Soil Moisture Active Passive (SMAP) Mission

Level 2 Passive Soil Moisture Product Specification Document

Prime Mission Release

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Soil Moisture Active Passive (SMAP)
Level 2 Passive Soil Moisture
Product Specification Document

Prime Mission Release

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DOCUMENT CHANGE LOG

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-	Jun 12, 2014		Initial Release
-	Aug 31, 2015		Beta Release
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TBD, TBR, TBS LOG

Section/Page	Description	Due Date
4.3	More accurate estimate of data volume to be determined from simulations	Mar 2013
References	Information on references was updated	Aug 2015

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1 INTRODUCTION

1.1 Identification

This is the Product Specification Document (PSD) for the Level 2 Passive Soil Moisture Product for the Science Data System (SDS) of the Soil Moisture Active Passive (SMAP) project. The product provides gridded data of SMAP radiometer-only soil moisture retrieval, ancillary data, and quality-assessment flags on a 36-km Earth-fixed grid. Only cells that are covered by the actual swath are written into the product.

1.2 Scope

This document describes the file format and data contents of the Level 2 Passive Soil Moisture Product (hereafter referred to as 'L2_SM_P' for brevity) for external software interfaces. The SMAP Science Data Management and Archive Plan Document provides a more comprehensive explanation of this product within the context of the SMAP instrument, algorithms, and software.

1.3 The SMAP Mission

The SMAP mission is a unique mission that combines passive (radiometer) and active (radar) observations to provide global mapping of soil moisture and freeze/thaw state with unprecedented accuracy, resolution, and coverage. The resulting space-based hydrosphere state measurements will improve:

- Understanding of the processes that link the terrestrial water, energy and carbon cycles
- Estimate of global water and energy fluxes at the land surface
- Measurement of net carbon flux in boreal landscapes
- Weather and climate forecast skill
- Flood prediction and drought monitoring capabilities

Table 1 is a summary of the SMAP instrument functional requirements derived from its science measurement needs. The goal is to combine the various positive attributes of the radar and radiometer observations, including spatial resolution, sensitivity to soil moisture, surface roughness, and vegetation, to estimate soil moisture at a resolution of 10 km and freeze-thaw state at a resolution of 1-3 km.

Table 1: SMAP Mission Requirements

Scientific Measurement Requirements	Instrument Functional Requirements
Soil Moisture: ~± 0.04 m3/m3 volumetric accuracy (1-sigma) in the top 5 cm for vegetation water content ≤ 5 kg/m^2 Hydrometeorology at ~10 km resolution Hydroclimatology at ~40 km resolution	**L-Band Radiometer (1.41 GHz):** Polarization: T_H, T_V, T_3, and T_4 Resolution: 40 km Radiometric Uncertainty*: 1.3 K **L-Band Radar (1.26 and 1.29 GHz):** Polarization: VV, HH, HV (or VH) Resolution: 10 km Relative accuracy*: 0.5 dB (VV and HH) Constant incidence angle** between 35° and 50°
Freeze/Thaw State: Capture freeze/thaw state transitions in integrated vegetation-soil continuum with two-day precision at the spatial scale of landscape variability (~3 km)	**L-Band Radar (1.26 GHz & 1.29 GHz):** Polarization: HH Resolution: 3 km Relative accuracy*: 0.7 dB (1 dB per channel if 2 channels are used) Constant incidence angle** between 35° and 50°
Sample diurnal cycle at consistent time of day (6 am/6 pm Equator crossing); Global, ~3 day (or better) revisit; Boreal, ~2 day (or better) revisit	Swath Width: ~1000 km Minimize Faraday rotation (degradation factor at L-band)
Observation over minimum of three annual cycles	Baseline three-year mission life
* Includes precision and calibration stability ** Defined without regard to local topographic variation	

The SMAP instrument incorporates an L-band radar and an L-band radiometer that share a single feedhorn and parabolic mesh reflector. As shown in Figure 1, the reflector is offset from nadir and rotates about the nadir axis at 14.6 rpm (nominal), providing a conically scanning antenna beam with a surface incidence angle of approximately 40°. The provision of constant incidence angle across the swath simplifies data processing and enables accurate repeat-pass estimates of soil moisture and freeze/thaw change. The reflector has a diameter of 6 m, providing a radiometer 3 dB antenna footprint of 40 km (root-ellipsoidal-area). The real-aperture radar footprint is 30 km, defined by the two-way antenna beamwidth. The real-aperture radar and radiometer data will be collected globally during both ascending and descending passes.

To obtain the desired high spatial resolution, the radar employs range and Doppler discrimination. The radar data can be processed to yield resolution enhancement to 1-3 km spatial resolution over the outer 70% of the 1000-km swath. Data volume constraints prohibit the downlinking of the entire radar data acquisition. Radar measurements that enable high-resolution processing will be collected during the morning overpass over all land regions as well as over surrounding coastal oceans. During the evening overpass, data north of 45° N will be collected and processed to support robust detection of landscape freeze/thaw transitions. The SMAP baseline orbit parameters are:

- Orbit altitude: 685 km (2-3 day average revisit globally and 8-day exact repeat)
- Inclination: 98 degrees, sun-synchronous
- Local time of ascending node: 6 pm (6 am descending local overpass time)

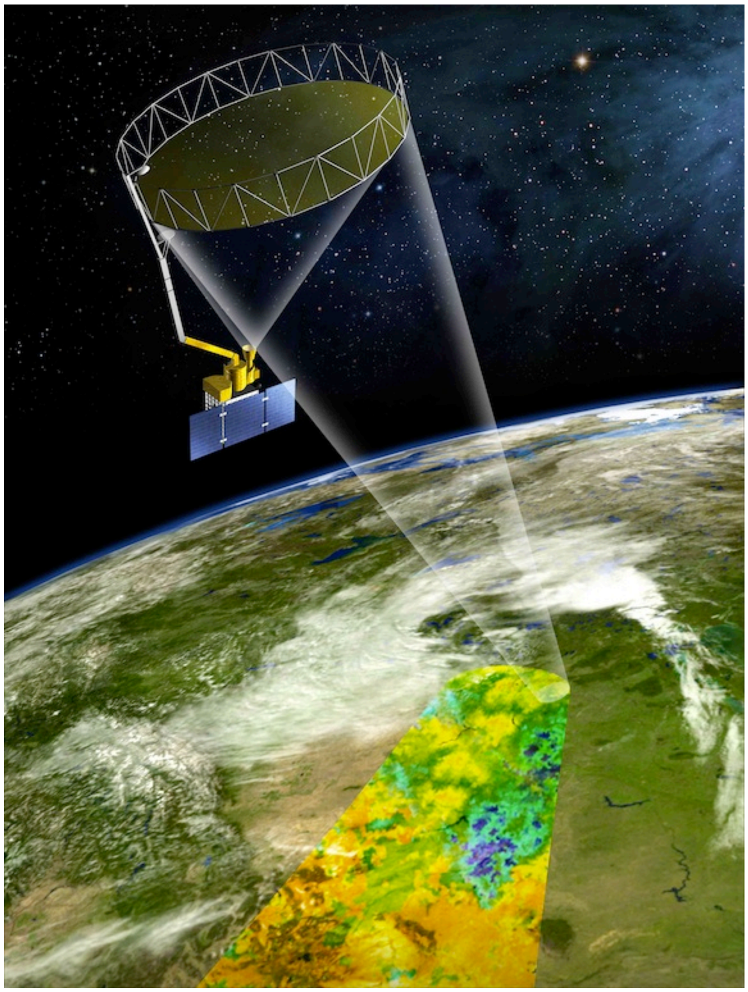

Figure 1: The SMAP mission concept consists of an L-band radar and radiometer sharing a single spinning 6-m mesh antenna in a sun-synchronous dawn / dusk orbit.

The SMAP radiometer measures the four Stokes parameters, T_H, T_V, T_3, and T_4 at 1.41 GHz. The T_H and T_V channels are the pure horizontally and vertically polarized brightness temperatures. The cross-polarized T_3-channel measurement can be used to correct for possible Faraday rotation caused by the ionosphere. Mission planners expect that the selection of the 6 am sun-synchronous SMAP orbit should minimize the effect of Faraday rotation.

Anthropogenic Radio Frequency Interference (RFI), principally from ground-based surveillance radars, can contaminate both radar and radiometer measurements at L-band. Early measurements and results from ESA's Soil Moisture and Ocean Salinity (SMOS) mission indicate that in some regions RFI is present and detectable. The SMAP radar and radiometer electronics and algorithms include design features to mitigate the effects of RFI. The SMAP radar utilizes selective filters and an adjustable carrier frequency to tune to predetermined RFI-free portions of the spectrum while on orbit. The SMAP radiometer will implement a combination of time and frequency diversity, kurtosis detection, and use of T_4 thresholds to detect and where possible mitigate RFI.

On July 7, 2015 the SMAP stopped operating, leaving the SMAP radiometer as the only operating instrument on the spacecraft. The following sections have been revised accordingly from the original PSD to acknowledge the current status of the SMAP observatory.

1.4 Data Products

The SMAP products represent four levels of data processing. Level 1 products contain instrument related data. Level 1 products appear in granules that are based on half orbits of the SMAP satellite. The Northernmost and Southernmost orbit locations demarcate half orbit boundaries. Level 2 products contain output from geophysical retrievals that are based on instrument data. Level 2 products also appear in half orbit granules. Level 3 products contain global output of the Level 2 geophysical retrievals for an entire day. Level 4 products contain output from geophysical models that employ SMAP data.

Table 2 lists the official SMAP data products. The table specifies two sets of short names. The SMAP Mission product short names were adopted by the SMAP mission to identify products. Users will find those short names in SMAP mission documentation, SMAP product file names and in the product metadata. The Data Centers will use ECS short names to categorize data products in their local databases. ECS short names will also appear in SMAP product metadata.

