SMAP Enhanced L2 Radiometer Half-Orbit 9 km EASE-Grid Soil Moisture, Version 4

USER GUIDE

How to Cite These Data

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

O'Neill, P. E., S. Chan, E. G. Njoku, T. Jackson, R. Bindlish, and J. Chaubell. 2020. *SMAP Enhanced L2 Radiometer Half-Orbit 9 km EASE-Grid Soil Moisture, Version 4*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/Q8J8E3A89923. [Date Accessed].

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

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/SPL2SMP_E

National Snow and Ice Data Center

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1 DATA DESCRIPTION

1.1 Parameters

The main output of this data set is surface soil moisture (representing approximately the top 5 cm of the soil column on average, given in cm^3/cm^3) presented on the global 9 km EASE-Grid 2.0. Also included are brightness temperature (T_B) measurements (K), representing SMAP Level-1B brightness temperatures.

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 two main groups, Metadata and Soil Moisture Retrieval Data, each of which contains sub-groups and/or data sets:

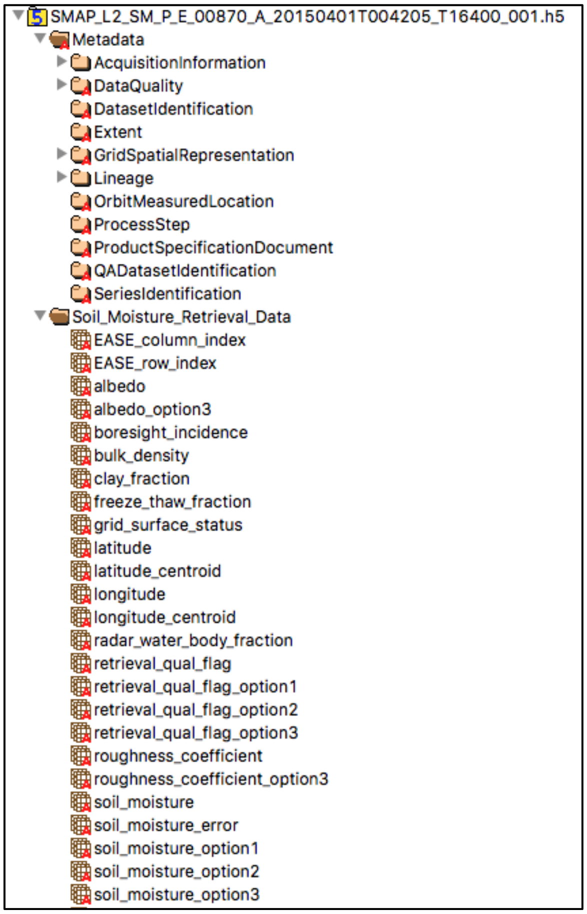

Figure 1. Subset of File Contents. For a complete list of file contents for the SMAP enhanced Level-2 soil moisture product, refer to the Appendix.

1.2.3 Data Fields

The Soil Moisture Retrieval Data group contains soil moisture data, ancillary data, and quality assessment flags. Corrected brightness temperatures are also provided.

All data element arrays are one-dimensional, with the exception of *landcover_class* and *landcover_class_fraction*, which are two-dimensional arrays.

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 (Chan, 2020).

1.2.5 File Naming Convention

Files are named according to the following convention:

`SMAP_L2_SM_P_E_[Orbit#]_[A/D]_yyyymmddThhmmss_RLVvvv_NNN.[ext]`

For example:

`SMAP_L2_SM_P_E_10508_A_20170119T005350_R14010_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_P_E</td><td>Indicates specific product (L2: Level-2; SM: Soil Moisture; P: Passive;
E: Enhanced)</td></tr>
<tr><td>[Orbit#]</td><td>5-digit sequential number of the orbit flown by the SMAP spacecraft when data were acquired. Orbit 00000 began at launch. Orbit numbers increment each time the spacecraft flies over the southernmost point in the orbit path.</td></tr>
<tr><td>[A/D]</td><td>Half-orbit pass of the satellite, such as:
A: Ascending (where satellite moves from South to North, and 6:00 p.m. is the local solar time)
D: Descending (where satellite moves from North to South, and 6:00 a.m. is the local solar time)</td></tr>
<tr><td>yyyymmddThhmmss</td><td>Date/time in Universal Coordinated Time (UTC) of the first 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>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: R14010 indicates a post-launch data product with a version of 4.010.
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 spans from 180°W to 180°E, and from approximately 85.044°N and 85.044°S for the global EASE-Grid 2.0 projection. The swath width is 1000 km, enabling nearly global coverage every two to three days. Figure 2 shows the spatial coverage of the SMAP L-Band Radiometer for one descending half orbit, which comprises one file of this data set.

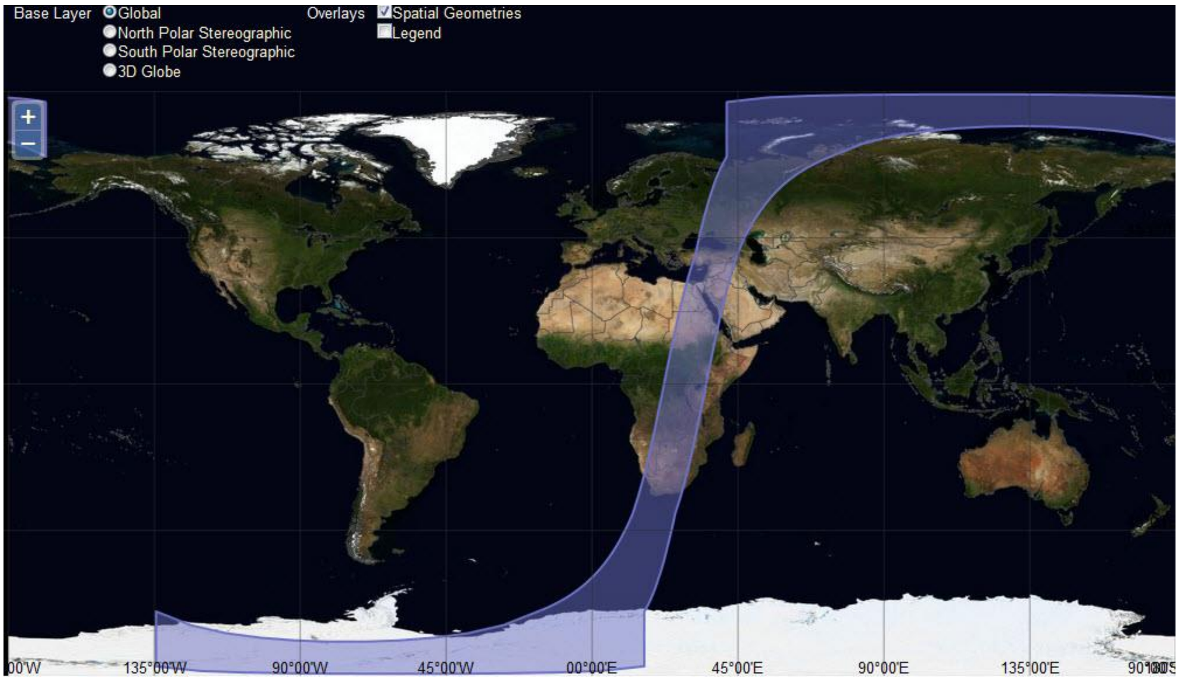

Figure 2. Spatial coverage map displaying one descending half orbit of the SMAP L-Band Radiometer.

