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Soil Moisture Active Passive (SMAP) Mission
Level 4 Surface and Root Zone Soil Moisture (L4_SM)
Product Specification Document

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Soil Moisture Active Passive (SMAP) Mission Level 4 Surface and Root Zone Soil Moisture (L4_SM) Product Specification Document

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REVISION HISTORY

Revision	Date	Sections Changed	Reason for Change
Initial Version 1.0	2/14/2013	All	Initial Document R. Reichle, B. Weiss, R. Lucchesi, J. Ardizzone
Initial Version 1.1	2/14/2014	4.1.3: spatial coord info 4.4 (Table 8): Collection column for LE_Source 4.5.1 (Table 9): pctl output 4.5.2 (Table 10): added orbit flag, revised obs time, removed F/T obs 4.5.6 (Figures 8-10): added sample QA files for gph and aup 4.6 (Table 14): footnote re. overpass averaging	Updated for science algorithm software Delivery 5.0
Initial Version 1.2	5/7/2014	1.4, Table 1; 4.4, Table 8: added ECS short names; added ECSVersionID 4.2, Table 7: added data volume estimates 4.3: revised text on Science Version ID 4.5.5 (Table 13), 4.6 (Table 14), App E: wetness units corrections and clarifications 4.5.6, Figure 11: added sample qa file for lmc	Updated for SDS Level 4 Software Release 5.0

Initial Version 1.3	6/17/2014	Prefatory material: converted to GMAO Office Note 4.1.3 and 4.5, Tables 9-13: clarified storage of spatial coordinate information (cell_lat, cell_lon, cell_row, cell_column) in hdf5 root directory 4.3: revised explanation of Science Version ID, Composite Release ID, and Product Counter 4.4, Table 8: revised explanation of ECSVersionID and Composite Release ID 4.4, Table 8: updated Source/*lfo* metadata descriptions 4.5.1, Table 9; 4.6, Table 14: added soil moisture output in volumetric units, removed surface soil moisture output in percentile units 4.5.5, Table 13; 4.5.6, Figure 11; 4.6 Table 14: changed output of wilting point to volumetric units Appendix D: revised discussion of soil moisture units	Updated for SDS Level 4 Software Post-R5 Point Release

Version 1.4	10/31/2015	4.2, Table 7: Revised data volume estimates. 4.3: Revised definition of "Launch Indicator" in file name 4.4, Table 8: Reduced Scope of DataQuality/SM metadata to only root zone soil moisture; revised SMAPShortName; revised ProcessSatep/documentation. 4.5.3, Table 11; 4.5.4, Table 12: Changed soil moisture output in "aup" Collection from wetness to volumetric units 4.5.6, Figures 8-11: Updated qa file samples. Appendix: Removed list of SMAP Product Specifications Documents. Removed section with sample hdf5 reader.	Updated for public beta-release of L4_SM data.

Version 1.5	06/14/2018	1.3, 1.4: Added NISDC URL as reference for most up-to-date information. 1.5: Clarified that SMAP L2_SM_AP and L2_SM_A products are not assimilated. 1.6: Added recent peer-reviewed journal publications. 3.3; 4.4, Table 8; 4.5.2; 4.5.3: Added availability of model forecast brightness temperatures for times/locations where obs are not assimilated for the only reason that scaling parameters are not available. 4.2, 4.3: Sample file name changed to Vv3030. 4.5.5, Table 13; 4.5.6, Table 14: Added new Land-Model-Constants output field “clsm_veghght”. 4.5.6, Tables 8-11: Replaced pre-launch sample qa files with samples from science version Vv3030. 4.1.3, 4.5, 4.6, Tables 9-14, Appendix B: Added spatial coordinate datasets (EASE2_global_projection, x, y)	Updated for public release of Version-4 L4_SM data.
Version 1.6	11/14/2022	1.6: Updated list of publications 4.2, Table 7: Updated data volume estimates. Expanded discussion of lossy and lossless compression. Tables 9, 14: Added three new “gph” output fields (“depth_to_water_table_from_surface_in_peat”, “free_surface_water_on_peat_flux”, “mwrtm_vegopacity”) Table 13: Updated “valid_max” values for seven “lmc” output fields (“clsm_poros”, “clsm_wp”, “clsm_cdcr1”,“mwrtm_poros”, “mwrtm_rghhmin”, “mwrtm_rghhmax”, “mwrtm_rghwmax”)	Updated for public release of Version-7 L4_SM data.

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1 INTRODUCTION

1.1 Identification

This is the Product Specification Document (PSD) for Level 4 Surface and Root Zone Soil Moisture (L4_SM) data for the Science Data System (SDS) of the Soil Moisture Active Passive (SMAP) project. The L4_SM data product provides estimates of land surface conditions based on the assimilation of SMAP observations into a customized version of the NASA Goddard Earth Observing System, Version 5 (GEOS-5) land data assimilation system (LDAS). This document applies to any standard L4_SM data product generated by the SMAP Project.

1.2 Scope

This Product Specification Document describes the file format of the L4_SM data product. Its intent is to elucidate the L4_SM data structure and content for external software interfaces. The SMAP Science Data Management and Archive Plan provides a more comprehensive explanation of these data within the complete context of the SMAP instrument, algorithms, and software.

1.3 The SMAP Experiment

[*This section has not been updated from the pre-launch version of this document. For the most recent information, please refer to the online documentation at the National Snow and Ice Data Center:* `http://nsidc.org/data/smap`.]

The Soil Moisture Active Passive (SMAP) mission will enhance the accuracy and the resolution of space-based measurements of terrestrial soil moisture and freeze-thaw state. SMAP data products will have a noteworthy impact on multiple relevant and current Earth Science endeavors. These include:

- Understanding of the processes that link the terrestrial water, the energy and the carbon cycles,
- Estimations of global water and energy fluxes over the land surfaces,
- Quantification of the net carbon flux in boreal landscapes
- Forecast skill of both weather and climate,
- Predictions and monitoring of natural disasters including floods, landslides and droughts, and
- Predictions of agricultural productivity.