Table 2: Standard and Enhanced SMAP data products

Product	Description	Gridding (Resolution)	Latency	
L1A_Radiometer	Radiometer Data in Time-Order	-	12 hrs	Instrument Data
L1A_Radar	Radar Data in Time-Order	-	12 hrs	
L1B_TB	Radiometer T_B in Time-Order	(36 x 47 km)	12 hrs	
L1B_TB_E	Radiometer T_B Interpolated on EASE Grid 2.0	9 km	12 hrs	
L1B_S0_LoRes	Low Resolution Radar σ_o in Time-Order	(5 x 30 km)	12 hrs	
L1C_S0_HiRes	High Resolution Radar σ_o in Half-Orbits	1 km (1 – 3 km)	12 hrs	
L1C_TB	Radiometer T_B in Half-Orbits	36 km	12 hrs	
L1C_TB_E	Radiometer T_B in Half-Orbits, Enhanced	9 km	12 hrs	
L2_SM_A	Soil Moisture (Radar)	3 km	24 hrs	Science Data (Half-Orbit)
L2_SM_P	Soil Moisture (Radiometer)	36 km	24 hrs	
L2_SM_P_E	Soil Moisture (Radiometer, Enhanced)	9 km	24 hrs	
L2_SM_AP	Soil Moisture (Radar + Radiometer)	9 km	24 hrs	
L2_SM_SP	Soil Moisture (Sentinel Radar + Radiometer)	3 km	Best effort	
L3_FT_A	Freeze/Thaw State (Radar)	3 km	50 hrs	Science Data (Daily Composite)
L3_FT_P	Freeze/Thaw State (Radiometer)	36 km	50 hrs	
L3_FT_P_E	Freeze/Thaw State (Radiometer, Enhanced)	9 km	50 hrs	
L3_SM_A	Soil Moisture (Radar)	3 km	50 hrs	
L3_SM_P	Soil Moisture (Radiometer)	36 km	50 hrs	
L3_SM_P_E	Soil Moisture (Radiometer, Enhanced)	9 km	50 hrs	
L3_SM_AP	Soil Moisture (Radar + Radiometer)	9 km	50 hrs	
L4_SM	Soil Moisture (Surface and Root Zone)	9 km	7 days	Science Value-Added
L4_C	Carbon Net Ecosystem Exchange (NEE)	9 km	14 days	

1.5 L2_SM_P Overview

The SMAP L2_SM_P product is derived from the SMAP L1C_TB product, which represents gridded data of SMAP Level 1B radiometer observations, ancillary data, and quality-assessment flags. To generate the standard L2_SM_P product the processing software ingests half-orbit granules of the L1C_TB product data. The ingested data are then inspected for retrievability according to input data quality, ancillary data availability, and land surface conditions. When retrievability criteria are met, the software invokes the baseline retrieval algorithm along with other option algorithms to generate soil moisture retrieval fields[1]. Only cells that are covered by the actual swath for a given projection are written in the product.

The final L2_SM_P product contains gridded data of SMAP passive soil moisture retrieval, ancillary data, and quality-assessment flags on the 36-km global cylindrical Equal-Area Scalable Earth Grid 2.0 (a.k.a. EASE-Grid 2.0) designed by the National Snow and Ice Data Center (NSIDC) for SMAP.

[1] As of beta-level release both baseline and option algorithms are executed and their results are stored in separate soil moisture retrieval fields in the product. It is anticipated that once the product meets the expected accuracy requirement only the soil moisture retrieval field from the operational algorithm will be written out in the product.

2 DATA PRODUCT ORGANIZATION

2.1 File Format

All SMAP standard products are in the Hierarchical Data Format version 5 (HDF5). The HDF5 is a general-purpose file format and programming library for storing scientific data. The National Center for Supercomputing Applications (NCSA) at the University of Illinois developed HDF to help scientists share data more easily. Use of the HDF library enables users to read HDF files regardless of the underlying computing environments. HDF files are equally accessible in Fortran, C/C++, and other high-level computation packages such as IDL or MATLAB.

The HDF Group, a spin-off organization of the NCSA, is responsible for development and maintenance of HDF. Users should reference The HDF Group website at http://www.hdfgroup.org to download HDF software and documentation.

2.2 HDF5 Notation

HDF5 represents a significant departure from the conventions of previous versions of HDF. The changes that appear in HDF5 provide flexibility to overcome many of the limitations of previous releases. The basic building blocks have been largely redefined, and are more powerful but less numerous. The key concepts of the HDF5 Abstract Data Model are Files, Groups, Datasets, Datatypes, Attributes and Property Lists. The following sections provide a brief description of each of these key HDF5 concepts.

2.2.1 **HDF5 File**

A File is the abstract representation of a physical data file. Files are containers for HDF5 Objects. These Objects include Groups, Datasets, and Datatypes.

2.2.2 **HDF5 Group**

Groups provide a means to organize the HDF5 Objects in HDF5 Files. Groups are containers for other Objects, including Datasets, named Datatypes and other Groups. In that sense, groups are analogous to directories that are used to categorize and classify files in standard operating systems.

The notation for files is identical to the notation used for Unix directories. The root Group is “/”. A Group contained in root might be called “/myGroup.” Like Unix directories, Objects appear in Groups through “links”. Thus, the same Object can simultaneously be in multiple Groups.

2.2.3 HDF5 Dataset

The Dataset is the HDF5 component that stores user data. Each Dataset associates with a Dataspace that describes the data dimensions, as well as a Datatype that describes the basic unit of storage element. A Dataset can also have Attributes.

2.2.4 HDF5 Datatype

A Datatype describes a unit of data storage for Datasets and Attributes. Datatypes are subdivided into Atomic and Composite Types.

Atomic Datatypes are analogous to simple basic types in most programming languages. HDF5 Atomic Datatypes include Time, Bitfield, String, Reference, Opaque, Integer, and Float. Each atomic type has a specific set of properties. Examples of the properties associated with Atomic Datatypes are:

- Integers are assigned size, precision, offset, pad byte order, and are designated as signed or unsigned.
- Strings can be fixed or variable length, and may or may not be null-terminated.
- References are constructs within HDF5 Files that point to other HDF5 Objects in the same file.

HDF5 provides a large set of predefined Atomic Datatypes. Table 3 lists the Atomic Datatypes that are used in SMAP data products.

Table 3: HDF5 Atomic Datatypes

HDF5 Atomic Datatypes	Description
H5T_STD_U8LE	unsigned, 8-bit, little-endian integer
H5T_STD_U16LE	unsigned, 16-bit, little-endian integer
H5T_STD_U32LE	unsigned, 32-bit, little-endian integer
H5T_STD_U64LE	unsigned, 64-bit, little-endian integer
H5T_STD_I8LE	signed, 8-bit, little-endian integer
H5T_STD_I16LE	signed, 16-bit, little-endian integer
H5T_STD_I32LE	signed, 32-bit, little-endian integer
H5T_STD_I64LE	Signed, 64-bit, little-endian integer
H5T_IEEE_F32LE	32-bit, little-endian, IEEE floating point
H5T_IEEE_F64LE	64-bit, little-endian, IEEE floating point
H5T_C_S1	character string made up of one or more bytes

Composite Datatypes incorporate sets of Atomic datatypes. Composite Datatypes include Array, Enumeration, Variable Length and Compound.

- The Array Datatype defines a multi-dimensional array that can be accessed atomically.
- Variable Length presents a 1-D array element of variable length. Variable Length Datatypes are useful as building blocks of ragged arrays.

- Compound Datatypes are composed of named fields, each of which may be dissimilar Datatypes. Compound Datatypes are conceptually equivalent to structures in the C programming language.

Named Datatypes are explicitly stored as Objects within an HDF5 File. Named Datatypes provide a means to share Datatypes among Objects. Datatypes that are not explicitly stored as Named Datatypes are stored implicitly. They are stored separately for each Dataset or Attribute they describe. None of the SMAP data products employ Enumeration or Compound data types.

2.2.5 HDF5 Dataspace

A Dataspace describes the rank and dimension of a Dataset or Attribute. For example, a “Scalar” Dataspace has a rank of 1 and a dimension of 1. Thus, all subsequent references to “Scalar” Dataspace in this document imply a single dimensional array with a single element.

Dataspaces provide considerable flexibility to HDF5 products. They incorporate the means to subset associated Datasets along any or all of their dimensions. When associated with specific properties, Dataspaces also provide the means for Datasets to expand as the application requires.

2.2.6 HDF5 Attribute

An Attribute is a small aggregate of data that describes Groups or Datasets. Like Datasets, Attributes are also associated with a particular Dataspace and Datatype. Attributes cannot be subsetted or extended. Attributes themselves cannot have Attributes.

2.3 SMAP File Organization

2.3.1 Structure

SMAP data products follow a common convention for all HDF5 Files. Use of this convention provides uniformity of data access and interpretation.

The SMAP Project uses HDF5 Groups to provide an additional level of data organization. All metadata that pertain to the complete data granule are members of the “/Metadata” Group. All other data are organized within Groups that are designed specifically to handle the structure and content of each particular data product.

2.3.2 Data

All data in HDF5 files are stored in individual Datasets. All of the Datasets in an SMAP product are assigned to an HDF5 Group. A standard field name is associated with each Dataset. The field name is a unique string identifier. The field name corresponds to the name of the data element the Dataset stores. This document lists these names with the description of each data element that they identify.

Each Dataset is associated with an HDF5 Dataspace and an HDF5 Datatype. They provide a minimally sufficient set of parameters for reading the data using standard HDF5 tools.

2.3.3 **Element Types**

SMAP HDF5 employs the Data Attribute "Type" to classify every data field as a specific data type. The "Type" is an embellishment upon the standard HDF5 Datatypes that is designed specifically to configure SMAP data products.

Table 4 lists all of the "Type" strings that appear in the SMAP data products. The table maps each SMAP "Type" to a specific HDF5 Datatype in both the HDF5 file and in the data buffer. The table also specifies the common conceptual data type that corresponds to the "Type" in SMAP executable code.

Table 4: Element Type Definitions

Type	HDF5 Datatype (File)	HDF5 Datatype (Buffer)	Conceptual Type
Unsigned8	H5T_STD_U8LE	H5T_NATIVE_UCHAR	unsigned integer
Unsigned16	H5T_STD_U16LE	H5T_NATIVE_USHORT	unsigned integer
Unsigned24	H5T_STD_U16LE, with precision set to 24 bits, and size set to 3 bytes.	H5T_NATIVE_INT	unsigned integer
Unsigned32	H5T_STD_U32LE	H5T_NATIVE_UINT	unsigned integer
Unsigned64	H5T_STD_U64LE	H5T_NATIVE_ULLONG	unsigned integer
Signed8	H5T_STD_I8LE	H5T_NATIVE_SCHAR	signed integer
Signed16	H5T_STD_I16LE	H5T_NATIVE_SHORT	signed integer
Signed32	H5T_STD_I32LE	H5T_NATIVE_INT	signed integer
Signed64	H5T_STD_I64LE	H5T_NATIVE_LLONG	signed integer
Float32	H5T_IEEE_F32LE	H5T_NATIVE_FLOAT	floating point
Float64	H5T_IEEE_F64LE	H5T_NATIVE_DOUBLE	floating point
FixLenStr	H5T_C_S1	H5T_NATIVE_CHAR	character string
VarLenStr	H5T_C_S1, where the length is set to H5T_VARIABLE	H5T_NATIVE_CHAR	character string

SMAP HDF5 files employ two different types of string representation. "VarLenStr" are strings of variable length. "VarLenStr" provides greater flexibility to represent character strings. In an effort to make SMAP HDF5 more friendly to users who wish to use netCDF software, SMAP products restrict the use of "VarLenStr". "FixLenStr" are strings with a prescribed fixed-length. "FixLenStr" are useful for fixed length strings that are stored in large multi-dimension array. UTC time stamps are an excellent example of the type of data that store well in a "FixLenStr".