1.3.2 Resolution

The native spatial resolution of the radiometer footprint is approximately 36 km. Data are then interpolated, using the Backus-Gilbert optimal interpolation algorithm, to a 9 km grid resolution.

1.3.3 Geolocation

These data are provided on the 9 km global cylindrical EASE-Grid 2.0 equal-area projection. The following tables provide information for geolocating this data set. For more on EASE-Grid 2.0, refer to the EASE Grids website.

Table 2. Geolocation details for the 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

Grid cell size (x, y pixel dimensions)	9,024.31 m (x) 9,024.31 m (y)
Number of columns	3,856
Number of rows	1,624
Geolocated lower left point in grid	85.044° S, 180.000° W
Nominal gridded resolution	9 km by 9 km
Grid rotation	N/A
ulxmap – x-axis map coordinate of the outer edge of the upper-left pixel	-17367530.45
ulymap – y-axis map coordinate of the outer edge of the upper-left pixel	7314540.83

1.4 Temporal Information

1.4.1 Coverage

Coverage spans from 31 March 2015 to 28 October 2021.

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

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.

1.4.3 Latencies

FAQ: What are the latencies for SMAP radiometer data sets?

1.4.4 Resolution

Each Level-2 half-orbit file spans approximately 49 minutes. The SMAP orbit yields a 2-3 day average revisit frequency and repeats the exact swath every 8 days.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

The microwave portion of the electromagnetic spectrum, which includes wavelengths from a few centimeters to a meter, has long held the most promise for estimating surface soil moisture remotely. Passive microwave sensors measure the natural thermal emission emanating from the Earth's surface. The variation in the intensity of this radiation depends on the dielectric properties and temperature of the target medium, which for the near-surface soil layer is a function of the amount of moisture present. Low microwave frequencies (long wavelengths), at L-band or approximately 1 GHz (20-30 cm), offer the following advantages:

- The atmosphere is almost completely transparent, providing all-weather sensing.
- Transmission of signals from the underlying soil is possible through sparse and moderate vegetation layers (up to at least 5 kg/m^2 of vegetation water content).
- Measurement is independent of solar illumination which allows for day and night observations.

For more details, refer to Section 2 of the Algorithm Theoretical Basis Document (ATBD) for this product (O'Neill et al., 2020a), which is available as a Technical Reference.

2.2 Instrumentation

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

2.3 Acquisition

SMAP enhanced Level-2 radiometer soil moisture data (SPL2SMP) are derived from SMAP Enhanced L1C Radiometer Half-Orbit 36 km EASE-Grid Brightness Temperatures, Version 3 (SPL1CTB) and generated by the SMAP Science Data Processing System (SDS) at the Jet Propulsion Laboratory (JPL).

2.4 Processing

SDS processing software ingests the 6:00 a.m. descending and 6:00 p.m. ascending half-orbit files of the SMAP Enhanced L1C Radiometer Half-Orbit 36 km EASE-Grid Brightness Temperatures, Version 3 (SPL1CTB_E) product. The ingested data are then inspected for retrievability criteria according to input data quality, ancillary data availability, and land cover conditions. When retrievability criteria are met, the software invokes the baseline retrieval algorithm, plus two optional soil moisture algorithms, to generate soil moisture retrieval; all algorithms convert SMAP brightness temperatures into estimates of the 0-5 cm surface soil moisture (cm^3/cm^3). Only cells that are covered by the actual swath for a given projection are included in this data set.

The three soil moisture retrieval algorithms are described below. For more information on the soil moisture retrieval algorithms, users should refer to this data set's ATBD (O'Neill et al., 2020a). For information regarding the Backus-Gilbert optimal interpolation algorithm used to enhance these data, refer to the SPL1CTB_E user guide.

2.4.1 Algorithm Inputs and Outputs

The main input to the processing algorithm is the SMAP Enhanced L1C Radiometer Half-Orbit 36 km EASE-Grid Brightness Temperatures, Version 3 (SPL1CTB_E) data set. This product contains time-ordered, geolocated, and calibrated enhanced Level-1B brightness temperatures (T_B) that have been resampled to the fixed 9 km EASE-Grid 2.0. In addition to general geolocation and calibration, the enhanced Level-1B T_B data have also been corrected for atmospheric effects, Faraday rotation, and low-level RFI effects prior to regridding. If the RFI encountered is too large to be corrected, the T_B data are flagged accordingly and no soil moisture retrieval is attempted. Refer to the SPL1BTB and SPL1CTB ATBDs for additional details.

The enhanced Level-1C T_B data (SPL1CTB_E) are the basic input to SPL2SMP_E processing and have been corrected for cases where a significant percentage of the grid cell contains a mix of land and open water (Water/Land Contamination Correction). This procedure corrects for anomalous soil moisture values seen near coastlines in previous versions and should result in less rejected data due to waterbody contamination. The correction is performed in the SPL1CTB_E product at the footprint level using the SMAP radiometer antenna gain pattern. When the antenna-gain-weighted water fraction within the antenna field of view (FOV) is less than or equal to 0.9, and when the antenna boresight falls on a land location as indicated by a static high-resolution land/water mask, the correction is applied. Conversely, when the antenna boresight falls on a water location, and when the water fraction within the antenna field of view (FOV) is greater than or equal to 0.1, the correction is applied. Over land, the resulting brightness temperatures will become warmer upon the removal of the contribution of water compared to the original uncorrected observations. Further details are provided in the Water/Land Contamination Correction section of the SPL1BTB User Guide or ATBD.

In addition to brightness temperature observations, the SPL2SMP_E algorithm requires ancillary data sets for soil moisture retrieval. In order for soil moisture to be accurately retrieved, a variety of global static and dynamic ancillary data are required. Static ancillary data are data which do not change during the mission, while dynamic ancillary data require periodic updates in time frames ranging from seasonally to daily. Static data include parameters such as permanent masks (land, water, forest, urban, mountain, etc.), the grid cell average elevation and slope derived from a Digital Elevation Model (DEM), and soil texture information (primarily sand and clay fraction). Dynamic ancillary data include land cover, surface roughness, precipitation, vegetation parameters, and effective soil temperatures. The specific parameters and sources of ancillary data are listed in Section 6 of the ATBD (O'Neill et al., 2020a).

Note: All input brightness temperatures and ancillary data sets are mapped to the 3-, 9-, and 36-km EASE-Grid 2.0 projection and then aggregated as applicable at a spatial extent that is approximately the same as the native resolution (~36 km) of the SMAP radiometer prior to entering the SPL2SMP_E processor.

2.4.2 Soil Moisture Algorithms

Decades of research by the passive microwave soil moisture community have resulted in a number of viable soil moisture retrieval algorithms that can be used with SMAP brightness temperature data. The European Space Agency (ESA) Soil Moisture and Ocean Salinity Mission (SMOS) mission currently flies an aperture synthesis L-band radiometer which produces T_B data at multiple incidence angles over the same ground location. The baseline SMOS retrieval algorithm is based on the tau-omega model described in Section 2.1 of this data product's ATBD (O'Neill et al., 2020a); SMAP retrievals are also based on the tau-omega model. In essence, this model relates T_B (SMAP Level-1 observations) to soil moisture (SMAP Level-2 retrievals) through ancillary information (e.g. soil texture, soil temperature, and vegetation water content) and a soil dielectric model.