To provide these data, the SMAP mission will deploy a satellite observatory in a near polar, sun synchronous orbit. The observatory will house an L-band radiometer that operates at 1.40 GHz and an L-band radar that operates at 1.26 GHz. The instruments will share a rotating reflector antenna with a 6 meter aperture that scans over a 1000 km swath.

As the spacecraft flies from north to south on *descending* orbits, the SMAP instruments will view Earth locations at approximately 06:00 local time. As the spacecraft flies from south to north, on *ascending* orbits, the SMAP instruments will view Earth locations at approximately 18:00 local time. The spacecraft will operate in a cycle of 117 repeatable orbits.

Each time that the spacecraft repeats the orbit cycle, the nadir path on the Earth's surface may not vary by more than 20 km. The flight plan enables scientists to collect data over any region of the Earth over seasonal and annual cycles and avoid diurnal variations. The combined flight pattern and viewing design will enable the observatory to view almost all of the Earth's land mass once every three days.

The SMAP radiometer records microwave emissions from the top 5 cm in the soil with a spatial resolution of about 40 km. Scientific applications based on radiometer measure in the same frequency range have established this approach as an accurate means to detect the presence or water in near surface soil. SMAP radar will provide backscatter measurements at 3 km resolution. The combined instrumentation will enable SMAP to generate highly accurate global soil moistures at 9 km resolution.

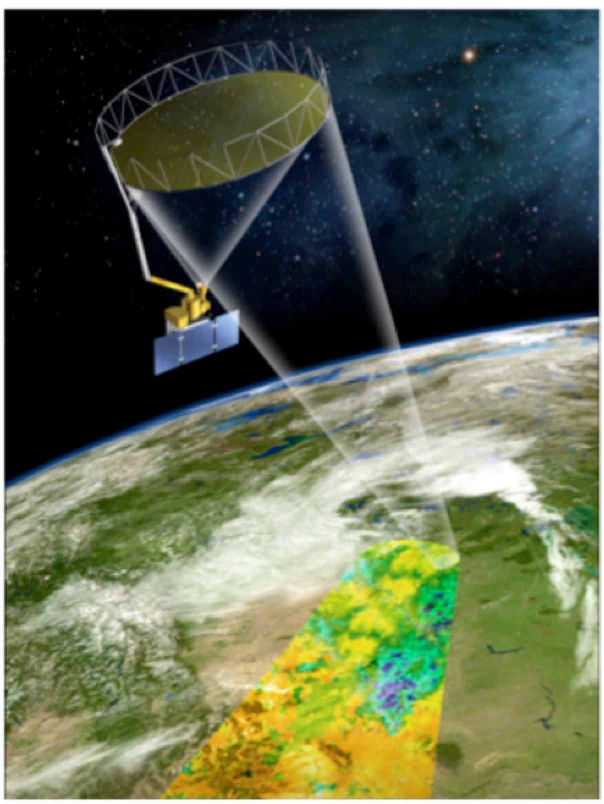

Figure 1: Artist's concept of the SMAP observatory.

Geophysical retrievals based on SMAP radar will indicate the presence of standing water, the freeze-thaw condition of the surface as well as measures of surface roughness and vegetation. The additional information will enable SMAP processors to select appropriate locations for soil moisture retrievals and modeling. In addition, the freeze-thaw data will contribute to models that measure the Net Ecosystem Exchange (NEE) of carbon between the Earth's surface and the atmosphere in Boreal regions.

1.4 SMAP Data Products

[*This section has not been updated from the pre-launch version of this document. For the most recent information, please refer to the online documentation at the National Snow and Ice Data Center:* http://nsidc.org/data/smap.]

The SMAP mission will generate 15 different distributable data products. The 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 1 lists the distributable SMAP data products. The colors in the table categorize the products by level. 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 short names defined for the Earth Observing System Data and Information System (EOSDIS) Core System (ECS). These short names categorize data products in local databases managed by the ECS. ECS short names will also appear in SMAP product metadata.

Table 1: SMAP data products.

SMAP Mission Product Short Name	ECS Short Name	SMAP Data Set Description	Gridding (km)	Latency[1]
L1A_Radar	SPL1AA	L1A Raw Radar Data in Time Order	—	12 hrs
L1A_Radiometer	SPL1AP	L1A Radiometer Raw Data in Time Order	—	12 hrs
L1B_S0_LoRes	SPL1BS0	L1B Low-Resolution Radar σ o Time Order	5x30	12 hrs
L1B_TB	SPL1BTB	L1B Radiometer *TB* in Time Order	36x47	12 hrs
L1C_S0_HiRes	SPL1CS0	L1C High-Resolution Radar σ o (half orbit gridded)	1	12 hrs
L1C_TB	SPL1CTB	L1C Radiometer *TB* (half orbit, gridded)	36	12 hrs
L2_SM_A	SPL2SMA	L2 Soil Moisture (radar, half orbit)	3	24 hrs
L2_SM_P	SPL2SMP	L2 Soil Moisture (radiometer, half orbit)	36	24 hrs
L2_SM_AP	SPL2SMAP	L2 Soil Moisture (radar/radiometer, half orbit)	9	24 hrs
L3_FT_A	SPL3FTA	L3 Freeze-Thaw State (radar, daily composite)	3	50 hrs
L3_SM_A	SPL3SMA	L3 Soil Moisture (radar, daily composite)	3	50 hrs
L3_SM_P	SPL3SMP	L3 Soil Moisture (radiometer, daily composite)	36	50 hrs
L3_SM_AP	SPL3SMAP	L3 Soil Moisture (radar/radiometer, daily composite)	9	50 hrs
L4_SM	**SPL4SMGP**	**L4 Surface and Root Zone Soil Moisture Geophysical Data**	**9**	**7 days**
	SPL4SMAU	**L4 Surface and Root Zone Soil Moisture Analysis Update Data**	**9**	**7 days**
	SPL4SMLM	**L4 Surface and Root Zone Soil Moisture Land Model Constants Data**	**9**	**7 days**
L4_C	SPL4C	L4 Carbon Net Ecosystem Exchange (NEE)	9	14 days

