SMAP L2 Radar Half-Orbit 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:

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FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/SPL2SMA

National Snow and Ice Data Center

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1 DATA DESCRIPTION

1.1 Parameters

Surface soil moisture (0-5 cm) in cm^3/cm^3 derived from sigma nought measurements is output on a fixed 3 km EASE-Grid 2.0.

Sigma nought (sigma0), or the backscatter coefficient, is a measure of the strength of radar signals reflected back to the instrument from a target, and is defined as per unit area on the ground. Usually expressed in dB, it is a normalized dimensionless number, comparing the strength observed to that expected from a defined area. The SMAP L-band Radar measures sigma0 using VV, HH, and HV transmit-receive polarizations, and uses separate transmit frequencies for the H (1.26 GHz) and V (1.29 GHz) polarizations. 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 Web site.

1.2.2 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 element arrays are one-dimensional with a size N, where N is the number of valid cells from the radar swath that appear on the grid.

1.2.2.1 Ancillary Data

Includes all ancillary data, such as surface temperature and vegetation water content.

1.2.2.2 Radar Data

Includes all radar data, such as cross-polarized sigma0 (sigma nought; also σ0) data.

1.2.2.3 Soil Moisture Retrieval Data

Includes soil moisture data and quality assessment flags.

1.2.3 Metadata Fields

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

1.2.4 Directory Structure

Figure 1. Subset of File Contents

For a complete list of file contents for the SMAP Level-2 radar soil moisture product, refer to the Appendix of this document.

1.2.5 Naming Convention

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

SMAP_SPL2SMA_[Orbit#]_D_yyyymmddThhmmss_RLVvvv_NNN.[ext]

For example:

SMAP_SPL2SMA_00934_D_20151225T074951_R13171_002.h5

Table 1. File Naming Conventions

Variable	Description
SMAP	Indicates SMAP mission data
SPL2SMA	Indicates specific product (L2: Level-2; SM: Soil Moisture; A: Active)
[Orbit#]	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.
D	Descending half-orbit pass of the satellite (where satellite moves from North to South, and 6:00 a.m. is the local solar equator crossing time)
yyyymmddThhmmss	Date/time in Universal Coordinated Time (UTC) of the first data element that appears in the product, where: • yyyymmdd4-digit year, 2-digit month, 2-digit day • T Time (delineates the date from the time, i.e. yyyymmddThhmmss) • hhmmss2-digit hour, 2-digit month, 2-digit second
RLVvvv	Composite Release ID, where: • R Release • L Launch Indicator (1: Post-launch standard data) • V 1-Digit Major Version Number • vvv 3-Digit Minor Version Number Example: R13171 indicates a standard data product with a version of 3.171. Refer to the SMAP Data Versions page for version information.
NNN	Number of times the file was generated under the same version for a particular date/time interval (002: 2nd time)
.[ext]	File extensions include: .h5 HDF5 data file .qa Quality assurance file .xml Metadata file

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. The gap in coverage at both the North and South Pole, called a pole hole, has a radius of approximately 400 km. The swath width is 1000 km, enabling nearly global coverage every three days.

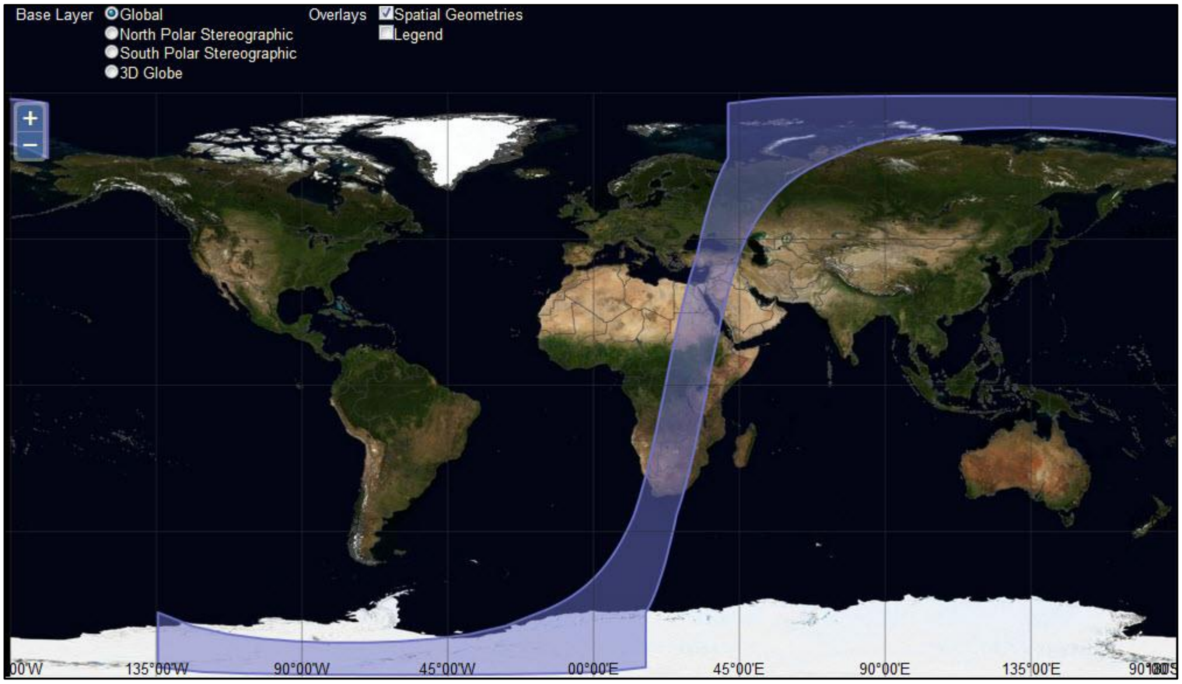

Figure 2. Spatial Coverage Map displaying one descending half orbit of the SMAP L-Band Radar.

1.3.2 Resolution

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

1.3.2.1 EASE-Grid 2.0

These data are provided on the global cylindrical EASE-Grid 2.0 (Brodzik et al. 2012). Each grid cell has a nominal area of approximately 3 x 3 km^2 regardless of longitude and latitude.

EASE-Grid 2.0 has a flexible formulation. By adjusting a single scaling parameter, a family of multi-resolution grids that nest within one another can be generated. The nesting can be adjusted so that smaller grid cells can be tessellated to form larger grid cells. Figure 3 shows a schematic of the nesting.

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

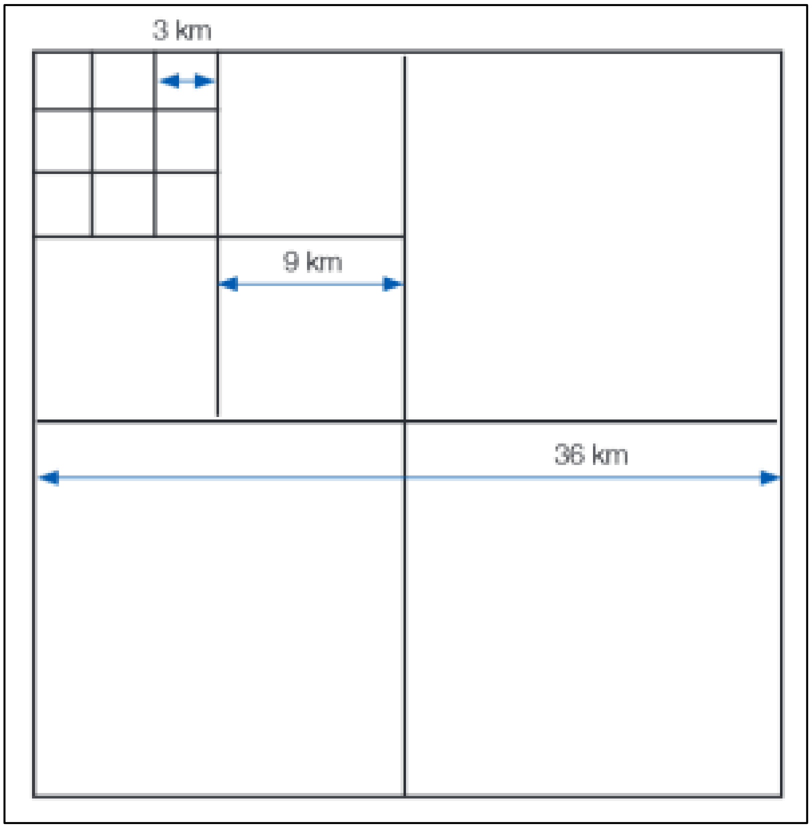

Figure 3. Perfect Nesting in EASE-Grid 2.0

1.4 Temporal Information

1.4.1 Coverage

Coverage spans from 13 April 2015 to 07 July 2015.

