SMAP L3 Radar Northern Hemisphere Daily 3 km EASE-Grid Freeze/Thaw State, Version 3

USER GUIDE

How to Cite These Data

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

Dunbar, R. S., X. Xu, A. Colliander, C. Derksen, K. C. McDonald, E. Podest, E. G. Njoku, J. S. Kimball, and Y. Kim. 2016. *SMAP L3 Radar Northern Hemisphere Daily 3 km EASE-Grid Freeze/Thaw State, Version 3*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/CPSA0M496MGB. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/SPL3FTA

National Snow and Ice Data Center

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1 DATA DESCRIPTION

1.1 Parameters

Freeze/thaw state and freeze/thaw transition direction derived from sigma nought measurements are output on a fixed 3 km EASE-Grid 2.0. The SMAP L-Band Radar measures the backscatter coefficient, or sigma nought (sigma0), which is the normalized measure of the strength of a radar signal reflected back to the antenna. Sigma nought, also a parameter of this product, is derived using Synthetic-Aperture Radar (SAR) processing.

Refer to the Appendix 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 Web site.

1.2.1.1 File Size

Each file is approximately 673 MB.

1.2.1.2 File Volume

The daily data volume is approximately 673 MB.

1.2.2 File Contents

1.2.2.1 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 of this document.

Data element arrays are three dimensional, with the exception of transition_direction and transition_state_flag arrays, which are two dimensional. All arrays have 6000 rows and 6000 columns in each a.m. and p.m. layer. 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.

ANCILLARY DATA

Includes all ancillary data, such as landcover classification and open water body fraction.

FREEZE/THAW RETRIEVAL DATA

Includes freeze/thaw data and quality assessment flags.

RADAR DATA

Includes all radar data, such as cross-polarized sigma nought (σ0, also referred to as sigma0) data, and quality assessment flags.

1.2.2.2 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.

1.2.3 Directory Structure

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

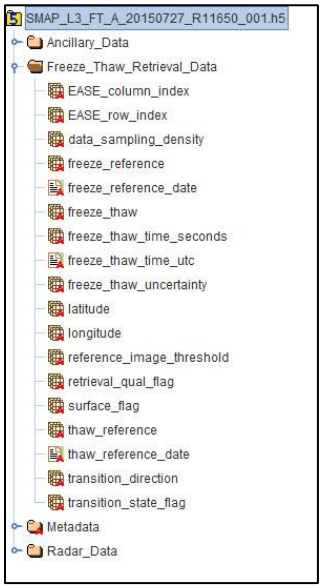

Figure 1. Subset of File Contents For a complete list of file contents for the SMAP Level-3 freeze/thaw product, refer to the Appendix.

1.2.4 Naming Convention

Files are named according to the following convention, which is described in Table 1:

SMAP_L3_FT_A_yyyymmdd_RLVvvv_NNN.[ext]

For example:

SMAP_L3_FT_A_20151225_R13171_002.h5

Where:

Table 1. File Naming Conventions

<table>
<tr><th>Variable</th><th>Description</th></tr>
<tr><td>SMAP</td><td>Indicates SMAP mission data</td></tr>
<tr><td>L3_FT_A</td><td>Indicates specific product (L3: Level-3; FT: Freeze/Thaw; A: Active)</td></tr>
<tr><td>yyyymmdd</td><td>4-digit year, 2-digit month, 2-digit day; date in Universal Coordinated Time (UTC) of the first data element that appears in the product.</td></tr>
<tr><td>RLVvvv</td><td>Composite Release ID, where:
<table>
<tr><td>R</td><td>Release</td></tr>
<tr><td>L</td><td>Launch Indicator (1: Post-launch standard data)</td></tr>
<tr><td>V</td><td>1-Digit Major Version Number</td></tr>
<tr><td>vvv</td><td>3-Digit Minor Version Number</td></tr>
</table>
Example: R13171 indicates a standard data product with a version of 3.171. Refer to the SMAP Data Versions page for version information.</td></tr>
<tr><td>NNN</td><td>Number of times the file was generated under the same version for a particular date/time interval (002: 2nd time)</td></tr>
<tr><td>.[ext]</td><td>File extensions include:
<table>
<tr><td>.h5</td><td>HDF5 data file</td></tr>
<tr><td>.qa</td><td>Quality Assurance file</td></tr>
<tr><td>.xml</td><td>XML Metadata file</td></tr>
</table></td></tr>
</table>

1.3 Spatial Information

1.3.1 Coverage

Coverage for this data set spans the Northern Hemisphere for all land regions north of 45°N latitude, and from 180°W to 180°E. The gap in coverage at both the North Pole, called a pole hole, has a radius of approximately 400 km. The swath width is 1000 km, enabling nearly complete coverage of the Northern Hemisphere every three days.