[1] *Mean latency under normal operating conditions (defined as time from data acquisition by the observatory to availability in the public data archive).*

1.5 Content Overview

The SMAP L4_SM data product contains estimates of land surface conditions, including surface and root zone soil moisture, based on the assimilation of SMAP L-band brightness temperatures. The L4_SM data product appears on an Earth-fixed, global, cylindrical Equal Area Scalable Earth grid, version 2.0 (EASE-Grid 2.0) at 9 km grid resolution. The L4_SM data product consists of three Collections of data granules (or files):

- The first Collection is a series of 3-hourly time average geophysical (“gph”) land surface fields that are output by the L4_SM algorithm. This Collection will be of primary interest to most users.
- The second Collection provides diagnostics from the land surface analysis updates (“aup”). This Collection consists of a series of 3-hourly instantaneous (or snapshot) files that contain the assimilated SMAP observations, the corresponding land model predictions and analysis estimates, and additional data assimilation diagnostics.
- The third Collection provides static (time-invariant) land surface model constants (“lmc”) that will be needed by some users for further interpretation of the geophysical land surface fields. This Collection consists of only one granule (file) per L4_SM data product version (as defined by a distinct Science Version ID, section 4.3).

Thus, for each 3-hour interval, there are therefore typically ***two*** granules (files), one “gph” granule and one “aup” granule, per data product version.

The SMAP measurements of land surface microwave emission (or brightness temperature) and radar backscatter at L-band frequencies provide information on surface soil moisture (top 5 cm of the soil column) and on the freeze-thaw state of the land surface. The main objectives of the L4_SM data product are:

(i) to provide estimates of root zone soil moisture (defined here nominally as soil moisture in the top 1 m of the soil column) based on SMAP observations, and

(II) to provide a global surface and root zone soil moisture product that is spatially and temporally complete.

Obtaining root zone soil moisture is important for several of the key applications targeted by SMAP.

The L4_SM algorithm uses an ensemble Kalman filter (EnKF) to merge SMAP observations with soil moisture estimates from the NASA Catchment land surface model. The Catchment model describes the vertical transfer of soil moisture between the surface and root zone reservoirs. The model is driven with observation-based surface meteorological forcing data, including precipitation, and runs on a global 9 km Earth-fixed grid with a 20 min model time step. The EnKF considers the respective uncertainties of each component estimate. Provided with properly calibrated uncertainty inputs, this approach yields a product that is superior to satellite or land model data alone. The L4_SM data product also includes error estimates.

The baseline L4_SM algorithm assimilates SMAP brightness temperature observations at 36 km resolution from the SMAP L1C_TB product. Note that the L4_SM data product structure contains placeholders for the assimilation of downscaled brightness temperatures from the L2_SM_AP product and of freeze-thaw retrievals from the L2_SM_A product. Since SMAP radar observations are only available for the period 13 April 2015 to 7 July 2015 because of a radar instrument malfunction, these radar-based Level 2 products are not assimilated.

Analysis updates are computed every three hours (at 0z, 3z, …, 21z) using the available SMAP products. The baseline L4_SM algorithm effectively assimilates brightness temperature anomalies (with respect to a long-term climatology that resolves the seasonal and diurnal cycles).

The L4_SM data product provides a variety of geophysical fields at 3 hour time resolution on the global 9 km modeling grid, along with the assimilated lower-level SMAP observations and related instantaneous model and analysis fields. L4_SM surface and root zone soil moisture estimates are validated to an RMSE requirement of 0.04 m^3 m^{-3} after removal of the long-term mean bias. This accuracy requirement is identical to Level 2 soil moisture product validation and excludes regions with snow and ice cover, frozen ground, mountainous topography, open water, urban areas, and vegetation with water content greater than 5 kg m^{-2}. Research outputs (not validated) include the surface meteorological forcing fields, land surface fluxes, soil temperature and snow states, runoff, and error estimates that are derived from the ensemble.

1.6 Related Publications and SMAP Project Documents

Colliander, A., R. H. Reichle, and Coauthors (2022), Validation of Soil Moisture Data Products from the NASA SMAP Mission, *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 15*, 364-392, doi:10.1109/JSTARS.2021.3124743.

Reichle, R. H., and Coauthors (2021), The Contributions of Gauge-Based Precipitation and SMAP Brightness Temperature Observations to the Skill of the SMAP Level-4 Soil Moisture Product, *Journal of Hydrometeorology, 22*, 405-424, doi:10.1175/JHM-D-20-0217.1.

Reichle, R. H., Q. Liu, R. D. Koster, J. V. Ardizzone, A. Colliander, W. T. Crow, G. J. M. De Lannoy, and J. S. Kimball (2022), Soil Moisture Active Passive (SMAP) Project Assessment Report for Version 6 of the L4_SM Data Product, NASA Technical Report Series on Global Modeling and Data Assimilation, NASA/TM-2022-104606, Vol. 60, National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland, USA, 68pp.

Reichle, R. H., and Q. Liu (2021), Observation-Corrected Precipitation for the SMAP Level 4 Soil Moisture (Version 6) Product and the GEOS R21C Reanalysis, NASA Technical Report Series on Global Modeling and Data Assimilation, NASA/TM-2021-104606, Vol. 59, National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland, USA, 28pp.

Reichle, R. H., and Coauthors (2019), Version 4 of the SMAP Level-4 Soil Moisture Algorithm and Data Product, *Journal of Advances in Modeling Earth Systems, 11*, 3106-3130, doi:10.1029/2019MS001729.