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

1.4.2 Satellite and Processing Events

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

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

1.4.3 Resolution

Each Level-2 half-orbit file spans approximately 49 minutes.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

Retrieval of soil moisture from measured backscatter data typically implies an inversion of the radar forward scattering process. Bare rough surfaces can be characterized in terms of their Root Mean Square (RMS) roughness height, correlation length, and moisture content (a surrogate for dielectric constant). The use of time-series data makes the retrieval a well-constrained estimation problem, under the assumption of a time invariant surface roughness. By taking a co-polarized ratio the soil moisture retrieval becomes insensitive to the correlation length except for very rough surfaces, which enables an accurate retrieval of soil moisture without correlation length information. This approach has been extended to the vegetated surface by introducing a vegetation axis to a lookup table (Kim et al. 2014). A one-axis representation of the vegetation effect is clearly a simplification, considering that different sets of vegetation parameters result in different backscattering coefficients. However, with SMAP's three measurement channels—HH, VV, and HV—at most three independent parameters can be uniquely estimated, and therefore simplified forward models must be represented in terms of at most three dominant parameters. The simplification results in some errors in soil moisture retrieval, especially in heavily vegetated areas such as forests. Allometric relationships reduce the number of unknowns and may improve the retrievals. The three parameters used to simplify the scattering model are then the dielectric constant of soil, ε, soil surface roughness, s, and VWC.

The SMAP radar HV-channel measurements are reserved for possible use in correcting vegetation effects. The remaining two co-polarized (co-pol) measurements (HH and VV) are not always sufficient to determine s and ε (Kim et al. 2014). One of the main causes is the ambiguity in bare surface scattering: a wet and smooth surface may have the same backscatter as a dry and moderately rough surface. Very often the timescale of the change in s is longer than that of ε (Jackson et al. 1997). Then s may be constrained to be a constant in time, thus resolving the ambiguity (Kim et al. 2014).

The SMAP baseline approach (Kim et al. 2012; Kim et al. 2014) is a multichannel retrieval algorithm that searches for a soil moisture solution such that the difference between modeled and observed backscatter is minimized in the least squares sense. A look-up table representation, or data cube, of a complicated forward model has been demonstrated to be an accurate and fast tool for retrieval (Kim et al. 2012; Kim et al. 2014). The algorithm estimates s first and then retrieves εr using the estimated s. Vegetation effects are included by selecting the sigma0 of the forward model at the VWC level given by an ancillary source. Note that the VWC provided by ancillary information is allowed to vary throughout the time series.

For in-depth information regarding the physics involved in deriving soil moisture from backscatter, refer to the ATBD for this product, Section 2: Physics of the Scattering Problem (Kim et al. 2014).

2.2 Acquisition

SMAP Level-2 radar soil moisture data (SPL2SMA) are derived from SMAP High-Resolution Radar Sigma Nought, Version 3 (SPL1CS0) data.

2.3 Derivation Techniques and Algorithms

SMAP Level-2 active soil moisture data are derived from SMAP High-Resolution Radar Sigma Nought, Version 3 (SPL1CS0) data. Utilizing the soil moisture algorithms discussed below, SMAP sigma0 measurements are converted into an estimate of the surface soil moisture of the 0-5 cm surface soil moisture in units of cm^3/cm^3. The following information has been adapted from Kim et al. 2014 and Kim et al. 2015.

2.3.1 Soil Moisture Algorithms

The baseline retrieval algorithm inverts a forward scattering model. The equation for forward scattering (Eq. 2-1 in Kim et al. 2015) presents four unknowns: RMS height (*s*), dielectric constant (ε), correlation length (*l*), and vegetation water content (VWC). It will be shown that mv retrievals are insensitive to errors in knowledge of the correlation length over a wide range of m_v, roughness, and correlation lengths (Appendix 5.2) (Kim et al. 2012b). An exponential function is known to describe empirical measurements well (Mattia et al. 1997; Shi et al. 1997), which was used in the forward model and was not considered as an unknown during the retrieval. As an introduction to the discussion of the retrieval algorithm, and to place the discussion of each algorithm component in the proper context, the overall algorithm processing flow is described in the following section. Each portion of the algorithm flow, and the details of the retrieval methods and options, will then be described in detail in the subsequent sections.

2.3.2 Algorithm Flow

The algorithm flow of the SPL2SMA is presented in Figure 11 of Kim et al. 2015. The portion of the flowchart through the land surface classification is the initial processing done as a precursor to the actual retrievals. The SPL2SMA processor reads in 1 km resolution sigma0 from the SMAP Level-1C sigma nought product. The 1 km data in natural unit are aggregated onto the 3 km EASE-Grid, during which various quality flags are applied. Three quality flags are derived using the 3 km sigma0 freeze-thaw state (refer to the SPL3FTA ATBD, Kim et al. 2014), radar vegetation index (Section 3.4.2 of the SPL3FTA ATBD, Kim et al. 2014), and transient water body (Section 3.4.3 of the SPL3FTA ATBD, Kim et al. 2014). Static and dynamic ancillary data are sampled for each pixel of the SPL2SMA product. Sigma0 values from the past time are sampled and used by the time-series algorithm. For each 3 km pixel, land cover class information is obtained from the mostly annual ancillary data. The land cover information allows to choose an appropriate data cube for each pixel. The retrieval over the different land cover classes is spatially assembled to create a half-orbit output, followed by the conversion from the dielectric constant to soil moisture.

2.3.3 Baseline Algorithm: Time-series Data-cube Approach

TIME-SERIES RETRIEVAL

The SMAP radar provides three independent channels (HH, VV, and HV). HV-channel measurements are reserved for possible use in correcting vegetation effects. The remaining two co-pol measurements (HH and VV) are not always sufficient to determine *s* and ε (see Section 3.2.4 in Kim et al. 2015) (Kim et al. 2012b). One of the main causes is the ambiguity in bare surface scattering: a wet and smooth surface may have the same backscatter as a dry and moderately rough surface has. Very often the time-scale of the change in s is longer than that of ε (Jackson et al. 1997). Then *s* may be constrained to be a constant in time, thus resolving the ambiguity (Kim et al. 2012b). The concept of ε time-invariant s has also been utilized in other studies (Joseph et al. 2008; Mattia et al. 2009; Verhoest et al. 2007). The SMAP baseline algorithm differs from these studies in that no ancillary or ground measurements or statistical assumptions are required to constrain *s*.

The SMAP baseline approach (Kim et al. 2012a; Kim et al. 2012b) is a multichannel retrieval algorithm that searches for a soil moisture solution such that the difference between computed and observed backscatter is minimized in the least squares sense. The algorithm estimates s first and then retrieves εr using the estimated *s*. Vegetation effects are included by selecting the forward model's sigma0 at the VWC level given by an ancillary source or the SMAP HV measurements. The algorithm retrieves *s* and real part of dielectric constant (εr) using a time series of N co-pol backscatter measurements: σ0 HH (t1), σ^0 VV (t1), σ^0 HH (t2), σ^0 VV (t2),..., σ^0 HH (t N), and σ^0 VV (tN).

There are thus 2 N independent input observations and N+1 unknowns consisting of N εr values and one *s* value. Note that the VWC provided by ancillary information is allowed to be varying throughout the time series.