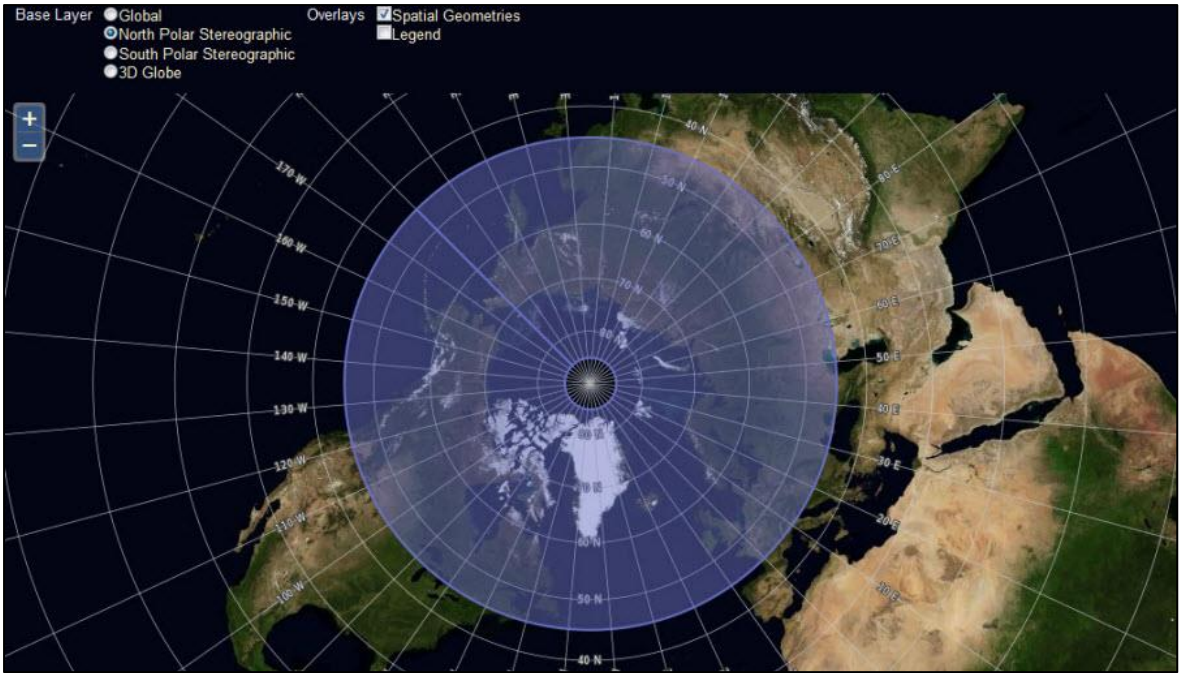

Figure 2. Spatial Coverage Map

1.3.2 Resolution

The native spatial resolution of the radar footprint is 1 km. Data are then gridded using the 3 km EASE-Grid 2.0 Northern Hemisphere azimuthal projection.

1.3.3 EASE-Grid 2.0

These data are provided on the Northern Hemisphere azimuthal EASE-Grid 2.0 (Brodzik et al. 2012). Each grid cell has a nominal area of approximately 3 x 3 km^2 regardless of longitude and latitude. Using this projection, all data arrays have dimensions of 6000 rows and 6000 columns.

EASE-Grid 2.0 has a flexible formulation. By adjusting a single scaling parameter, a family of multi-resolution grids that nest within one another can be generated. The nesting can be adjusted so that

smaller grid cells can be tessellated to form larger grid cells. Figure 3 shows a schematic of the nesting.

This feature of perfect nesting provides SMAP data products with a convenient common projection for both high-resolution radar observations and low-resolution radiometer observations, as well as for their derived geophysical products. For more on EASE-Grid 2.0, refer to the EASE-Grid 2.0 Format Description.

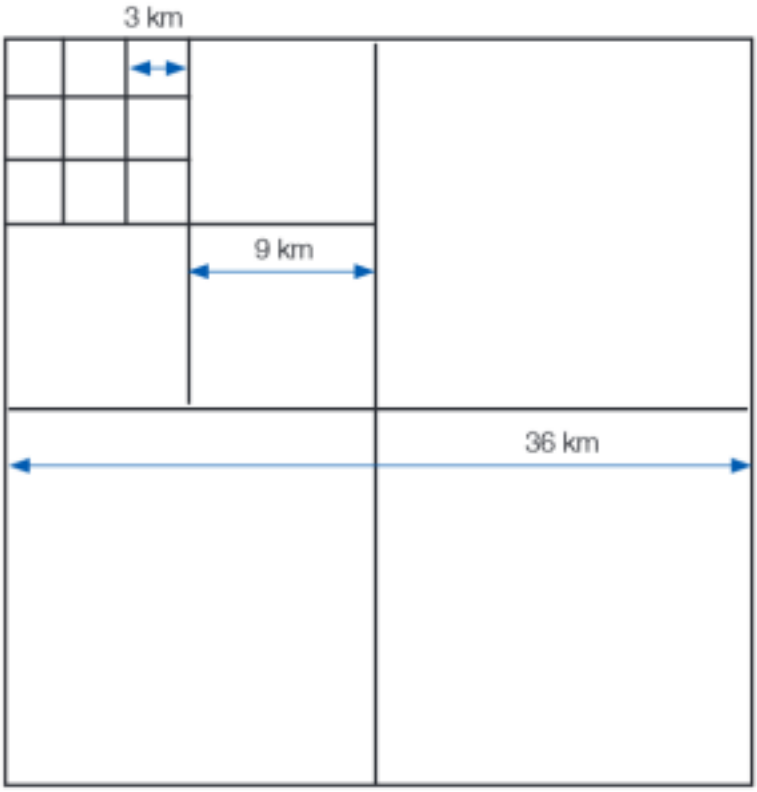

Figure 3. Perfect Nesting in EASE-Grid 2.0

1.4 Temporal Information

1.4.1 Coverage

Coverage spans from 13 April 2015 through 07 July 2015.