Reichle, R. H., and Coauthors (2017), Global Assessment of the SMAP Level-4 Surface and Root-Zone Soil Moisture Product Using Assimilation Diagnostics, *Journal of Hydrometeorology, 18*, 3217-3237, doi:10.1175/JHM-D-17-0130.1.

Reichle, R. H., and Coauthors (2017), Assessment of the SMAP Level-4 Surface and Root-Zone Soil Moisture Product Using In Situ Measurements, *Journal of Hydrometeorology, 18*, 2621-2645, doi:10.1175/JHM-D-17-0063.1.

SMAP Algorithm Theoretical Basis Document: Level 4 Surface and Root Zone Soil Moisture (L4_SM), Reichle, R. H., R. Koster, G. De Lannoy, W. Crow, and J. Kimball, JPL D-66483, Revision A, December 9, 2014.

SMAP Science Data Management and Archive Plan, JPL D-45973, August 29, 2011.

SMAP Pointing, Positioning, Phasing and Coordinate Systems, Volume 0: Definitions and Principle Coordinate Systems, JPL D-46018, Initial Release, May 18, 2010

1.7 Applicable Documents

ISO 19115:2003(E) International Standard – Geographic Information – Metadata, May 1, 2003.

ISO 19115-2:2009 International Standard – Geographic Information – Part 2: Extensions for imagery and gridded data, December 12, 2009.

ISO 19139:2007 International Standard – Geographic Information – Metadata – XML schema implementation, May 14 2009.

Introduction to HDF5, The HDF Group, http://www.hdfgroup.org/HDF5/doc/H5.intro.html.

HDF5: API Specification Reference Manual, The HDF Group
http://www.hdfgroup.org/HDF5/doc/RM/RM_H5Front.html

HDF5 User's Guide Release 1.8.9, The HDF Group,
http://hdfgroup.com/HDF5/doc/UG, May 2012.

NetCDF Climate and Forecast (CF) Metadata Conventions, Version 1.6,
December 5, 2011.

EASE-Grid 2.0: Incremental but Significant Improvements for Earth-Gridded Data Sets, Brodzik, M.J., et. al., National Snow and Ice Data Center, Cooperative Institute of Environmental Sciences, University of Colorado, ISPRS International Journal of Geo-Information, ISSN 2220-9964, DOI: 10.3390/igji1010032.

2 DATA PRODUCT ORGANIZATION

2.1 File Format

All SMAP standard products are in the Hierarchical Data Format version 5 (HDF5). 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 regardless of the source. Use of the HDF library enables users to read HDF files on multiple platforms regardless of the architecture the platforms use to represent integer and floating point numbers. HDF files are equally accessible to routines written either in Fortran, C or C++.

A spin-off organization of the NCSA, named The HDF Group, 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 2 lists the Atomic Datatypes that are used in SMAP data products.

Table 2: 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

HDF5 Atomic Datatypes	Description
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 3 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 3: 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, “XML” and “HDF5 Groups”. The first form, “XML”, appears in two HDF5 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.

The metadata structure of the L4_SM data product is discussed in sections 4.1.2 and 4.4.

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 4 lists the CF names for the HDF5 Attributes that SMAP products typically employ.

Table 4: SMAP specific local attributes.

CF Compliant Attribute Name	Description	Required?
units	Units of measure. Appendix D lists applicable units for various data elements in this product.	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 the type of the associated Dataset. Thus, if the associated Dataset stores float32 values, the corresponding _FillValue will also be float32.	Yes for all numeric data types
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

CF Compliant Attribute Name	Description	Required?
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 5 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 5: 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. Appendix B lists all of the valid shapes that appear in this data product.
Valid_min	The expected minimum value for a data element. In most instances, data element values never fall below this limit. However, some data 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”, “degC”, “Kelvins”, “m/s”, “m”, “m**2”, “s” and “counts”. Appendix A and Appendix D include references to important data measurement unit symbols.

2.4.1 Double Precision Time Variables

SMAP double precision time variables contain measurements relative to the J2000 epoch. Thus, these variables represent a real number of Standard International (SI) compatible seconds since 11:58:55.816 on January 1, 2000 UTC.

2.4.2 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.

3 INTERFACE CHARACTERISTICS

3.1 Coordinate Systems

The SMAP mission will use the Science Orbit Reference Frame (SRF) and the Earth Centered Rotating (ECR) coordinate systems to represent spacecraft attitude, position and relative motion.

The Science Orbit Reference Frame (SRF) is a right-handed coordinate system with its three axes mutually orthogonal. The SRF is defined such that the origin is at the spacecraft center of mass (CM). The +Z axis points toward Geodetic Nadir. Due to the oblateness of the Earth, the vector from the spacecraft to the geometric center of the Earth (Geocentric Nadir) is different from the vector from the spacecraft to the local WGS84 ellipsoid normal (Geodetic Nadir). The +X axis is coplanar with both the +Z axis and the spacecraft inertial velocity vector. The +X axis closely adheres to the direction of the spacecraft inertial velocity vector. The +Y axis completes the right-handed, orthogonal coordinate system. The +Y axis is normal to the orbit plane with positive sense in the direction opposite the orbit angular momentum vector.