Radar backscattering coefficients before conversion to decibels can be modeled as Gaussian random variables (Ulaby et al. 1986) to account for speckle and thermal noise effects. Assuming sufficient integration following power detection, the backscattering coefficient after conversion to decibels can also be modeled as a Gaussian random variable. Because SMAP will observe HH and VV returns at slightly different center frequencies, the effects of speckle and thermal noise on these measurements are statistically independent. Statistical independence of speckle in measurements at differing time steps is also expected. These facts and a maximum likelihood formulation motivate least-squares retrieval approaches based on the average of individual error terms. It is noted that calibration, radio frequency interference, and other error sources may produce correlated error terms. The systematic and correlated components from these sources will be corrected. Any residual *s* may impact overall algorithm performance and are modeled as uncorrelated Gaussian noise in the ATBD for this product (although they may still contain correlated noise).

Additional details are provided in the ATBD (Kim et al. 2014).

2.3.4 Snapshot Retrieval

When the number of time-series input is set to 1, the time-series method becomes a conventional snapshot approach. εr and *s* are adjusted simultaneously at each time instance so as to minimize the distance between the data cube prediction and the observation. The snapshot retrieval algorithm was also tested with the two sets of field campaign data used in Section 3.2.3 of the ATBD (Kim et al. 2015). Figure 14a in the ATBD (Kim et al. 2015) shows that the bare surface retrieval has an RMSE of 0.055 cm^3/cm^3, which is larger than the error of the time-series retrieval. Closer examination however indicates that the retrieval error increases for larger soil moisture. When the performance of the Monte Carlo simulation of the Kp effect is compared between time-series (Figure 12a of the ATBD) and snapshot (Figure 12c of the ATBD) retrievals, the performance difference is much greater than the in situ validation shows (Kim et al. 2015). The radar measurement error of the in situ data (~0.3 dB) is smaller than simulated by the Monte Carlo analysis, which may explain why the Monte Carlo analysis of the snapshot retrieval show the poorer performance.

The snapshot retrieval over the pasture surface is poor. Figure 14b in the ATBD (Kim et al. 2015) shows a retrieval error of 0.105 cm^3/cm^3. It is possible that the structure of the grass was important in characterizing the backscatter to be very different from that of the bare surface. The possibility is supported also by the large retrieval error (not shown) when the retrieval was performed using the bare surface data cube (NMM3D) after treating the grass surface as if it is a bare surface. The evaluation results suggest the limited applicability of the snapshot retrieval, and highlights the need for time-series retrievals.

2.3.5 Optional Algorithm

CHANGE DETECTION BY KIM AND VAN ZYL (KVZ)

The full details of this algorithm are described by Kim and van Zyl (2009). A brief summary is presented here. An expression will be derived to relate the backscattering cross section to soil moisture as:

$$m_v = f\,(\sigma_{hh}, \sigma_{vv})$$

where the normalized radar cross sections are expressed in decibels. Since this expression depends on the biomass level, the cross-polarization will be used to compensate the biomass variation over time: how this will be implemented is being studied. One potential choice for f is given by:

Equation 1

$$f(\sigma_{hh}, \sigma_{vv}) = C_0 + C_1 \frac{\sigma_{hh} + \sigma_{vv}}{2}$$

These two coefficients for each pixel will be determined using the expected minimum and maximum values for soil moisture and the time-series backscattering cross section data. Accommodating different vegetation phenology during the implementation of the above relationship remains as a task. The obvious assumption contained in Equation 1 is that there is a linear relationship between the radar cross-sections and the soil moisture. However, simulated data suggests that this relationship may be nonlinear. Ground radar and airborne data will be used to derive the final expression for the function $f\,(\sigma_{hh}, \sigma_{vv})$.

The slowly varying backscattering cross section component due to the biomass variation will be estimated and compensated using the cross-polarization backscattering cross section. Ground radar measurements will help derive the expression before the SMAP instrument is launched. However, since the ground measurements are limited, with simulated data various vegetation environments will be considered. When the two extreme conditions (completely dry and wet) of the soil moisture and radar backscatter are known exactly, a test with a corn field experiment shows that the soil moisture may be retrieved with an error of 0.026 cm^3/cm^3 (Table 3 of Kim and van Zyl). When the errors in the two extreme values are simulated with the random noise, the retrieval error reaches 0.05 cm^3/cm^3. Alternatively, Kim and van Zyl proposed that C1 at each radar pixel (e.g., at 3 km resolution) is inverted using the mv retrieved at a coarse scale (such as at 36 km resolution) using the radiometer records. The radar-radiometer method is the subject of the ATBD for the SPL2SMAP and SPL3SMAP products (Kim et al. 2015).

Additional details are provided in the ATBD (Kim et al. 2014, Kim et al. 2015).

Note: Algorithms that are currently not being used for these data include Snapshot, Dubois/van Zyl (DVZ), and Shi. Thus, the following data fields contain a fill value of -9999.0:

- soil_moisture_snapshot
- soil_moisture_snapshot_DVZ
- soil_moisture_snapshot_shi

2.3.6 Algorithm Inputs and Outputs

Table 2 lists the required input data sets to the radar-only soil moisture inversion. These include the primary choices that meet the ancillary data requirements. Ancillary data sets are defined as external data sets that are required as inputs to SMAP retrieval algorithms in the generation of the standard Level-2 and Level-3 active products. Ancillary data needed by the SMAP mission fall into two categories: static ancillary data, which do not change during the mission, and dynamic ancillary data, which require periodic updates in timeframes ranging from seasonally to daily. Static data include parameters such as permanent masks (land/water/forest/urban/mountain), the grid cell average elevation and slope derived from a Digital Elevation Model (DEM), permanent open water fraction, and soils information (primarily sand and clay fraction). All static ancillary data are resampled to the 3 km EASE-Grid 2.0 as the output products. The dynamic ancillary data include land cover, precipitation, and effective soil temperatures. The choice of which ancillary data set to use for a particular SMAP product is based on a number of factors, including its availability and ease of use, and its inherent error and resulting impact on the overall soil moisture or freeze/thaw retrieval accuracy. Latency, spatial resolution, temporal resolution, and global coverage are also important. The choice of a primary source for each of the ancillary data parameters is fully documented in individual SMAP Ancillary Data Reports (refer to Section 6.1 in the ATBD, Kim et al. 2015). Brief descriptions are provided below for the input radar backscatter, and for the ancillary parameters generated by the SPL2SMA processor.

Table 2. List of Input Data for the Level-2 Active Soil Moisture Algorithm

Data Type	Data Source
Radar Backscatter (HH/VV/HV)	SPL1CS0
Land Cover Class	MODIS-International Geosphere Biosphere Programme (IGBP)
Crop Type	Cropland Data Layer (US) Environment Canada (Canada) ECOCLIMAP (Europe) Global Crop Map (Rest of the world)
Vegetation Water Content	SPL2SMA MODIS Normalized Difference Vegetation Index (NDVI)
Data Cube	SMAP Science Team
Soil Texture	Harmonized World Soil Database + Regional + Food Agricultural Organization (FAO)

Data Type	Data Source
Soil Surface Temperature	Global Modeling and Assimilation Office (GMAO) or European Center for Medium Range Weather Forecasting (ECMWF)
Mountain Area	Combination of Shuttle Radar Topography Mission (SRTM), Alaska United States Geological Survey (USGS) DEM, Canada Geobase DEM, and GTOPO30 (a global DEM with a horizontal grid spacing of 30 arc seconds or approximately 1 km)
Freeze/Thaw Flag	GMAO
Permanent Ice	MODIS IGBP
Snow	Snow & Ice Mapping System (IMS) - NOAA
Static Water Body	MODIS MOD44W
Transient Water Body	SPL2SMA
Precipitation	ECMWF Total Precipitation Forecasts [or Global Precipitation Measurement (GPM)
Urban Area	Global Rural-Urban Mapping Project (GRUMP)
RFI Contamination	SPL1CS0

2.3.6.1 Radar Backscatter

As previously stated, the primary input to the SPL2SMA algorithm is the Level-1C gridded radar product. This product consists of the calibrated high-resolution (SAR-mode) multiple polarization radar backscatter measurements and associated parameters, Earth-located and mapped to a swath-based, along-track/cross-track, 1 km EASE-Grid 2.0. It is assumed that the backscatter measurements have been fully calibrated and corrected for atmospheric attenuation and ionospheric effects such as Faraday rotation. Information provided in the Level-1C data set or in ancillary calibration files should enable estimates of the sigma nought (σ0) accuracy (Kp) for each measurement based on instrument characteristics.