2.3.4 **File Level Metadata**

All metadata that describe the full content of each granule of the SMAP data product are stored within the explicitly named "/Metadata" Group. SMAP metadata are handled using exactly the same procedures as those that are used to handle SMAP data. The contents of each Attribute that stores metadata conform to one of the SMAP Types. Like data, each metadata element is also assigned a shape. Most metadata elements are stored as scalars. A few metadata elements are stored as arrays.

SMAP data products represent file level metadata in two forms. One form appears in one or more Attributes within the Metadata Group. Combined, those Attributes contain a complete representation of the product metadata. The content conforms to the ISO 19115-2 models in ISO 19139 compliant XML.

The second form of the metadata appears in a set of HDF5 Groups under the "/Metadata" Group. Each of these HDF5 Groups represents one of the major classes in the ISO 19115-2 model. These HDF5 Groups contain a set of HDF5 Attributes. Each HDF5 Attributes represents a specific ISO attribute of the associated ISO class. Although this representation inherits design from the ISO model, it does not completely conform to the model. In many cases, the names of the HDF5 Attributes match those used in the ISO model. In some situations, names were changed to provide greater clarity to SMAP users who are not familiar with the ISO model. Furthermore, to ease metadata searches, the structure of Groups within Groups was limited to four levels.

2.3.5 Local Metadata

SMAP standards incorporate additional metadata that describe each HDF5 Dataset within the HDF5 file. Each of these metadata elements appear in an HDF5 Attribute that is directly associated with the HDF5 Dataset. Wherever possible, these HDF5 Attributes employ names that conform to the Climate and Forecast (CF) conventions. Table 5 lists the CF names for the HDF5 Attributes that SMAP products typically employ.

Table 5: SMAP Specific Local Attributes

CF Compliant Attribute Name	Description	Required?
units	Units of measure.	Yes
valid_max	The largest valid value for any element in the Dataset. The data type in valid_max matches the type of the associated Dataset. Thus, if the associated Dataset stores float32 values, the corresponding valid_max will also be float32.	No
valid_min	The smallest valid value for any element in the Dataset. The data type in valid_min matches the type of the associated Dataset. Thus, if the associated Dataset stores float32 values, the corresponding valid_min will also be float32.	No
_FillValue	Specification of the value that will appear in the Dataset when an element is missing or undefined. The data type of _FillValue matches	Yes for all numeric data types

CF Compliant Attribute Name	Description	Required?
	the type of the associated Dataset. Thus, if the associated Dataset stores float32 values, the corresponding _FillValue will also be float32.	
long_name	A descriptive name that clearly describes the content of the associated Dataset.	Yes
coordinates	Identifies auxiliary coordinate variables in the data product.	No
flag_values	Provides a list of flag values that appear in bit flag variables. Should be used in conjunction with local HDF5 attribute *flag_meanings*. Only appears with bit flag variables.	No
flag_masks	Provides a list of bit fields that express Boolean or enumerated flags. Only appears with bit flag variables or enumerated data types.	No
flag_meanings	Provides descriptive words or phrases for each potential bit flag value. Should be used in conjunction with local HDF5 attribute *flag_values*.	No

2.4 Data Definition Standards

Section 4.6 of this document specifies the characteristics and definitions of every data element stored in this SMAP data product. Table 6 defines each of the specific characteristics that are listed in that section of this document. Some of these characteristics correspond with the SMAP HDF5 Attributes that are associated with each Dataset. Data element characteristics that correspond to SMAP HDF5 Attributes bear the same name. The remaining characteristics are descriptive data that help users better understand the data product content.

In some situations, a standard characteristic may not apply to a data element. In those cases, the field contains the character string 'n/a'. Hexadecimal representation sometimes indicates data content more clearly. Numbers represented in hexadecimal begin with the character string '0x'.

Table 6: Data Element Characteristic Definitions

Characteristic	Definition
Type	The data representation of the element within the storage medium. The storage class specification must conform to a valid SMAP type. The first column in table 3 lists all of the valid values that correspond to this characteristic.
Shape	The name of the shape data element that specifies the rank and dimension of a particular data set.
Valid_min	The expected minimum value for a data element. In most instances, data element values never fall below this limit. However, some data

Characteristic	Definition
	elements, particularly when they do not reflect normal geophysical conditions, may contain values that fall below this limit.
Valid_max	The expected maximum value for a data element. In most instances, data element values never exceed this limit. However, some data elements, particularly when they do not reflect normal geophysical conditions, may contain values that exceed this limit.
Valid Values	Some data elements may store a restricted set of values. In those instances, this listing specifies the values that the data element may store.
Nominal Value	Some data elements have an expected value. In those instances, this listing provides that expected value. Nominal values are particularly common among a subset of the metadata elements.
String Length	This characteristic specifies the length of the data string that represents a single instance of the data element. This characteristic appears exclusively for data elements of FixLenStr type.
Units	Units of measure. Typical values include “deg”, “deg C”, “Kelvins”, “m/s”, “m”, “m**2”, “s” and “counts”.

2.4.1 **Array Representation**

This document employs array notation to demonstrate and clarify the correspondence among data elements in different product data elements. The array notation adopted in this document is similar to the standards of the Fortran programming language. Indices are one based. Thus, the first index in each dimension is one. This convention is unlike C or C++, where the initial index in each dimension is zero. In multidimensional arrays, the leftmost subscript index changes most rapidly. Thus, in this document, array elements ARRAY(15,1,5) and ARRAY(16,1,5) are stored contiguously.

HDF5 is designed to read data seamlessly regardless of the computer language used to write an application. Thus, elements that are contiguous using the dimension notation in this document will appear in contiguous locations in arrays for reading applications in any language with an HDF5 interface.

This document differentiates among array indices based on relative contiguity of storage of elements referenced with consecutive numbers in that index position. A faster or fastest moving index implies that the elements with consecutive numbers in that index position are stored in relative proximity in memory. A slower or slowest moving index implies that the elements referenced with consecutive indices are stored more remotely in memory. For instance, given array element ARRAY(15,1,5) in Fortran, the first index is the fastest moving index and the third index is the slowest moving index. On the other hand, given array element array[4][0][14] in C, the first index is the slowest moving index and the third index is the fastest moving index.

2.5 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 L2_SM_P Product when the L2_SM_P 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 L2_SM_P 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 L2_SM_P 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 L1C_TB 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. Table 7 lists the values that represent fill in SMAP products based on data type:

Table 7: Fill Values in SMAP Data Products

Type	Value	Pattern
Float32, Float64	-9999.0	Large, negative number
Signed8, NormSigned8	-127	Type minimum + 1
Signed16, NormSigned16	-32767	Type minimum + 1
Signed24	-8388607	Type minimum + 1
Signed32	-2147483647	Type minimum + 1
Signed64	-9223372036854775807	Type minimum + 1
Unsigned8	254	Type maximum - 1
Unsigned16	65534	Type maximum - 1
Unsigned24	16777214	Type maximum - 1
Unsigned32	4294967294	Type maximum - 1
Unsigned64	18446744073709551614	Type maximum - 1
FixedLenString, VarLenString	N\A	Not available

No valid value in the L2_SM_P product is equal to the values that represent fill. If any exceptions should exist in the future, the L2_SM_P 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 L2_SM_P 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 L1C_TB 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.

2.6 Flexible Data Design

HDF5 format gives the SMAP Level Products a high degree of flexibility. This flexibility in turn gives SMAP end product users the capability to write software that does not need to be modified to accommodate unforeseeable changes in the SMAP products. Since changes to the products are certain to take place over the life of the SMAP mission, users are encouraged to use software techniques that take advantage of some of the features in HDF5.

For example, users can write a product reader that selects only those product data elements they wish to read from an SMAP Level Product file. With the appropriate design, this software will not need to change, regardless of the number, the size, or the order of the current data product entries. Indeed, the only changes users need to implement would take place if they should choose to read a newly defined data element after a product upgrade.

For those users who wish to extract a specific subset of the data from an SMAP Product, the HDF5 routines H5Dopen and H5Dread (h5dopen_f and h5dread_f in FORTRAN) are very useful. H5Dopen requires two input parameters, the first is an HDF5 file/group identifier, the second is a character string that contains the name of a Dataset. H5Dopen returns the identifier for the specified Dataset in the product file. HDF5 routine H5Dread then uses the Dataset identifier to fetch the contents. H5Dread places the contents of the Dataset in a specified output variable.

Once the data element is located and read, users can generate standardized code that reads the metadata associated with each element. Users of the SMAP Level Products should employ the same methods to read metadata and standard data elements.

3 EASE-Grid 2.0

The data in the SMAP L2_SM_P product are presented on a 36-km global cylindrical projection. The projection is based on the NSIDC's EASE-Grid 2.0 specifications for SMAP. The EASE-Grid 2.0 has a flexible formulation. By adjusting one scaling parameter it is possible to generate a family of multi-resolution grids that "nest" within one another. The nesting can be made "perfect" in that smaller grid cells can be tessellated to form larger grid cells, as shown in Fig. 2.