Note: Temporal coverage for this data set is limited due to the premature failure of the SMAP L-Band Radar. On 07 July 2015, the radar stopped transmitting due to an anomaly involving the instrument's high-power amplifier (HPA). For details, refer to the SMAP News Release issued 02 September 2015 by the Jet Propulsion Laboratory (JPL).

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

1.4.3 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 SPL3FTA 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 approach is to identify the landscape Freeze/Thaw (F/T) transition by identifying the temporal response of backscatter to changes in the dielectric constant of the landscape components that occur as the water within the components transitions between frozen and non-frozen conditions.

Classification algorithms assume that the large changes in dielectric constant occurring between frozen and non-frozen conditions dominate the corresponding backscatter temporal dynamics across the seasons, rather than other potential sources of temporal variability such as changes in canopy structure and biomass or large precipitation events. This assumption is valid for most areas of the terrestrial cryosphere.

2.2 Acquisition

SMAP Level-3 radar freeze/thaw data (SPL3FTA) are derived from SMAP High-Resolution Radar Sigma Nought, Version 3 (SPL1CS0) data.

2.2.1 Derivation Techniques and Algorithms

This section has been adapted from Dunbar et al. (2014), the Algorithm Theoretical Basis Document (ATBD) for this data set.

SMAP Level-3 radar freeze/thaw data set is derived from SMAP High-Resolution Radar Sigma Nought, Version 1 (SPL1CS0) data set. The derivation of freeze/thaw from SMAP sigma nought measurements occurs during an intermediate Level-2 processing step of the input Level-1 sigma nought data. During the Level-2 processing step, the F/T algorithm utilizes a seasonal threshold approach to convert SMAP sigma nought measurements to F/T state. Refer to Figure 4.

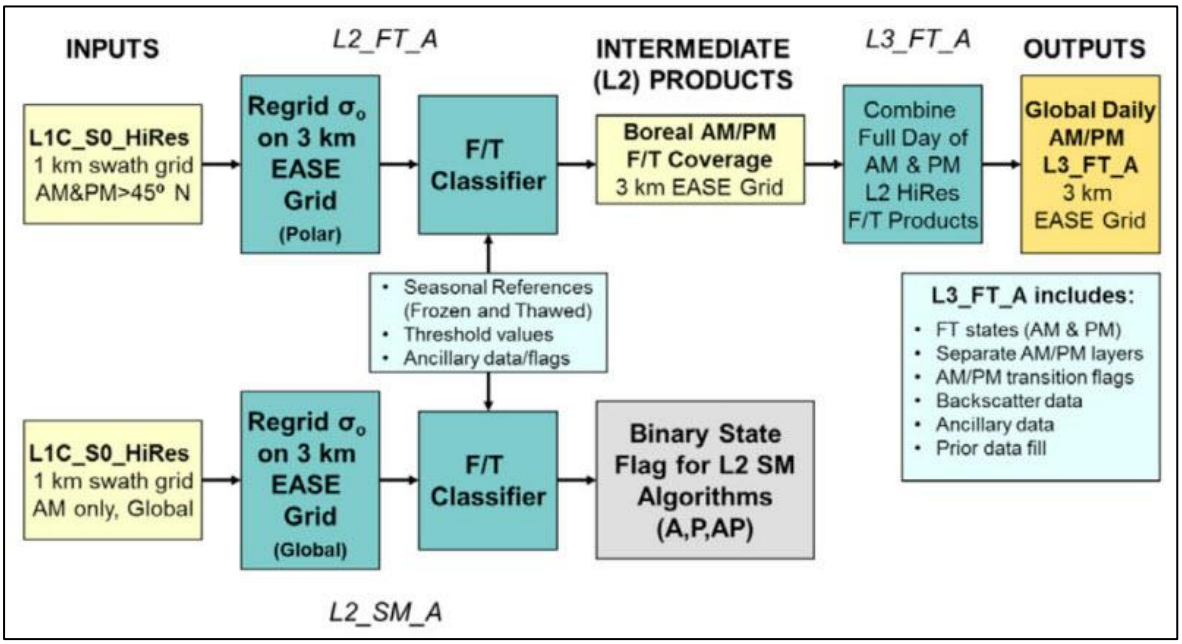

Figure 4. Processing sequence for generation of the L3 F/T product and the binary F/T state flag used in generation of SMAP soil moisture products

2.2.1.1 Baseline Algorithm

The seasonal threshold baseline algorithm for SPL3FTA examines the time-series progression of the remote sensing signature relative to signatures acquired during seasonal reference frozen and thawed states. A seasonal scale factor D(t) is defined for an observation acquired at time t as:

$$D(t) = s(t) - sfr/sth - sfr$$

where s(t) is the measurement acquired at time t, for which a F/T classification is sought, and sfr and sth are backscatter measurements corresponding to the frozen and thawed reference states, respectively. A major component of the SMAP baseline algorithm development involved the

application of existing satellite L-band radar measurements from the Aquarius/SAC-D mission over the F/T domain to develop pre-launch maps of sfr and sth. The thaw reference (sth) was replaced with the average of the last ten days of SMAP radar data (27 June through 6 July 2015). The new freeze reference (sfr) was derived based on the assumption that the sth reference difference between SMAP and the pre-launch Aquarius values is the same for the freeze case.