2.3.6.2 Vegetation Water Content derived from Radar Vegetation Index

The SPL2SMA algorithm requires information on the VWC. One potential source of vegetation information is a polarimetric parameter derived from SMAP data such as the Radar Vegetation Index (RVI) (Kim and van Zyl 2000).

Alternatively, the vegetation amount may be derived based on low-order polynomial of the NDVI and optical remote-sensing images (refer to the SPL2SMP ATBD). In principle the RVI or any other parameter based on the radar backscatter should correlate with the vegetation amount more strongly than the optical NDVI, because fundamentally optical radiation cannot penetrate vegetation canopies while the L-band microwave signal can. Furthermore, the RVI is concurrent with the radar observation. Studies are ongoing with regard to whether the radar backscatter may improve estimates of vegetation effects. The Data Fields Ancillary Data group contains VWC derived from both RVI and NDVI.

2.3.6.3 Radar Water Bodies

An algorithm for discriminating transient water bodies from land surfaces is also part of the SPL2SMA processor. There are many combinations of water surfaces adjoined by land surfaces, (depending on both land and water surface roughness and presence of vegetation) that affect this discrimination capability. At present, the case of a calm water surface next to lightly vegetated land was studied. It was found that a threshold (3 dB) applied to the ratio of HH to VV effectively separated water from land at SMAP's 40 deg incidence angle. In this study, Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) images were analyzed over fairly flat terrain. Despite the apparent differences between UAVSAR and SMAP, the measurement quality for both instruments is determined by the same statistical processes inherent in SAR imaging. Calibration error and the number of single looks of one UAVSAR pixel are similar to those of one pixel of the SMAP SAR.The algorithm was tested over numerous locations with a detection error of smaller than 10% (Kim et al. 2014). For details refer to the appendix for details.

2.4 Processing

This data set is generated by the SMAP Science Data Processing System (SDS) at the Jet Propulsion Laboratory (JPL) in Pasadena, California USA. To generate this data set, the processing software ingests only the 6:00 a.m. descending half-orbit files of the SMAP High-Resolution Radar Sigma Nought, Version 3 (SPL1CS0) data set. The SPL1CS0 data set contains swath-gridded radar backscatter observations acquired by the radar and processed using synthetic-aperture processing providing measurements at 1 km resolution. After the 1 km sigma0 data are gridded on the 3 km EASE-Grid 2.0, the gridded data are then tested for retrievability criteria according to input data quality, ancillary data availability, and land cover conditions. These criteria are tested by applying various quality flags.

Two quality flags are derived using the 3 km sigma0: radar vegetation index and radar water body. Static and dynamic ancillary data are sampled for each pixel of the SPL2SMA product. Sigma0 values from the past are sampled and used by the time-series algorithm. For each 3 km pixel, land cover class information is obtained from the mostly annual ancillary data. The land cover information allows one to choose an appropriate data cube for each pixel. The retrieval over the different land cover classes is spatially assembled to create a half-orbit output, followed by the conversion from the dielectric constant to soil moisture.

When retrievability criteria are met, the software invokes the baseline retrieval algorithm to generate soil moisture retrieval. Only cells that are covered by the actual swath for a given projection are written in the product.

For more information on each portion of the algorithm processing flow, and the details of the retrieval methods and options, refer to Section 3: Retrieval Algorithms of the ATBD for this product (Kim et al. 2015).

2.5 Quality, Errors, and Limitations

2.5.1 Error Sources

Anthropogenic Radio Frequency Interference (RFI), principally from ground-based surveillance radars, can contaminate both radar and radiometer measurements at L-band. Early measurements and results from ESA's Soil Moisture and Ocean Salinity (SMOS) mission indicate that in some regions RFI is present and detectable. The SMAP radar and radiometer electronics and algorithms include design features to mitigate the effects of RFI. The SMAP radar utilizes selective filters and an adjustable carrier frequency to tune to predetermined RFI-free portions of the spectrum while on orbit.

More information about error sources is provided in Section 3.5: Error Budget of the ATBD.

2.5.2 Quality Assessment

For in-depth details regarding the quality of these Version 3 Validated data, refer to the following reports:

- Validated Assessment Report
- Beta Assessment Report

2.5.3 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 Appendix A.

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

A separate QA file with a .qa file extension is also associated with each data file. QA files are ASCII text files that contain statistical information in order to help users better assess the quality of the associated data file.

If a product does not fail QA, it is ready to be used for higher-level processing, browse generation, active science QA, archive, and distribution. If a product fails QA, it is never delivered to NSIDC DAAC.

2.5.3.1 Data Flags

Note: As SPL2SMA is a research product, the accuracy requirements are tentative and are set to 0.06 cm^3/cm^3 for soil moisture and up to 5 kg/m^2 for vegetation water content (VWC).

Quality Control (QC) is an integral part of the SPL2SMA processing. The QC steps of the SPL2SMA processing are based on the flags that are provided with the input data stream (SPL1CS0), different types of masks, flags, and fractional coverage of other variables provided by ancillary data. The soil moisture retrieval flags are listed in Table 3.

Table 3. Flags used in SPL2SMA

Sigma0 Flags
Sigma0 Quality (HH)
Sigma0 Quality (VV)
Sigma0 Quality (HV)
Soil Moisture Retrieval Flag: Key Bits
Retrieval Success
Freeze/Thaw
Radar Vegetation Index
Radar/Permanent Water Body
Surface Quality Flag: Key Bits
Dense Vegetation (VWC)
Nadir Region
Urban
Precipitation
Snow, Ice, Frozen Surface
Mountain

The overall sigma0 quality flags are deemed good if the following flags are good: range, null data, RFI cleaned, RFI detected, and Kp. Faraday flag is ignored while evaluating the overall sigma0 flag. Generally, 0 is assigned to the favorable condition for soil moisture retrieval. The SPL2SMA processes all data that have favorable conditions for soil moisture retrieval, including no snow cover, no frozen ground, no permanent water, no wetland, no urban, and no snow. As long as sigma0 value in natural unit is greater than 0, soil moisture is retrieved. However, for soil moisture retrieval conducted for regions with high VWC and nadir regions, appropriate flags are added to these data points indicating their susceptibility to high errors. Therefore, there are three flagging states associated with soil moisture retrieval:

- Retrieve and assign good flag (retrieval recommend)
- Retrieve and assign bad flag (retrieval success)
- Do not retrieve and assign bad flag (retrieval attempt)

2.5.3.2 Radar Backscatter and RFI Flags

The SPL2SMA product also uses the radar backscatter and RFI flag from the SPL1CS0 product.

2.5.3.3 Freeze/Thaw Flag

The freeze/thaw flag for SPL2SMA is generated from modeled surface temperature information called TSURF from the Global Modeling and Assimilation Office (GMAO). The GMAO-modeled TSURF parameter is used due to the maturity of the SMAP radar freeze/thaw algorithm and availability of radar measurements.

2.5.3.4 Water Body Flag

The SPL2SMA water body flag is generated from a priori information on permanent open freshwater from the Moderate Resolution Imaging Spectroradiometer (MODIS) MOD44W database. The MOD44W database is used due to the maturity of the SMAP radar open-water algorithm and availability of radar measurements.

2.5.3.5 Nadir Region Flag

The SPL2SMA product also has a nadir region degradation where the effective resolution in the cross-track direction gradually becomes 36 km. The flag, called the 3 km nadir region flag, is assigned to identify this region.

For more information regarding data flags, refer to the Appendix of this document.

