SMAP/Sentinel-1 L2 Radiometer/Radar 30-Second Scene 3 km EASE-Grid Soil Moisture, Version 3

USER GUIDE

How to Cite These Data

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

Das, N., D. Entekhabi, R. S. Dunbar, S. Kim, S. Yueh, A. Colliander, P. E. O'Neill, T. Jackson, T. Jagdhuber, F. Chen, W. T. Crow, J. Walker, A. Berg, D. Bosch, T. Caldwell, and M. Cosh. 2020. *SMAP/Sentinel-1 L2 Radiometer/Radar 30-Second Scene 3 km EASE-Grid Soil Moisture, Version 3*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/ASB0EQO2LYJV. [Date Accessed].

We also request that you acknowledge the author(s) of this data set by referencing the following peer-reviewed publication:

Das, N., D. Entekhabi, S. Dunbar, J. Chaubell, A. Colliander, S. Yueh, T. Jagdhuber, F. Chen, W. T. Crow, P. E. O'Neill, J. Walker, A. Berg, D. Bosch, T. Caldwell, M. Cosh, C. H. Collins, E. Lopez-Baeza, and M. Thibeault. 2019. The SMAP and Copernicus Sentinel 1A/B microwave active-passive high-resolution surface soil moisture product, *Remote Sensing of Environment*. 233. 111380. https://doi.org/10.1016/j.rse.2019.111380

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/SPL2SMAP_S

National Snow and Ice Data Center

TABLE OF CONTENTS

1 DATA DESCRIPTION

1.1 Parameters

Surface soil moisture (approximately 0-5 cm) in cm^3/cm^3 derived from brightness temperatures and sigma nought measurements is output on fixed 3-km and 1-km EASE-Grids 2.0. Note that the 1-km data are research quality, meaning they have not undergone validation.

Brightness temperatures are derived from native 36 km SMAP footprint using Backus-Gilbert interpolation on the 9 km EASE-Grid, and are then disaggregated to 3-km and 1-km grid cells by comparison with the background Sentinel-1 radar backscatter data to produce high-resolution soil moisture retrievals. Brightness temperature (TB; given in kelvins) is a measure of the radiance of the microwave radiation welling upward from the top of the atmosphere to the satellite. The SMAP L-Band Radiometer measures four brightness temperature Stokes parameters: TH, TV, T3, and T4 at 1.41 GHz. TH and TV are the horizontally and vertically polarized brightness temperatures, respectively, and T3 and T4 are the third and fourth Stokes parameters, respectively.

Sigma nought (sigma0), or the backscatter coefficient, is a measure of the strength of radar signal reflected back to the instrument from a target, and is defined as per unit area on the ground. It is a normalized dimensionless number comparing the strength observed to that expected from a defined area, and is provided in natural units (not dB) in this product. The Copernicus Sentinel-1 C-band Synthetic Aperture Radar (C-SAR) measures dual polarization VV + VH in the Interferometric Wide Swath Mode (IW) over land with a center frequency of 5.405 GHz. Sigma0 measurements are 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 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:

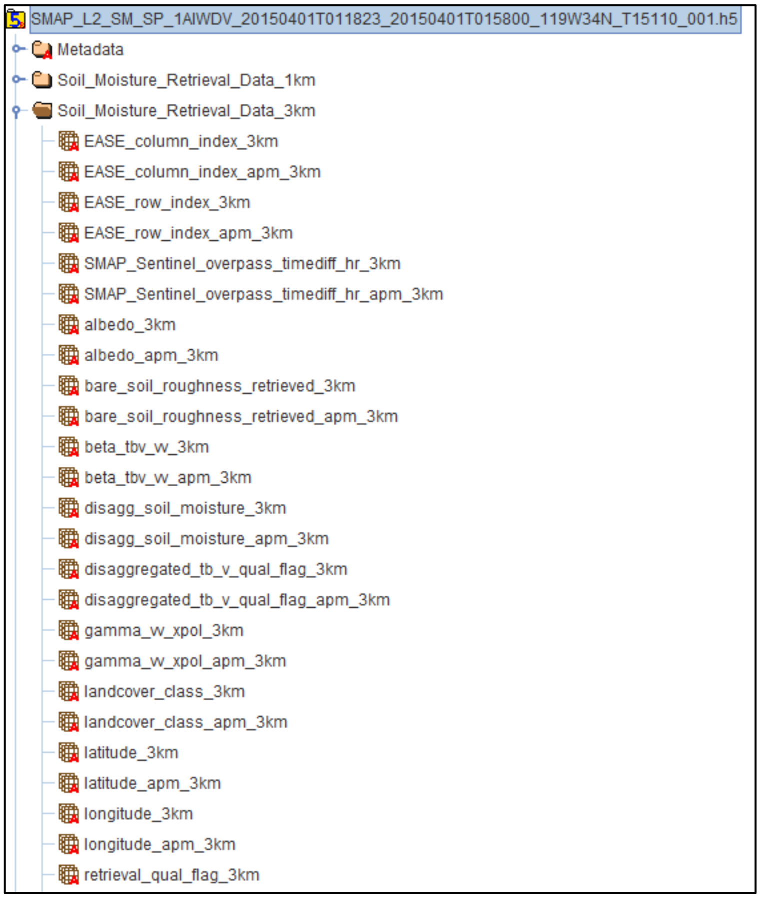

Figure 1. Subset of File Contents. For a complete list of file contents for the SMAP/Sentinel-1 Level-2 radar/radiometer soil moisture product, refer to the Appendix.

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 of this document.

All data arrays are two-dimensional. Each two-dimensional data field (or element) represents a subset of the grid which contains the pixels of Sentinel-1 data along with the SMAP data that are overlaid on the grid within approximately 24 hours. The arrays in the 1-km data group have the same dimensions as the Sentinel-1 (L2_S0_S1) data. The dimensions of the arrays in the 3-km group are one-third the size in each direction.

3 KM SOIL MOISTURE RETRIEVALS

Includes combined radar and radiometer soil moisture data at 3 km resolution, ancillary data, and quality assessment flags. Data are provided in two different sets of fields, including;

- **SMAP a.m.-only:** Only the closest SMAP a.m. data (from 6:00 a.m. descending half orbits) in time are used to spatially match up with the Sentinel-1 scene

- **SMAP a.m.-or-p.m.:** The closest SMAP a.m. or p.m. data (from 6:00 a.m. descending or 6 p.m. ascending half orbits) are used to spatially match up with the Sentinel-1 scene

Note: Data fields containing SMAP a.m.-or-p.m. data are named with *apm*, such as *disaggregated_tb_v_qual_flag_apm_3km*. Note that if the SMAP a.m. pass is the closest, the two arrays will have the same values.

1 KM SOIL MOISTURE RETRIEVALS

Includes combined radar and radiometer soil moisture data at 1 km resolution, ancillary data, and quality assessment flags. As with the 3 km group, data are provided in two sets of fields:

- **SMAP a.m.-only:** Only the closest SMAP a.m. data (from 6:00 a.m. descending half orbits) in time are used to spatially match up with the Sentinel-1 scene
- **SMAP a.m.-or-p.m.:** The closest SMAP a.m. or p.m. data (from 6:00 a.m. descending or 6 p.m. ascending half orbits) are used to spatially match up with the Sentinel-1 scene

Note: 1 km data are research quality, meaning they have not undergone validation.

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 (Das & Dunbar, 2020).