A threshold level *T* is then defined such that:
D(t) > T
D(t) <=T
defines the thawed and frozen landscape states, respectively. This series of equations is run on a cell-by-cell basis for unmasked portions of the F/T domain. The output is a dimensionless binary state variable designating either frozen or thawed condition for each unmasked grid cell. The parameter T was fixed at 0.5 across the entire F/T domain at the start of the SMAP mission. Given the short operating period of the SMAP radar, post-launch optimization experiments were limited to the spring 2015 freeze to thaw transition, which has been evaluated using in situ measurements from the Calibration/Validation (Cal/Val) network.

2.2.1.2 Ancillary Data

Ancillary data sets are used to:

1. Support initialization of the thresholds employed in the algorithm,
2. Set flags that indicate potential problem regions, and
3. Define masks where no retrievals should be performed.

Ancillary data used in SPL3FTA processing includes data sets of inland open water, permanent ice and snow, and urban areas are used to derive masks so that no retrievals occur over these regions. Ancillary data sets of mountainous areas, fractional open water cover, and precipitation are used to derive flags so that a confidence interval can be associated with the retrieval. A primary source for each of the above ancillary parameters has been selected. This data set is common to all algorithms using that specific parameter. For SPL3FTA Validated data, the lake fraction has been fixed at 50%. Surface soil temperature and 2-meter air temperature from the NASA Global Modeling and Assimilation Office (GMAO) are used offline for optimization of the retrieval thresholds. Measurements from dense and sparse in situ networks have been utilized for error analysis and Cal/Val, and described further in Dunbar et al. (2014). Table 2 lists the ancillary data employed in support of the SPL3FTA product.

Table 2. Input Ancillary Data for SPL3FTA

Data Type	Data Source	Frequency	Resolution	Extent	Use
Vegetation Type	MODIS-International Geosphere Biosphere Programme (IGBP)	Once	250 m	Global	Sensitivity Analysis
Land Surface and 2 m Air Temperature	MERRA and Station Data	Daily or close to time of acquisition	25 km and point data	Global	Algorithm Parameterization (offline)
Precipitation	ECMWF Forecasts	Time of acquisition	0.25 degrees	Global	Flag
Static Water Bodies	MODIS44W	Once	250 m	Global	Flag
Transient Water Bodies	SMAP L2_SM_A	As processed	3 km	Global	Flag
Mountainous Areas	NASA Global DEM	Once	30 m	Global	Flag
Permanent Ice and Snow	MODIS-IGBP Permanent Ice and Snow Class	Once	500 m	Global	Flag
Urban Areas	Global Urban Mapping Project (GRUMP)	Once	1 km	Global	Flag

For more information, refer to the ATBD, Section 4: Retrieval Algorithms (Dunbar et al. 2014).

2.3 Processing

This product is generated by the SMAP Science Data Processing System (SDS) at the Jet Propulsion Laboratory (JPL) in Pasadena, California USA. To generate this product, the processing software ingests one day's worth of Level-2 files and creates individual Northern Hemisphere composites as two-dimensional or three-dimensional arrays for each output parameter defined in the intermediate Level-2 data. 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.

Wherever data overlap occurs, as is typical at high latitudes, data which were acquired closest to 6:00 a.m. and 6:00 p.m. local solar times are chosen. The intermediate Level-2 data distinguish

four levels of freeze/thaw conditions determined from the ascending 6:00 a.m. and descending 6:00 p.m. SPL1CS0 data, including frozen (from both a.m. and p.m. overpass times), non-frozen (a.m. and p.m.), transitional (a.m. frozen; p.m. non-frozen) and inverse-transitional (a.m. non-frozen; p.m. frozen) states.

For more information on each portion of the algorithm processing flow, refer to the ATBD for this product, Section 2.2: L3_FT_A Production (Dunbar et al. 2014).

2.4 Quality, Errors, and Limitations

2.4.1 Error Sources

Anthropogenic Radio Frequency Interference (RFI), principally from ground-based surveillance radars, can contaminate both radar and radiometer measurements at L-band. Early measurements and results from ESA's Soil Moisture and Ocean Salinity (SMOS) mission indicate that in some regions RFI is present and detectable. The SMAP radar and radiometer electronics and algorithms include design features to mitigate the effects of RFI. The SMAP radar 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 SPL3FTA algorithm and product 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 low frequency L-band SAR retrievals from SMAP are expected to have sensitivity to surface soil freeze/thaw conditions under low to moderate vegetation cover, but effective radar penetration depth and microwave freeze/thaw sensitivity is strongly constrained by intervening vegetation biomass, soil moisture levels, and snow wetness. Ambiguity in relating changes in the radar signal to these specific landscape components is a challenge to validation of the F/T product.