Prior to implementing the soil moisture retrieval, T_B estimates are corrected for water/land contamination (described above and in the SPL1BTB User Guide). Beginning with Version 2 in

2018, the SPL2SMP_E product also includes an improved depth correction scheme for the effective soil temperature (i.e. the *surface_temperature* field), which is a critical parameter in passive soil moisture retrieval - note that **the effective soil temperature is not to be confused with an actual physical temperature measured at a single depth**. This correction scheme reduces the dry bias previously seen when comparing SMAP data to *in situ* data from the core validation sites.

At L-band frequency, the soil depth contributing to microwave emissions (or penetration depth) may be slightly different from the discrete soil depths at which the soil temperatures are available from a land surface model. The resulting discrepancy will lead to dry bias in retrieved soil moisture (i.e. retrieval lower than *in situ* soil moisture) if the model-based effective soil temperature is colder than the soil temperature sensed by the radiometer. Conversely, wet bias of retrieved soil moisture will occur if the model-based effective soil temperature is warmer than the soil temperature sensed by the radiometer. Since the contributing soil depth of microwave emission varies with soil moisture, the corresponding depth correction scheme for the effective soil temperature must account for soil moisture variability in T_B observations acquired between a.m./descending overpasses and p.m./ascending passes. The following modified Choudhury model (Choudhury et al., 1982) achieves this objective, resulting in good agreement between the *in situ* soil temperatures and modeled effective temperatures, and between the *in situ* soil moisture data and the retrieved soil moisture:

$$T_{eff} = K \times [T_{soil2} + C(T_{soil1} - T_{soil2})]$$

where:

C = 0.246 for a.m. soil moisture retrieval and *C* = 1.0 for p.m. soil moisture retrieval; *K* = 1.007 for both a.m and p.m. retrievals; T_{soil1} refers to the average soil temperature for the first soil layer (5-15 cm); and T_{soil2} refers to the average soil temperature for the second soil layer (15-35 cm) of the GMAO GEOS land surface model, also known as the Global Modeling and Assimilation Office (GMAO) Goddard Earth Observing System Model, Version FP (GEOS-FP). A justification for this formulation can be found in the Appendix of this product's ATBD (O'Neill et al., 2020a).

Version 4 of the SPL2SMP_E product contains soil moisture retrieval fields produced by the baseline algorithm and two other optional algorithms (refer to Table 4). The operational SPL2SMP Science Production Software (SPS) produces and stores soil moisture retrieval results from all three algorithms. Within an SPL2SMP file, **the *soil_moisture* field is linked to the retrieval result produced by the current baseline algorithm, the Single Channel Algorithm V-pol (SCA-V)**.

Table 4. Soil Moisture Algorithm Options

Algorithm Options	Corresponding Data Field
Single Channel Algorithm H-pol (SCA-H)	*soil_moisture_option1*
Single Channel Algorithm V-pol (SCA-V) – **current baseline**	*soil_moisture_option2* **(internally linked to the *soil_moisture* field)**
Dual Channel Algorithm (DCA, formerly known as Modified Dual Channel Algorithm or MDCA)	*soil_moisture_option3*

The soil moisture retrieval performance of all three algorithms will be continuously assessed. Recent calibration/validation (cal/val) analyses show similar performance for the current SCA-V baseline and the new DCA algorithm; results from the SCA-H algorithm are somewhat worse than the other two (refer to the Assessment Report; O'Neill et al., 2020b).

All three algorithms operate on the same zeroth-order microwave emission model, commonly known as the tau-omega model. However, the algorithms differ in their approaches and solve for soil moisture under different constraints and assumptions. A brief description of each algorithm is provided below. Users should refer to the SPL2SMP ATBD (O'Neill et al., 2020a) for more details.

2.4.2.1 Single Channel Algorithm (SCA)

In SCA, horizontally (SCA-H) or vertically (SCA-V) polarized brightness temperature (T_B) observations are converted to emissivity using a surrogate for the physical temperature of the emitting layer. The derived emissivity is corrected for vegetation and surface roughness to obtain the soil emissivity. The Fresnel equation is then used to determine the dielectric constant from the soil emissivity. Finally, a dielectric mixing model is used to solve for soil moisture given knowledge of the soil texture.

Analytically, SCA attempts to solve for one unknown variable (soil moisture) from one equation that relates the vertically or horizontally polarized T_B to soil moisture. Vegetation information is provided by a 13-year climatological data base of global Normalized Difference Vegetation Index (NDVI) and a table of parameters based on land cover class.

Although SCA can apply to vertically or horizontally polarized T_B measurements, **SCA-V is the current baseline soil moisture algorithm**. It outperforms the SCA-H algorithm.

2.4.2.2 Dual Channel Algorithm (DCA, formerly known as Modified Dual Channel Algorithm or MDCA)

The Dual Channel Algorithm (DCA) is an extension of the SCA. DCA uses both the vertically and horizontally polarized T_B observations to solve for soil moisture and vegetation optical depth. The algorithm iteratively minimizes a cost function F that is constrained by the vegetation optical depth

(VOD) climatology (τ) that is used as an ancillary input to SCA. The analytical form of this cost function is:

$$F(sm,\tau) = \left(T_{B,V}^{obs} - T_{B,V}^{mod}\right)^2 + \left(T_{B,H}^{obs} - T_{B,H}^{mod}\right)^2 + \lambda^2(\tau - \tau^*)^2$$

where $T_{B,V}^{obs}$ and $T_{B,H}^{obs}$ are the brightness temperatures modeled by the tau-omega model described in the ATBD (O'Neill et al., 2020a) and λ = 20.0. Estimates of certain model parameters (e.g., surface temperature, surface roughness, and vegetation single scattering albedo) must be provided using ancillary data sets in the inversion process. Unlike SCA, the polarization mixing factor is assumed to be linearly related to the roughness parameter *h* as in *Q = 0.1771 h*, where *h* (*roughness_coefficient_option3*, in the product) is provided to the algorithm through a pre-computed static ancillary file with global values of *h* over the 3-km EASE Grid 2.0 projection (see ATBD Section 6.5 for details). In addition to these differences, DCA uses different values than SCA for the vegetation single scattering albedo (*albedo_option3*, in the product). The new values of omega were selected based on several independent sources. Table 4 in the ATBD displays the values of albedo proposed by different independent teams (SMAP L2, SMAP L4, SMOS-I and the Multi-Temporal Dual Channel Algorithm (MTDCA)) and the resulting values used in the DCA implementation. Users should refer to the ATBD (O'Neill et al., 2020a) for more details.

The performance of the DCA implemented in Version 4 is comparable to the performance of the baseline SCA-V algorithm and therefore the SMAP team encourages the users to evaluate both algorithms and opt for the one that is the best fit for the specific application. Note that there is currently no independent verification of the accuracy of the DCA tau retrievals.

2.5 Quality, Errors, and Limitations

2.5.1 Error Sources

Anthropogenic RFI, principally from ground-based surveillance radars, can contaminate both radar and radiometer measurements at L-band frequencies. The SMAP radar and 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 thresholds to detect and, where possible, mitigate RFI.