1.2.5 File Naming Convention

Files are named according to the following convention:

```
SMAP_L2_SM_SP_[Sat/Mode/Pol]_[SMAP]yyyymmddThhmmss_[Sentinel-1]yyyymmddThhmmss_[Scene Center Location]_RLVvvv_NNN.[ext]
```

For example:

```
SMAP_L2_SM_SP_1AIWDV_20160901T061527_20160901T184245_007W06N_R15180_001.h5
```

Table 1 describes the variables within a file name:

Table 1. File Naming Convention

<table>
<tr><th>Variable</th><th>Description</th></tr>
<tr><td>SMAP</td><td>Indicates SMAP mission data</td></tr>
<tr><td>L2_SM_SP</td><td>Indicates specific product [L2: Level-2; SM: Soil Moisture;
S: Sentinel-1; P: Passive (refers to SMAP passive radiometer)]</td></tr>
<tr><td>[Sat/Mode/Pol]</td><td>Identifies specific Sentinel-1 satellite (1A or 1B), the SAR mode (IW: Interferometric Wide-swath), and the polarization mode (DV: Dual-polarization VV and VH)</td></tr>
<tr><td>[SMAP]yyyymmddThhmms</td><td>Date/time in Universal Coordinated Time (UTC) of the first SMAP data element that appears in the product, where:
<table>
<tr><td>yyyymmdd</td><td>4-digit year, 2-digit month, 2-digit day</td></tr>
<tr><td>T</td><td>Time (delineates the date from the time, i.e. yyyymmddThhmmss)</td></tr>
<tr><td>hhmmss</td><td>2-digit hour, 2-digit minute, 2-digit second</td></tr>
</table></td></tr>
<tr><td>[Sentinel-1]
yyyymmddThhmmss</td><td>Date/time in Universal Coordinated Time (UTC) of the first Sentinel-1 data element that appears in the product, where:
<table>
<tr><td>yyyymmdd</td><td>4-digit year, 2-digit month, 2-digit day</td></tr>
<tr><td>T</td><td>Time (delineates the date from the time, i.e. yyyymmddThhmmss)</td></tr>
<tr><td>hhmmss</td><td>2-digit hour, 2-digit minute, 2-digit second</td></tr>
</table></td></tr>
<tr><td>[Scene Center Location]</td><td>Approximate longitude (E or W) and latitude (N or S) of the center of the EASE-Grid area containing the Sentinel-1 radar scene.
Note: This is useful for finding data over regional subsets.</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 CRID Major Version Number (Note: the data set's major version does not necessarily coincide with the CRID major version)</td></tr>
<tr><td>vvv</td><td>3-Digit CRID Minor Version Number</td></tr>
</table>
Example: R15180 indicates a post-launch data product with a version of 5.180.
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>.xml</td><td>XML Metadata file</td></tr>
</table></td></tr>
</table>

1.3 Spatial Information

1.3.1 Coverage

Coverage spans from 180°W to 180°E, and from approximately 60°N and 60°S. Latitude coverage for this product is constrained by the Shuttle Radar Topography Mission Digital Elevation Model

(SRTM DEM) data used for terrain correction of the Sentinel-1A/1B radar data. In addition, Sentinel-1A/1B coverage is predominantly over land targets. Note that it takes 12 consecutive days of data to obtain global coverage.

Figure 2 shows the spatial coverage of this product for one day.

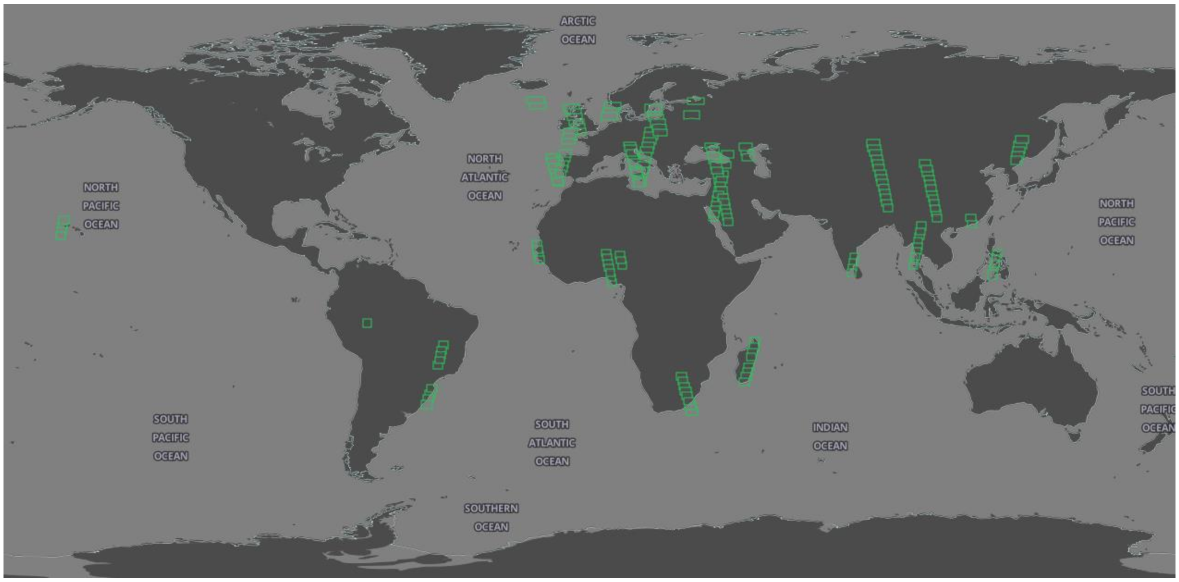

Figure 2. Spatial coverage map displaying SMAP/Sentinel-1A/1B match-up scenes for 01 November 2017. The map was created using the NASA Earthdata Search tool.

1.3.2 Resolution

SMAP 9-km radiometer brightness temperature data (SPL3SMP_E) and Sentinel-1 1-km SAR backscatter data (L2_S0_S1) are combined using the SMAP Active-Passive algorithm to derive soil moisture data that are gridded using the 3-km and 1-km EASE-Grid 2.0 projections. The gridded 9-km SMAP brightness temperatures are derived from the native 36-km***** SMAP radiometer footprint by Backus-Gilbert interpolation directly to the 9-km EASE-Grid 2.0. The 1-km backscatter data from Sentinel-1 are aggregated and regridded on the 1-km EASE-Grid 2.0 starting from raw intensities at approximately 20-m native resolution.

*** Note:** The effective native resolution of the SMAP radiometer can range from approximately 25 km to 36 km depending on parameter extraction methods.

1.3.3 Geolocation

These data are provided on the global cylindrical EASE-Grid 2.0 projection. The SPL2SMAP_S data product is posted on both 3-km and 1-km EASE-Grids that are nested consistently with the 9-km brightness temperatures, and the 3-km and 1-km radar backscatter cross-section data. For more on EASE-Grid 2.0, refer to the EASE Grids website.

The following tables provide information for geolocating this data set.