2.6 Instrumentation

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

3 SOFTWARE AND TOOLS

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

4 VERSION HISTORY

Table 4. Version History Summary

Version	Release Date	Description of Changes
V2	November 2015	First public data release
V3	April 2016	Changes to this version include: Transitioned to Validated-Stage 1 Uses updated SPL1CS0 V3 as input Updates to some of the data cubes Update of crop database Modified iterative bias correction Estimation of VWC

5 RELATED DATA SETS

SMAP Data at NSIDC | Overview

SMAP Radar Data at the ASF DAAC

6 RELATED WEBSITES

SMAP at NASA JPL

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9 DOCUMENT INFORMATION

9.1 Publication Date

02 January 2019

9.2 Date Last Updated

25 November 2020

1 APPENDIX A – DATA FIELDS

This appendix provides a description of all data fields within the SMAP L2 Radar Half-Orbit 3 km EASE-Grid Soil Moisture (SPL2SMA) product. The data are grouped into four main HDF5 groups:

- Metadata
- Ancillary_Data
- Radar_Data
- Soil_Moisture_Retrieval_Data

For a description of metadata fields for this product, refer to the Product Specification Document.

1.1 Ancillary_Data

Table A1 describes the data fields of a typical SPL2SMA descending half-orbit granule. All data element arrays are one-dimensional with a size N, where N is the number of valid cells from the radar swath that appear on the grid.

Table A - 1. Ancillary Data

Data Field Name	Shape	Concept	Byte	Signed	Unit	Min	Max	Fill/Gap Value
bare_soil_roughness_tabular	EASEGridCell_Array	real	4	N/A	meters	0.0	0.04	-9999.0
faraday_rotation_angle	EASEGridCell_Array	real	4	N/A	degrees	-999999.9	999999.9	-9999.0
landcover_class	EASEGridCell_Array	enum	1	N/A	N/A	N/A	N/A	254
normalized_difference_vegetation_index	EASEGridCell_Array	real	4	N/A	N/A	-999999.9	999999.9	-9999.0
static_water_body_fraction	EASEGridCell_Array	real	4	N/A	N/A	0.0	1.0	-9999.0
surface_temperature	EASEGridCell_Array	real	4	N/A	degrees Celsius	-50.0	60.0	-9999.0
vegetation_water_content_NDVI	EASEGridCell_Array	real	4	N/A	kg/m**3	0.0	10.0	-9999.0
vegetation_water_content_RVI	EASEGridCell_Array	real	4	N/A	kg/m**3	0.0	10.0	-9999.0

1.2 Radar_Data

Table A2 describes the data fields of a typical SPL2SMA descending half-orbit granule. All data element arrays are one-dimensional with a size *N*, where *N* is the number of valid cells from the radar swath that appear on the grid.

Table A - 2. Radar Data

Data Field Name	Shape	Concept	Byte	Signed	Unit	Min	Max	Fill/Gap Value
altitude_std_dev	EASEGridCell_Array	real	4	N/A	meters	0.0	1000.0	-9999.0
cell_radar_mode_flag	EASEGridCell_Array	bit flag	2	N/A	N/A	N/A	N/A	65534
earth_boresight_azimuth_aft	EASEGridCell_Array	real	4	N/A	degrees	0.0	360.0	-9999.0
earth_boresight_azimuth_fore	EASEGridCell_Array	real	4	N/A	degrees	0.0	360.0	-9999.0
kp_hh	EASEGridCell_Array	real	4	N/A	normalized	0.0	1.0	-9999.0
kp_hh_aft	EASEGridCell_Array	real	4	N/A	normalized	0.0	1.0	-9999.0
kp_hh_fore	EASEGridCell_Array	real	4	N/A	normalized	0.0	1.0	-9999.0
kp_vv	EASEGridCell_Array	real	4	N/A	normalized	0.0	1.0	-9999.0
kp_vv_aft	EASEGridCell_Array	real	4	N/A	normalized	0.0	1.0	-9999.0
kp_vv_fore	EASEGridCell_Array	real	4	N/A	normalized	0.0	1.0	-9999.0
kp_xpol	EASEGridCell_Array	real	4	N/A	normalized	0.0	1.0	-9999.0
kp_xpol_aft	EASEGridCell_Array	real	4	N/A	normalized	0.0	1.0	-9999.0
kp_xpol_fore	EASEGridCell_Array	real	4	N/A	normalized	0.0	1.0	-9999.0
sigma0_hh_mean	EASEGridCell_Array	real	4	N/A	normalized	-0.01	10.0	-9999.0
sigma0_hh_mean_aft	EASEGridCell_Array	real	4	N/A	normalized	-0.01	10.0	-9999.0
sigma0_hh_mean_fore	EASEGridCell_Array	real	4	N/A	normalized	-0.01	10.0	-9999.0
sigma0_hh_std_dev	EASEGridCell_Array	real	4	N/A	normalized	0.0	5.0	-9999.0
sigma0_hh_std_dev_aft	EASEGridCell_Array	real	4	N/A	normalized	0.0	5.0	-9999.0
sigma0_hh_std_dev_fore	EASEGridCell_Array	real	4	N/A	normalized	0.0	5.0	-9999.0
sigma0_vv_mean	EASEGridCell_Array	real	4	N/A	normalized	-0.01	10.0	-9999.0
sigma0_vv_mean_aft	EASEGridCell_Array	real	4	N/A	normalized	-0.01	10.0	-9999.0
sigma0_vv_mean_fore	EASEGridCell_Array	real	4	N/A	normalized	-0.01	10.0	-9999.0
sigma0_vv_std_dev	EASEGridCell_Array	real	4	N/A	normalized	0.0	5.0	-9999.0

Data Field Name	Shape	Concept	Byte	Signed	Unit	Min	Max	Fill/Gap Value
sigma0_vv_std_dev_aft	EASEGridCell_Array	real	4	N/A	normalized	0.0	5.0	-9999.0
sigma0_vv_std_dev_fore	EASEGridCell_Array	real	4	N/A	normalized	0.0	5.0	-9999.0
sigma0_xpol_mean	EASEGridCell_Array	real	4	N/A	normalized	-0.01	10.0	-9999.0
sigma0_xpol_mean_aft	EASEGridCell_Array	real	4	N/A	normalized	-0.01	10.0	-9999.0
sigma0_xpol_mean_fore	EASEGridCell_Array	real	4	N/A	normalized	-0.01	10.0	-9999.0
sigma0_xpol_std_dev	EASEGridCell_Array	real	4	N/A	normalized	0.0	5.0	-9999.0
sigma0_xpol_std_dev_aft	EASEGridCell_Array	real	4	N/A	normalized	0.0	5.0	-9999.0
sigma0_xpol_std_dev_fore	EASEGridCell_Array	real	4	N/A	normalized	0.0	5.0	-9999.0

1.3 Soil_Moisture_Retrieval_Data

Table A3 describes the data fields of a typical SPL2SMA descending half-orbit granule. All data element arrays are one-dimensional with a size N, where N is the number of valid cells from the radar swath that appear on the grid.