Level-2 radiometer data can also contain bit errors caused by noise in communication links and memory storage devices. More information about error sources is provided in Section 4.6 of the ATBD (O'Neill et al., 2020a).

2.5.2 Quality Assessment

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

2.5.3 Quality Overview

Each HDF5 file contains metadata with Quality Assessment (QA) metadata flags that are set by the SDS at the JPL prior to delivery to the National Snow and Ice Data Center Distributed Active Archive Center (NSIDC DAAC). A separate 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.

2.5.4 6:00 p.m. Ascending / 6:00 a.m. Descending Half Orbits

Data from both 6:00 a.m. descending and 6:00 p.m. ascending half-orbit passes are used as input for soil moisture derivation. However, the radiometer soil moisture algorithm assumes that the air, vegetation, and near-surface soil are in thermal equilibrium in the early morning hours; thus, retrievals from 6:00 p.m. ascending half-orbit passes may show a slight degradation in quality. Nonetheless, ubRMSE (unbiased root mean square error) and correlation of the p.m. and a.m. retrievals are relatively close.

2.5.5 Data Flags

Bit flags generated from input SMAP data and ancillary data are employed to help determine the quality of the retrievals. Ancillary data help determine either specific aspects of the processing, such as corrections for transient water, or the quality of the retrievals, such as the precipitation flag. These flags provide information as to whether the ground is frozen, covered with snow, flooded, or whether it is actively precipitating at the time of the satellite overpass. Other flags will indicate whether masks for steeply sloped topography or for urban, heavily forested, or permanent snow/ice areas are in effect. Unless otherwise stated, all areal fractions defined below refer to 36 x 36 km^2 inversion domain.

A brief description of data flags contained in *surface_flag* is provided below, including which Bit identifies them (Bit 0 being the "rightmost" bit). For more details on all data flags, users should refer to the Appendix of this User Guide and the Product Specification Document (Chan, 2020).

- **Open Water Flag (Bits 0 and 1)**
  Open water fraction is determined by *a priori* information on permanent open freshwater from the Moderate Resolution Imaging Spectroradiometer (MODIS) MOD44W database. Open water fraction is reported in Bits 0 and 1 in the *surface_flag* field of the SPL2SMP product, with Bit 0 using the MOD44W database. Bit 1 was set to be equal to Bit 0 after the

failure of the SMAP radar on July 5, 2015. This water fraction information serves as a flag to affect soil moisture retrieval processing in the following ways:

- If water fraction is 0.00–0.05, then retrieve soil moisture, but flag for recommended quality.
- If water fraction is 0.05–0.50, then retrieve soil moisture, and flag for uncertain quality.
- If water fraction is 0.50–1.00, then flag, but do not retrieve soil moisture.

- **Urban Area Flag (Bit 3)**
  Since the T_B of man-made, impervious, and urban areas cannot be estimated theoretically, the presence of urban areas in the 36 km Level-2 soil moisture grid cell cannot be corrected for during soil moisture retrieval. Thus, the presence of even a small amount of urban area in the radiometer footprint is likely to adversely bias the retrieved soil moisture. The SMAP urban flag is set based on the Columbia University Global Rural-Urban Mapping Project (GRUMP) data set (O'Neill et al., 2020a). The urban fraction affects soil moisture retrieval processing in the following ways:
    - If urban areal fraction is 0.00–0.25, then retrieve soil moisture, but flag for recommended quality.
    - If urban areal fraction is 0.25–1.00, then flag for uncertain quality, and retrieve soil moisture.
    - If urban areal fraction is above 1.00, then flag, but do not retrieve soil moisture.

- **Precipitation Flag (Bit 4)**
  The SMAP precipitation flag is set based on either forecasts of precipitation or using data from the Global Precipitation Mission (GPM). It is a binary *precipitation/no precipitation* flag which indicates the presence or absence of precipitation in the 36 km grid cell at the time of the SMAP overpass. The presence of liquid precipitation at the time of the SMAP overpass can adversely bias the retrieved soil moisture due to its large impact on T_B; corrections for precipitation are part of the Level-1B T_B processing. Unlike other flags, soil moisture retrieval will always be attempted even if precipitation is flagged. However, this flag serves as a warning to users to view the retrieved soil moisture with some skepticism if precipitation is present.
    - If precipitation is 0–1 mm/hr, then retrieve soil moisture, but flag for recommended quality.
    - If precipitation is 1–25.4 mm/hr, then flag for uncertain quality, and retrieve soil moisture.
    - If precipitation is above 25.4 mm/hr, then flag, but do not retrieve soil moisture.

- **Snow Flag (Bit 5)**
  Although the SMAP L-Band Radiometer can theoretically see through dry snow to the soil underneath a snowpack, the snow flag is set based on the snow fraction as reported in the National Oceanic and Atmospheric Administration (NOAA) Interactive Multisensor Snow

and Ice Mapping System (IMS) database. The snow flag affects soil moisture retrieval processing in the following ways:

- If snow areal fraction is 0.00–0.05, then retrieve soil moisture, but flag for recommended quality.
- If snow areal fraction is 0.05–0.50, then flag for uncertain quality, and retrieve soil moisture.
- If snow areal fraction is above 0.50, then flag, but do not retrieve soil moisture.

- **Frozen Ground Flag (Bits 7 and 8)**

  Frozen ground conditions are reflected in Bits 7 and 8 of the *surface_flag*. Bit 7 is determined by the SMAP radiometer-derived freeze/thaw state and Bit 8 is determined by the effective soil temperature (T_{eff}) estimated using GMAO model soil temperatures (which is stored in the *surface_temperature* data field). The SMAP Level 2 passive soil moisture retrieval processor uses T_{eff} to determine if frozen ground is observed by the SMAP radiometer. When frozen ground is detected, the frozen ground bit (Bit 8) will be set to 1 in the *surface_flag* data field in the product. The frozen soil flag affects soil moisture retrieval processing in the following ways:

  - If frozen ground areal fraction is 0.00–0.05, then retrieve soil moisture, but flag for recommended quality.
  - If frozen ground areal fraction is 0.05–0.50, then flag for uncertain quality, and retrieve soil moisture.
  - If frozen ground areal fraction is 0.50–1.00, then flag, but do not retrieve soil moisture.

  Note: SMAP radiometer freeze/thaw flags are presently validated only for all land regions north of 45°N. While the SPL2SMP_E product contains global SMAP freeze/thaw flags, uncertainty in the flags is higher south of 45°N due to small differences in the SMAP radiometer-derived reference freeze and thaw states upon which the freeze/thaw algorithm is based. More information is available in the SMAP Level-3 Freeze/Thaw (SPL3FTP) Assessment Report (O'Neill et al., 2020b).

- **Mountainous Area Flag (Bit 9)**

  Large and highly variable slopes present in the radiometer footprint will adversely affect the retrieved soil moisture. The SMAP mountainous area flag is derived from high elevation information from a DEM coupled with a statistical threshold based on the slope variability within each 36 km grid cell.

  - If slope standard deviation is 0.0–3.0°, then retrieve soil moisture, but flag for recommended quality.
  - If slope standard deviation is 3.0°–6.0°, then flag for uncertain quality, and retrieve soil moisture.
  - If slope standard deviation is above 6.0°, then flag, but do not retrieve soil moisture.