Table 2. Geolocation details for the Global EASE-Grid 2.0

Geographic coordinate system	WGS 84
Projected coordinate system	EASE-Grid 2.0 Global
Longitude of true origin	0
Standard Parallel	30° N
Scale factor at longitude of true origin	N/A
Datum	WGS 84
Ellipsoid / spheroid	WGS 84
Units	meter
False easting	0
False northing	0
EPSG code	6933
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
Reference	http://epsg.io/6933

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

	3 km	**1 km**
Grid cell size (x, y pixel dimensions)	3,002.69 m (x) 3,002.69 m (y)	1,000.90 m (x) 1,000.90 m (y)
Number of columns	11,568	34,704
Number of rows	4,872	14,616
Geolocated lower left point in grid	85.044° S, 180.000° W	85.044° S, 180.000° W
Nominal gridded resolution	3 km by 3 km	1 km by 1 km
Grid rotation	N/A	N/A
ulxmap – x-axis map coordinate of the outer edge of the upper-left pixel	-17367530.45	-17367530.45
ulymap – y-axis map coordinate of the outer edge of the upper-left pixel	7314540.83	7314540.83

1.4 Temporal Information

1.4.1 Coverage

Coverage spans from 31 March 2015 to present, but is not continuous. Please note the following gaps:

Ongoing Temporal Coverage Gaps

- The less frequent coverage of Sentinel-1 data results in more gaps for this match-up product than exist in the standard SMAP time series.
- In addition, the Sentinel-1 data stream varies considerably; data from many days/months prior may be received and/or downtimes may interrupt coverage, for example.
- SPL3SMP_E data from the previous, current, and next day are used to create this product, resulting in at least a day or two of standard latency.
- Small gaps in the SMAP time series will also occur due to instrument maneuvers, data downlink anomalies, data quality screening, and other factors. Details of these events are maintained on two master lists: SMAP On-Orbit Events List for Instrument Data Users and Master List of Bad and Missing Data
- A significant gap in coverage occurred between 19 June and 23 July 2019 after the SMAP satellite went into Safe Mode. A brief description of the event and its impact on data quality is available in the SMAP Post-Recovery Notice.

1.4.2 Resolution

Each match-up file spans approximately 30 seconds. Note that although each Sentinel-1 scene is approximately 30 seconds, the resolution varies based on how closely SMAP half-orbit passes match up with Sentinel-1 scenes. While SMAP half-orbit passes acquire 49 minutes of data, it is the overlap of Sentinel-1 scenes that determines the temporal resolution of this product. Similarly, while the SMAP orbit yields a 2-3 day average revisit frequency and repeats the exact swath every 8 days, the narrow swath width of the Sentinel-1 orbit degrades the revisit frequency of this data set to ~12 days over most areas of the world (exceptions exist over Europe and California, where the frequency is ~6 days; see the Algorithm Theoretical Basis Document (ATBD) for this product (Das et al., 2019) for more details).

2 DATA ACQUISITION AND PROCESSING

2.1 Background

The original goal of SMAP mission is to combine the favorable attributes of radar and radiometer observations in terms of their spatial resolution and sensitivity to soil moisture, surface roughness, and vegetation in order to estimate soil moisture at a resolution of 10 km, and freeze/thaw state at a resolution of 1-3 km. Microwave radiometry and radar are well-established techniques for surface remote sensing. Combining passive and active sensors provides complementary information contained in the surface emissivity and backscatter signatures, which make it possible to obtain optimal accuracy of retrieved soil moisture at higher resolutions. Over land, it has been demonstrated that L-band radiometer and radar measurements both provide information to retrieve optimal soil moisture estimates (Das et al., 2011, Dan et al., 2014, and Dan et al., 2016).

The SMAP Active-Passive algorithm is capable of incorporating other SAR measurements to obtain high-resolution brightness temperature and subsequently high-resolution soil moisture. The SMAP radar stopped functioning on 07 July 2015, and various radar data were explored to find suitable alternatives for SAR data. Sentinel-1 was found to be suitable to fulfill most of the requirements of the radar measurements as input to the SMAP Active-Passive algorithm. Few modifications needed to be made in the SMAP Active-Passive algorithm to accommodate the Sentinel-1 SAR measurements. Details of these modifications are included in the ATBD (Das et al., 2019) and in the Assessment Report (Das et al., 2020).

2.2 Instrumentation

For a detailed description of the SMAP instrument, visit the SMAP Instrument page at Jet Propulsion Laboratory (JPL) SMAP website. For information regarding the SAR satellites Sentinel-1A and -1B, refer to the European Space Agency (ESA) Copernicus Sentinel-1 website.

2.3 Acquisition

Version 3 of the SMAP/Sentinel-1 Level-2 radiometer/radar soil moisture data (SPL2SMAP_S) are derived from the following:

- SMAP Enhanced L3 Radiometer Half-Orbit 9 km EASE-Grid Soil Moisture, Version 4 (SPL3SMP_E)
- Copernicus Sentinel-1A C-SAR Data
- Copernicus Sentinel-1B C-SAR Data

2.4 Derivation Techniques and Algorithms

This section has been adapted from Entekhabi et al. (2014), Das et al. (2019), and the ATBD (Das et al., 2019).

SPL2SMAP_S data are based on the merger of SMAP radiometer and Sentinel-1 radar data at two discrete grid resolutions: gridded 9 km and 1 km. The Equal-Area-Scalable-Earth Grid (EASE-Grid) cells of the radiometer and radar products nest perfectly; refer to the Spatial Information section of this document. Therefore, the SPL2SMAP_S 3-km/1-km soil moisture product has 9:1/81:1 correspondence with the radiometer and radar products. The grid definition used in the algorithm is illustrated in Figure 2 of the ATBD of this product (Das et al., 2019), which is available as a technical reference. The SPL2SMAP_S baseline algorithm disaggregates the coarse resolution radiometer brightness temperature product based on the spatial variation in high-resolution radar backscatter. In addition, the algorithm requires static and dynamic ancillary data. These ancillary data are resampled to the same EASE-Grid prior to ingest in the SPL2SMAP_S processing. The dynamic ancillary data used to retrieve soil moisture for a particular 3-km or 1-km grid cell at a specific point in time are listed in the SPL2SMAP_S output files for the benefit of end-users.

2.4.1 Formulation of the Active-Passive Algorithm

The L-band radiometer measures the natural microwave emission in the form of the brightness temperature (T_B) of the land surface, while the L/C-band SAR measures the energy backscattered (sigma0, also referred to as S0 or σ_0) from the land surface after transmission of an electromagnetic pulse. On short time scales, an increase of surface soil moisture produces an increase in soil dielectric constant, which leads to a decrease in radiometer T_B and an increase in radar backscatter, and vice versa. Thus, variations in soil moisture cause T_B and σ_0 to be negatively correlated. This time period is generally shorter than the seasonal phenology of vegetation. The conceptual framework of the active-passive algorithm is described in Section 2 of the ATBD (Das et al., 2019).

The land surface vegetation and surface roughness factors are expected to vary on time scales longer that those associated with soil moisture variability. However, over short time periods the radiometer T_B and SAR σ_0 are expected to have a linear functional relationship: $T_B = \alpha + \beta \times \sigma_0$. The unknown parameters α and β are dependent on the dominant vegetation and soil roughness characteristics. The T_B polarization can either be *v* or *h* and the σ polarization can be *vv*, *hh* (though *hh* is not used for this product), or *vh* (double letters indicate the transmit and receive polarizations). The parameter β can be derived in a snapshot approach based on pairs of radiometer T_B and spatially-averaged radar σ_0 from successive observations of the same Earth grid cell (Jagdhuber et al. 2018).

The parameter β is unique for each location since it is a sensitivity parameter relating T_B and σ_0 and it is a function of surface characteristics like the local vegetation cover and soil roughness for a particular period of time. The parameter varies seasonally as well as geographically. To develop the satellite-based Active-Passive algorithm further, the relationship between T_B and σ_0 can also be conceptually evaluated at the 3 km scale within the radiometer footprint. At this scale, brightness temperature is not available given the SMAP radiometer instrument resolution. However, determining T_B at this scale is the target of the algorithm and it is referred to as the disaggregated brightness temperature. The way to incorporate the effects of the variations of the parameter β at the 3-km and 1-km scales with respect to the coarser 33-km scale is to determine subgrid heterogeneity parameter Γ from high-resolution co- and cross-polarization at 1 km. The methodology is described in Section 3.2 of the ATBD (Das et al., 2019).