The SMAP seasonal threshold freeze/thaw classification algorithm requires the establishment of accurate and stable frozen and non-frozen reference state backscatter conditions for each 3 km resolution grid cell. Initial reference conditions were established pre-launch from relatively coarse (approximately 100 km) resolution Aquarius/SAC-D satellite L-band scatterometer measurements. The Aquarius data have a different sensor geometry and sampling, and a much coarser FOV than SMAP. Hybrid SMAP/Aquarius-derived references were utilized for the Version 2 Beta release and for this validated release, due to the demise of the SMAP radar on 07 July 2015. The thaw references were derived from SMAP data covering the period from 27 June to 07 July 2015. Using

Aquarius (thaw-freeze) reference differences, the hybrid SMAP/Aquarius frozen references were derived using the formula:

Equation 1

$$F_{ref} = T_{ref} - (T_{AQref} - F_{AQref})$$

The resulting freeze/thaw reference conditions determined from these data may cause some SMAP freeze/thaw classification error, especially for areas with substantial sub-grid scale freeze/thaw heterogeneity relative to the coarse Aquarius FOV.

A major assumption of the seasonal threshold-based temporal dB change freeze/thaw classification is that the major temporal shifts in radar backscatter 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 (Kim et al. 2012). However, freeze/thaw classification accuracy is expected to be reduced where other environmental factors may cause large temporal shifts in radar backscatter, including large rainfall events and surface inundation, and abrupt changes in vegetation biomass such as phenology, disturbance and land cover change.

More information about error sources is provided in the ATBD for this product (Dunbar et al. 2014).

2.4.2 Quality Assessment

For in-depth details regarding the quality of these Version 2 Beta data, refer to the following reports:
Validation Assessment Report
Beta Assessment Report

2.4.3 Quality Overview

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 Appendix of this document and the Product Specification Document.

Each HDF5 file contains metadata with Quality Assessment (QA) metadata flags that are set by the Science Data Processing System (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.

2.5 Instrumentation

2.5.1 Description

For a detailed description of the SMAP instrument, visit the SMAP Instrument page at the JPL SMAP Web site.

3 SOFTWARE AND TOOLS

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

4 VERSION HISTORY

Version	Date	Version Changes
Version 2	November 2015	First public data release
Version 3	April 2016	Changes to this version include: Transitioned to Validated-Stage 2 Uses SPL1CS0 V3 Validated data as input Using full swath except for nadir-anomaly flagged areas to provide better coverage Resolved some flag and fillValue errors

5 RELATED DATA SETS

SMAP Data at NSIDC | Overview

SMAP Radar Data at the ASF DAAC

6 RELATED WEBSITES

SMAP at NASA JPL

7 CONTACTS AND ACKNOWLEDGMENTS

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9 DOCUMENT INFORMATION

9.1 Publication Date

03 January 2019

9.2 Date Last Updated

03 December 2020

1 APPENDIX A – APPENDIX A TITLE

This page provides a description of all data fields within the SMAP L3 Radar Northern Hemisphere Daily 3 km EASE-Grid Freeze/Thaw State product. The data are grouped into four main HDF5 groups:

- Ancillary_Data
- Freeze_Thaw_Retrieval_Data
- Metadata
- Radar_Data

For a description of metadata fields for this product, refer to the Product Specification Document. Tables A1-A3 describe the data fields of a typical SPL3FTA descending north polar granule. All data element arrays are one-dimensional with a size "N," where N is the number of valid cells from the radar swath that appear on the grid

1.1 Ancillary_Data

Table A - 1. Data Fields for Ancillary_Data

Data Field Name	Shape	Concept	Byte	Signed	Unit	Min	Max	Fill/Gap Value
altitude_dem	AMPM_LatCell_LonCell_Array	real	float32	4	m	0	10000	-9999.0
altitude_std_dev	AMPM_LatCell_LonCell_Array	real	float32	4	m	0	1000	-9999.0
landcover_class	AMPM_LatCell_LonCell_Array	enum	uint32	4	n/a	0	16	254
open_water_body_fraction	AMPM_LatCell_LonCell_Array	real	float32	4	normalized	0	1	-9999.0

1.2 Freeze_Thaw_Retrieval_Data

Table A - 2. Data Fields for Freeze_Thaw_Retrieval_Data

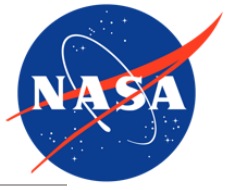
Data Field Name	Shape	Concept	Byte	Signed	Unit	Min	Max	Fill/Gap Value
EASE_column_index	AMPM_LatCell_LonCell_Array	integer	uint16	2	N/A	0	65535	65534
EASE_row_index	AMPM_LatCell_LonCell_Array	integer	uint16	2	N/A	0	65535	65534
data_sampling_density	AMPM_LatCell_LonCell_Array	real	float32	4	km	0	2	-9999.0
freeze_reference	AMPM_LatCell_LonCell_Array	real	float32	4	dB	-999999.9	999999.9	-9999.0
freeze_reference_date	AMPM_LatCell_LonCell_Array	string	char	10	N/A	2013-01-01	2023-12-31	-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
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

Data Field Name	Shape	Concept	Byte	Signed	Unit	Min	Max	Fill/Gap Value
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
surface_flag	AMPM_LatCell_LonCell_Array	bit flag	uint32	4	N/A	N/A	N/A	65534
thaw_reference	AMPM_LatCell_LonCell_Array	real	float32	4	dB	-999999.9	999999.9	-9999.0
thaw_reference_date	AMPM_LatCell_LonCell_Array	string	char	10	N/A	2013-01-01	2023-12-31	N/A
transition_direction	LatCell_LonCell_Array	boolean	uint8	1	N/A	0	1	254
transition_state_flag	LatCell_LonCell_Array	boolean	uint8	1	N/A	0	1	254