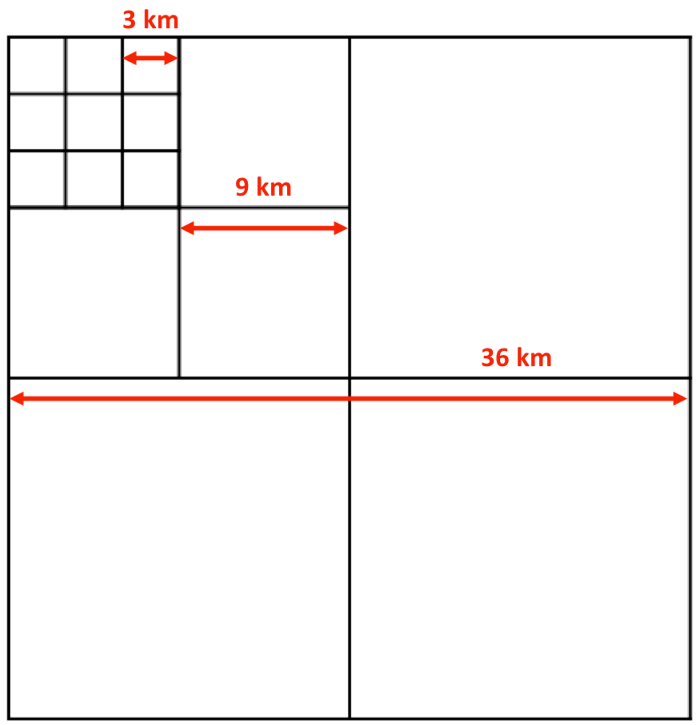

Figure 2: Perfect nesting in EASE-Grid 2.0 – smaller grid cells can be tessellated to form larger grid cells.

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 their derived geophysical products.

A nominal EASE-Grid 2.0 dimension of 36 km has been selected for the L1C_TB and L2/3_SM_P products. This spatial scale is close to the 40-km resolution of the radiometer footprint and it scales conveniently with the 3 km and 9 km grid dimensions that have been selected for the radar (L2/3_SM_A) and combined radar/radiometer (L2/3_SM_AP) soil moisture products, respectively. A comparison of EASE-Grid 2.0 at these three grid resolutions is shown in Fig. 3.

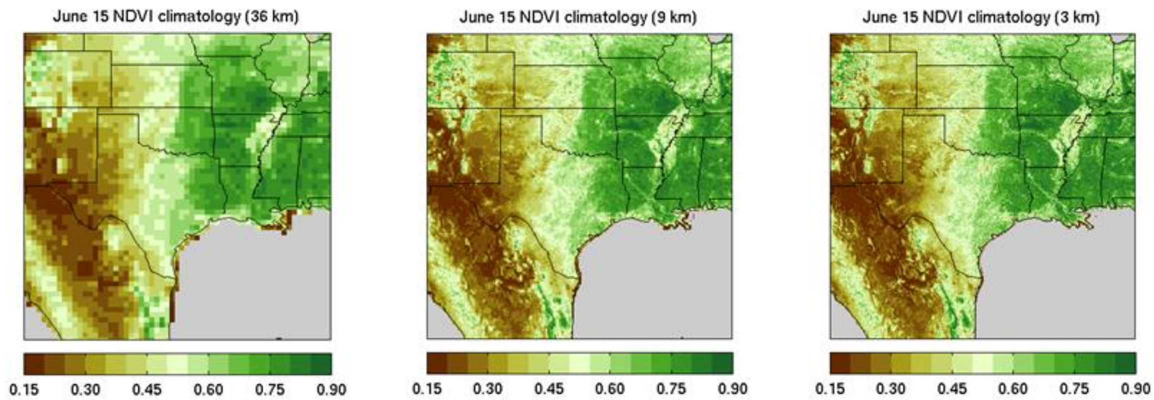

Figure 3: Example of ancillary NDVI climatology data displayed on the SMAP 36-km, 9-km, and 3-km grids.

The 36-km global cylindrical EASE-Grid 2.0 projection is shown in Fig. 4 below. Each grid cell has a nominal area of about 36 × 36 km^2, regardless of longitudes and latitudes. Under this projection, all global data arrays have dimensions of 406 rows and 964 columns.

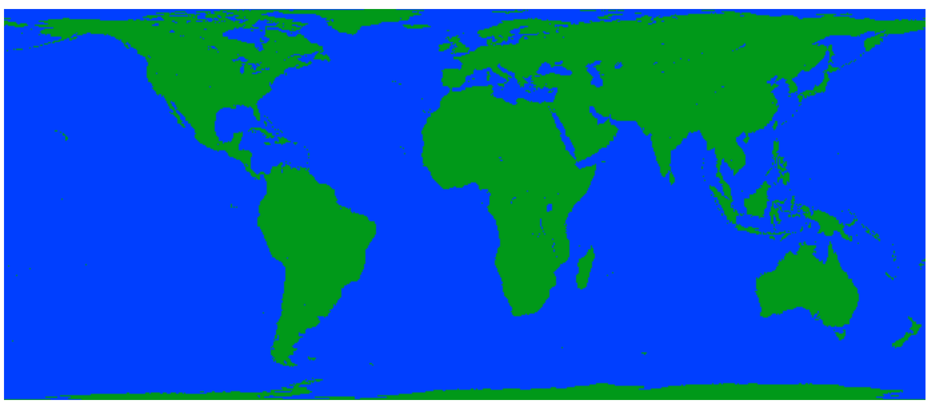

Figure 4: Global Cylindrical EASE-Grid 2.0 projection
(Figure credited to NSIDC)

4 PRODUCT DEFINITION

4.1 Overview

The SMAP L2_SM_P product is derived from the SMAP L1C_TB product, which represents gridded data of SMAP Level 1B radiometer observations, ancillary data, and quality-assessment flags. To generate the standard L2_SM_P product the processing software ingests half-orbit granules of the L1C_TB product data. The ingested data are then inspected for retrievability according to input data quality, ancillary data availability, and land surface conditions. When retrievability criteria are met, the software invokes the baseline retrieval algorithm along with other option algorithms to generate soil moisture retrieval fields[2]. Only cells that are covered by the actual swath for a given projection are written in the product.

4.2 Product Names

L2_SM_P data product file names conform to the following convention:

SMAP_L2_SM_P_[Orbit Number]**_**[A|D]_[First Date/Time Stamp]_[Composite Release ID]_[Product Counter].[extension]

Example: SMAP_L2_SM_P_00934_D_20141225T074951_ R00400_002.h5

Orbit Number	A five-digit sequential number of the orbit flown by the SMAP spacecraft when the data was acquired. Orbit 0 begins at launch.
Half Orbit Designator	'D' for 6:00 am descending pass; 'A' for 6:00 pm ascending pass
First Date/Time Stamp	Date/time stamp in Universal Coordinated Time (UTC) of the first data element that appears in the product. The stamp conforms to the *YYYYMMDD**T**hhmmss* convention.
Composite Release ID	An ID that incorporates changes to any processing condition that might impact product results. The Composite Release ID contains three other shorter ID's: [R][Launch Indicator][Major ID][Minor ID]. The Launch Indicator distinguishes between pre-launch or pre-instrument commissioned data. ('0' for simulated or preliminary observations whereas '1' for observations at or after the time of instrument commissioning) A two-digit Major ID indicates major

[2] As of beta-level release both baseline and option algorithms are executed and their results are stored in separate soil moisture retrieval fields in the product. It is anticipated that once the product meets the expected accuracy requirement only the soil moisture retrieval field from the operational algorithm will be written out in the product.

	releases due to changes in algorithm or processing approach. A two-digit Minor ID indicates minor releases due to changes not considered by a change in Major ID.
Product Counter	A three-digit counter that tracks the number of times that a particular product type for a specific half orbit has been generated.
Extension	'.h5' for science product data and '.qa' for QA product data.

4.3 Volume

The following estimates represent the combined data volume of metadata and the actual science data of the product:

Daily volume: 36.63 MBytes

Yearly volume: 13.05 GBytes

4.4 L2_SM_P Product Metadata

The metadata elements in the L2_SM_P product appear in two forms. One form appears in one or more Attributes within the Metadata Group. Combined, those Attributes contain a complete representation of the product metadata. The content conforms to the ISO 19115-2 models in ISO 19139 compliant XML.

The second form of the metadata appears in a set of HDF5 groups under the Metadata Group. Each of these HDF5 Groups represents one of the major classes in the ISO structure. These groups contain a set of HDF5 attributes. Each HDF5 Attribute set represents a specific ISO attribute of the associated ISO class. Although this representation inherits design from the ISO model, it does not completely conform to the model. In many cases, the names of the HDF5 Attributes match those used in the ISO model. In some situations, names were changed to provide greater clarity to SMAP users who are not familiar with the ISO model. Furthermore, to ease metadata searches, the structure of Groups within Groups was limited to four levels.

Table 8 describes the subgroups of the Metadata group, and the attributes within each group. The first column of table 8 specifies a major class in the ISO 19115 metadata model. The second column provides the name of the HDF5 Group under "/Metadata" where attributes associated with the corresponding class will appear. The third column lists the names of the subgroups and attributes where specific metadata values appear. The fourth column provides valid values for each element. Constant values appear with no diacritical marks. Variable values are encapsulated by angle brackets. All of the metadata elements that appear in table 8 should also appear in every L2_SM_P Product file.

Table 8: Granule Level Metadata in the L2_SM_P Product

Representative ISO Class	SMAP HDF5 Metadata Subgroup	SMAP HDF5 Subpath	SMAP HDF5 Attribute	Definition
MD_AcquisitionInformation	AcquisitionInformation	platform	antennaRotationRate	<The antenna rotation rate in revolution per minute (rpm)>
			description	The SMAP observatory houses an L-band radiometer that operates at 1.40 GHz and an L-band radar that operates at 1.26 GHz. The instruments share a rotating reflector antenna with a 6 meter aperture that scans over a 1000 km swath. The bus is a 3 axis stabilized spacecraft that provides momentum compensation for the rotating antenna.
			identifier	SMAP
		radar, radiometer	description	The SMAP radar instrument employs an L-band conically scanned system and SAR processing techniques to achieve moderate resolution (1 km) backscatter measurements over a very wide 1000 km swath.
			identifier	SMAP SAR
			type	L-band Synthetic Aperture Radar
		platformDocument, radarDocument, radiometerDocument	edition	<The edition of publication of the reference document, if available to the general public.>
			publicationDate	<The date of publication of the reference document, if available to the general public.>
			title	<The title of the publication of the reference document, if available to the general public.>
DQ_DataQuality	DataQuality	DomainConsistency	evaluationMethodType	<The type of data quality evaluation method. "directInternal" means the method of evaluating the quality of a dataset based