The performance of the brightness temperature disaggregation is heavily dependent on robust estimates of β and Γ parameters, which are specific for a given location and reflect the local roughness and vegetation cover conditions. The parameters vary seasonally as well as due to change in local surface conditions; therefore, it is optimal to derive these parameters for every radiometer and SAR overlap instance.

2.4.2 Baseline Active-Passive Algorithm for SPL2SMAP_S Product

As mentioned in the previous section, the brightness temperature disaggregation is based on relating the high-resolution radar measurements with the radiometer measurements. The SPL2SMAP_S baseline algorithm is based on the disaggregation of the SMAP L-band radiometer brightness temperatures using the Sentinel-1A/B C-band SAR backscatter spatial patterns within the SMAP radiometer footprint (33-km resolution). The spatial patterns need to account for the different levels of radar backscatter cross-section sensitivity to soil moisture, vegetation cover, and soil surface roughness. For this reason, the radar measurements within the radiometer footprint are scaled by parameters that are derived from the spatially averaged radar and radiometer measurements over the scene. The co-variation at a coarse scale (radiometer grid scale) over specified periods of time (short relative to plant phenology) are mostly related to surface soil moisture changes rather than contributions of vegetation and surface roughness. The derived co-variation parameter from the radiometer and radar measurements address the high-resolution variability of soil moisture within the coarse radiometer grid cell. The high-resolution variability of vegetation and surface roughness with the coarse radiometer grid cell is addressed by the heterogeneity parameter derived using the high-resolution snapshot co-pol and x-pol radar measurements. However, the Sentinel-1A/B observations are temporally sparse, and therefore the time series required to get the algorithm parameters are not optimal. A snapshot approach developed by Jagdhuber at al. (2018) is used to obtain the algorithm parameters for any given day of overlap between the SMAP radiometer and Sentinel-1A/B SAR, and this alleviated the problem of having a statistically significant time series to get the active-passive algorithm parameter (β).

Once the disaggregated brightness temperatures at 3 km and 1 km are produced through the active-passive algorithm as described in the Section 3.2 of the ATBD (Das et al., 2019), the Single Channel Algorithm (SCA)/Tau-Omega model is applied on the disaggregated brightness temperatures at 3 km and 1 km along with the high-resolution ancillary information at 3 km and 1 km to produce the SPL2SMAP_S product. Note that for this version of the SPL2SMAP_S product, the tau-omega parameters have been adjusted to be consistent with the values used in the SPL2SMP and SPL2SMP_E algorithms.

2.4.3 Algorithm Process Flow

Figure 3 shows a simplified process flow diagram for the implementation of the active-passive algorithm to produce the SPL2SMAP_S product.

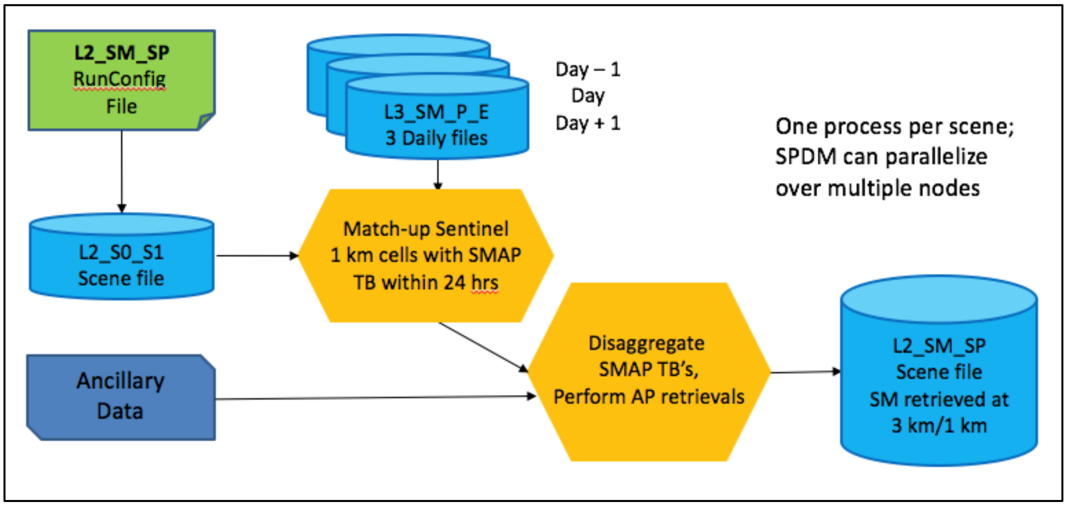

Figure 3. Process Flow Diagram of the active-passive Baseline Algorithm for the SPL2SMAP_S product.

Note: As shown in this figure and reflected in the file names, L2_SM_SP is an abbreviation for this product (also referred to as SPL2SMAP_S), SPDM refers to the Science Processing and Data Management system that can parallelize, or run many single-thread processes on multiple nodes, to process a scene.

2.5 Processing

This product is generated by the SMAP Science Data Processing System (SDS) at the Jet Propulsion Laboratory (JPL) in Pasadena, California USA. Prior to generating this product, Copernicus Sentinel-1A and -1B satellite imagery was acquired by the European Space Agency (ESA) and distributed through the Alaska Satellite Facility (ASF). To generate this product, the processing software:

1. Ingests one file containing a single scene of Sentinel-1 1-km L2_S0_S1 backscatter data (filtered and aggregated from the native resolution of ~15 m) from either Sentinel-1A or Sentinel-1B and three daily files of SMAP gridded 9-km SPL3SMP_E brightness temperature data. The SMAP files include SMAP data for the three days nearest the time of the Sentinel-1 data, along with the required static and dynamic ancillary data that cover those three days.

   - The brightness temperatures available in SPL3SMP_E have been corrected for the presence of water bodies (up to 0.1 fraction) before being used in SPL2SMAP_S product generation. Beyond water body fraction of 0.1, no correction is conducted as it introduces high errors due to uncertainty present in the water fraction information.
   - The sigma0 measurements have been calibrated, terrain-corrected, and aggregated onto 1-km EASE-Grid 2.0 pixels before being used in SPL2SMAP_S product generation. Level-2 sigma0 Sentinel-1 data (also referred to as L2_S0_S1) in the dual-polarization "SDV" mode (VV,VH) is used exclusively for SMAP/Sentinel-1 SPL2SMAP_S processing.

Note: For the SPL2SMAP_S product, a new method of identifying and eliminating spurious sigma0 values (mostly from urban areas and manmade structures) in Sentinel-1A/B Level-1 S0 data has been implemented (Das et al., 2019). This method, referred to as a hybrid filter, combines a median filter (i.e. replaces the value at each pixel with the median value of adjacent pixels) with thresholding to remove undesirable sigma0 values that bias the aggregated 1-km data.