1.3 Radar_Data

Table A - 3. Data Fields for Radar_Data

Data Field Name	Shape	Concept	Byte	Signed	Unit	Min	Max	Fill/Gap Value
kp_hh	AMPM_LatCell_LonCell_Array	real	float32	4	normalized	0.0	5.0	-9999.0
kp_vv	AMPM_LatCell_LonCell_Array	real	float32	4	normalized	0.0	5.0	-9999.0
kp_xpol	AMPM_LatCell_LonCell_Array	real	float32	4	normalized	0.0	5.0	-9999.0
sigma0_hh_mean	AMPM_LatCell_LonCell_Array	real	float32	4	normalized	0.0	1.0	-9999.0
sigma0_qual_flag_hh	AMPM_LatCell_LonCell_Array	bit flag	uint16	2	N/A	N/A	N/A	4294967294
sigma0_qual_flag_vv	AMPM_LatCell_LonCell_Array	bit flag	uint16	2	N/A	N/A	N/A	4294967294
sigma0_qual_flag_xpol	AMPM_LatCell_LonCell_Array	bit flag	uint16	2	N/A	N/A	N/A	4294967294
sigma0_vv_mean	AMPM_LatCell_LonCell_Array	real	float32	4	normalized	0.0	1.0	-9999.0
sigma0_xpol_mean	AMPM_LatCell_LonCell_Array	real	float32	4	normalized	0.0	1.0	-9999.0



1.4 Data Field Definitions

altitude_dem

The Earth surface elevation within the 3km cell.

altitude_std_dev

The standard deviation of the Earth surface elevation within the 3km cell. This element provides a surface roughness measure.

landcover_class

An enumerated type that specifies the predominant surface vegetation found in the grid cell. See Table A4.

Table A - 4. 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	Mixed forest
12	Closed shrubland
13	Open shrubland
14	Woody savanna
15	Savanna
16	Grassland
>16	TBD

open_water_body_fraction
Fraction of the grid cell area covered by open water. Open water areas do not have vegetation at or on the water surface.

EASE_column_index
The column index of the 3 km EASE grid 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 3 km EASE grid cell that contains the associated data. The AM (dimension AMPM=0) and PM (AMPM=1) observations are stored separately in the array.

data_sampling_density
Number of sigma0 measurements gridded in the freeze-thaw data cell.

freeze_reference
Reference sigma0 value used as a basis to indicate frozen conditions.

freeze_reference_date
Date of the data used to determine the reference freeze condition.

freeze_thaw
Boolean that indicates whether soil within cell is frozen or thawed. A value of zero value implies thawed, a value of 1 implies frozen.

freeze_thaw_time_seconds
Time of spacecraft overpass relative to ground swath in UTC seconds from the J2000 epoch (1 January 2000 12:00z).

freeze_thaw_time_utc
Time of spacecraft overpass relative to ground swath in UTC.

freeze_thaw_uncertainty
Uncertainty assigned to quantify the confidence in the retrieved freeze-thaw state.

latitude
Latitude of the center of the Earth based grid cell.

longitude
Longitude of the center of the Earth based grid cell.

reference_image_threshold
Threshold based on reference freeze and thaw to differentiate between freeze and thaw conditions.

retrieval_qual_flag
Sequence of bit flags that indicate the conditions and the quality of the freeze-thaw retrieval. See Table A5.

Table A - 5. Retrieval Quality Bit Flag Definitions

Name	Bit Position	Interpretation of Values (0:off, 1:on)
Reserved	0	0: Always clear.
Freeze-thaw retrieval success flag	1	0: Freeze-thaw retrieval deemed good quality.
		1: Freeze-thaw retrieval unsuccessful or poor quality.
Reserved	2-15	0: Always clear.
AM freeze-thaw data available flag	16	0: AM freeze-thaw data are available.
		1: AM freeze-thaw data are not available.
PM freeze-thaw data available flag	17	0: PM freeze-thaw data are available.
		1: PM freeze-thaw data are not available.
Undefined	18-31	0: Always clear.

surface_flag
Bit flags that record ambient surface conditions for the grid cell. See Table A6

Table A - 6. Surface Condition Quality Bit Flag Definitions

Bit Position	Bit Value and Interpretation
0	0: The fraction of the 3 km grid cell area that is over a permanent water body is less than metadata element PermanentWaterBodyThreshold. Determined by DEM. 3 km permanent water body flag.
	1: The fraction of the 3 km grid cell area that is over a permanent water body is greater than or equal to metadata element PermanentWaterBodyThreshold. Determined by DEM.
1	0: Flag indicates either water less than given threshold, or water that was not detected in locations other than were permanent water is known to exist.
	1: Flag indicates either water greater than given threshold, or water that was detected in locations other than were permanent water is known to exist.
2	0: The fraction of the 3 km grid cell area that is over urban development is less than metadata element UrbanAreaThreshold.
	1: The fraction of the 3 km grid cell area that is over urban development is greater than or equal to metadata element UrbanAreaThreshold.
3	0: No precipitation detected within the 3 km grid cell when data were being acquired.
	1: Precipitation detected within the 3 km grid cell when data were being acquired
4	0: No snow or ice detected within the 3 km grid cell.
	1: Snow and/or ice were detected within the 3 km grid cell.
5	0: No frozen ground detected within the 3 km grid cell.