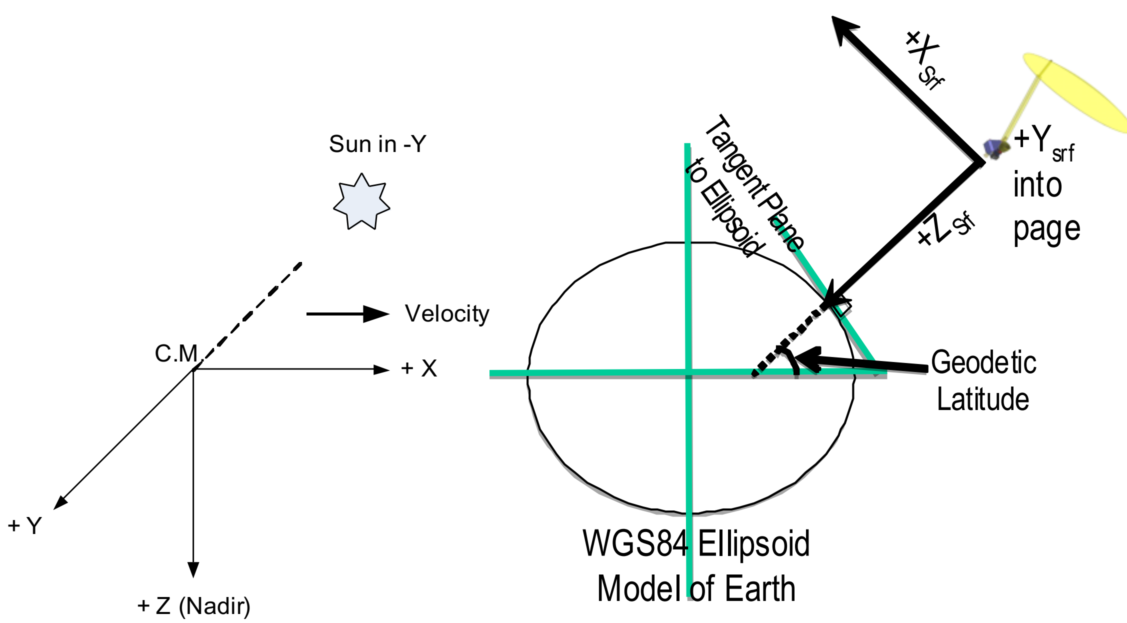

Figure 2: The Science Orbit Reference Frame coordinate system.

The Earth Centered Rotating (ECR) or Earth Centered Fixed coordinate system is a right-handed coordinate system with three mutually orthogonal axes. The origin of the system is the Earth's center of mass. The positive x-axis extends from the origin through the intersection of the Equator at 0° latitude and the Greenwich

Meridian at 0° longitude. The positive z-axis extends directly North from the origin of the ECR system. Due to a slight wobbling of the Earth, the z-axis does not coincide exactly with the instantaneous rotation axis of the Earth. The y-axis completes the right- handed coordinate system as a vector from the origin to the intersection of the Equator and 90° East longitude.

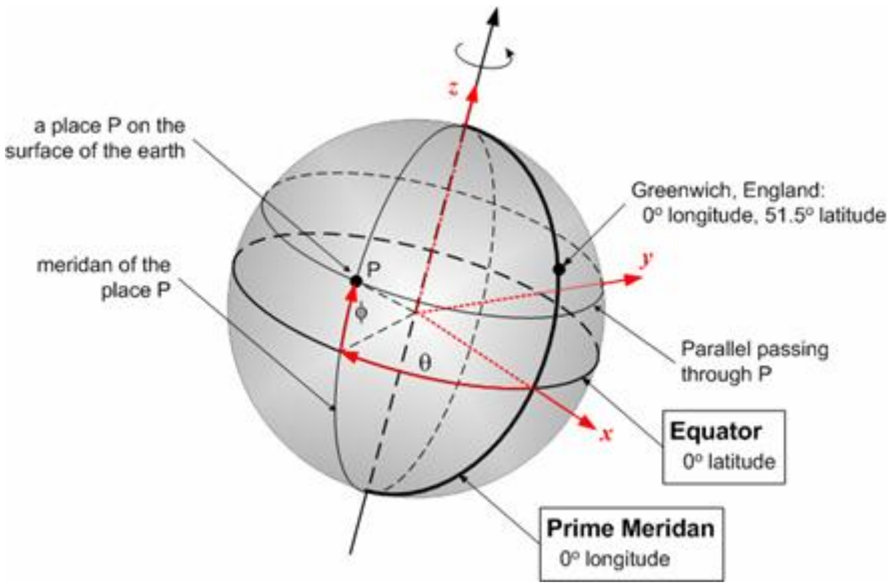

Figure 3: Earth Centered Rotating coordinate system.

The SMAP mission adopted the World Reference System WGS84 ellipsoid to define the horizontal Earth reference coordinates. The WGS84 geoid was adopted as the vertical Earth reference coordinates. Geodetic measure is used to define both the spacecraft location and the instrument target location relative to the Earth's surface.

3.2 The Global Cylindrical EASE-Grid 2.0

The data in the SMAP L4_SM data product are provided on the global cylindrical EASE-Grid 2.0 with a nominal grid spacing of 9 km. Each grid cell has an area of about 81 km^2, regardless of longitude and latitude. Using this projection, all global data arrays have dimensions of 1624 rows and 3856 columns. Figure 4 illustrates the region covered by the global cylindrical EASE-Grid 2.0 projection.

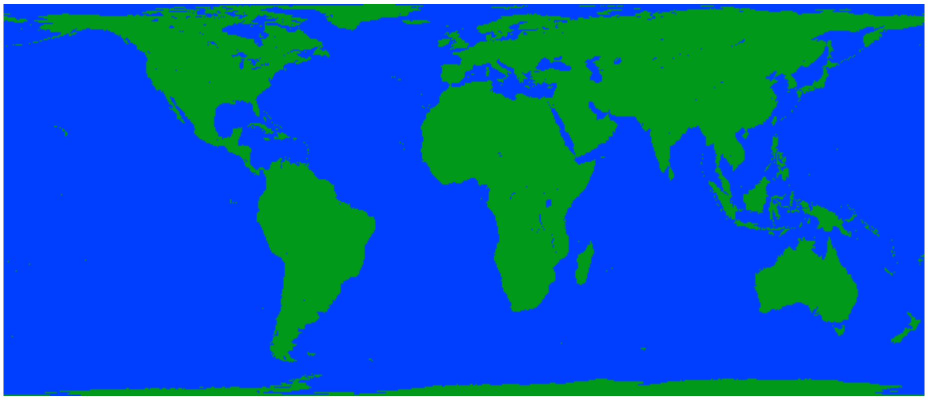

Figure 4: Global EASE-Grid 2.0.