2. The ingested data are then inspected for retrievability criteria according to input data quality, ancillary data availability, and land cover conditions. The nearest SMAP data in time at the location of the Sentinel-1 scene is determined, including:

   - Data from SMAP a.m.-only (6:00 a.m. descending) orbits
   - Data from SMAP a.m.-or-p.m. (6:00 a.m. descending or 6 p.m. ascending) orbits

   Within each resolution data group (3 km and 1 km) there are two sets of outputs: SMAP a.m.-only and SMAP a.m.-or-p.m. One of the following four outcomes are possible:

   - No match — Neither SMAP a.m. nor p.m. data match the Sentinel-1 scene, resulting in no output file.
   - SMAP a.m.-only is closest — In this case the values of the SMAP a.m.-only and SMAP a.m.-or-p.m. elements are identical.
   - SMAP a.m.-only and SMAP a.m.-or-p.m. are different — In general, the SMAP a.m.-or-p.m. data are the closest of all in time to the Sentinel-1 scene, but there are two different sets of retrievals due to SMAP data from different times.
   - SMAP a.m.-only has fill values, SMAP a.m.-or-p.m. has valid data — This occurs when there are no SMAP a.m.-only matches, but a p.m. match can be found.

3. When retrievability criteria are met, the software invokes the brightness temperature disaggregation algorithm followed by the baseline retrieval algorithm to generate soil moisture. The brightness temperatures disaggregated at 3 km and 1 km are converted to soil moisture using the Tau-Omega algorithms. Note that the disaggregation is not performed if the coarse resolution brightness temperature does not meet the quality requirements, especially if large water bodies, urban areas, presence of snow/ice, complex DEM characteristics, and RFI are present.

2.6 Quality, Errors, and Limitations

2.6.1 Error Sources

Errors in SPL2SMAP_S data come from various sources with the most prominent potential error source being anthropogenic Radio Frequency Interference (RFI). Principally from ground-based surveillance radars and ancillary data, RFI can contaminate both radar and radiometer measurements at L-band and C-band. Early measurements and results from European Space Agency's Soil Moisture and Ocean Salinity (SMOS) mission indicate RFI is a major source of concern because of high RFI present and detectable in many parts of the world. The SMAP radiometer electronics and algorithms include design features to mitigate the effects of RFI. The SMAP radiometer implements a combination of time and frequency diversity, kurtosis detection, and use of T4 thresholds to detect and, where possible, mitigate RFI. Owing to such robust measures in the SMAP radiometer hardware and data processing, the SPL2SMAP_S product has lesser impact than SMOS measurements from anthropogenic RFI. The Sentinel-1 C-band radar data have no RFI indicators; the expectation is that the impact of RFI on the Sentinel-1 radar is reduced due to the radar frequency relative to the L-band SMAP radiometer. Another source of errors is incurred during the implementation of the active-passive algorithm to obtain the high-resolution brightness temperature. These errors are quantified analytically for the disaggregated brightness temperatures at 3 km and 1 km (Entekhabi et al. 2014 and Das et al. 2016). Other sources of errors get involved during the soil moisture retrievals from the high-resolution brightness temperature, they are the uncertainties in the Tau-Omega model parameters and in the ancillary data (such as clay fraction and land surface temperature). The retrieved soil moisture data in the SPL2SMAP_S product have contributions from all the above error and uncertainty sources. Based on the validation study over the SMAP Core Cal sites and the Sparse Network, the SPL2SMAP_S soil moisture at 3 km has an unbiased root mean square error (ubRMSE) of 0.05 m^3/m^3 (see Assessment Report; Das et al., 2020).

More information about error sources is provided in Section 5.2 of the ATBD. The validation over the Core Cal/Val sites and Sparse Network is provided in the Assessment Report.

2.6.2 Quality Assessment

Science and application communities should take certain caveats into consideration before using the SPL2SMAP_S product. There is a tradeoff between adding spatial resolution with C-band SAR data. The high resolution (3 km and 1 km) of this product comes at a cost of degradation in temporal statistics of disaggregated brightness temperature and retrieved soil moisture. The combined revisit interval (6-12 days) of Sentinel 1A/B satellites over a given region governs the temporal statistics. Whereas the more spatially-averaged SPL2SMP_E product has finer temporal frequency when compared to SPL2SMAP_S, the SPL2SMAP_S has higher spatial resolution in terms of resolving sharp and large-contrast features as compared to the SPL2SMP_E product. Therefore, users of SMAP data who require more frequent revisit can use the SPL2SMP_E product (posted at 9 km), and those users who need high resolution soil moisture patterns and details with slightly degraded accuracy and less frequent revisit can use SPL2SMAP_S data (posted at 3 km) for their science studies and geophysical applications. For in-depth details regarding the quality of these Version 3 data, refer to the Assessment Report (Das et al., 2020).

2.6.3 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 (Das & Dunbar, 2020).

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 NSIDC. A separate metadata file with an .xml file extension is also delivered to NSIDC with the HDF5 file; it contains the same information as the HDF5 file-level metadata.

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.

2.6.4 Data Flags

Quality control (QC) is an integral part of the SPL2SMAP_S processing. The QC steps of SPL2SMAP_S processing are based on the flags that are provided with the SMAP input data stream (SPL3SMP_E), different types of masks, flags, and fractional coverage of other variables provided by ancillary data. The SPL2SMAP_S Science Data System process all the data that have favorable conditions for soil moisture retrieval (Vegetation Water Content (VWC) <= 3 kg/m^2, no rain, no snow cover, no frozen ground, no RFI, sufficient distance from open water). However, soil moisture retrieval will also be conducted for regions with VWC > 3 kg/m^2, rain, RFI repaired data, and places closer to water bodies, but appropriate flags are added to these data points indicating their susceptibility to potentially high errors. In addition, due to differences in spatial resolution of the input data, the assignment of QC flags in SPL2SMAP_S may differ from the flags associated with the inputs. The thresholds of ancillary data that initiate flagging in the SPL2SMAP_S product are mentioned below. For example, T_B data in SPL3SMP_E are corrected for the presence of water bodies. Studies conducted to assess the quality of corrected T_B data that are acceptable and within the desired uncertainty level that could be used in SPL2SMAP_S processing. The assessment shows that 5% water body fraction within the 9 km grid cell of SPL3SMP_E has the acceptable quality and low error levels in kelvins. All the 3 km and 1 km nested grid cells of SPL2SMAP_S within the 9 km grid cell of SPL3SMP_E are flagged for suspected quality if the water body fraction is >5%. The water body fraction is reported for all land-based 3 km and 1 km grid cells in SPL2SMAP_S product file, and the water body flag bit is set in the retrieval quality field if the water body fraction is greater than a threshold value of 5%. In the case of VWC, SPL2SMAP_S retrieval is performed at all the grid cells irrespective of VWC but the QC flag is set only for a grid cell having VWC >3 kg/m^2. Retrievals are performed for SPL2SMAP_S grid cells that are associated with RFI and water body fraction above a particular threshold; however, appropriate QC flags are raised to inform the user about the suspected quality of disaggregated brightness temperature and retrieved soil moisture. No retrievals are performed over frozen ground, presence of snow, and 100% urban fraction. Thresholds from masks that will initiate flags and operational decisions to process the SPL2SMAP_S product are mentioned below.

For users, the overall QC flag is composited in the soil moisture retrieval flag (for example, *retrieval_qual_flag_3km* for the am part of the soil moisture at 3 km). The user should also pay attention to the disaggregated brightness temperature quality flag (for example, *disaggregated_tb_v_qual_flag_3km* for the am part of the disaggregated brightness temperature at 3 km) to obtain certain relevant information. The detail usage/description of the surface flag, disaggregated brightness temperature quality flag, and retrieval quality flag are as follows with some examples.