Bit Position	Bit Value and Interpretation
	1: Frozen ground detected within the 3 km grid cell.
6	0: The variability of land elevation in the 3 km grid cell is less than metadata element MountainousTerrainThreshold.
	1: The variability of land elevation in the 3 km grid cell is greater than or equal to metadata element MountainousTerrainThreshold.
7	0: The vegetation density within the 3 km grid cell is less than metadata element DenseVegetationThreshold.
	1: The vegetation density within the 3 km grid cell area is greater than or equal to metadata element DenseVegetationThreshold.
9	0: Data within the the grid cell were not acquired in the nadir region of the swath where sigma0s may not meet the 3 km resolution requirement.
	1: A significant fraction (TBD) of the 3 km grid cell data were acquired within the nadir region of the swath where sigma0s may not meet the 3 km resolution requirement.
10-15	Always clear.

thaw_reference
Reference sigma0 value used as a basis to indicate thawed conditions.

thaw_reference_date
Date of the data used to determine the reference thawed conditon.

transition_direction
Boolean that indicates transitional direction. 0 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. 0 indicates state is not in transition, 1 indicates state is in transition.

kp_hh
Overall error measure for HH-pol σ0 within the 3 km cell based on Level 1C kp values, includes calibration, RFI and contamination effects.

kp_vv
Overall error measure for VV-pol σ0 within the 3 km cell based on Level 1C kp values, includes calibration, RFI and contamination effects.

kp_xpol
Overall error measure for VV-pol σ0 within the 3 km cell based on Level 1C kp values, includes calibration, RFI and contamination effects.

sigma0_hh_mean
Standard deviation of 1 km instrument resolution HH-pol σ0 in the 3 km Earth grid cell.

sigma0_qual_flag_hh
Representative quality flags of horizontal polarization sigma0 measures in the grid cell. See Table A7.

Table A - 7. Sigma Quality Bit Flag Definitions

Bit Position	Description of Values (0: off, 1: on)
0	0: All of the input forward looking horizontal polarization sigma0s have acceptable quality.
	1: At least one of the forward looking horizontal polarization sigma0s has questionable or poor quality.
1	0: All of the input aft looking horizontal polarization sigma0s have acceptable quality.
	1: At least one of the input aft looking horizontal polarization sigma0s has questionable or poor quality.
2	0: All of the input forward looking horizontal polarization sigma0s fall within the expected range.
	1: At least one of the forward looking horizontal polarization sigma0s is out of range
3	0: All of the input aft looking horizontal polarization sigma0s falls within the expected range.
	1: At least one of the input aft looking horizontal polarization sigma0s is out of range.
4	0: Insignificant RFI detected for all of the input forward looking horizontal polarization sigma0s in the grid cell.
	1: RFI level is unsuitably high for at least one of the forward looking horizontal polarization sigma0s in the grid cell.
5	0: At least one of the input forward looking horizontal polarization sigma0s in the grid cell is based on repaired RFI.
	1: Unable to repair at least one of the forward looking horizontal polarization sigma0s in the grid cell due to RFI.
6	0: Insignificant RFI detected for all of the input aft looking horizontal polarization sigma0s in the grid cell.
	1: RFI level is unsuitably high for at least one of the aft looking horizontal polarization sigma0s in the grid cell.
7	0: At least one of the input aft looking horizontal polarization sigma0s in the grid cell is based on repaired RFI.
	1: Unable to repair at least one of the aft looking horizontal polarization sigma0s in the grid cell due to RFI.
8	0: Faraday Rotation has little or no impact on forward looking horizontally polarized sigma0.

Bit Position	Description of Values (0: off, 1: on)
	1: Faraday Rotation has significant impact on forward looking horizontally polarized sigma0.
9	0: Faraday Rotation has little or no impact on aft looking horizontally polarized sigma0.
	1: Faraday Rotation has significant impact on aft looking horizontally polarized sigma0.
10-15	0: Always clear. (Bits 10 and 11 are reserved for Radar Level 1C use. Bits 12 through 15 are reserved for Level 2 use.)

sigma0_qual_flag_vv
Representative quality flags of vertical polarization sigma0 measures in the grid cell. See Table A8.

Table A - 8. Sigma0 Vertical Polarization Quality Bit Flag Definitions

Bit Position	Description of Values (0: off, 1: on)
0	0: All of the input forward looking vertical polarization sigma0s have acceptable quality.
	1: At least one of the forward looking vertical polarization sigma0s has questionable or poor quality.
1	0: All of the input aft looking vertical polarization sigma0s have acceptable quality.
	1: At least one of the input aft looking vertical polarization sigma0s has questionable or poor quality.
2	0: All of the input forward looking vertical polarization sigma0s fall within the expected range.
	1: At least one of the forward looking vertical polarization sigma0s is out of range
3	0: All of the input aft looking vertical polarization sigma0s falls within the expected range.
	1: At least one of the input aft looking vertical polarization sigma0s is out of range.
4	0: Insignificant RFI detected for all of the input forward looking vertical polarization sigma0s in the grid cell.
	1: RFI level is unsuitably high for at least one of the forward looking vertical polarization sigma0s in the grid cell.
5	0: At least one of the input forward looking vertical polarization sigma0s in the grid cell is based on repaired RFI.
	1: Unable to repair at least one of the forward looking vertical polarization sigma0s in the grid cell due to RFI.
6	0: Insignificant RFI detected for all of the input aft looking vertical polarization sigma0s in the grid cell.
	1: RFI level is unsuitably high for at least one of the aft looking vertical polarization sigma0s in the grid cell.

