozen or thawed. A value of zero value implies thawed conditions, a value of 1 implies frozen. The AM (dimension AMPM:0) and PM (AMPM:1) observations are stored separately in the array.

freeze_thaw_time_seconds
Time of the freeze-thaw determination for this particular element in seconds from the standard epoch. The AM (dimension AMPM:0) and PM (AMPM:1) observations are stored separately in the array.

freeze_thaw_time_utc
Time of the freeze-thaw determination for this particular element in UTC. The AM (dimension AMPM:0) and PM (AMPM:1) observations are stored separately in the array.

freeze_thaw_uncertainty
Uncertainty measure for the recorded freeze-thaw result. Method to determine uncertainty is TBD. The AM (dimension AMPM:0) and PM (AMPM:1) observations are stored separately in the array.

latitude
Latitude of the center of the Earth based grid cell. The AM (dimension AMPM:0) and PM (AMPM:1) observations are stored separately in the array.

longitude
Longitude of the center of the Earth based grid cell. The AM (dimension AMPM:0) and PM (AMPM:1) observations are stored separately in the array.

normalized_polarization_ratio
Normalized Tb polarization ratio at the Earth based grid cell, defined as (TBH-TBV)/(TBH+TBV). The AM (dimension AMPM:0) and PM (AMPM:1) observations are stored separately in the array.

reference_image_threshold
Threshold based on reference freeze and thaw to differentiate between freeze and thaw conditions. The AM (dimension AMPM:0) and PM (AMPM:1) observations are stored separately in the array.

retrieval_qual_flag
Sequence of bit flags that indicate the conditions and the quality of the freeze-thaw retrieval. The AM (dimension AMPM:0) and PM (AMPM:1) observations are stored separately in the array. See Table A - 3 for more information.

surface_flag
Bit flags that record ambient surface conditions for the grid cell. See Table A - 4 for more information.

Table A - 3. Retrieval Quality Bit Flag Definitions

Name	Bit Position	Interpretation of Values (0:off, 1:on)
FT retrieval attempted	0	0: Retrieval was attempted
		1: Retrieval not attempted due to excess water fraction in cell (nominally > 50%)
FT high water caution flag	1	0: Water body fraction lower than threshold (20%)
		1: Water body fraction between 20-50%
FT permanent ice retrieval caution flag	2	0: Freeze-thaw retrieval not over permanent ice
		1: Freeze-thaw retrieval was attempted over permanent ice landcover
FT SCV low correlation caution flag	3	0: FT SCV retrieval was attempted where the absolute value of SCV correlation is > 0.5
		1: FT SCV retrieval was attempted where the absolute value of SCV correlation is ≤ 0.5
AMSR-E/TB false flag mitigation caution flag	4	0: No AMSR-E or TB mitigation was used
		1: AMSR-E or TB mitigation was used to correct retrieved FT state
Reserved	5-15	0: Always clear

Table A - 4. Surface Condition Quality Bit Flag Definitions

Bit Position	Bit Definition	Bit Value and Interpretation
0	Static Water Body Flag	0: The fraction of the 9 km grid cell area that is over a permanent water body is less than metadata element *PermanentWaterBodyThreshold*.
		1: The fraction of the 9 km grid cell area that is over a permanent water body is greater than or equal to metadata element *PermanentWaterBodyThreshold*.
~~1 *~~	~~Radar Water Body Detection Flag~~	~~0: Transient water body not detected within 9 km cell~~
		~~1: Transient water body detected within 9 km cell~~
~~2 *~~	~~Coastal Proximity Flag~~	~~0: Cell is more than 1 grid cell from coastline~~
		~~1: Cell is within on grid cell of coastline~~
~~3 *~~	~~Urban Area Flag~~	~~0: The fraction of the 9 km grid cell area that is over urban development is less than metadata element UrbanAreaThreshold.~~
		~~1: The fraction of the 9 km grid cell area that is over urban development is greater than or equal to metadata element UrbanAreaThreshold.~~