2.6.4.1 Surface Flag

The surface flags are available for the corresponding resolutions at 3 km and 1km (for example, *surface_flag_3 km* and *surface_flag_1km*). The surface flag is 2 bytes integer data field. The surface condition during the acquisition time of brightness temperature and is used to populate surface flag in the bits of 2 bytes integer. The bits are arranged as follows:

Table 4. Surface Flag data field definition of the SPL2SMAP_S product

Name of Bit Flag	Bit	Comment
Static water body	0	Raised to 1 if static waterbody is > 0.1 with the grid cell, otherwise set to 0
Radar water body detection	1	Always clear, set to 0, not used in this version
Region close to large water bodies	2	Raised to 1, if the T_B 9 km grid cell is within 36 km of large water body, otherwise set to 0
Urban area	3	Raised to 1, it the urban fraction is > 0.25, otherwise set to 0
Precipitation	4	Raised to 1, if the precip is > 5 mm, otherwise set to 0
Snow or ice	5	Raised to 1, snow and ice is reported through ancillary data, otherwise set to 0
Permanent snow or ice	6	Raised to 1 in presence of ice based on landcover map, otherwise set to 0
Frozen ground based on F/T	7	Always clear, set to 0, not used in this version
Frozen ground based on LST	8	Raised to 1, if Land Surface Temperature < 273.15 K, otherwise set to 0
Mountainous terrain	9	Raised to 1, if the std of slope is > 3.0, otherwise set to 0
Dense vegetation	10	Raised to 1, it the vegetation-water-content is > 3.0 kg/m2, otherwise set to 0
Edge	11	Raised to 1, if the Sentinel data is close to the edge of the granule (leads to suboptimal algorithm parameters), otherwise set to 0
For σ_0 anomalous region	12	Raised to 1, if the σ_0 values beyond +/- 2.5 stdv within the 33 km of TB footprint

The user should pay attention to the surface flags to assess the quality of the soil moisture retrievals. The easiest way is to get the value of the surface flag. If the value is 0 then all the bit flags are cleared and the soil moisture retrieval has no issues pertaining to the surface or the grid cell over which the retrieval is conducted. If the value is greater than 0 then the user is encouraged to unpack the integer into bits and look for the flag that is raised. It is up to users' discretion to use it according to the need of their study or application. For example, if the VWC content flag is raised (bit #10 from Table 4), it is up to the user to use if their application permits to a absorb higher magnitude of error in soil moisture retrieval. A How-To is offered with MATLAB code to read a file and then unpack the surface flags (How-To's are provided under the Support Tab).

2.6.4.2 Disaggregated T_B Quality Flag

The disaggregated T_B quality flag is another important QC data field for the users interested in the high-resolution brightness temperature data. This QC data field is 2 bytes integer. Table 5 illustrates the bits of the QC flag.

Table 5. Disaggregated T_B Quality data field definition of the SPL2SMAP_S product

Name of Bit Flag	Bit	Comment
Disaggreggated T_B v-pol quality	0	Raised to 1, if the overall quality of the high res T_B is compromised. Otherwise set to 0 showing good quality.
Sigma0_vv quality	1	Raised to 1, if the σ_0_vv quality is bad, otherwise set to 0
Sigma0_vh quality	2	Raised to 1, if the σ_0_vh quality is bad, otherwise set to 0
T_B 33 km v-pol quality	3	Raised to 1, if the T_B 33 km is bad, otherwise set to 0
T_B 33 km v-pol RFI detected	4	Raised to 1, if the T_B 33 km has RFI, otherwise set to 0
T_B 33 km v-pol RFI corrected	5	Raised to 1, if the T_B 33 km has RFI and corrected, otherwise set to 0
σ_0_vv RFI detected	6	Raised to 1, if the σ_0_vv has RFI, otherwise set to 0
σ_0_vv RFI corrected	7	Raised to 1, if the σ_0_vv has RFI and corrected, otherwise set to 0
σ_0_hv RFI detected	8	Raised to 1, if the σ_0_vh has RFI, otherwise set to 0
σ_0_hv RFI corrected	9	Raised to 1, if the σ_0_vh has RFI and corrected, otherwise set to 0
σ_0_vv negative value	10	Raised to 1, if the σ_0_vv value is negative, otherwise set to 0
σ_0_hv negative value	11	Raised to 1, if the σ_0_vh value is negative, otherwise set to 0
T_B 33 km Waterbody correction	12	Raised to 1, if T_B at 33 km is corrected for waterbody, otherwise set to 0
T_B 33 km v-pol Des and Asc	13	Raised to 1 if T_B at 33 km comes from Ascending swath (6PM local time), set to 0 if the T_B at 33 km comes from Descending swath (6AM local time)
36 hrs time difference	14	Raised to 1 if the time difference of overlay between the T_B at SMAP and Sentinel is greater than 36 hr. Otherwise set to 0 (for less than 36 hrs diff)

An example of the Disaggregated T_B quality flag is elaborated in the How-To. If the value of bit position ‘0’ is 0 then the disaggregated T_B is clean and has no issues. If the value is greater than 0 then it is better to unpack the integer into bits and look for the bit flags that are raised. It is up to the discretion of the user then to use it according to the needs of their study or application. For example, if the Disaggregated T_B QC flag is raised for bit #5 (from Table 5), it is up to the user to decide if they can use the RFI corrected high-resolution brightness temperature for the study or application. The Disaggregated T_B quality flag also informs the user about two important aspects of the SPL2SMAP_S product:

i) Bit position 13 informs the user about the SMAP T_B input at 33 km comes from ascending (6:00 PM) and descending (6:00 AM) swaths, and;

ii) Bit position 14 is raised to 1 if the time difference between the SMAP T_B and the Sentinel-1A/B SAR observations is greater than 36 hrs.

2.6.4.3 Soil Moisture Retrieval Quality Flag

It is critical for the user of SPL2SMAP_S products to be aware of the quality of the soil moisture data. For this purpose, the user should use the soil moisture retrieval quality flag. The use of this quality flag is very straight forward. If the value of the soil moisture retrieval quality flag (for example, data field *retrieval_qual_flag_3km*) is 0, then the soil moisture retrieval is of good quality at 3 km resolution for the am part. Besides the information gathered during tau-omega model retrieval process for this quality flag, the information of the surface flag and the disaggregated brightness temperature quality flag are also used and composited. This means that the value of 0 for the soil moisture retrieval quality flag indicates that all the preceding process and quality are good. If the value is greater than 0, then the user should unpack the corresponding surface flag and disaggregated brightness temperature quality flag to understand why the flag is raised. However, the bit position 6 of the soil moisture retrieval quality flag (Table 6) also informs the user about the quality of the disaggregated brightness temperature (bit position 6 value of 0 indicates good quality disaggregated T_B, and 1 indicates inferior quality disaggregated T_B). The How-To elaborates more about reading and unpacking the bits of the soil moisture retrieval quality flag.