The EASE-Grid 2.0 has a flexible formulation. By adjusting a single scaling parameter, a family of multi-resolution grids that "nest" within one another can be generated. The nesting can be made "perfect" so that smaller grid cells can be tessellated to form larger grid cells. Figure 5 shows a schematic of the nesting.

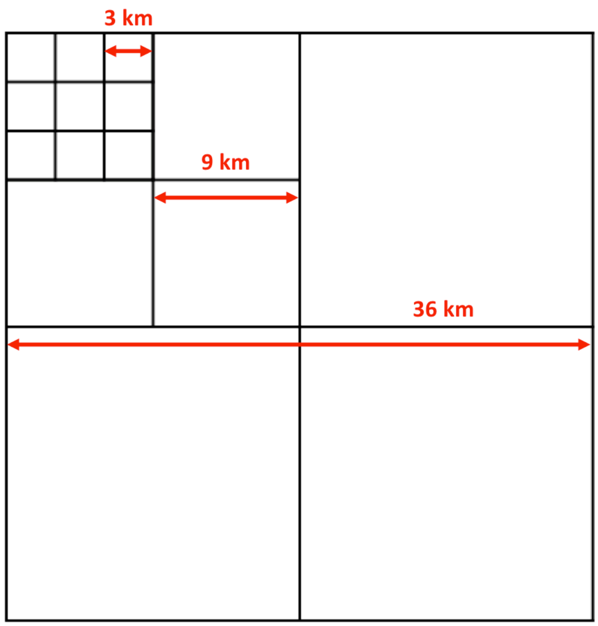

Figure 5: Perfect nesting in EASE-Grid 2.0. Smaller grid cells tessellate into larger grid cells.

The perfect nesting provides SMAP data products with a convenient common projection for both high-resolution radar observations and low-resolution radiometer observations, as well as for their derived geophysical products. Other SMAP data products use 3 km, 9 km and 36 km grid spacings. Figure 6 provides an example of sample Normalized Difference Vegetation Index (NDVI) data on the EASE-Grid 2.0 at these three resolutions.

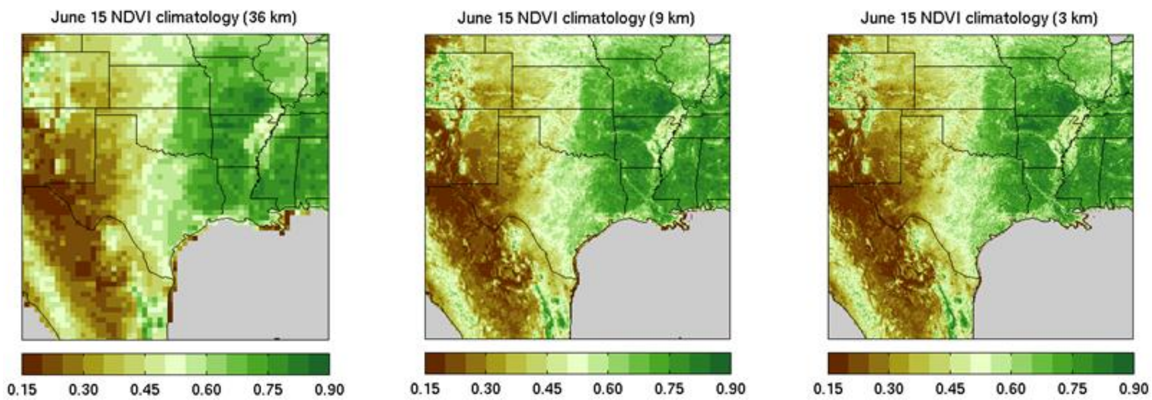

Figure 6: Sample NDVI data displayed on the SMAP EASE-Grid 2.0 with (left) 36 km, (middle) 9 km, and (right) 3 km nominal grid spacing.

3.3 Fill and 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 L4_SM data product over ocean and water surfaces, or for variables that are not meaningful, for example, snow temperatures in the absence of snow. Fill values are also used, for example, in the "aup" file Collection for all grid cells for which SMAP observations were not ingested. The latter may occur for any of the following circumstances:

- There was no SMAP overpass for the grid cell in question during the assimilation time window.
- The SMAP observations were not available due to quality control, missing science or engineering input data, or any other reason in the Level 1, 2, or 3 processing algorithms.
- The SMAP observations were rejected for assimilation due to quality control by the L4_SM algorithm.

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 6 lists the values that represent fill in SMAP products based on data type:

Table 6: SMAP data product fill values.

Type	Value	Pattern
Float32, Float64	-9999.0	Unique 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	NA	Not available

No *valid* value in the L4_SM data product is equal to the values that represent fill. If any exceptions should exist in the future, the L4_SM 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.

Because the L4_SM data product is partially based on modeling, gaps are not expected to occur in the L4_SM data stream. Note, however, that there might well be 3-hour intervals for which no SMAP data were assimilated. This situation would be reflected in the “aup” Collection when the total number of assimilated observations for the time interval in question is zero.

3.4 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.

3.5 Access to Product Element Dimensions

Each data element in every SMAP data product is assigned a specific shape. Elements with the same shape have the same number of dimensions, and each of those dimensions have the same extent and meaning. Thus, if two data elements have the same shape, then their constituent array elements with identical indices correspond.

The L4_SM data product employs a naming convention for shapes. The convention specifies the component dimensions. The final word in all shape names is always “Array”. The text that precedes the word “Array” provides the order of dimensions. The word that just precedes “Array” represents the dimension with the “fastest moving” index. In other words, consecutive indices in this dimension, provided the other dimension indices are identical, represent contiguous storage. For example, the Shape name LatCell_LonCell_Array implies that the dimension where consecutive indices imply contiguous storage represents longitude location. The other, slower moving, dimension represents latitude positions. Appendix B provides the nominal rank and dimension sizes for each shape that appears in the L4_SM data product.