				on inspection of items within the dataset, where all data required is internal to the dataset being evaluated.>
			measureDescription	<The description of the Domain Consistency measurement.>
			nameOfMeasure	<The name of the measurements>
			unitOfMeasure	Percent
			value	<A measure between 0 and 100>
		CompletenessOmission	evaluationMethodType	<The type of data quality evaluation method. "directInternal" means the method of evaluating the quality of a dataset based on inspection of items within the dataset, where all data required is internal to the dataset being evaluated.>
			measureDescription	<The description of the Completeness Omission measurement.>
			nameOfMeasure	Percent of Missing Data
			unitOfMeasure	Percent
			value	<A measure between 0 and 100>
			scope	<A list of data elements of the product, that are used for DataQuality measurement>
DS_Dataset/ MD_DataIdentification	DatasetIdentification		CompositeReleaseID	<SMAP Composite Release ID associated with this data product>
			ECSVersionID	<Identifier that specifies major version delivered to ECS (EOSDIS Core System). Value runs from 001 to 999>
			SMAPShortName	<The SMAP Mission product short name of this data product.>
			UUID	<A universally unique identifier for each data granule.>
			abstract	<A short description of this data product.>
			characterSet	utf8
			creationDate	<Date when this data product file was created>
			credit	<Identify the institutional authorship of the product generation software and the data system that automates its production.>

			fileName	<The name of this data product file.>
			language	eng
			originatorOrganizationName	Jet Propulsion Laboratory
			purpose	<The description of the purpose of this data product file.>
			shortName	<The ECS short name of this data product in 8 characters.>
			spatialRepresentationType	grid
			status	onGoing
			topicCategory	geoscientificInformation
EX_Extent	Extent		description	<The description of the spatial and temporal extents of the data product.>
			eastBoundLongitude	<The most eastern boundary of the spatial extent the data product covers (Longitude measure between -180 degrees and 180 degrees)>
			northBoundLatitude	<The most northern boundary of the spatial extent the data product covers (Latitude measure between -90 degrees and 90 degrees)>
			rangeBeginningDateTime	<Character string that indicates the date and time of the initial data element in the product>
			rangeEndingDateTime	<Character string that indicates the date and time of the final data element in the product.>
			southBoundLatitude	<The most southern boundary of the spatial extent the data product covers (Latitude measure between -90 degrees and 90 degrees)>
			westBoundLongitude	<The most western boundary of the spatial extent the data product covers (Longitude measure between -180 degrees and 180 degrees)>
MD_GridSpatialRepresentation	GridSpatialRepresentation	GridDefinitionDocument	edition	<The version of the grid definition document>
			publicationDate	<The publication date of the grid definition document>
			title	<The title of the grid definition document>

		GridDefinition	description	<The description of the grid definition applied for the data product generation>
			identifier	<The short name identifying the grid definition of this data product>
			cellGeometry	<Indication of grid data as point or area>
			controlPointAvailability	<Indication of whether or not control points are available (0 implies not available and 1 implies available)>
			dimensionSize	<The size of the dimension of the arrays in this specific projection are organized in this data product file>
			georeferencedParameters	<The parameters used for the conversion of the geographic location information to the map projection of interest>
			numberOfDimensions	<The number of dimensions of the arrays in this specific projection are organized in this data product file>
			orientationParameterAvailability	<Indication of whether or not orientation parameters are available (0 implies not available and 1 implies available)>
			resolution	<The spatial resolution each data point represents, in kilometer>
			transformationParameterAvailability	<The indication of whether the parameters for transformation exists or not (0 implies not available and 1 implies available)>
LI_Lineage/LE_Source	Lineage	DEMSLP, LANDCOVER_CLASS, LANDCOVER_CLASS_FRACTION_TOP3, LANDCOVER_CLASS_TOP3, MetadataConfiguration, NDVI, NDVI_MAX, OutputConfiguration, PRECIP, RunConfiguration, SNOW, SOIL_TEXTURE_BULK, SOIL_TEXTURE_CLAY, SOIL_TEXTURE_SAND, SURFACE_ROUGHNESS_COEFF, TSURF,	creationDate	<Date when the corresponding ancillary input file was created>
			description	May be we should list 3 files in a single record; no need to duplicate the same information
			fileName	<The name of the ancillary input file.>
			version	<The version number of the ancillary input file.>

		URBAN_FRACTION, WATER_FRACTION		
		L1C_TB, L2_SM_A	DOI	<A digital object identifier associated with the input product. This field appears only for the Lineage class that describes the SMAP science data product.>
			creationDate	<Date when the corresponding input product file was created>
			description	<Description of each of the input files used to generate this data product.>
			fileName	<The name of the corresponding input product file.>
			identifier	<The short name associated with the input SMAP science data product.>
			resolution	<The spatial resolution each data point represents, in kilometer>
			version	<The SMAP Composite Version ID associated with the input data product.>
		InputConfiguration/L1C_TB, InputConfiguration/L2_SM_A	creationDate	<Date when the corresponding ancillary input file was created>
			description	<Description of each ancillary input file used to generate this data product.>
			fileName	<The name of the ancillary input file.>
			version	<The version number of the ancillary input file.>
SD_OrbitMeasuredLocation	OrbitMeasuredLocation		argumentOfPerigee	<The angle in the orbit plane of SMAP satellite between the point of perigee and ascending node. The angle is measured in the direction of spacecraft motion.>
			cycleNumber	<The SMAP satellite flies in a cycle that

				repeats after 117 orbits. This element specifies the cycle of orbits when the data were taken. First cycle is assigned the number 1.>
			eccentricity	<The eccentricity of the satellite orbit.>
			epoch	<The effective time of the data in the OrbitMeasuredLocation class. This may be identical to the equatorCrossingDateTime.>
			equatorCrossingDateTime	<A time stamp that specifies the date and time of ascending node crossing for the current orbit.>
			equatorCrossingLongitude	<The longitude of the ascending node crossing for the current orbit.>
			halfOrbitStartDateTime	<A time stamp that specifies the date and time of the instant the spacecraft crosses either the southernmost point or the northernmost point in its path, marking the beginning of the half orbit.>
			halfOrbitStopDateTime	<A time stamp that specifies the date and time of the instant the spacecraft crosses either the southernmost point or the northernmost point in its path, marking the end of the half orbit.>
			inclination	<The angle between the orbital plane of the spacecraft and the equatorial plane of the Earth. An angle greater than 90 degrees indicates a orbit retrograde path.>
			meanMotion	<The constant angular speed that would be required for a body travelling in an undisturbed elliptical orbit with the specified semimajor axis to complete one revolution in the actual orbital period, expressed as a number of revolutions per day.>
			orbitDirection	<SMAP Level 1 and Level 2 products appear in half orbit granules. This element provides direction of orbital path relative to equatorial plane. Values are "ascending" or "descending">
			orbitPathNumber	< The SMAP satellite flies in a cycle the repeats after 117 orbits. This element specifies which of the 117 possible paths the spacecraft flew when the data in the file were acquired. The orbitPathNumber

				varies from 1 to 117.>
			orbitPeriod	<Time required to complete a the spacecraft orbit.>
			referenceCRS	<A description of the coordinate reference system used to describe spacecraft orbital data.>
			revNumber	<The count of orbits from beginning of mission to the orbit that the spacecraft flew when the data in the file were acquired. Orbit zero begins at launch and extends until the spacecraft crosses the southernmost point in its path for the first time. Orbit one commences at that instant.>
			rightAscensionAscendingNode	<The angle eastward on the equatorial plan from the vernal equinox to the orbit ascending node.>
			semiMajorAxis	<The length of the semi-major axis of the spacecraft orbit.>
LI_Lineage/LE_ProcessStep	ProcessStep		ATBDDate	<Time stamp that specifies the release date of the ATBD>
			ATBDTitle	<The title of the ATBD>
			ATBDVersion	<Version identifier for the ATBD.>
			FrozenGroundFractionLowerThreshold	<The threshold value used in the scientific algorithm software>
			FrozenGroundFractionUpperThreshold	<The threshold value used in the scientific algorithm software>
			IceFractionLowerThreshold	<The threshold value used in the scientific algorithm software>
			IceFractionUpperThreshold	<The threshold value used in the scientific algorithm software>
			MountainousTerrainLowerThreshold	<The threshold value used in the scientific algorithm software>
			MountainousTerrainUpperThreshold	<The threshold value used in the scientific algorithm software>
			RainFractionLowerThreshold	<The threshold value used in the scientific algorithm software>
			RainFractionUpperThreshold	<The threshold value used in the scientific algorithm software>
			SWVersionID	<A software version identifier that runs from 001 to 999>
			SnowFractionLowerThreshold	<The threshold value used in the scientific algorithm software>

			SnowFractionUpperThreshold	<The threshold value used in the scientific algorithm software>
			UrbanFractionLowerThreshold	<The threshold value used in the scientific algorithm software>
			UrbanFractionUpperThreshold	<The threshold value used in the scientific algorithm software>
			VWCLowerThreshold	<The threshold value used in the scientific algorithm software>
			VWCUpperThreshold	<The threshold value used in the scientific algorithm software>
			WaterFractionLowerThreshold	<The threshold value used in the scientific algorithm software>
			WaterFractionUpperThreshold	<The threshold value used in the scientific algorithm software>
			algorithmDate	<Date associated with current version of the algorithm.>
			algorithmDescription	<Descriptive text about the algorithm(s) in the product generation software for this data product.>
			algorithmSelection	<The algorithm(s) applied to generate this data product.>
			algorithmTitle	<The representative name of the algorithm for this data product.>
			algorithmVersionID	<Identifier that specifies the current algorithm version. Value runs from 001 to 999>
			documentDate	<Release date for the software description document.>
			documentVersion	<Version identifier for the software description document.>
			documentation	<A reference to software description document.>
			epochJulianDate	<Julian Date of the Epoch J2000, 2451545>
			epochUTCDateTime	<UTC Date Time of the Epoch J2000, 2000-01-01T11:58:55.816Z>
			identifier	<Name of the product generation software for this data product>
			parameterVersionID	<Identifier that specifies the current version of processing parameters. Value runs from 001 to 999.>
			processDescription	<Short description of the data processing concept by the product generation software.>

			processor	<Name of the product generation facility>
			softwareDate	<A date stamp that specifies when software used to generate this product was released.>
			softwareTitle	<The title of the product generation facility>
			stepDateTime	< A character string that specifies the date and the time when the product was generated.>
			timeVariableEpoch	<The Epoch of the time variable for the SMAP mission>
DS_Series/MD_DataIdentification	ProductSpecificationDocument		SMAPShortName	<The SMAP Mission product short name of this data product.>
			characterSet	utf8
			edition	<Edition identifier for the Product Specification Document>
			language	eng
			publicationDate	<Date of publication of the Product Specification Document>
			title	<The title of the product specification document>
DQ_DataQuality	QA		MissingSamples	<The number of samples missing in this data products>
			OutOfBoundsSamples	<The number of samples that are exceeding the predefined boundary>
			QAPercentOutOfBoundsData	<Percent of the samples that are exceeding the predefined boundary with respect tot the total samples in this data product>
			TotalSamples	<The number of all samples in this data product>
DS_Dataset/MD_DataIdentification	QADatasetIdentification		abstract	An ASCII product that contains statistical information on data product results. These statistics enable data producers and users to assess the quality of the data in the data product granule.
			creationDate	<The date that the QA product was generated.>
			fileName	<The name of QA product.>