Table 6. Soil Moisture Retrieval Quality data field definition of the SPL2SMAP_S product

Name of Bit Flag	Bit	Comment
Retrieval recommended	0	Raised to 1 if Soil Moisture Overall Quality Flag is compromised, otherwise set to 0 indicating good quality
Retrieval attempted	1	Raised to 1 if Soil Moisture retrieval attempted fails, otherwise set to 0 indicating successful attempt.
Retrieval success	2	Raised to 1 if Soil Moisture retrieval is not successful, otherwise set to 0 indicating successful retrieval.
Radar waterbody detection success	3	Always set to 0, as this flag is not used in current implementation
F/T retrieval success	4	Always set to 0, as this flag is not used in current implementation
RVI retrieval success	5	Always set to 0, as this flag is not used in current implementation
Disaggregated T_B quality	6	Raised to 1 if the disaggregated T_B is bad quality, otherwise set to 0 indicating good quality disaggregated T_B
Retrieval Saturated Water Content quality	7	Raised to 1 if the soil moisture is greater than the possible saturated water content based on soil bulk density, otherwise set to 0 indicating the soil moisture retrieval below or equal to the saturated water content

3 SOFTWARE AND TOOLS

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

4 VERSION HISTORY

Table 7. Summary of Version Changes

Version	Release Date	Description of Changes
V1	October 2017	First public data release
V2	June 2018	Changes to this version include: • Implemented a new method of identifying and eliminating spurious σ_0 values in Sentinel-1A/B Level-1 σ_0 data using a hybrid approach that combines a median filter with thresholding. As a result, fewer spurious σ_0 values (mainly due to small man-made structures) bias the aggregated 1 km data. • Replaced the previous 3 km resolution urban fraction map with a new 1 km map. • Adjusted the thresholds used with the new 1 km urban fraction map to: 0.25 (no flag), 0.25 – 0.5 (flagged, retrieval performed), and 0.5 (masked, no retrieval). These are provided in bit 3 of the *surface_flag* data field. • Adjusted the tau-omega parameters to be consistent with the values used in SPL2SMP/SPL2SMP_E algorithm. • Implemented minor bug fix to the SMAP and Sentinel-1 overlap computation code.
V3	August 2020	Changes to this version include: • An improved calibration methodology was applied to the SMAP Level-1B brightness temperatures. • Revised the coefficients in the land surface temperature computation to be consistent with the SMAP Level-2 soil moisture passive enhanced product. The new coefficients are C=0.246, K=1.007 for AM passes and C=1.0, K=1.007 for PM passes. • Changed the omega parameter of the tau-omega model for forest landcover classes (1-5) from 0.05 to 0.07. • Uses a new high-resolution soil database (Das & O'Neill, 2020). • Uses bulk density to set the upper limit of the soil moisture retrievals. Previous versions used a fixed value of 0.65 m^3/m^3. • Enhanced documentation on Data Flags in the User Guide to help data users to better understand and use the flags. • Added a bit in the T_B Disaggregation QC flag to indicate (1) the use of SMAP AM or PM data; and (2) the time difference (greater or less than 36 hours) between the SMAP and Sentinel observations overlap. • Fixed the *EASE_[row/column]_index_apm_[1km/3km]* data fields to make them 0-based. • Fixed the range beginning and ending time in the file metadata. • In June 2024, the validated state was retroactively applied to all 3-km data from August 21, 2020 onward.

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

September 2020

9.2 Date Last Updated

June 2024

APPENDIX – DATA FIELDS

This appendix provides a description of all data fields within the *SMAP/Sentinel-1 L2 Radiometer/Radar 30-Second Scene 3 km EASE-Grid Soil Moisture* product. The data are grouped into three main HDF5 groups:

- Metadata
- Soil_Moisture_Retrieval_Data_1km
- Soil_Moisture_Retrieval_Data_3km

For a description of metadata fields for this product, refer to the Product Specification Document (Das & Dunbar, 2020).

Table A1 describes the data fields of a typical SPL2SMAP_S. All data fields exist in both 1 km and 3 km groups. Data in the 1 km group are research quality, meaning they have not undergone validation. Also note that data fields containing SMAP a.m.-or-p.m. data are named with *apm*, such as *disaggregated_tb_v_qual_flag_apm_3km*. If the SMAP a.m. pass is the closest, the two arrays will have the same values.

Table A - 1. Data fields included in both *Soil_Moisture_Retrieval_Data_1km* and *Soil_Moisture_Retrieval_Data_3km* groups.

Data Field Name	Concept	Byte	Unit	Min	Max	Fill/Gap Value
EASE_column_index_[apm_][1/3]km	integer	2	N/A	0	34703 / 11567	66534
EASE_row_index_[apm_][1/3]km	integer	2	N/A	0	14615 / 4871	66534
SMAP_Sentinel-1_overpass_ timediff_hr_[apm_][1/3]km	real	4	hours	0.0	40.0	-9999
albedo_[apm_][1/3]km	real	4	N/A	0.0	1.0	-9999
bare_soil_roughness_retrieved_ [apm_][1/3]km	real	4	N/A	0.0	2.0	-9999
beta_tbv_vv_[apm_][1/3]km	real	4	K/dB	-20.0	0.0	-9999
disagg_soil_moisture_[apm_][1/3]km	real	4	m^3/m^3	0.01	**	-9999
disaggregated_tb_v_qual_flag_ [apm_][1/3]km	bit flag	2	N/A	0	65535	66534
gamma_vv_xpol_[apm_][1/3]km	real	4	dB/dB	0.0	5.0	-9999
landcover_class_[apm_][1/3]km	integer	2	N/A	0	16	254
latitude_[apm_][1/3]km	real	4	degree	-90.0	90.0	-9999
longitude_[apm_][1/3]km	real	4	degree	-180.0	180.0	-9999

Data Field Name	Concept	Byte	Unit	Min	Max	Fill/Gap Value
retrieval_qual_flag_[apm_][1/3]km	bit flag	2	N/A	0	65535	66534
sigma0_incidence_angle_[apm_][1/3]km	real	4	degree	20.0	60.0	-9999
sigma0_vh_aggregated_[apm_][1/3]km	real	4	normalized	0.0	1.0	-9999
sigma0_vv_aggregated_[apm_][1/3]km	real	4	normalized	0.0	1.0	-9999
soil_moisture_[apm_][1/3]km	real	4	m^3/m^3	0.01	**	-9999
soil_moisture_std_dev_[apm_][1/3]km	real	4	m^3/m^3	0.01	0.30	-9999
spacecraft_overpass_time_seconds_[apm_][1/3]km	real	8	seconds	0.0	N/A	-9999
surface_flag_[apm_][1/3]km	bit flag	2	N/A	0	65535	66534
surface_temperature_[apm_][1/3]km	real	4	K	253.15	320.15	-9999
tb_v_disaggregated_[apm_][1/3]km	real	4	K	0.0	320.0	-9999
tb_v_disaggregated_std_[apm_][1/3]km	real	4	K	0.0	100.0	-9999
vegetation_opacity_[apm_][1/3]km	real	4	N/A	0.0	5.0	-9999
vegetation_water_content_[apm_][1/3]km	real	4	kg/m^2	0.0	30.0	-9999
water_body_fraction_[apm_][1/3]km	real	4	N/A	0	1	-9999
** Based on the soil bulk density (BD), porosity of soil = 1 – (BD/2.65)						

Data Field Definitions

The data fields with _apm_ in their name are omitted from this list, as their definition is identical to their counterparts. Note again that the _apm_ fields contain SMAP a.m.-or-p.m. data.

EASE_column_index_[1km/3km]
The column index of the 1 km (or 3 km) EASE-Grid 2.0 cell that contains the associated data. This field contains SMAP a.m.-only data.

EASE_row_index_[1km/3km]
The row index of the 1 km (or 3 km) EASE-Grid 2.0 cell that contains the associated data. This field contains SMAP a.m.-only data.