As with any satellite retrieval data product, proper data usage is encouraged. The following two simple practices are recommended for using SMAP soil moisture retrievals with maximum scientific benefits:

1. Use the *retrieval_qual_flag* field to identify retrievals in the *soil_moisture* field estimated to be of recommended quality. A *retrieval_qual_flag* value of either 0 or 8 indicates high-quality retrievals (8 because a failed F/T retrieval does not affect soil moisture retrieval). Proper use of the *retrieval_qual_flag* field is an effective way to ensure that only retrievals of recommended quality will be used in data analyses.

2. For further investigation, use the *surface_flag* field and the associated definition described above to determine why the *retrieval_qual_flag* field did not report recommended quality at a given grid cell.

3 SOFTWARE AND TOOLS

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

4 VERSION HISTORY

Table 5. Version History

Version	Release Date	Description of Changes
V1	December 2016	First public data release
V2	June 2018	Changes to this version include: • Level-1B water-corrected brightness temperatures are used in passive soil moisture retrieval. This procedure corrects for anomalous soil moisture values seen near coastlines in the previous version and should result in less rejected data due to waterbody contamination. Five new data fields accommodate this correction: *grid_surface_status, surface_water_fraction_mb_h, surface_water_fraction_mb_v, tb_h_uncorrected*, and *tb_v_uncorrected.* • Improved depth correction for effective soil temperature used in passive soil moisture retrieval; new results are captured in the *surface_temperature* data field. This correction reduces the dry bias seen when comparing SMAP data to in situ data from the core validation sites. • Frozen ground flag updated to reflect improved freeze/thaw detection algorithm, providing better accuracy; new results are captured in bit 7 of the *surface_flag*.

Version	Release Date	Description of Changes
V3	August 2019	Changes to this version include: • The Dual Channel Algorithm (DCA) has been replaced by the Modified Dual Channel Algorithm (MDCA). MDCA achieves better retrieval performance through the modeling of polarization mixing between the vertically and horizontally polarized brightness temperature channels, as well as new estimates of single-scattering albedo and roughness coefficients. MDCA supersedes optional algorithms MPRA (option 4) and E-DCA (option 5). • As part of the option algorithm changes, the following data fields were removed: *soil_moisture_option4, vegetation_opacity_option4, retrieval_qual_flag_option4, soil_moisture_option5, vegetation_opacity_option5, retrieval_qual_flag_option5*. • As part of the option algorithm changes, the following data fields were added: *albedo_option3, roughness_coefficient_option3, bulk_density, clay_fraction*. • The baseline algorithm (SCA-V) remains unchanged. • Improved aggregation of values in input ancillary data, e.g. roughness, soil texture, NDVI. The fix has negligible impacts on retrievals estimated to be of recommended quality.
V4	August 2020	Changes to this version include: • Improved calibration methodology was applied to the Level-1B radiometer brightness temperatures. • Improved land surface model outputs from the NASA Global Modeling and Assimilation Office (GMAO) were used to estimate the effective soil temperature used as input to Level-2 soil moisture geophysical inversion. This effective soil temperature is not to be confused with the physical soil temperature at a given depth (Choudhury et al., 1982). • Improved retrieval performance of DCA (formerly known as MDCA or "the option 3" option algorithm in previous releases). DCA retrieves both soil moisture and vegetation optical depth (VOD or tau). • Use of a new global 250-m resolution soils data base called SoilGrid250m, available at https://openlandmap.org. Work is underway to address limited spatial anomalies of these soil property estimates at high latitudes over areas rich in organic soils. • Data quality flags were updated and corrected where faulty. • The baseline algorithm (SCA-V) remains unchanged.

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

April 2022

APPENDIX – DATA FIELDS

This appendix provides a description of all data fields within the *SMAP Enhanced L2 Radiometer Half-Orbit 36 km EASE-Grid Soil Moisture (SPL2SMP)* product. The data are grouped into two main HDF5 groups:

- Metadata
- Soil_Moisture_Retrieval_Data

For a description of metadata fields for this product, refer to the Product Specification Document (Chan, 2020). Table A - 1 describes the Soil_Moisture_Retrieval_Data groups associated with this product, with a more detailed description of each data field below.

Table A - 1. Data Fields for *Soil_Moisture_Retrieval_Data*

Data Field Name	Type	Byte	Unit	Valid Min	Valid Max	Fill/Gap Value	Derivation Method(s)**
EASE_column_index	Uint16	2	N/A	0	963	65534	2
EASE_row_index	Uint16	2	N/A	0	405	65534	2
albedo	Float32	4	N/A	0	1	-9999.0	6
albedo_option3	Float32	4	N/A	0	1	-9999.0	6
boresight_incidence	Float32	4	degrees	0	90	-9999.0	1
bulk_density	Float32	4	N/A	0	3	-9999.0	6
clay_fraction	Float32	4	N/A	0	1	-9999.0	6
freeze_thaw_fraction	Float32	4	N/A	0	1	-9999.0	6, 7
grid_surface_status	Uint16	2	N/A	0	1	65534	8
latitude	Float32	4	degrees	-90	90	-9999.0	2
latitude_centroid	Float32	4	degrees	-90	90	-9999.0	1
longitude	Float32	4	degrees	-180	180	-9999.0	2
longitude_centroid	Float32	4	degrees	-180	180	-9999.0	1
radar_water_body_fraction	Float32	4	N/A	0	1	-9999.0	7
retrieval_qual_flag*	Uint16	2	N/A	0	65536	65534	4
retrieval_qual_flag_option1	Uint16	2	N/A	0	65536	65534	4
retrieval_qual_flag_option2	Uint16	2	N/A	0	65536	65534	4
retrieval_qual_flag_option3	Uint16	2	N/A	0	65536	65534	4
roughness_coefficient	Float32	4	N/A	0	3	-9999.0	6
roughness_coefficient_option3	Float32	4	N/A	0	3	-9999.0	6
soil_moisture*	Float32	4	cm^3/cm^3	0.02	soil porosity	-9999.0	4
soil_moisture_error	Float32	4	cm^3/cm^3	0.0	soil porosity	-9999.0	4 or 6
soil_moisture_option1	Float32	4	cm^3/cm^3	0.02	soil porosity	-9999.0	4
soil_moisture_option2	Float32	4	cm^3/cm^3	0.02	soil porosity	-9999.0	4
soil_moisture_option3	Float32	4	cm^3/cm^3	0.02	soil porosity	-9999.0	4

static_water_body_fraction	Float32	4	N/A	0	1	-9999.0	6
surface_flag	Uint16	2	N/A	0	65536	65534	4
surface_temperature	Float32	4	K	253.15	313.15	-9999.0	6
surface_water_fraction_mb_h	Float32	4	N/A	0	1	-9999.0	1
surface_water_fraction_mb_v	Float32	4	N/A	0	1	-9999.0	1
tb_3_corrected	Float32	4	K	-50	50	-9999.0	1
tb_4_corrected	Float32	4	K	-50	50	-9999.0	1
tb_h_corrected	Float32	4	K	0	330	-9999.0	1
tb_h_uncorrected	Float32	4	K	0	340	-9999.0	1
tb_qual_flag_3	Uint16	2	N/A	0	65536	65534	4
tb_qual_flag_4	Uint16	2	N/A	0	65536	65534	4
tb_qual_flag_h	Uint16	2	N/A	0	65536	65534	4
tb_qual_flag_v	Uint16	2	N/A	0	65536	65534	4
tb_time_seconds	Float64	8	seconds	0	N/A	-9999.0	1
tb_time_utc	Char24	24	N/A	2014-10-31T00:00:00.000Z	N/A	N/A	1
tb_v_corrected	Float32	4	K	0	330	-9999.0	1
tb_v_uncorrected	Float32	4	K	0	340	-9999.0	1
vegetation_opacity*	Float32	4	N/A	0	5	-9999.0	6
vegetation_opacity_option1	Float32	4	N/A	0	5	-9999.0	6
vegetation_opacity_option2	Float32	4	N/A	0	5	-9999.0	6
vegetation_opacity_option3	Float32	4	N/A	0	5	-9999.0	5
vegetation_water_content	Float32	4	kg/m^2	0.0	30.0	-9999.0	6