DS_Series/MD_DataIdentification	SeriesIdentification		CompositeReleaseID	<SMAP Composite Release ID that identifies the release used to generate this data product>
			abstract	<A short description of this data product series.>
			characterSet	utf8
			credit	<Identify the institutional authorship of the product generation software and the data system that automates its production.>
			format	HDF5
			formatVersion	<The version of the HDF5 library used for the product generation>
			identifier_product_DOI	<digital object identifier for the Level 1C S0 HiRes Product>
			language	eng
			longName	<The long name of this data product (up to 80 characters long)>
			maintenanceAndUpdateFrequency	As needed
			maintenanceDate	<Specifies a date when the next update to this product might be anticipated>
			mission	Soil Moisture Active Passive (SMAP)
			otherCitiationDetails	JIRA RAD-166
			pointOfContact	<The name of the DAAC this data product is distributed from.>
			purpose	<The description of the purpose of this data product file.>
			resourceProviderOrganizationName	National Aeronautics and Space Administration
			revisionDate	<Date and time of the software release that was used to generate this data product.>
			shortName	<The ECS short name of this data product in 8 characters.>
			spatialRepresentationType	grid
			status	onGoing
			topicCategory	geoscientificInformation

4.5 Data Structure

The L2_SM_P product contains gridded data of SMAP radiometer-based soil moisture retrieval, ancillary data, and quality-assessment flags on the 36-km global EASE2 Grid. This organization is reflected schematically in Fig. 5. All data elements appear in the HDF5 Global Projection Group.

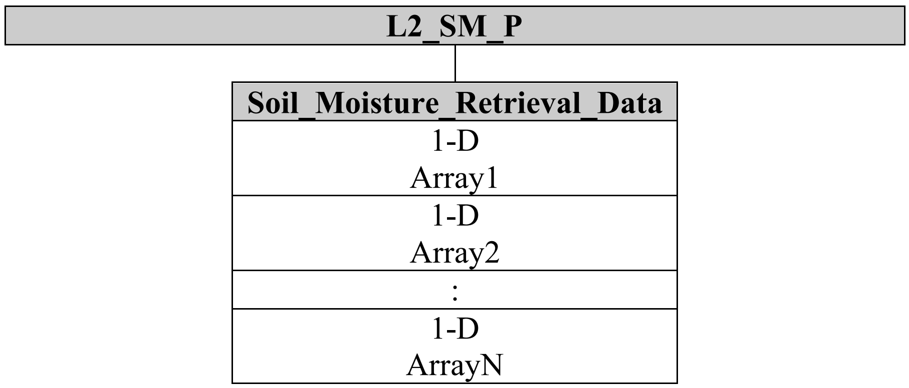

Figure 5: L2_SM_P data organization.

Table 9 describes the output parameters of a typical L2_SM_P half-orbit granule. All data element arrays are one-dimensional with a size *N*, where *N* is the number of valid cells covered by the radiometer swath on the grid.

Table 9: L2_SM_P output parameters

Output Parameter	Precision	Byte	Unit	Note	Section
EASE_row_index	Uint16	2	N\A	2	4.6.1
EASE_col_index	Uint16	2	N\A	2	4.6.2
grid_surface_status	Uint16	2	N\A	8	4.6.3
latitude	Float32	4	Degree	2	4.6.4
longitude	Float32	4	Degree	2	4.6.5
tb_time_seconds	Float64	8	Second	1	4.6.6
tb_time_utc	Char24	24	N\A	1	4.6.7
latitude_centroid	Float32	4	Degree	1	4.6.8
longitude_centroid	Float32	4	Degree	1	4.6.9
boresight_incidence	Float32	4	Degree	1	4.6.10
tb_h_corrected	Float32	4	Kelvin	1	4.6.11
tb_v_corrected	Float32	4	Kelvin	1	4.6.12
tb_3_corrected	Float32	4	Kelvin	1	4.6.13
tb_4_corrected	Float32	4	Kelvin	1	4.6.14
tb_qual_flag_h	Uint16	2	N\A	4	4.6.15
tb_qual_flag_v	Uint16	2	N\A	4	4.6.16
tb_qual_flag_3	Uint16	2	N\A	4	4.6.17

tb_qual_flag_4	Uint16	2	N\A	4	4.6.18
tb_h_uncorrected	Float32	4	Kelvin	1	4.6.19
tb_v_uncorrected	Float32	4	Kelvin	1	4.6.20
surface_water_fraction_mb_h	Float32	4	N\A	1	4.6.21
surface_water_fraction_mb_v	Float32	4	N\A	1	4.6.22
soil_moisture_error	Float32	4	m3/m3	4 or 6	4.6.23
soil_moisture	Float32	4	m3/m3	4	4.6.24
soil_moisture_option1	Float32	4	m3/m3	4	4.6.24
soil_moisture_option2	Float32	4	m3/m3	4	4.6.24
soil_moisture_option3	Float32	4	m3/m3	4	4.6.24
soil_moisture_option4	Float32	4	m3/m3	4	4.6.24
soil_moisture_option5	Float32	4	m3/m3	4	4.6.24
vegetation_opacity	Float32	4	N\A	6	4.6.25
vegetation_opacity_option1	Float32	4	N\A	6	4.6.25
vegetation_opacity_option2	Float32	4	N\A	6	4.6.25
vegetation_opacity_option3	Float32	4	N\A	5	4.6.25
vegetation_opacity_option4	Float32	4	N\A	5	4.6.25
vegetation_opacity_option5	Float32	4	N\A	5	4.6.25
retrieval_qual_flag	Uint16	2	N\A	4	4.6.26
retrieval_qual_flag_option1	Uint16	2	N\A	4	4.6.26
retrieval_qual_flag_option2	Uint16	2	N\A	4	4.6.26
retrieval_qual_flag_option3	Uint16	2	N\A	4	4.6.26
retrieval_qual_flag_option4	Uint16	2	N\A	4	4.6.26
retrieval_qual_flag_option5	Uint16	2	N\A	4	4.6.26
surface_flag	Uint16	2	N\A	4	4.6.27
vegetation_water_content	Float32	4	kg/m^2	6	4.6.28
surface_temperature	Float32	4	Kelvin	6	4.6.29
static_water_body_fraction	Float32	4	N\A	6	4.6.30
radar_water_body_fraction	Float32	4	N\A	7	4.6.31
freeze_thaw_fraction	Float32	4	N\A	6, 7	4.6.32
landcover_class	Uint8	1	N\A	6	4.6.33
landcover_class_fraction	Float32	4	N\A	6	4.6.34
albedo	Float32	4	N\A	6	4.6.35
roughness_coefficient	Float32	4	N\A	6	4.6.36

Method:

1. From L1C_TB.
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 L2_SM_P 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. From L2_SM_A.
8. Nearest-neighbor interpolation.

4.6 Parameter Definitions

4.6.1 **EASE_row_index**

Zero-based row index of a 36-km EASE-Grid 2.0 cell. In most grid cells, both fore-looking L1C_TB data and aft-looking L1C_TB data are available for soil moisture retrieval. But when one group (e.g., fore-looking group) is not available, the row index parameter of the other group (i.e., aft-looking group) will be written into this parameter.

Precision:	Uint16
Dimension:	*N* = Number of grid cells covered by the swath
Valid_min:	0
Valid_max:	405 (Global Cylindrical projection)
Unit:	N\A

4.6.2 **EASE_col_index**

Zero-based column index of a 36-km EASE-Grid 2.0 cell. In most grid cells, both fore-looking L1C_TB data and aft-looking L1C_TB data are available for soil moisture retrieval. But when one group (*e.g.*, fore-looking group) is not available, the row index parameter of the other group (i.e., aft-looking group) will be written into this parameter.

Precision:	Uint16
Dimension:	*N* = Number of grid cells covered by the swath
Valid_min:	0
Valid_max:	963 (Global Cylindrical projection)
Unit:	N\A

4.6.3 **grid_surface_status**

Surface type (land or water) as determined by the antenna boresight location.

Precision:	Uint16
Dimension:	*N* = Number of grid cells covered by the swath
Valid_min:	0; indicates land
Valid_max:	1; indicates water
Unit:	N\A

4.6.4 **latitude**

Latitude of the center of a 36-km EASE-Grid 2.0 cell.

Precision:	Float32
Dimension:	*N* = Number of grid cells covered by the swath
Valid_min:	−90.0
Valid_max:	+90.0
Unit:	Degree

4.6.5 **longitude**

Longitude of the center of a 36-km EASE-Grid 2.0 cell.

Precision:	Float32
Dimension:	*N* = Number of grid cells covered by the swath
Valid_min:	−180.0
Valid_max:	+180.0
Unit:	Degree

4.6.6 **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 36-km EASE-Grid 2.0 cell. The result is then expressed in J2000 seconds (the number of seconds since 11:58:55.816 on January 1, 2000 UT).

Precision:	Float64
Dimensions:	*N* = Number of grid cells covered by the swath
Valid_min:	0
Valid_max:	N\A
Unit:	Second

4.6.7 **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 36-km EASE-Grid 2.0 cell.

Precision:	Char24
Dimensions:	*N* = Number of grid cells covered by the swath
Valid_min:	‘2014-10-31T00:00:00.000Z’
Valid_max:	N\A
Unit:	N\A

4.6.8 **latitude_centroid**

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 latitudes of L1B_TB observations whose boresights fall within a 36-km EASE-Grid 2.0 cell.

Precision:	Float32
Dimensions:	*N* = Number of grid cells covered by the swath
Valid_min:	−90.0
Valid_max:	+90.0
Unit:	Degree

4.6.9 **longitude_centroid**

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 longitudes of L1B_TB observations whose boresights fall within a 36-km EASE-Grid 2.0 cell.