Appendix C provides the nominal or expected maximum product dimensions.

4 DATA DEFINITION

4.1 Product Overview

4.1.1 L4_SM Data Product

The major contents of the L4_SM data product are global, 3-hourly, time-average surface and root zone soil moisture estimates on the Earth-fixed, cylindrical, 9 km EASE-Grid 2.0. Additional data elements in the product provide related land surface states and fluxes as well as data assimilation diagnostics.

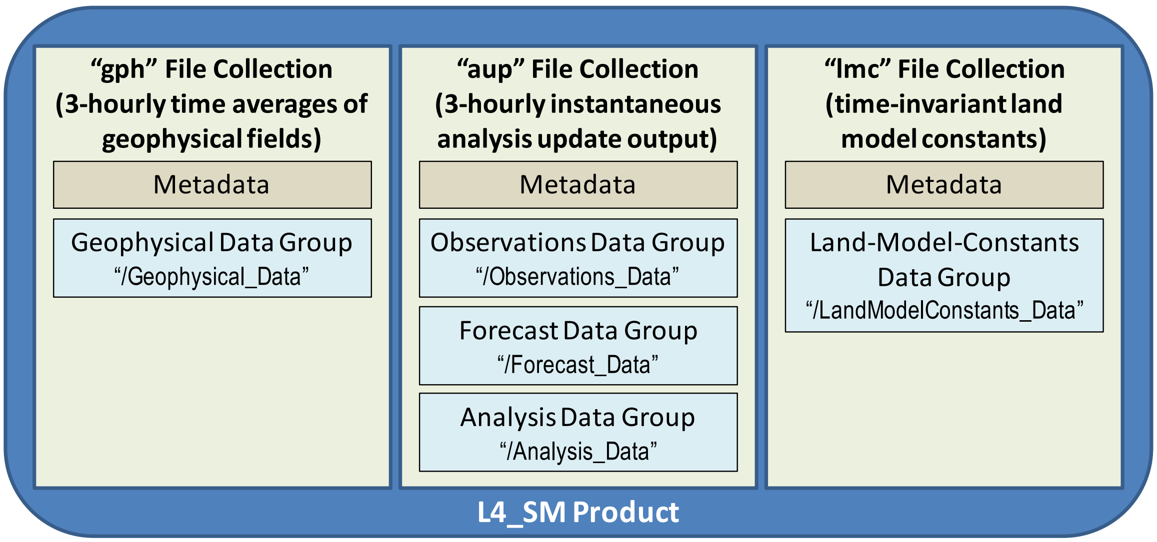

Figure 7: Overview of the L4_SM data product.

Figure 7 illustrates the components of the L4_SM data product. The L4_SM data product consists of three Collections of data granules (or files; section 1.5):

- the geophysical data ("gph") Collection,
- the analysis update data ("aup") Collection, and
- the land model constants data ("lmc") Collection.

Each L4_SM "gph" granule incorporates the 3-hour average estimates of land surface geophysical fields generated by the L4_SM algorithm. Each L4_SM "aup" granule provides supplemental information in the form of snapshots of the assimilated observations, the corresponding model forecast and analysis estimates, and assimilation diagnostics for the 3-hour assimilation time window. Each L4_SM "lmc" granule provides time-invariant land surface model constants. For each of the three Collections, the data within each granule (or file) are organized into Metadata (section 4.1.2) and other Data Groups (section 4.1.3).

4.1.2 L4_SM Metadata

The SMAP L4_SM metadata are representative of the entire contents of the file. The metadata appear in two forms, "XML" and "HDF5 Groups", that each provides a complete representation of the product metadata (section 2.3.4).

The first form of the metadata, "XML", appears in two HDF5 Attributes that conform to the ISO 19115-2 model in ISO 19139 compliant XML. Metadata in ISO 19139 conformant XML enables users who are familiar with the ISO metadata standards to extract the metadata they need using software that operates with the ISO 19115-2 model and its formal representation.

The second form of the metadata appears in a set of HDF5 Groups that contain a set of HDF5 Attributes. The arrangement and names of these groups and their Attribute components approximate major contents of the ISO model. This second form of HDF5 groups and Attributes enable users who are not familiar with the ISO standard to find the particular metadata elements they need to better comprehend product content and format.

Section 4.4 provides details about the metadata of the L4_SM data product.

4.1.3 L4_SM Data Groups

All elements in the L4_SM data product are stored as HDF5 Datasets. Each of these datasets belongs to a distinct HDF5 Data Group. The data design employs HDF5 Data Groups to categorize datasets that have corresponding array elements and that relate to a common application.

As shown in Figure 7, the HDF5 Data Groups in the L4_SM data product are

- the Geophysical Data Group in the "gph" file Collection,
- the Observations Data Group, the Forecast Data Group, and the Analysis Data Group in the "aup" file Collection, and
- the LandModelConstants Data Group in the "lmc" file Collection.

The spatial coordinate Datasets (EASE2_global_projection, latitude, longitude, x coordinates, y coordinates, row index, and column index for each grid cell) are the same for all three Data Groups within the "aup" Collection, and there is only one Data Group (besides the Metadata Group) in the "gph" and "lmc" Collections. For all Collections the spatial coordinate Datasets are therefore stored in the HDF5 root Data Group (section 2.2.2).

Section 4.5 of this document includes more detailed descriptions of each of the HDF5 Data Groups in the data product.

All of the L4_SM HDF5 Data Groups are on the Earth-fixed, global, cylindrical, 9 km EASE-Grid 2.0.

4.2 Data Volume Estimates

Table 7 provides data volume estimates. The file size of the compressed "gph" and "aup" hdf5 granules is approximately 145 and 92 MB per granule, respectively. Granule size varies slightly over time, depending on how well the data can be compressed by the built-in HDF5 utilities. The file size of the "lmc" granule is approximately 51 MB per granule. Per (non-leap) data-year, the L4_SM data product consists of 5,840 "gph" and "aup" granules with a total data volume of approximately 676 GB.