Table A - 3. Soil Moisture Retrieval Data

Data Field Name	Shape	Concept	Byte	Signed	Unit	Min	Max	Fill/Gap Value
EASE_column_index	EASEGridCell_Array	integer	2	false	count	0	65535	65534
EASE_row_index	EASEGridCell_Array	integer	2	false	count	0	65535	65534
bare_soil_roughness_retrieved	EASEGridCell_Array	real	4	N/A	meters	0.0	0.1	-9999.0
distance_from_nadir	EASEGridCell_Array	real	4	N/A	meters	0.0	500000.0	-9999.0
latitude	EASEGridCell_Array	real	4	N/A	degrees_north	-90.0	90.0	N/A
longitude	EASEGridCell_Array	real	4	N/A	degrees_east	-180.0	180.0	N/A
num_input_sigma0s_hh	EASEGridCell_Array	integer	2	false	count	0	100	65534
num_input_sigma0s_vv	EASEGridCell_Array	integer	2	false	count	0	100	65534
num_input_sigma0s_xpol	EASEGridCell_Array	integer	2	false	count	0	100	65534
num_time_series	EASEGridCell_Array	integer	1	false	count	0	255	254
radar_vegetation_index	EASEGridCell_Array	real	4	N/A	count	0.0	2.0	-9999.0
radar_water_flag3	EASEGridCell_Array	integer	1	false	count	0	255	254
retrieval_qual_flag	EASEGridCell_Array	bit flag	2	N/A	N/A	N/A	N/A	65534
retrieval_qual_flag_change_index	EASEGridCell_Array	bit flag	2	N/A	N/A	N/A	N/A	65534
retrieval_qual_flag_cube	EASEGridCell_Array	bit flag	2	N/A	N/A	N/A	N/A	65534
retrieval_qual_flag_kvz	EASEGridCell_Array	bit flag	2	N/A	N/A	N/A	N/A	65534
sigma0_qual_flag_hh	EASEGridCell_Array	bit flag	4	N/A	N/A	N/A	N/A	4294967294
sigma0_qual_flag_vv	EASEGridCell_Array	bit flag	4	N/A	N/A	N/A	N/A	4294967294
sigma0_qual_flag_xpol	EASEGridCell_Array	bit flag	4	N/A	N/A	N/A	N/A	4294967294

Data Field Name	Shape	Concept	Byte	Signed	Unit	Min	Max	Fill/Gap Value
soil_moisture	EASEGridCell_Array	real	4	N/A	cm^3/cm^3	0.02	0.5	-9999.0
soil_moisture_change_index	EASEGridCell_Array	real	4	N/A	cm^3/cm^3	0.0	0.2	-9999.0
soil_moisture_error	EASEGridCell_Array	real	4	N/A	cm^3/cm^3	0.0	0.2	-9999.0
soil_moisture_kvz	EASEGridCell_Array	real	4	N/A	cm^3/cm^3	0.02	0.5	-9999.0
soil_moisture_snapshot[1]	EASEGridCell_Array	real	4	N/A	cm^3/cm^3	0.02	0.5	-9999.0
soil_moisture_snapshot_DVZ[1]	EASEGridCell_Array	real	4	N/A	cm^3/cm^3	0.02	0.5	-9999.0
soil_moisture_snapshot_shi[1]	EASEGridCell_Array	real	4	N/A	cm^3/cm^3	0.02	0.5	-9999.0
soil_moisture_time_series	EASEGridCell_Array	real	4	N/A	cm^3/cm^3	0.02	0.5	-9999.0
spacecraft_overpass_time_seconds	EASEGridCell_Array	real	8	N/A	seconds	0.00000	999999.9	-9999.0
spacecraft_overpass_time_utc	EASEGridCell_Array	string	24	N/A	N/A	N/A	N/A	N/A
surface_flag	EASEGridCell_Array	bit flag	2	N/A	N/A	N/A	N/A	65534

[1]Algorithms that are not currently being used for these data include Snapshot, Dubois/van Zyl (DVZ), and Shi. Thus, the data fields corresponding to these algorithms contain a fill value of -9999.0.

1.4 Data Field Definitions

bare_soil_roughness_tabular: Measure of soil roughness from tabular source compiled from published literature.

faraday_rotation_angle: Faraday rotation angle. The Faraday rotation effect is the effect of a magnetic field on the transmission of linearly polarized light through a dispersive medium.

landcover_class: An enumerated type that specifies the predominant surface vegetation found in the grid cell. See Table A4 for landcover classification values.

Table A - 4. Landcover Classification Values

Value	Description
0	Water
1	Evergreen needleleaf forest
2	Evergreen broadleaf forest
3	Deciduous needleleaf forest
4	Deciduous broadleaf forest
5	Mixed forest
6	Closed shrubland
7	Open shrubland
8	Woody savanna
9	Savanna
10	Grassland
11	Mixed forest
12	Closed shrubland
13	Open shrubland
14	Woody savanna
15	Savanna
16	Grassland
>16	TBD

normalized_difference_vegetation_index: A measure of the green character of vegetation. (IR-Red)/(IR+Red)

static_water_body_fraction: The fraction of the area of the 3 km grid cell that is covered by static water based on a Digital Elevation Map.

surface_temperature: Temperature at land surface based on ancillary data.

vegetation_water_content_NDVI: Representative measure of water in the vegetation within the 3 km grid cell based on the Normalized Difference Vegetation Index (NDVI).

vegetation_water_content_RVI: Representative measure of water in the vegetation within the 3 km grid cell based on the radar vegetation index.

altitude_std_dev: The standard deviation of the Earth surface elevation within the 3 km cell.

cell_radar_mode_flag: Bit flags that specify modes or conditions of radar instrument operation that impact the data represented in the SPL2SMA product. Table A5 contains more information.

Table A - 5. Bit Values and Interpretation

Bit Position	Bit Value and Interpretation
0	0 = Radar is operating in transmit-receive mode
	1 = Radar is operating in receive only mode
1	Always clear (This bit is used to designate the nadir region in Level 1. It is redundant in Level 2.)
2	0 = Cross polarized data are v-pol transmitted; h-pol received.
	1 = Cross polarized data are h-pol transmitted; v-pol received.
3	0 = Cross polarized data are consistent within this EASE grid cell.
	1 = Cross polarized data are in transition, some are v-pol transmitted, h-pol received, others are h-pol transmitted, v-pol received.
4-15	Always clear (Bits 5 through 7 are reserved for Radar Level 1C use. Bits 8 through 15 are reserved for Level 2 use.)

earth_boresight_azimuth_aft: Mean direction of the projection of the antenna boresight vector on the Earth's surface relative to North for aft looking sigma0s within 3 km cell. Level 1C azimuth is based on instrument coordinate system, not geographical North.

earth_boresight_azimuth_fore: Mean direction of the projection of the antenna boresight vector on the Earth's surface relative to North for forward looking sigma0s within 3 km cell. Level 1C azimuth is based on instrument coordinate system, not geographical North.

kp_hh: Overall error measure for HH-pol $\sigma0$ within the 3 km cell based on Level 1C kp values, includes calibration, RFI and contamination effects.

kp_hh_aft: Overall error measure for aft-looking HH-pol $\sigma0$ within the 3 km cell based on Level 1C kp values, includes calibration, RFI and contamination effects.

kp_hh_fore: Overall error measure for fore-looking HH-pol $\sigma0$ within the 3 km cell based on Level 1C kp values, includes calibration, RFI and contamination effects.

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

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

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

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

kp_xpol_aft: Overall error measure for aft-looking cross-pol σ0 within the 3 km cell based on Level 1C kp values, includes calibration, RFI and contamination effects.

kp_xpol_fore: Overall error measure for fore-looking cross-pol σ0 within the 3 km cell based on Level 1C kp values, includes calibration, RFI and contamination effects.

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

sigma0_hh_mean_aft: Mean of 1 km instrument resolution aft-looking HH-pol σ0 in the 3 km Earth grid cell.

sigma0_hh_mean_fore: Mean of 1 km instrument resolution fore-looking HH-pol σ0 in the 3 km Earth grid cell.

sigma0_hh_std_dev: Standard deviation of 1 km instrument resolution HH-pol σ0 in the 3 km Earth grid cell.

sigma0_hh_std_dev_aft: Standard deviation of 1 km instrument resolution aft-looking HH-pol σ0 in the 3 km Earth grid cell.

sigma0_hh_std_dev_fore: Standard deviation of 1 km instrument resolution fore-looking HH-pol σ0 in the 3 km Earth grid cell.

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

sigma0_vv_mean_aft: Mean of 1 km instrument resolution aft-looking VV-pol σ0 in the 3 km Earth grid cell.

sigma0_vv_mean_fore: Mean of 1 km instrument resolution fore-looking VV-pol σ0 in the 3 km Earth grid cell.

sigma0_vv_std_dev: Standard deviation of 1 km instrument resolution VV-pol σ0 in the 3 km Earth grid cell.

sigma0_vv_std_dev_aft: Standard deviation of 1 km instrument resolution aft-looking VV-pol σ0 in the 3 km Earth grid cell.

sigma0_vv_std_dev_fore: Standard deviation of 1 km instrument resolution fore-looking VV-pol σ0 in the 3 km Earth grid cell.