Precision:	Float32
Dimensions:	*N* = Number of grid cells covered by the swath
Valid_min:	−180.0
Valid_max:	+180.0
Unit:	Degree

4.6.10 **boresight_incidence**

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 incidence angles of L1B_TB observations whose boresights fall within a 36-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.

Precision:	Float32
Dimensions:	*N* = Number of grid cells covered by the swath
Valid_min:	0.0

Valid_max:	90.0
Unit:	Degree

4.6.11 **tb_h_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 horizontally polarized brightness temperatures whose boresights fall within a 36-km EASE-Grid 2.0 cell. Wherever water fraction is below a threshold, water brightness temperature correction is applied to this parameter prior to L2_SM_P inversion.

Precision:	Float32
Dimensions:	*N* = Number of grid cells covered by the swath
Valid_min:	0.0
Valid_max:	330.0
Unit:	Kelvin

4.6.12 **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 36-km EASE-Grid 2.0 cell. Wherever water fraction is below a threshold, water brightness temperature correction is applied to this parameter prior to L2_SM_P inversion.

Precision:	Float32
Dimensions:	*N* = Number of grid cells covered by the swath
Valid_min:	0.0
Valid_max:	330.0
Unit:	Kelvin

4.6.13 **tb_3_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 36-km EASE-Grid 2.0 cell. Wherever water fraction is below a threshold, water brightness temperature correction is applied to this parameter prior to L2_SM_P inversion.

Precision:	Float32

Dimensions:	*N* = Number of grid cells covered by the swath
Valid_min:	−50.0
Valid_max:	+50.0
Unit:	Kelvin

4.6.14 **tb_4_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 36-km EASE-Grid 2.0 cell. Wherever water fraction is below a threshold, water brightness temperature correction is applied to this parameter prior to L2_SM_P inversion.

Precision:	Float32
Dimensions:	*N* = Number of grid cells covered by the swath
Valid_min:	−50.0
Valid_max:	+50.0
Unit:	Kelvin

4.6.15 **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 granule. A '0' indicates that both the fore-looking and aft-looking L1C_TB observations satisfy a given quality criterion described in L1B_TB'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 observations. Bit position '0' refers to the least significant digit.

Precision:	Uint16
Dimensions:	*N* = Number of grid cells covered by the swath
Valid_min:	0
Valid_max:	65,536
Unit:	N\A

Bit Position	Bit Value and Interpretation
0	0 = Observation has 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 had 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	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 = Water correction was not performed
	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 free of RFI
	1 = Observation was RFI contaminated

4.6.16 **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 granule. A ‘0’ indicates that both the fore-looking and aft-looking L1C_TB observations satisfy a given quality criterion described in L1B_TB’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 observations. Bit position '0' refers to the least significant digit.

Precision: Uint16
Dimensions: *N* = Number of grid cells covered by the swath
Valid_min: 0
Valid_max: 65,536
Unit: N\A

Bit Position	Bit Value and Interpretation
0	0 = Observation has 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 had 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	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 = Water correction was not performed
	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 free of RFI
	1 = Observation was RFI contaminated

4.6.17 **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 granule. A '0' indicates that both the fore-looking and aft-looking L1C_TB observations satisfy a given quality criterion described in L1B_TB'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 observations. Bit position '0' refers to the least significant digit.

Precision: Uint16
Dimensions: *N* = Number of grid cells covered by the swath

Valid_min: 0
Valid_max: 65,536
Unit: N\A

Bit Position	Bit Value and Interpretation
0	0 = Observation has 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 had 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
12	0 = Observation was a valid value
	1 = Observation was a null value
13	0 = Observation was within half orbit
	1 = Observation was outside half orbit
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 free of RFI
	1 = Observation was RFI contaminated

4.6.18 **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 granule. A '0' indicates that both the fore-looking and aft-looking L1C_TB observations satisfy a given quality criterion described in L1B_TB'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 observations. Bit position '0' refers to the least significant digit.

Precision:	Uint16
Dimensions:	*N* = Number of grid cells covered by the swath
Valid_min:	0
Valid_max:	65,536
Unit:	N\A

Bit Position	Bit Value and Interpretation
0	0 = Observation has 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 had 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
12	0 = Observation was a valid value
	1 = Observation was a null value
13	0 = Observation was within half orbit
	1 = Observation was outside half orbit
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 free of RFI
	1 = Observation was RFI contaminated

4.6.19 **tb_h_uncorrected**

L1B_TB's horizontally polarized brightness temperature interpolated at a 9-km EASE 2.0 grid cell as reported in the fore- and aft-looking groups in the input L1C_TB_E granule. No water correction is performed to this parameter.

Precision:	Float32
Dimensions:	*N* = Number of grid cells covered by the swath
Valid_min:	0.0
Valid_max:	340.0
Unit:	Kelvin

4.6.20 **tb_v_uncorrected**

L1B_TB's vertically polarized brightness temperature interpolated at a 9-km EASE 2.0 grid cell as reported in the fore- and aft-looking groups in the input L1C_TB_E granule. No water correction is performed to this parameter.

Precision:	Float32
Dimensions:	*N* = Number of grid cells covered by the swath
Valid_min:	0.0
Valid_max:	340.0
Unit:	Kelvin

4.6.21 **surface_water_fraction_mb_h**

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

Precision:	Float32
Dimension:	*N* = Number of grid cells covered by the swath
Valid_min:	0.0
Valid_max:	1.0
Unit:	N\A

4.6.22 **surface_water_fraction_mb_v**

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

Precision:	Float32
Dimension:	*N* = Number of grid cells covered by the swath
Valid_min:	0.0

Valid_max:	1.0
Unit:	N\A

4.6.23 **soil_moisture_error**

Estimated '1-sigma' error of the soil_moisture output parameter. The valid minimum and maximum below are subject to further analysis on real data.

Precision:	Float32
Dimensions:	*N* = Number of grid cells covered by the swath
Valid_min:	0.00
Valid_max:	Soil porosity
Unit:	m3/m3

As of beta release this data field is filled with FillValue.

4.6.24 **soil_moisture, soil_moisture_option[1-5]**

Estimated soil moisture at 36-km spatial scale, as returned by the L2_SM_P processing software. The valid minimum and maximum below are subject to further analysis on real data. As of beta-level release the *soil_moisture* field is currently internally linked to the soil moisture field produced by the baseline algorithm.

Precision:	Float32
Dimensions:	*N* = Number of grid cells covered by the swath
Valid_min:	0.02
Valid_max:	Soil porosity
Unit:	m3/m3
Legend:	Option 1: Single Channel Algorithm (H-pol)
	Option 2: Single Channel Algorithm (V-pol)
	Option 3: Dual Channel Algorithm
	Option 4: Microwave Polarization Ratio Algorithm
	Option 5: Extended Dual Channel Algorithm

4.6.25 **vegetation_opacity, vegetation_opacity_option[1-5]**

Estimated vegetation opacity at 36-km spatial scale, as returned by the L2_SM_P processing software when one of the option algorithms is used. 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 deg) for SMAP. The valid minimum and maximum below are subject to further analysis on real data. As of beta-level release the *vegetation_opacity* field is currently internally linked to the vegetation opacity field associated with the baseline algorithm.

Precision:	Float32
Dimensions:	*N* = Number of grid cells covered by the swath
Valid_min:	0.00
Valid_max:	2.00
Unit:	N\A
Legend:	Option 1: Single Channel Algorithm (H-pol)
	Option 2: Single Channel Algorithm (V-pol)
	Option 3: Dual Channel Algorithm
	Option 4: Microwave Polarization Ratio Algorithm
	Option 5: Extended Dual Channel Algorithm

4.6.26 **retrieval_qual_flag, retrieval_qual_flag_option[1-5]**

A 16-bit integer field whose binary representation consists of bits that indicate whether retrieval is 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. The quality of retrieval is determined by the outcome of the inversion convergence test as well as the surface conditions as reported in the *surface_flag* field in Section 4.6.22. A summary of bit definition of the *retrieval_qual_flag* field is listed below. As of beta-level release the *retrieval_qual_flag* field is currently internally linked to the retrieval quality flag produced by the baseline algorithm.

Precision:	Uint16
Dimensions:	*N* = Number of grid cells covered by the swath
Valid_min:	0
Valid_max:	65,536
Unit:	N\A
Legend:	Option 1: Single Channel Algorithm (H-pol)
	Option 2: Single Channel Algorithm (V-pol)
	Option 3: Dual Channel Algorithm
	Option 4: Microwave Polarization Ratio Algorithm
	Option 5: Extended Dual Channel Algorithm

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 in L2_SM_P)

4.6.27 **surface_flag**

A 16-bit integer field whose binary representation consists of bits that indicate the presence or absence of certain surface conditions at a grid cell. In Table 10, a '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. A summary of surface conditions and their thresholds are listed below. The *surface_flag* field is internally linked to the *surface_flag* field associated with the baseline algorithm.

Precision:	Uint16
Dimensions:	*N* = Number of grid cells covered by the swath
Valid_min:	0
Valid_max:	65,536
Unit:	N\A
Legend:	Option 1: Single Channel Algorithm (H-pol) Option 2: Single Channel Algorithm (V-pol) Option 3: Dual Channel Algorithm Option 4: Microwave Polarization Ratio Algorithm Option 5: Extended Dual Channel Algorithm

Table 10: L2_SM_P surface condition bit flag definition. Bit position '0' refers to the least significant bit. Final bit positions and definitions are subject to future revision and expansion as needed.

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 < 0.5: • Retrieval attempted for fraction ≤ T2
				1: Otherwise: • Retrieval skipped for fraction > T2
1	Radar-derived Water Fraction	0.05	0.50	0: Water areal fraction ≤ T1 and IGBP wetland fraction < 0.5:

				• 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 (number 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 (equivalent to 1.0 mm/hr)	7.06e-03 (equivalent to 25.4 mm/hr)	0: Precipitation rate ≤ T1: • Retrieval attempted for rate ≤ T2 1: Otherwise: • Retrieval skipped for rate > 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: VWC ≤ T1: • Retrieval attempted for VWC ≤ T2 1: Otherwise: • Retrieval skipped for VWC > T2
11	Nadir Region / Undefined			0 (not used in the product)
12-15	Undefined			0

4.6.28 **vegetation_water_content**

Vegetation water content at 36-km spatial scale. 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 and maximum below are subject to further analysis on real data.