Bit Position	Bit Definition	Bit Value and Interpretation
4	Precipitation Flag	0: No significant precipitation detected within the 9 km grid cell when data were being acquired.
		1: Precipitation greater than threshold was detected within the 9 km grid cell.
5	Snow/Ice Flag (dynamic)	0: Snow or ice cover less than threshold was detected within the 9 km grid cell.
		1: Snow and/or ice greater than threshold were detected within the 9 km grid cell.
6	Permanent Snow/Ice Flag	0: Cell landcover (from IGBP) is not dominantly permanent snow or ice
		1: Cell landcover (from IGBP) is dominantly permanent snow or ice
7	Frozen Ground Flag (from SMAP radiometer FT algorithm)	0: No frozen ground detected within the 9 km grid cell.
		1: Frozen ground detected within the 9 km grid cell.
~~8 *~~	~~Frozen Ground Flag (from GMAO TSURF)~~	~~0: No frozen ground detected within the 9 km grid cell. TSURF > 0C.~~
		~~1: Frozen ground detected within the 9 km grid cell. TSURF < 0C.~~
9	Mountainous Terrain Flag	0: The variability of land elevation in the 9 km grid cell is less than metadata element *MountainousTerrainThreshold*.
		1: The variability of land elevation in the 9 km grid cell is greater than or equal to metadata element *MountainousTerrainThreshold*.
~~10 *~~	~~Dense Vegetation Flag~~	~~0: The vegetation density within the 9 km grid cell is less than metadata element *DenseVegetationThreshold*.~~
		~~1: The vegetation density within the 9 km grid cell area is greater than or equal to metadata element *DenseVegetationThreshold*.~~
~~11 *~~	~~Nadir Swath Flag~~	~~0: Data within the grid cell were not acquired in the nadir region of the swath where sigma0s may not meet the 9 km resolution requirement.~~
		~~1: A significant fraction (TBD) of the 9 km grid cell data were acquired within the nadir region of the swath where sigma0s may not meet the 9 km resolution requirement.~~
12-15		Always clear

Note: Bits shown with strikethrough in this table (1-3, 8, 10, 11) are not used in the SPL3FTP_E product, and are always set to 0.

thaw_reference
Reference normalized polarization ratio value used as a basis to indicate thawed conditions. The AM (dimension AMPM:0) and PM (AMPM:1) observations are stored separately in the array.

transition_direction
Boolean that indicates transitional direction. 2 indicates AM frozen, PM thawed, 1 indicates AM thawed, PM frozen. Value is always zero if not in transition state.

transition_state_flag
Boolean that indicates whether soil is in transitional state from AM to PM on the same day. 1 indicates state is not in transition (does not change from AM to PM), 2 indicates state is in transition (AM and PM states are different).

tbh_error
Overall error measure for H-pol brightness temperature within the grid cell, includes calibration, RFI and contamination effects. The AM (dimension AMPM:0) and PM (AMPM:1) observations are stored separately in the array.

tbh_mean
Mean of H-pol brightness temperature in the 9 km Earth grid cell. The AM (dimension AMPM:0) and PM (AMPM:1) observations are stored separately in the array.

tbh_qual_flag
Bit flags that represent the quality of the horizontal polarization brightness temperature within each grid cell. See Table A - 5 for more information.

tbv_error
Overall error measure for V-pol brightness temperature within the grid cell, includes calibration, RFI and contamination effects. The AM (dimension AMPM:0) and PM (AMPM:1) observations are stored separately in the array.

tbv_mean
Mean of V-pol brightness temperature in the 9 km Earth grid cell. The AM (dimension AMPM:0) and PM (AMPM:1) observations are stored separately in the array.

tbv_qual_flag
Bit flags that represent the quality of the vertical/horizontal polarization brightness temperature within each grid cell. See Table A - 5 for more information.

Table A - 5. TB Quality Bit Definitions

Flag Definition	Bit Position	Bit Value and Interpretation
Mean vertical/horizontal polarization quality flag	0	0: The mean of the forward looking and aft looking vertical/horizontal polarization Tb has acceptable quality.
		1: The mean of the forward looking and aft looking vertical/horizontal polarization Tb does not have acceptable quality.
Mean vertical/horizontal polarization range flag	1	0: The mean of the forward looking and aft looking vertical/horizontal polarization Tb falls within the expected range.
		1: The mean of the forward looking and aft looking vertical/horizontal polarization Tb is out of range.
Mean vertical/horizontal polarization RFI detected flag	2	0: Insignificant RFI was detected in the mean of the forward looking and aft looking vertical/horizontal polarization Tb.
		1: RFI was detected in the mean of the forward looking and aft looking vertical/horizontal polarization Tb.
Mean vertical/horizontal polarization RFI repair flag	3	0: Some components of the mean of the forward looking and aft looking vertical/horizontal polarization Tb are based on corrections for RFI contamination.
		1: Unable to correct the mean of the forward looking and aft looking vertical/horizontal polarization Tb for RFI contamination.
Mean vertical/horizontal polarization NEDT flag	4	0: The mean vertical/horizontal polarization Tb had acceptable NEDT (Noise Equivalent Delta Temperature).
		1: NEDT is unsuitably high for the mean vertical/horizontal polarization Tb.
vertical/horizontal polarization direct sun correction flag	5	0: Direct sun correction was successful.
		1: Direct sun correction was not successful.
vertical/horizontal polarization reflected sun correction flag	6	0: Reflected sun correction was successful.
		1: Reflected sun correction was not successful.
vertical/horizontal polarization reflected moon correction flag	7	0: Reflected moon correction was successful.
		1: Reflected moon correction was not successful.
vertical/horizontal polarization direct galaxy correction flag	8	0: Direct galaxy correction was successful.
		1: Direct galaxy correction was not successful.
vertical/horizontal polarization reflected galaxy correction flag	9	0: Reflected galaxy correction was successful.
		1: Reflected galaxy correction was not successful.