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

sigma0_xpol_mean_aft: Mean of 1 km instrument resolution aft-looking cross-pol σ0 in the 3 km Earth grid cell.

sigma0_xpol_mean_fore: Mean of 1 km instrument resolution fore-looking cross-pol σ0 in the 3 km Earth grid cell.

sigma0_xpol_std_dev: Standard deviation of 1 km instrument resolution cross-pol σ0 in the 3 km Earth grid cell.

sigma0_xpol_std_dev_aft: Standard deviation of 1 km instrument resolution aft-looking cross-pol σ0 in the 3 km Earth grid cell.

sigma0_xpol_std_dev_fore: Standard deviation of 1 km instrument resolution fore-looking cross-pol σ0 in the 3 km Earth grid cell.

EASE_column_index: EASE grid column index of cell on world grid in longitude direction.

EASE_row_index: EASE grid row index of cell on world grid in latitude direction.

bare_soil_roughness_retrieved: Bare soil roughness measure retrieved using the active soil moisture algorithm.

distance_from_nadir: The distance from the center of the 3 km EASE grid cell to the spacecraft's sub-nadir track on the Earth's surface.

Latitude: Latitude of the center of the Earth-based grid cell.

Longitude: Longitude of the center of the Earth-based grid cell.

num_input_sigma0s_hh: Total number of horizontal polarization sigma0s from the Level 1C product that were used for retrievals in an EASE grid cell.

num_input_sigma0s_vv: Total number of vertical polarization sigma0s from the Level 1C product that were used for retrievals in an EASE grid cell.

num_input_sigma0s_xpol: Total number of cross-polarization sigma0s from the Level 1C product that were used for retrievals in an EASE grid cell.

num_time_series: The number of time-series data used to retrieve soil moisture in the corresponding grid cell.

radar_vegetation_index: Vegetation index derived from radar backscatter.

radar_water_flag3: Radar waterbody flag at 3km.

retrieval_qual_flag: Bit flags that record the conditions and the quality of the soil moisture and freeze/thaw retrieval for the grid cell. See Table A6 for bit flag definitions.

For a listing of retrieval quality flag data fields and their corresponding soil moisture fields, see Table A8.

Table A - 6. Quality Bit Flag Definitions

Name	Bit Position	Interpretation of Values (0:off, 1:on)
Retrieval recommended flag	0	0: Use of the soil moisture value retrieved for this pixel is recommended.
		1: Use of soil moisture value retrieved for this pixel is not recommended.
Retrieval attempted flag	1	0: The algorithm attempted to retrieve soil moisture for this grid cell.
		1: The algorithm did not attempt to retrieve soil moisture for this grid cell.
Retrieval success flag	2	0: Retrieval for this algorithm was successfully executed or the algorithm was not attempted.
		1: The retrieval for this algorithm was attempted but failed.
Radar water body detection success flag	3	0: Radar water body detection ran successfully.
		1: Unable to detect water bodies using retrieval techniques based on radar.
freeze/thaw retrieval success flag	4	0: freeze/thaw retrieval ran successfully.
		1: Unable to ascertain freeze/thaw conditions.
Radar vegetation index retrieval success flag	5	0: Radar vegetation index retrieval ran successfully.
		1: Radar vegetation index retrieval unsuccessful.

retrieval_qual_flag_change_index: Bit flags that record the conditions and the quality of the soil moisture and freeze/thaw retrieval for the grid cell. See Table A6.

For a listing of retrieval quality flag data fields and their corresponding soil moisture fields, see Table A8.

retrieval_qual_flag_cube: Bit flags that record the conditions and the quality of the soil moisture and freeze/thaw retrieval for the grid cell. See Table A6.

retrieval_qual_flag_kvz: Bit flags that record the conditions and the quality of the soil moisture and freeze/thaw retrieval for the grid cell. See Table A6.

For a listing of retrieval quality flag data fields and their corresponding soil moisture fields, see Table A8.

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

Table A - 7. Sigma Quality Bit Flag Definitions

Name	Bit Position	Description of Values (0: off, 1: on)
Mean horizontal polarization quality flag	0	0: The mean of the forward looking and aft looking horizontal polarization sigma0s has acceptable quality.
		1: The mean of the forward looking and aft looking horizontal polarization sigma0s does not have acceptable quality.
Forward looking horizontal polarization quality flag	1	0: The forward-looking horizontal polarization sigma0 has acceptable quality.
		1: The forward-looking horizontal polarization sigma0 has questionable or poor quality.
Aft looking horizontal polarization quality flag	2	0: The aft looking horizontal polarization sigma0 has acceptable quality.
		1: The aft looking horizontal polarization sigma0 has questionable or poor quality.
Mean horizontal polarization range flag	3	0: The mean of the forward looking and aft looking horizontal polarization sigma0s falls within the expected range.
		1: The mean of the forward looking and aft looking horizontal polarization sigma0s is out of range.
Forward looking horizontal polarization range flag	4	0: The forward-looking horizontal polarization sigma0 falls within the expected range.
		1: The forward-looking horizontal polarization sigma0 is out of range.
Aft looking horizontal polarization range flag	5	0: The aft looking horizontal polarization sigma0 falls within the expected range.
		1: The aft looking horizontal polarization sigma0 is out of range.

Name	Bit Position	Description of Values (0: off, 1: on)
Mean horizontal polarization RFI clean flag	6	0: Insignificant RFI detected in the mean of the forward looking and aft looking horizontal polarization sigma0s.
		1: RFI level is unsuitably high for the mean of the forward looking and aft looking horizontal polarization sigma0s.
Mean horizontal polarization RFI repair flag	7	0: Some components of the mean of the forward looking and aft looking horizontal polarization sigma0s are based on repairs for RFI contamination.
		1: Unable to repair the mean of the forward looking and aft looking horizontal polarization sigma0s for RFI contamination.
Forward looking horizontal polarization RFI clean flag	8	0: Insignificant RFI detected in the forward-looking horizontal polarization sigma0s.
		1: RFI level is unsuitably high for the forward-looking horizontal polarization sigma0s.
Forward looking horizontal polarization RFI repair flag	9	0: At least one of the input forward looking horizontal polarization sigma0s is based on repairs for RFI contamination.
		1: Unable to repair the forward-looking horizontal polarization sigma0s for RFI contamination.
Aft looking horizontal polarization RFI clean flag	10	0: Insignificant RFI detected in the aft looking horizontal polarization sigma0s.
		1: RFI level is unsuitably high for the aft looking horizontal polarization sigma0s.
Aft looking horizontal polarization RFI repair flag	11	0: At least one of the input aft looking horizontal polarization sigma0s is based on repairs for RFI contamination.
		1: Unable to repair the aft looking horizontal polarization sigma0s for RFI contamination.
Mean horizontal polarization Faraday Rotation Flag	12	0: Faraday Rotation has little or no impact on the mean of the forward looking and aft looking horizontal polarization sigma0s.
		1: Faraday Rotation has significant impact on the mean of the forward looking and aft looking horizontal polarization sigma0s.
Forward looking horizontal polarization Faraday Rotation Flag	13	0: Faraday Rotation has little or no impact on the forward-looking horizontal polarization sigma0.
		1: Faraday Rotation has significant impact on the forward-looking horizontal polarization sigma0.
Aft looking horizontal polarization Faraday Rotation Flag	14	0: Faraday Rotation has little or no impact on the aft looking horizontal polarization sigma0.
		1: Faraday Rotation has significant impact on the aft looking horizontal polarization sigma0.
Mean horizontal polarization Kp flag	15	0: Kp for the mean of the forward and aft looking horizontal polarization sigma0s is acceptably low.