* These parameters are HDF soft links to the respective baseline value (currently SCA-V)

** **Derivation methods are:**

1. From enhanced Level-1C brightness temperature data
2. From 36 km EASE-Grid 2.0 array definition
3. Value corrected for the presence of water wherever water/land areal fraction is below a threshold; when the fraction is zero, no correction is performed
4. Determined by enhanced Level-2 radiometer soil moisture processing software
5. Available only with option algorithms that use two polarization channels
6. From external ancillary data whose location and time stamp coincide with those of the input data
7. Nearest-neighbor interpolation

Data Field Definitions

EASE_col_index

Zero-based column index of a 9 km EASE-Grid 2.0 cell. In most grid cells, both fore-looking L1C_TB_E data and aft-looking L1C_TB_E data are available for soil moisture retrieval. But when one group (e.g. fore-looking group) is not available, the GridCol parameter of the other group (i.e. aft-looking group) will be written into this parameter.

EASE_row_index

Zero-based row index of a 9 km EASE-Grid 2.0 cell. In most grid cells, both fore-looking L1C_TB_E data and aft-looking L1C_TB_E data are available for soil moisture retrieval. But when one group (e.g. the fore-looking group) is not available, the GridRow parameter of the other group (i.e. the aft-looking group) will be written into this parameter.

albedo

Single-scattering albedo at 9 km grid posting. Note that this parameter is the same 'omega' parameter in the 'tau-omega' model for a given polarization channel.

albedo_option3

Single-scattering albedo at 9-km grid posting derived from landcover-based table used for the Dual-Channel Algorithm (DCA). Note that this parameter is the same ‘omega’ parameter in the ‘tau-omega’ model when used in DCA.

boresight_incidence

Arithmetic average of the same parameters found in the fore- and aft-looking groups in the input L1C_TB_E granule. The resulting parameter thus describes the weighted average of incidence angles of L1B_TB_E observations whose boresights fall within a 9 km EASE-Grid 2.0 cell. The incidence angle is defined as the included angle between the antenna boresight vector and the normal to the Earth's surface.

bulk_density

Bulk density at 9 km grid posting.

clay_fraction

Clay fraction at 9 km grid posting.

freeze_thaw_fraction

Freeze/thaw fraction at 9 km grid posting. The fraction is computed based on the number of frozen land pixels and thawed land pixels reported on the 3-km global cylindrical EASE-Grid 2.0 projection in the SMAP Level 2 Active Soil Moisture Product (L2_SM_A). If there are NF frozen ground pixels and NT thawed land pixels within a 9-km grid cell, this parameter refers to the fraction of NF / (NF + NT). At present the L2_SM_P processing software can be configured to provide this parameter from a dynamic ancillary data database or from the SMAP L2_SM_A product. **Since the failure of the SMAP radar this field has been derived from external soil temperature ancillary data.**

grid_surface_status

Surface type (land or water) as determine by the antenna boresight location. Indicates if the grid point lies on land (0) or water (1).

latitude

Latitude of the center of a 9 km EASE-Grid 2.0 cell.

latitude_centroid

Arithmetic average of the same parameters found in the fore- and aft-looking groups in the input L1C_TB_E granule. The resulting parameter thus describes the weighted average of latitudes of L1B_TB_E observations whose boresights fall within a 9 km EASE-Grid 2.0 cell.

longitude

Longitude of the center of a 9 km EASE-Grid 2.0 cell.

longitude_centroid

Arithmetic average of the same parameters found in the fore- and aft-looking groups in the input L1C_TB_E granule. The resulting parameter thus describes the weighted average of longitudes of L1B_TB_E observations whose boresights fall within a 9 km EASE-Grid 2.0 cell.

radar_water_body_fraction

Radar-derived water body fraction at 9 km spatial scale. The fraction is computed based on the number of water pixels and land pixels reported on the 3-km global cylindrical EASE-Grid 2.0 projection in the SMAP Level 2 Active Soil Moisture Product (L2_SM_A). If there are NW water pixels and NL land pixels within a 9 km grid cell, this parameter refers to the fraction of NW / (NW + NL). Note that NW is the number of water pixels regardless of their temporal span – NW captures both static water pixels and transient water pixels. **Since the failure of the SMAP radar, this field has been set to the *static_water_body_fraction* field**.

retrieval_qual_flag, retrieval_qual_flag_option[1-3]

A 16-bit binary string that indicates whether retrieval was performed or not at a given grid cell. When retrieval is performed, it contains additional bits to further indicate the exit status and quality of the retrieval. A summary of bit definition of the *retrieval_qual_flag* field is listed in Table A - 2. The *retrieval_qual_flag* field is internally linked to the *retrieval_qual_flag_option2* field produced by the baseline algorithm. All soil moisture algorithm options, soil moisture data fields, and corresponding retrieval quality flags are listed in Table A - 3.

roughness_coefficient

Roughness coefficient at 9 km grid posting. Note that this parameter is the same 'h' coefficient in the 'tau-omega' model for a given polarization channel.

roughness_coefficient_option3

Roughness coefficient at 9-km grid posting derived from 3 km global map of ‘h’ created by the Dual-channel Algorithm (DCA). Note that this parameter is the same ‘h’ coefficient in the ‘tau-omega’ model when used in DCA.

soil_moisture_error

Estimated '1-sigma' error of the *soil_moisture* output parameter. The valid minimum (0.00) and maximum (soil porosity) are subject to further analysis on real data. This data field is currently filled with FillValue (-9999.0).

soil_moisture, soil_moisture_option[1-3]
Estimated soil moisture at 9 km grid posting, as returned by the L2_SM_P processing software. The *soil_moisture* field is internally linked to the *soil_moisture_option2* field produced by the baseline algorithm. At present, the operational SPL2SMP Science Production Software (SPS) produces and stores soil moisture retrieval results from the three algorithms listed in Table A - 3; retrieval quality flags that correspond to each of these algorithms are also listed in Table A - 3.

static_water_body_fraction
Static water body fraction at 9 km grid posting. The fraction is computed based on the number of water pixels and land pixels reported on a 250-meter grid. If there are NW water pixels and NL land pixels within a 9 km grid cell, this parameter refers to the fraction of NW / (NW + NL). Note that NW is the number of water pixels regardless of their temporal span – NW captures both static water pixels and transient water pixels from when the original data were acquired.