SMAP_Sentinel-1_overpass_timediff_hr_[1km/3km]
Number of hours difference between the SMAP overpass and the Sentinel-1 overpass. This field contains SMAP a.m.-only data.

albedo_[1km/3km]
Diffuse reflecting power of the Earth's surface within the EASE-Grid 2.0 cell. This field contains SMAP a.m.-only data.

bare_soil_roughness_retrieved_[1km/3km]
Soil roughness provided by the MODIS International Geosphere-Biosphere Programme (IGBP) land cover map at 1 km (or 3 km) EASE-Grid 2.0 cell. The relative dominance of each land cover type is determined based on ranking among land cover classes using statistical mode. Table A-2 provides a description of MODIS IGBP classes and the percentage of each land type. This field contains SMAP a.m.-only data.

beta_tbv_vv_[1km/3km]
Beta parameter used in the Active/Passive retrieval algorithm for the corresponding EASE-Grid 2.0 cell, derived using time series Tbv and sigma0_vv. This field contains SMAP a.m.-only data.

disagg_soil_moisture_[1km/3km]
Representative soil moisture measurement for the 1 km EASE-Grid 2.0 cell obtained from disaggregating the coarse resolution soil moisture. This field contains SMAP a.m.-only data.

disaggregated_tb_v_qual_flag_[1km/3km]
Bit flags that record the conditions and the quality of the disaggregated vertical polarization brightness temperature for the option 1 soil moisture algorithm generated for the EASE-Grid 2.0 cell. Refer to Table 5 in this User Guide for bit flag definitions. This field contains SMAP a.m.-only data.

Table A - 2. MODIS IGBP Land Classification and Percentage of Land Cover

Class	Description	% of Land Cover
0	Water	-
1	Evergreen Needleleaf Forest	3.96
2	Evergreen Broadleaf Forest	10.04
3	Deciduous Needleleaf Forest	0.63
4	Deciduous Broadleaf Forest	1.59
5	Mixed Forests	4.69
6	Closed Shrublands	0.55
7	Open Shrublands	18.26
8	Woody Savannas	7.52
9	Savannas	6.97
10	Grasslands	9.27
11	Permanent Wetlands	0.22
12	Croplands	8.95
13	Urban and Built-Up	0.50
14	Cropland/Natural Vegetation Mosaic	2.10
15	Snow and Ice	11.04
16	Barren or Sparsely Vegetated	13.70

gamma_vv_xpol_[1km/3km]
Gamma parameter used in the Active/Passive retrieval algorithm for the corresponding EASE-Grid 2.0 cell, derived using high resolution sigma0_vv and sigma0_xpol. This field contains SMAP a.m.-only data.

landcover_class_[1km/3km]
An enumerated type that specifies the predominant surface vegetation found in the

EASE-Grid 2.0 cell at 1 km or 3 km. Refer to Table A - 2 for classification values. This field contains SMAP a.m.-only data.

latitude_[1km/3km]
Latitude of the center of the EASE-Grid 2.0 cell. This field contains SMAP a.m.-only data.

longitude_[1km/3km]
Longitude of the center of the EASE-Grid 2.0 cell. This field contains SMAP a.m.-only data.

retrieval_qual_flag_[1km/3km]
Bit flags that record the conditions and the quality of the retrieved baseline soil moisture. When translated to decimal representation, this parameter contains an integer indicating one of the following inversion outcomes. Refer to Table 6 in this User Guide for bit flag definitions. This field contains SMAP a.m.-only data.

sigma0_incidence_angle_[1km/3km]
The outcome of aggregating a set of 1 km (or 3 km) incidence angle of radar backscatter measurements into a 1 km (or 3 km) EASE-Grid 2.0 cell. This field contains SMAP a.m.-only data.

sigma0_vh_aggregated_[1km/3km]
The outcome of aggregating a set of 1 km (or 3 km) cross-polarized radar backscatter measurements into a 1 km (or 3 km) EASE-Grid 2.0 cell. This field contains SMAP a.m.-only data.

sigma0_vv_aggregated_[1km/3km]
The outcome of aggregating a set of 1 km (or 3 km) vertical polarization radar backscatter measurements into a 1 km (or 3 km) EASE-Grid 2.0 cell. This field contains SMAP a.m.-only data.

soil_moisture_[1km/3km]
Representative soil moisture measurement for the 1 km (or 3 km) EASE-Grid 2.0 cell for option 1. This field contains SMAP a.m.-only data. **Note:** The soil_moisture_3km field contains data for the baseline algorithm.

soil_moisture_std_dev_[1km/3km]
Standard deviation of soil moisture measure for the 1km EASE-Grid 2.0 cell. This field contains SMAP a.m.-only data.

spacecraft_overpass_time_seconds_[1km/3km]
Number of seconds since a specified epoch that represents the spacecraft overpass relative to the 9 km EASE-Grid 2.0 cell that contains each 1 km (or 3 km) EASE-Grid 2.0 cell represented in this data product. This field contains SMAP a.m.-only data.

surface_flag_[1km/3km]
Bit flags that record ambient surface conditions for the EASE-Grid 2.0 cell. This field contains SMAP a.m.-only data. Refer to section 2.6.4.1 for guidance on its use.

surface_temperature_[1km/3km]
Temperature at land surface based on GMAO GEOS-5 Land Surface Model; represents the effective soil temperature in radiative transfer modeling at L-band frequencies. This field contains SMAP a.m.-only data.

Note: It has come to our attention that this parameter is often mistaken for the physical temperature of the top soil layer. The designation “effective” signifies an attempt to capture the soil integrated temperature and canopy temperature in a single parameter, as is widely reported in the literature.

Depending on the actual emission sensing depth (which varies with soil moisture), this parameter usually does not coincide with a thermal physical temperature at a fixed depth (e.g. 5 cm or 10 cm).

tb_v_disaggregated_[1km/3km]
Vertical polarization brightness temperature adjusted for the presence of water bodies and disaggregated from the 9 km EASE-Grid 2.0 cells into 1 km (or 3 km) EASE-Grid 2.0 cells. This field contains SMAP a.m.-only data.

tb_v_disaggregated_std_[1km/3km]
Standard deviation of the vertical polarization brightness temperature adjusted for the presence of water bodies and disaggregated from the 9 km EASE-Grid 2.0 cells into 1 km (or 3 km) EASE-Grid 2.0 cells. This field contains SMAP a.m.-only data.

vegetation_opacity_[1km/3km]
The measured opacity of the vegetation in the EASE-Grid 2.0 cell. Estimated vegetation opacity at 1 km 3 km spatial scale. Note that this parameter is the same 'tau' parameter normalized by the cosine of the incidence angle in the 'tau-omega' model, where:

$$\tau = \frac{b\,VWC}{\cos\theta}$$

The valid minimum and maximum below are subject to further analysis. This field contains SMAP a.m.-only data.

vegetation_water_content_[1km/3km]
Representative measure of water in the vegetation within the 1 km (or 3 km) EASE-Grid 2.0 cell. This field contains SMAP a.m.-only data.

water_body_fraction_[1km/3km]
Fraction of the area of 1 km (or 3 km) EASE-Grid 2.0 cell that is a permanent or transient water body. Derived from the Digital Elevation Model (DEM) and radar processing. This field contains SMAP a.m.-only data.

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 SPL2SMAP_S product when the SPL2SMAP_S Science Production Software (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 SPL2SMAP_S 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 SPL2SMAP_S 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 SPL3SMP_E product. If only some of the input that contributes to a particular grid cell is fill data, the SPL2SMAP_S SPS will most likely be able to generate some output. However, some portion of the SPL2SMAP_S 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 SPL2SMAP_S product is equal to the values that represent fill. If any exceptions should exist in the future, the SPL2SMAP_S 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 SPL2SMAP_S 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 - 3. 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
UTC	Universal Coordinated Time
V-pol	Vertically polarized