Name	Bit Position	Description of Values (0: off, 1: on)
		1: Kp for the mean of forward and aft looking horizontal polarization sigma0s is unacceptably high.
Forward looking horizontal polarization Kp flag	16	0: Kp for the forward-looking horizontal polarization sigma0 is acceptably low.
		1: Kp for the forward-looking horizontal polarization sigma0 is unacceptably high.
Aft looking horizontal polarization Kp flag	17	0: Kp for the aft looking horizontal polarization sigma0 is acceptably low.
		1: Kp for the aft looking horizontal polarization sigma0 is unacceptably high.

sigma0_qual_flag_vv: Representative quality flags of vertical polarization sigma0 measures in the grid cell. See Table A7.

sigma0_qual_flag_xpol: Representative quality flags of cross polarization sigma0 measures in the grid cell. See Table A7.

soil_moisture: Retrieved soil moisture for the Earth-based grid cell retrieved using the time series algorithm. The soil_moisture field is internally linked to the soil_moisture_time_series field produced by the baseline algorithm. At present, the operational SPL2SMA Science Production Software (SPS) produces and stores soil moisture retrieval results from two of the five soil moisture algorithms listed in Table A3: soil_moisture_time_series and soil_moisture_kvz. For a listing of the soil moisture data fields and the corresponding retrieval quality flag data fields, see Table A8.

Table A - 8. Soil Moisture Data Fields and Corresponding Retrieval Quality Flags

Soil Moisture Data Field	Internal Link	Corresponding Retrieval Quality Flag Data Field
soil_moisture	*soil_moisture_time_series*	*retrieval_qual_flag*
soil_moisture_change_index		*retrieval_qual_flag_change_index*
soil_moisture_kvz		*retrieval_qual_flag_kvz*
soil_moisture_snapshot[1]	N/A	N/A
soil_moisture_snapshot_DVZ[1]	N/A	N/A
soil_moisture_snapshot_shi[1]	N/A	N/A
soil_moisture_time_series		*retrieval_qual_flag*
[1]Algorithms that are not currently being used for SPL2SMA data include Snapshot, Dubois/van Zyl (DVZ), and Shi. Thus, the data fields corresponding to these algorithms contain a fill value of -9999.0.		

soil_moisture_change_index: Retrieved normalized change in soil moisture. For a listing of the soil moisture data fields and the corresponding retrieval quality flag data fields, see Table A8.

soil_moisture_error: Net uncertainty measure of soil moisture measure for the Earth-based grid cell. Calculation method is TBD. May be replaced by other quality indicators.

soil_moisture_kvz: Retrieved soil moisture for the Earth-based grid cell retrieved using the Kim/van Zyl time series algorithm. At present, the operational SPL2SMA Science Production Software (SPS) produces and stores soil moisture retrieval results from two of the five soil moisture algorithms listed in Table A3: soil_moisture_time_series and soil_moisture_kvz. For a listing of the soil moisture data fields and the corresponding retrieval quality flag data fields, see Table A8.

soil_moisture_snapshot: Representative soil moisture measurement for the Earth-based grid cell, retrieved using the snapshot algorithm. For a listing of the soil moisture data fields and the corresponding retrieval quality flag data fields, see Table A8.

soil_moisture_snapshot_DVZ: Retrieved soil moisture for the Earth-based grid cell, retrieved using the Dubois/van Zyl snapshot algorithm. For a listing of the soil moisture data fields and the corresponding retrieval quality flag data fields, see Table A8.

soil_moisture_snapshot_shi: Retrieved soil moisture for the Earth-based grid cell, retrieved using the Shi snapshot algorithm. For a listing of the soil moisture data fields and the corresponding retrieval quality flag data fields, see Table A8.

soil_moisture_time_series: Retrieved soil moisture for the Earth-based grid cell retrieved using the time series algorithm. The soil_moisture field is internally linked to the soil_moisture_time_series field produced by the baseline algorithm. At present, the operational SPL2SMA Science Production Software (SPS) produces and stores soil moisture retrieval results from two of the five soil moisture algorithms listed in Table A3: soil_moisture_time_series and soil_moisture_kvz. For a listing of the soil moisture data fields and the corresponding retrieval quality flag data fields, see Table A8.

spacecraft_overpass_time_seconds: Number of seconds since a specified epoch (J2000) that represents the spacecraft overpass relative to ground swath.

spacecraft_overpass_time_utc: Time of spacecraft overpass relative to ground swath in UTC.

surface_flag: Bit flags that record ambient surface conditions for the grid cell. See Table A9.

Table A - 9. Surface Quality Bit Flag Definitions

Name	Bit Position	Description of Values (0: off, 1: on)
3 km static water body flag	0	0: The fraction of the 3 km grid cell area that is over a permanent water body is less than metadata element PermanentWaterBodyThreshold. Determined by DEM.

Name	Bit Position	Description of Values (0: off, 1: on)
		1: The fraction of the 3 km grid cell area that is over a permanent water body is greater than or equal to metadata element PermanentWaterBodyThreshold. Determined by DEM.
3 km radar water body detection flag	1	0: Radar retrieval algorithm did not detect significant surface water within the 3 km grid cell.
		1: Radar retrieval algorithm detected significant surface water withing the 3 km grid cell.
3 km urban area flag	2	0: The fraction of the 3 km grid cell area that is over urban development is less than metadata element UrbanAreaThreshold.
		1: The fraction of the 3 km grid cell area that is over urban development is greater than or equal to metadata element UrbanAreaThreshold.
3 km precipitation flag	3	0: No precipitation detected within the 3 km grid cell when data were being acquired.
		1: Precipitation detected within the 3 km grid cell when data were being acquired
3 km snow or ice flag	4	0: No snow or ice detected within the 3 km grid cell.
		1: Snow and/or ice were detected within the 3 km grid cell.
3 km permanent snow or ice flag	5	0: The fraction of the 3 km grid cell area that is over permanent snow or ice is less than a specified algorithmic threshold.
		1: The fraction of the 3 km grid cell area that is over permanent snow or ice is greater than or equal to a specified algorithmic threshold.
3 km frozen ground flag	6	0: No frozen ground detected within the 3 km grid cell.
		1: Frozen ground detected within the 3 km grid cell.
3 km mountainous terrain flag	7	0: The variability of land elevation in the 3 km grid cell is less than metadata element MountainousTerrainThreshold.
		1: The variability of land elevation in the 3 km grid cell is greater than or equal to metadata element MountainousTerrainThreshold.
3 km dense vegetation flag	8	0: The vegetation density within the 3 km grid cell is less than metadata element DenseVegetationThreshold.
		1: The vegetation density within the 3 km grid cell area is greater than or equal to metadata element DenseVegetationThreshold.
3 km nadir region flag	9	0: Data within the the grid cell were not acquired in the nadir region of the swath where sigma0s may not meet the 3 km resolution requirement.
		1: A significant fraction (TBD) of the 3 km grid cell data were acquired within the nadir region of the swath where sigma0s may not meet the 3 km resolution requirement.
3 km coastal mask flag	10	0: Data within the grid cell were not acquired in the coastal region of the large water bodies where especially brightness temperature on land may get severely contaminated due to presence of water.

Name	Bit Position	Description of Values (0: off, 1: on)
		1: Data within the the grid cell were acquired in the coastal region of the large water bodies where especially brightness temperature on land may get severely contaminated due to presence of water.

1.5 Fill/Gap Values

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

Fill values appear in the SMAP SPL2SMA Product when the SPL2SMA SPS can process some, but not all, of the input data for a particular swath grid cell. Fill data may appear in the product in any of the following circumstances:

- One of Science Production Software (SPS) executables that generate the SMAP SPL2SMA 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 SPL2SMA 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 radar L1C_S0_Hires product. If only some of the input that contributes to a particular grid cell is fill data, the SPL2SMA SPS will most likely be able to generate some output. However, some portion of the SPL2SMA 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 SPL2SMA product is equal to the values that represent fill. If any exceptions should exist in the future, the SPL2SMA 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 SPL2SMA product records gaps when entire frames within the time span of a particular data granule do not appear. Gaps can occur under one of two conditions:

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

The Level SPL2SMA Product records gaps in the product level metadata. The following conditions will indicate that no gaps appear in the data product:

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

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

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

1.6 Notations

Table A10 lists the notations used in this document.

Table A - 10. Notation Definitions

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