surface_flag
A 16-bit binary string that indicates the presence or absence of certain surface conditions at a grid cell. Table A - 4 includes a summary of surface conditions and their thresholds, where ‘0’ indicates the presence of a surface condition favorable to soil moisture retrieval. Each surface condition is numerically compared against two non-negative thresholds: T1 and T2, where T1 < T2. In most cases, when a surface condition is found to be below T1, retrieval is attempted and flagged for recommended quality. Between T1 and T2, retrieval is still attempted but flagged for uncertain quality. Above T2, retrieval is skipped. The *surface_flag* field is internally linked to the *surface_flag* field associated with the baseline algorithm.
Note: Bit position '0' refers to the least-significant bit. Final bit positions and definitions are subject to future revision and expansion as needed.

surface_temperature
Effective soil temperature (Choudhury, 1982) at 9-km grid spacing. This parameter is used as an input ancillary data parameter to the L2_SM_P processing software for both baseline and option algorithms, **and is not to be confused with an actual physical temperature measured at a single depth**. The valid minimum and maximum below are subject to further analysis on real data.
Note: 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).

Table A - 2. Retrieval Quality Flag Definition

Bit	Retrieval Information	Bit Value and Interpretation
0	Recommended Quality	0: Soil moisture retrieval has recommended quality
		1: Soil moisture retrieval doesn't have recommended quality
1	Retrieval Attempted	0: Soil moisture retrieval was attempted
		1: Soil moisture retrieval was skipped
2	Retrieval Successful	0: Soil moisture retrieval was successful
		1: Soil moisture retrieval was not successful
3*	Retrieval Successful	0: Freeze/thaw state retrieval was successful
		1: Freeze/thaw state retrieval was not successful
4-15	Undefined	0 (not used)

Table A - 3. Soil Moisture Algorithm Options and Corresponding Data Fields

Soil Moisture Algorithm Option	Corresponding Soil Moisture Data Field	Corresponding Retrieval Quality Flag Data Field
Single Channel Algorithm H-pol (SCA-H)	*soil_moisture_option1*	*retrieval_qual_flag_option1*
Single Channel Algorithm V-pol (SCA-V) – Current Baseline	*soil_moisture_option2* (Internally linked to the *soil_moisture* field)	*retrieval_qual_flag_option2* (Internally linked to the *retrieval_qual_flag* field)
Dual Channel Algorithm (DCA)	*soil_moisture_option3*	*retrieval_qual_flag_option3*

Table A - 4. Surface Condition Bit Flag Definition

Bit	Surface Condition	T1	T2	Bit Value and Interpretation
0	Static Water	0.05	0.50	0: Water areal fraction ≤ T1 and IGBP wetland fraction < 0.50: ⇒ Retrieval attempted for fraction ≤ T2
				1: Otherwise ⇒ Retrieval skipped for fraction > T2
1	Radar-derived Water Fraction (no longer available and now defaults to match Bit 0)	0.05	0.50	0: Water areal fraction ≤ T1 and IGBP wetland fraction < 0.50: ⇒ Retrieval attempted for fraction ≤ T2
				1: Otherwise ⇒ Retrieval skipped for fraction > T2
2	Coastal Proximity	N/A	1.0	0: Distance to nearby significant water bodies > T2 (# of 36-km grid cells)
				1: Otherwise
3	Urban Area	0.25	1.00	0: Urban areal fraction ≤ T1 ⇒ Retrieval attempted for fraction ≤ T2
				1: Otherwise ⇒ Retrieval skipped for fraction > T2
4	Precipitation	2.78e-04 (= 1.0 mm/hr)	7.06e-03 (= 25.4 mm/hr)	0: Precipitation fraction ≤ T1 ⇒ Retrieval attempted for fraction ≤ T2
				1: Otherwise: ⇒ Retrieval skipped for fraction > T2
5	Snow	0.05	0.50	0: Snow areal fraction ≤ T1 ⇒ Retrieval attempted for fraction ≤ T2
				1: Otherwise: ⇒ Retrieval skipped for fraction > T2
6	Permanent Ice	0.05	0.50	0: Ice areal fraction ≤ T1 ⇒ Retrieval attempted for fraction ≤ T2
				1: Otherwise ⇒ Retrieval skipped for fraction > T2
7	Frozen Ground (from radiometer-derived FT state)	0.05	0.50	0: Frozen ground areal fraction ≤ T1 ⇒ Retrieval attempted for fraction ≤ T2
				1: Otherwise ⇒ Retrieval skipped for fraction > T2
8	Frozen Ground (from modeled effective soil temperature)	0.05	0.50	0: Frozen ground areal fraction ≤ T1 ⇒ Retrieval attempted for fraction ≤ T2
				1: Otherwise ⇒ Retrieval skipped for fraction > T2
9	Mountainous Terrain	3°	6°	0: Slope standard deviation ≤ T1
				1: Otherwise
10	Dense Vegetation	5.0	30.0	0: Vegetation Water Content (VWC) ≤ T1 ⇒ Retrieval attempted for VWC ≤ T2
				1: Otherwise ⇒ Retrieval skipped for VWC > T2
11	Nadir Region / Undefined			0 (not used in SPL2SMP)
12-15	Undefined			0

surface_water_fraction_mb_h

Water fraction with the SMAP radiometer main-beam (mb) IFOV weighted by antenna gain pattern at the horizontal polarization.

surface_water_fraction_mb_v

Water fraction with the SMAP radiometer main-beam (mb) IFOV weighted by antenna gain pattern at the vertical polarization.

tb_3_corrected

Arithmetic average of the same parameters found in the fore- and aft-looking groups in the input L1C_TB_E granule. The resulting parameter thus describes the weighted average of L1B_TB_E 3^{rd} Stokes polarized brightness temperatures whose boresights fall within a 9 km EASE-Grid 2.0 cell.

tb_4_corrected

Arithmetic average of the same parameters found in the fore- and aft-looking groups in the input L1C_TB_E granule. The resulting parameter thus describes the weighted average of L1B_TB_E 4^{th} Stokes vertically polarized brightness temperatures whose boresights fall within a 9 km EASE-Grid 2.0 cell.

tb_h_corrected

Arithmetic average of the same parameters found in the fore- and aft-looking groups in the input L1C_TB_E granule. The resulting parameter thus describes the weighted average of L1B_TB_E horizontally polarized brightness temperatures whose boresights fall within a 9 km EASE-Grid 2.0 cell. Wherever water fraction is below a threshold, water brightness temperature correction is applied to this parameter prior to SPL2SMP inversion.

tb_h_uncorrected

Arithmetic average of the same parameters found in the fore- and aft-looking groups in the input L1C_TB granule. The resulting parameter describes the weighted average of the L1B_TB horizontally polarized brightness temperatures *prior to water correction* whose boresights fall within a 9 km EASE-Grid 2.0 cell.

tb_qual_flag_3

A 16-bit or two-byte binary number formed by applying a Boolean 'AND' operation between the same parameters from both fore- and aft-looking groups in the input L1C_TB_E granule. A '0' indicates that both the fore-looking and aft-looking L1C_TB_E observations satisfy a given quality criterion described in L1B_TB_E's *tb_qual_flag_3* output parameter; a '1' indicates that the same criterion is violated by either fore-looking or aft-looking (or both) L1C_TB_E observations. Bit position '0' refers to the least-significant digit. The possible values for each bit position are shown in Table A - 5.