Bit Position	Description of Values (0: off, 1: on)
7	0: At least one of the input aft looking vertical polarization sigma0s in the grid cell is based on repaired RFI.
	1: Unable to repair at least one of the aft looking vertical polarization sigma0s in the grid cell due to RFI.
8	0: Faraday Rotation has little or no impact on forward looking horizontally polarized sigma0.
	1: Faraday Rotation has significant impact on forward looking horizontally polarized sigma0.
9	0: Faraday Rotation has little or no impact on aft looking horizontally polarized sigma0.
	1: Faraday Rotation has significant impact on aft looking horizontally polarized sigma0.
10-15	0: Always clear. (Bits 10 and 11 are reserved for Radar Level 1C use. Bits 12 through 15 are reserved for Level 2 use.)

sigma0_qual_flag_xpol
Representative quality flags of cross polarization sigma0 measures in the grid cell. See Table A9.

Table A - 9. Sigma Quality Bit Flag Definitions

Bit Position	Description of Values (0: off, 1: on)
0	0: All of the input forward looking cross-polarized sigma0s have acceptable quality.
	1: At least one of the forward looking cross-polarized sigma0s has questionable or poor quality.
1	0: All of the input aft looking cross-polarized sigma0s have acceptable quality.
	1: At least one of the input aft looking cross-polarized sigma0s has questionable or poor quality.
2	0: All of the input forward looking cross-polarized sigma0s fall within the expected range.
	1: At least one of the forward looking cross-polarized sigma0s is out of range
3	0: All of the input aft looking cross-polarized sigma0s falls within the expected range.
	1: At least one of the input aft looking cross-polarized sigma0s is out of range.
4	0: Insignificant RFI detected for all of the input forward looking cross-polarized sigma0s in the grid cell.
	1: RFI level is unsuitably high for at least one of the forward looking cross-polarized sigma0s in the grid cell.
5	0: At least one of the input forward looking cross-polarized sigma0s in the grid cell is based on repaired RFI.

Bit Position	Description of Values (0: off, 1: on)
	1: Unable to repair at least one of the forward looking cross-polarized sigma0s in the grid cell due to RFI.
6	0: Insignificant RFI detected for all of the input aft looking cross-polarized sigma0s in the grid cell.
	1: RFI level is unsuitably high for at least one of the aft looking cross-polarized sigma0s in the grid cell.
7	0: At least one of the input aft looking cross-polarized sigma0s in the grid cell is based on repaired RFI.
	1: Unable to repair at least one of the aft looking cross-polarized sigma0s in the grid cell due to RFI.
8	0: Faraday Rotation has little or no impact on forward looking horizontally polarized sigma0.
	1: Faraday Rotation has significant impact on forward looking horizontally polarized sigma0.
9	0: Faraday Rotation has little or no impact on aft looking horizontally polarized sigma0.
	1: Faraday Rotation has significant impact on aft looking horizontally polarized sigma0.
10-15	0: Always clear. (Bits 10 and 11 are reserved for Radar Level 1C use. Bits 12 through 15 are reserved for Level 2 use.)

sigma0_vv_mean
Mean of 1 km instrument resolution VV-pol σ0 in the 3 km Earth grid cell.

sigma0_xpol_mean
Mean of 1 km instrument resolution HV-pol σ0 in the 3 km Earth grid cell.

1.5 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 SPL3SMA Product when the SPL3SMA 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 Science Production Software (SPS) executables that generate the SMAP SPL3SMA 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 SPL3SMA 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 L1B_TB product. If only some of the input that contributes to a particular grid cell is fill data, the Level SPL3SMA SPS will most likely be able to generate some output. However, some portion of the SPL3SMA 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 SPL3SMA product is equal to the values that represent fill. If any exceptions should exist in the future, the SPL3SMA 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 SPL3SMA product records gaps when entire frames within the time span of a particular data granule do not appear. Gaps can occur under one of two conditions:

- One or more complete frames of data are missing from all data streams.
- The subset of input data that is available for a particular frame is not sufficient to process any frame output.

The Level 3_SM_A 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.

1.6 Notations

Table A - 10. Notation Definitions

Notation	Definition
Int8	8-bit (1-byte) signed integer
Int16	16-bit (2-byte) signed integer
Int32	32-bit (4-byte) signed integer
Uint8	8-bit (1-byte) unsigned integer
Uint16	16-bit (2-byte) unsigned integer
Float32	32-bit (4-byte) floating-point integer
Float64	64-bit (8-byte) floating-point integer
Char	8-bit character
H-pol	Horizontally polarized
V-pol	Vertically polarized