Precision: Float32
Dimensions: *N* = Number of grid cells covered by the swath

Valid_min:	0.0
Valid_max:	30.0
Unit:	kg/m^2

4.6.29 **surface_temperature**

Depth-corrected soil temperature at 36-km spatial scale. This parameter is used as input ancillary data parameter to the L2_SM_P processing software for both baseline and option algorithms. The valid minimum and maximum below are subject to further analysis on real data.

Precision:	Float32
Dimensions:	*N* = Number of grid cells covered by the swath
Valid_min:	253.15
Valid_max:	313.15
Unit:	Kelvin

4.6.30 **static_water_body_fraction**

Static water body areal fraction at 36-km spatial scale. 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 36-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 when the original data was acquired.

Precision:	Float32
Dimensions:	*N* = Number of grid cells covered by the swath
Valid_min:	0.0
Valid_max:	1.0
Unit:	N\A

4.6.31 **radar_water_body_fraction**

Radar-derived water body areal fraction at 36-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 36-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.

Precision:	Float32

Dimensions:	N = Number of grid cells covered by the swath
Valid_min:	0.0
Valid_max:	1.0
Unit:	N\A

4.6.32 **freeze_thaw_fraction**

Freeze/thaw areal fraction at 36-km spatial scale. 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 36-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.

Precision:	Float32
Dimensions:	N = Number of grid cells covered by the swath
Valid_min:	0.0
Valid_max:	1.0
Unit:	N\A

4.6.33 **landcover_class**

The first three most dominant land cover classes according to the IGBP land cover map. The relative dominance is determined based on ranking among land cover classes using statistical mode.

Precision:	Uint8
Dimensions:	$N \times 3$ = Number of grid cells covered by the swath
Valid_min:	0
Valid_max:	16
Unit:	N\A

4.6.34 **landcover_class_fraction**

The areal fractions of the first three most dominant land cover classes according to a 500-meter MODIS IGBP land cover map. The relative dominance is determined based on ranking among all land cover classes using statistical mode. For example, if there are N1 pixels that correspond to first class and there are NT pixels comprising all land cover classes within a 36-km grid cells, the corresponding percentage refers to (N1 / NT).

Precision:	Float32
Dimensions:	$N \times 3$ = Number of grid cells covered by the swath

Valid_min:	0
Valid_max:	1.0
Unit:	N\A

4.6.35 **albedo**

Single-scattering albedo at 36-km spatial scale. Note that this parameter is the same 'omega' parameter in the 'tau-omega' model for a given polarization channel.

Precision:	Float32
Dimensions:	*N* = Number of grid cells covered by the swath
Valid_min:	0.0
Valid_max:	1.0
Unit:	N\A

4.6.36 **roughness_coefficient**

Roughness coefficient at 36-km spatial scale. Note that this parameter is the same 'h' coefficient in the 'tau-omega' model for a given polarization channel.

Precision:	Float32
Dimensions:	*N* = Number of grid cells covered by the swath
Valid_min:	0.0
Valid_max:	3.0
Unit:	N\A

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6 APPENDIX A: ACRONYMS AND ABBREVIATIONS

This is the standard Soil Moisture Active Passive (SMAP) Science Data System (SDS) list of acronyms and abbreviations. Not all of these acronyms and abbreviations appear in every SMAP SDS document.

ADT	Algorithm Development Team
AMSR	Advanced Microwave Scanning Radiometer
ANSI	American National Standards Institute
APF	Algorithm Parameter File
ARS	Agricultural Research Service
ASF	Alaska Satellite Facility
ATBD	Algorithm Theoretical Basis Document
ATLO	Assembly Test Launch and Operations
BFPQ	Block Floating Point Quantization
BIC	Beam Index Crossing
CARA	Criticality and Risk Assessment
CBE	Current Best Estimate
CCB	Configuration Control Board
CCSDS	Consultative Committee on Space Data Systems
CDR	Critical Design Review
CEOS	Committee on Earth Observing Systems
CF	Climate and Forecast (metadata convention)
CM	Configuration Management
CM	Center of Mass
CONUS	Continental United States
COTS	Commercial Off the Shelf
CR	Change Request
DAAC	Distributed Active Archive Center
DB	Database
DBA	Database Administrator
dB	Decibels
deg	Degrees
deg/sec	Degrees per second
deg C	Degrees Celsius
DEM	Digital Elevation Model
DFM	Design File Memorandum
DIU	Digital Interface Unit
DN	Data Number
DOORS	Dynamic Object Oriented Requirements
DQC	Data Quality Control
DSK	Digital Skin Kernel
DVD	Digital Versatile Disc
EASE	Equal Area Scalable Earth
ECMWF	European Centre for Medium Range Weather Forecasts
ECHO	EOS Clearing House

ECI	Earth Centered Inertial Coordinate System
ECR	Earth Centered Rotating Coordinate System
ECR	Engineering Change Request
ECS	EOSDIS Core System
EDOS	EOS Data Operations System
EM	Engineering Model
EOS	Earth Observing System
EOSDIS	Earth Observing System Data and Information System
EPO	Education and Public Outreach
ESDIS	Earth Science Data and Information System Project
ESDT	Earth Science Data Type
ESSP	Earth Science System Pathfinder
ET	Ephemeris Time
EU	Engineering Units
FOV	Field of View
FRB	Functional Requirements Baseline
FS	Flight System
FSW	Flight Software
F/T	Freeze/Thaw
FTP	File Transfer Protocol
Gbyte	Gigabyte
GDS	Ground Data System
GHA	Greenwich Hour Angle
GHz	Gigahertz
GLOSIM	Global Simulation
GMAO	Government Modeling and Assimilation Office
GMT	Greenwich Mean Time
GN	Ground Network
GPMC	Governing Program Management Council
GPP	Gross Primary Production
GPS	Global Positioning System
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
HDF	Hierarchical Data Format
HK	Housekeeping (telemetry)
Hz	Hertz
HSD	Health and Status Data
ICE	Integrated Control Electronics
ICESat	Ice, Cloud and Land Elevation Satellite
IDL	Interactive Data Language
I&T	Integration and Test
ICD	Interface Control Document
IEEE	Institute of Electrical and Electronics Engineers
IFOV	Instantaneous Field of View
I/O	Input/Output
IOC	In-Orbit Checkout

IRU	Inertial Reference Unit
ISO	International Organization for Standardization
IV&V	Independent Verification and Validation
ITAR	International Traffic in Arms Regulations
I&T	Integration and Test
JPL	Jet Propulsion Laboratory
kHz	Kilohertz
km	Kilometers
LAN	Local Area Network
LBT	Loopback Trap
LEO	Low Earth Orbit
LEOP	Launch and Early Operations
LOE	Level Of Effort
LOM	Life Of Mission
LOS	Loss of Signal
LSK	Leap Seconds Kernel
LZPF	Level Zero Processing Facility
m	Meters
MHz	Megahertz
MIT	Massachusetts Institute of Technology
MMR	Monthly Management Review
MOA	Memorandum of Agreement
MOC	Mission Operations Center
MODIS	Moderate Resolution Imaging Spectroradiometer
MOS	Mission Operations System
m/s	Meters per second
ms	Milliseconds
MS	Mission System
NAIF	Navigation and Ancillary Information Facility
NASA	National Aeronautics and Space Administration
NCEP	National Centers for Environmental Protection
NCP	North Celestial Pole
NCSA	National Center for Supercomputing Applications
NEDT	Noise Equivalent Diode Temperature
NEE	Net Ecosystem Exchange
NEN	Near Earth Network
netCDF	Network Common Data Form
NFS	Network File System/Server
NISN	NASA Integrated Services Network
NRT	Near Real Time
NOAA	National Oceanic and Atmospheric Administration
NSIDC	National Snow and Ice Data Center
NVM	Non-Volatile Memory
NWP	Numerical Weather Prediction
N\A	Not applicable
OCO	Orbiting Carbon Observatory

ORBNUM	Orbit Number File
OODT	Object Oriented Data Technology
ORR	Operational Readiness Review
ORT	Operational Readiness Test
OSSE	Observing System Simulation Experiment
OSTC	One Second Time Command
PALS	Passive and Active L-Band System
PALSAR	Phased Array L-Band Synthetic Aperture Radar
PcK	Planetary Constants Kernel
PDR	Preliminary Design Review
PPPCS	Pointing, Position, Phasing and Coordinate System
PR	Problem Report
PRF	Pulse Repetition Frequency
PRI	Pulse Repetition Interval
PROM	Programmable Read Only Memory
PSD	Product Specification Document
QA	Quality Assurance
rad	Radians
RAM	Random Access Memory
RBA	Reflector Boom Assembly
RBD	Rate Buffered Data
RBE	Radiometer Back End
RDD	Release Description Document
RDE	Radiometer Digital Electronics
RF	Radio Frequency
RFA	Request For Action
RFE	Radiometer Front End
RFI	Radio Frequency Interference
RMS	Root mean square
RSS	Root sum square
ROM	Read Only Memory
RPM	revolutions per minute
RVI	Radar Vegetation Index
SA	System Administrator
SAR	Synthetic Aperture Radar
S/C	Spacecraft
SCE	Spin Control Electronics
SCLK	Spacecraft Clock
SDP	Software Development Plan
SDS	Science Data System
SDT	Science Definition Team
SI	International System
SITP	System Integration and Test Plan
SMAP	Soil Moisture Active Passive
SMEX	Soil Moisture Experiment
SMOS	Soil Moisture and Ocean Salinity Mission

SMP	Software Management Plan
SNR	Signal to noise ratio
SOC	Soil Organic Carbon
SOM	Software Operators Manual
SQA	Software Quality Assurance
SPDM	Science Process and Data Management
SPG	Standards Process Group
SPK	Spacecraft Kernel
SQA	Software Quality Assurance
SPS	Science Production Software
SRF	Science Orbit Reference Frame
SRR	System Requirements Review
SRTM	Shuttle Radar Topography Mission
SSM/I	Special Sensor Microwave/Imager
STP	Software Test Plan
sec	Seconds
TAI	International Atomic Time
TB	Brightness Temperature
TBC	To Be Confirmed
TBD	To Be Determined
TBR	To Be Resolved
TCP/IP	Transmission Control Protocol/Internet Protocol
TEC	Total Electron Content
TM	Trademark
TOA	Time of Arrival
TPS	Third Party Software
UML	Unified Modeling Language
U-MT	University of Montana
USDA	United States Department of Agriculture
UTC	Coordinated Universal Time
V&V	Verification and Validation
VWC	Vegetation Water Content