tb_qual_flag_4

A 16-bit or two-byte binary number formed by applying a Boolean 'AND' operation between the same parameters from both fore- and aft-looking groups in the input L1C_TB_E granule. A '0' indicates that both the fore-looking and aft-looking L1C_TB_E observations satisfy a given quality criterion described in L1B_TB_E's *tb_qual_flag_4* output parameter; a '1' indicates that the same criterion is violated by either fore-looking or aft-looking (or both) L1C_TB_E observations. Bit position '0' refers to the least significant digit. The possible values for each bit position are shown in Table A - 5.

tb_qual_flag_h

A 16-bit or two-byte binary number formed by applying a Boolean 'AND' operation between the same parameters from both fore- and aft-looking groups in the input L1C_TB_E granule. A '0' indicates that both the fore-looking and aft-looking L1C_TB_E observations satisfy a given quality criterion described in L1B_TB_E's *tb_qual_flag_h* output parameter; a '1' indicates that the same criterion is violated by either fore-looking or aft-looking (or both) L1C_TB_E observations. Bit position '0' refers to the least significant digit. The possible values for each bit position are shown in Table A - 5.

tb_qual_flag_v

A 16-bit or two-byte binary number formed by applying a Boolean 'AND' operation between the same parameters from both fore- and aft-looking groups in the input L1C_TB_E granule. A '0' indicates that both the fore-looking and aft-looking L1C_TB_E observations satisfy a given quality criterion described in L1B_TB_E's *tb_qual_flag_v* output parameter; a '1' indicates that the same criterion is violated by either fore-looking or aft-looking (or both) L1C_TB_E observations. Bit position '0' refers to the least significant digit. The possible values for each bit position are shown in Table A – 5.

tb_time_seconds

Arithmetic average of the same parameters found in the fore- and aft-looking groups in the input L1C_TB granule. The resulting parameter thus describes the average of UTC acquisition times of L1B_TB observations whose boresights fall within a 9 km EASE-Grid 2.0 cell. The result is then expressed in J2000 seconds [the number of seconds since 12:00:00.000 on January 1, 2000 Barycentric Dynamical Time (TDB)].

tb_time_utc

Arithmetic average of the same parameters found in the fore- and aft-looking groups in the input L1C_TB granule. The resulting parameter thus describes the average of UTC acquisition times, in ASCII representation, of L1B_TB observations whose boresights fall within a 9 km EASE-Grid 2.0 cell.

Table A - 5. Bit Definitions for Brightness Temperature Quality Flags

Bit Position	Bit Value and Interpretation for *tb_qual_flag_3|4*	Bit Value and Interpretation for *tb_qual_flag_h|v*
0	0 = Observation had acceptable quality	
	1 = Observation does not have acceptable quality	
1	0 = Observation within physical range	
	1 = Observation beyond physical range	
2	0 = RFI was not detected in the observation	
	1 = RFI was detected in the observation	
3	0 = RFI was detected and corrected in the observation	
	1 = RFI was detected but not correctable in the observation	
4	0 = Observation has acceptable NEDT	
	1 = Observation did not have acceptable NEDT	
5	0 = Direct sun correction was successful	
	1 = Direct sun correction was not successful	
6	0 = Reflected sun correction was successful	
	1 = Reflected sun correction was not successful	
7	0 = Reflected moon correction was successful	
	1 = Reflected moon correction was not successful	
8	0 = Direct galaxy correction was successful	
	1 = Direct galaxy correction was not successful	
9	0 = Reflected galaxy correction was successful	
	1 = Reflected galaxy correction was not successful	
10	0 = Atmosphere correction was successful	
	1 = Atmosphere correction was not successful	
11	*Intentionally left undefined*	0 = Faraday rotation correction was successful
		1 = Faraday rotation correction was not successful
12	0 = Observation was a valid value	
	1 = Observation was a null value	
13	0 = Observation was within half orbit	0 = Water correction was not performed
	1 = Observation was outside half orbit	1 = Water correction was performed
14	0 = TA minus TA_FILTERED was less than a threshold	
	1 = TA minus TA_FILTERED was greater than a threshold	
15	0 = Observation was RFI-free	
	1 = Observation was RFI-contaminated	

tb_v_corrected

Arithmetic average of the same parameters found in the fore- and aft-looking groups in the input L1C_TB granule. The resulting parameter thus describes the weighted average of L1B_TB vertically polarized brightness temperatures whose boresights fall within a 9 km EASE-Grid 2.0 cell. Wherever water fraction is below a threshold, water brightness temperature correction is applied to this parameter prior to SPL2SMP inversion.

tb_v_uncorrected

Arithmetic average of the same parameters found in the fore- and aft-looking groups in the input L1C_TB granule. The resulting parameter describes the weighted average of the L1B_TB vertically polarized brightness temperatures **prior to water correction** whose boresights fall within a 9 km EASE-Grid 2.0 cell.

vegetation_opacity, vegetation_opacity_option[1-3]

Estimated vegetation opacity at 9-km grid posting, as returned by the L2_SM_P processing software. Note that this parameter is the same 'tau' parameter normalized by the cosine of the incidence angle in the 'tau-omega' model:

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

where b is a landcover-based parameter described in the SMAP Level 2/3 Passive Soil Moisture Product ATBD, VWC is vegetation water content in kg/m^2 derived from NDVI climatology, and θ is the incidence angle (= 40°) for SMAP. The valid minimum (0.0) and maximum (5.0) are subject to further analysis on real data. The *vegetation_opacity* field is internally linked to the *vegetation_opacity_option2* field produced by the baseline algorithm.

vegetation_water_content

Vegetation water content at 9 km grid posting. This parameter is used as input ancillary data parameter to the L2_SM_P processing software when the baseline algorithm is used. The valid minimum (0.0) and maximum (30.0) are subject to further analysis on real 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 SMAP enhanced Level-2 soil moisture product when the enhanced Level-2 soil moisture 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 SMAP enhanced Level-2 soil moisture 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 enhanced Level-2 soil moisture product records any outcome that can be calculated with the available input. Missing data appear as fill values.
- Non-essential information is missing from the input data stream. The lack of non-essential information does not impair the algorithm from generating needed output. The missing data appear as fill values.
- Fill values appear in the input radiometer the enhanced Level-1C brightness temperature product.

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 enhanced Level-2 soil moisture product is equal to the values that represent fill. If any exceptions should exist in the future, the enhanced Level-2 soil moisture 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 enhanced Level-2 soil moisture product records gaps in the product level metadata. The following conditions will indicate that no gaps appear in the data product:

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

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

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

Acronyms and Abbreviations

Table A - 6. Acronyms and Abbreviations

Abbreviation	Definition
Char	8-bit character
IGBP	International Geosphere-Biosphere Programme
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
NF	Number of frozen ground pixels
NL	Number of land pixels
NT	Number of thawed land pixels
NW	Number of water pixels
SI	International System of Units
SPL2SMP_E	SMAP Enhanced L2 Radiometer Half-Orbit 36 km EASE-Grid Soil Moisture
SPS	Science Production Software
T1, T2	Threshold 1, Threshold 2
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
VWC	Vegetation Water Content