vertical/horizontal polarization atmospheric correction flag	10	0: Atmospheric correction was successful.
		1: Atmospheric correction was not successful.
vertical/horizontal polarization Faraday rotation correction flag	11	0: Faraday rotation correction was successful.
		1: Faraday rotation correction was not successful.
vertical/horizontal polarization null value bit	12	0: Tb has a valid value.
		1: Tb has a null value.
vertical/horizontal polarization water correction	13	0: Water correction was not performed.
		1: Water correction was performed.
vertical/horizontal polarization RFI check	14	0: TA minus TA_FILTERED was less than a threshold
		1: TA minus TA_FILTERED was greater than a threshold
vertical/horizontal polarization RFI clean	15	0: TB was free of RFI
		1: TB was RFI contaminated

Fill/Gap Values

SMAP data products employ fill and gap values to indicate when no valid data appear in a particular data element. Fill values ensure that data elements retain the correct shape. Gap values locate portions of a data stream that do not appear in the output data file.

Fill values appear in the SMAP SPL3FTP_E Product when the SPL3FTP_E SPS can process some, but not all, of the input data for a particular swath grid cell. Fill data may appear in the product in any of the following circumstances:

- One of SPS executables that generate the SMAP SPL3FTP_E product is unable to calculate a particular science or engineering data value. The algorithm encounters an error. The error disables generation of valid output. The SPS reports a fill value instead.
- Some of the required science or engineering algorithmic input are missing. Data over the region that contributes to particular grid cell may appear in only some of the input data streams. Since data are valuable, the SPL3FTP_E product records any outcome that can be calculated with the available input. Missing data appear as fill values.
- Non-essential information is missing from the input data stream. The lack of non-essential information does not impair the algorithm from generating needed output. The missing data appear as fill values.
- Fill values appear in the input radiometer the SPL1CTB_E product. If only some of the input that contributes to a particular grid cell is fill data, the SPL3FTP_E SPS will most likely be able to generate some output. However, some portion of the SPL3FTP_E output for that grid cell may appear as fill values.

SMAP data products employ a specific set of data values to connote that an element is fill. The selected values that represent fill are dependent on the data type.

No valid value in the SPL3FTP_E product is equal to the values that represent fill. If any exceptions should exist in the future, the SPL3FTP_E content will provide a means for users to discern between elements that contain fill and elements that contain genuine data values. This document will also contain a description of the method used to ascertain which elements are fill and which elements are genuine.

The SPL3FTP_E product records gaps in the product level metadata. The following conditions will indicate that no gaps appear in the data product:

- Only one instance of the attributes *Extent/rangeBeginningDateTime* and *Extent/rangeEndingDateTime* will appear in the product metadata.
- The character string stored in metadata element *Extent/rangeBeginningDateTime* will match the character string stored in metadata element *OrbitMeasuredLocation/halfOrbitStartDateTime*.
- The character string stored in metadata element *Extent/rangeEndingDateTime* will match the character string stored in metadata element *OrbitMeasuredLocation/halfOrbitStopDateTime*.

One of two conditions will indicate that gaps appear in the data product:

- The time period covered between *Extent/rangeBeginningDateTime* and *Extent/RangeEndingDateTime* does not cover the entire half orbit as specified in *OrbitMeasuredLocation/halfOrbitStartDateTime* and *OrbitMeasuredLocation/halfOrbitStartDateTime*.
- More than one pair of *Extent/rangeBeginningDateTime* and *Extent/rangeEndingDateTime* appears in the data product. Time periods within the time span of the half orbit that do not fall within the sets of *Extent/rangeBeginningDateTime* and *Extent/rangeEndingDateTime* constitute data gaps.

Acronyms and Abbreviations

Table A - 6. Acronyms and Abbreviations

Abbreviation	Definition
Char	8-bit character
Int8	8-bit (1-byte) signed integer
Int16	16-bit (2-byte) signed integer
Int32	32-bit (4-byte) signed integer
Float32	32-bit (4-byte) floating-point integer
Float64	64-bit (8-byte) floating-point integer
H-pol	Horizontally polarized
N/A	Not Applicable
RFI	Radio Frequency Interference
SPS	Science Production Software
TB	Brightness Temperature
Uint8	8-bit (1-byte) unsigned integer
Uint16	16-bit (2-byte) unsigned integer
V-pol	Vertically polarized