A lossy compression ("bit shaving") is applied to reduce the volume of the Geophysical Data ("gph"). Specifically, this lossy compression retains only the 12 most important bits (out of 24) that make up the mantissa of each science data value. The 12 least important bits, which generally do not contain meaningful science information, are modified to enhance compressibility. (In Version 6 only, this lossy compression was also applied to the "aup" granules, but this interfered with the determination of vanishing increments in post-processing. In Version 5, only lossless compression was inadvertently applied to all granules.)

Table 7: Average data volume estimates for the L4_SM data product.

Collection	Group	Expected Total Volume (Compressed)
"gph"	Single Granule*	145 MB
"aup"	Single Granule*	92 MB
"lmc"	Single Granule*	51 MB
L4_SM data product per data-year*		***692 GB***

**Single granule estimates are based on Version 7 (Vv7032) data for April-December 2015.*

**Data product total is for one year's worth of data of a single data product version, including 8 "gph" and 8 "aup" granules per day.*

4.3 SMAP L4_SM Data Product File Names

Distributable SMAP L4_SM data product file names are 41 characters in length (excluding the file name extension). The first 5 characters in the name of all mission distributable products are 'SMAP_'. These characters identify all products generated by the SMAP mission. The following 6 characters are always 'L4_SM_'. These characters identify the L4_SM data product. The subsequent 3 characters identify the file Collection ID ("gph", "aup", or "lmc"). The following 27 characters uniquely identify the data stored in the file. The final 3 characters of each SMAP hdf5 Product file name are '.h5'. These characters specify the format of the data in the file.

More specifically, all SMAP L4_SM data product file names must conform to the following convention:

SMAP_L4_SM_[Collection ID]_[Date/Time Stamp]_[Science Version ID]_[Product Counter].[extension]

The outline below describes the content of each field in the file naming convention:

Collection ID – Identifies whether the granule belongs to the "gph", the "aup", or the "lmc" Collection of the L4_SM data product.

Date/Time Stamp – The date/time stamp of the data elements that appear in the product. Date/time stamps in SMAP file names are always recorded in Universal Coordinated Time (UTC). Date/time stamps conform to the following convention:

YYYYMMDD**T**hhmmss

where:

YYYY is the calendar year. The full calendar year must appear in the file name.

MM designates the month of the year. The month designator always occupies two digits. Months that can be represented with fewer than two digits must employ a leading zero.

DD designates the day of the month. The day designator always occupies two digits. Days of the month that can be represented with fewer than two digits must employ a leading zero.

T delineates the date from the time, and is a required character in all time stamps in product names.

hh designates the hour of the day on a 24 hour clock in UTC. The hour designator always occupies two digits. Hours that can be represented with fewer than two digits must employ a leading zero.

mm designates the minute of the hour in UTC. The minute designator always occupies two digits. Minutes that can be represented with fewer than two digits must employ leading zeroes.

ss designates the truncated second of the minute in UTC. Fractional second specification is not necessary in file names. The second designator always occupies two digits. Seconds that can be represented with fewer than two digits must employ leading zeroes.

For the "gph" Collection, the date/time stamp corresponds to the center point of the time averaging interval. For example, "**T**013000" corresponds to the time average from 00:00:00 UTC to 03:00:00 UTC on a given day.

For the "aup" Collection, the date/time stamp indicates the time of the analysis update. For example, "**T**030000" indicates an analysis for 03:00:00 UTC on a given day. This analysis would typically assimilate all SMAP data observed between 01:30:00 UTC and 04:30:00 UTC.

For the "lmc" Collection (time-invariant constants), the date/time stamp is "00000000**T**000000".

Science Version ID – The Science Version ID reflects L4_SM algorithm updates that impact the science content of the product. The Science Version ID conforms to the following template

V[L][M][nnn]

where:

"**V**" The character "V" always precedes the version identifier

Launch indicator [L]

Distinguishes between pre-launch and post-launch operating conditions and indicates validation status. One digit launch indicators are assigned as follows:

0: pre-launch output (simulated data)

a: output prior to public beta release ("alpha")

b: beta-release output

v: validated-release output

Major ID [M] One digit that indicates the major version number. Major changes in algorithm or processing approach will generate an update to this identifier.

Minor ID [nnn] Three digits that indicate the minor version number. Any change to any component that impacts the science content of the data product will lead to a change in this identifier.

Note that the data product **Science Version ID** is the first part of the data product **Composite Release ID**. The Science Version ID is incremented whenever a change in the L4_SM algorithm or its time-invariant ancillary inputs impacts the science content of the L4_SM product. The Composite Release ID captures all changes in the L4_SM production system, including changes in dynamic ancillary inputs and changes that have no impact on the science content. The Composite Release ID is stored in the metadata (section 4.4) and consists of the Science Version ID plus a four-digit appendix.

Product Counter – The Product Counter tracks the number of times that a particular L4_SM data file (or granule) was generated under the same Science Version ID and for the same Collection and time period (or instant). The system assigns a Product Counter of 001 to the first instance of a granule. Subsequent instances of the same granule (that is, representing the same Collection, time period, and Science Version ID) are assigned a Product Counter that represents the next consecutive integer. The Product Counter always occupies three digits. Product Counters that do not require three digits contain leading zeroes.

Extension – The extension for all SMAP L4_SM data products is "h5". That extension indicates that the product contents are in HDF5 format. The SMAP SDS will generate a QA file with every data granule. The QA file contains statistical information that will enable users to better assess the quality of the associated granule. QA products bear exactly the same name as the products that they represent. The only difference in names is the extension. The extension for all QA products is ".qa".

Example File Names – Based on the above standard, the following name describes a data product from the validated-release science version 3.030 (Vv3030) of the L4_SM data product that provides the time-average geophysical ("gph") output for the interval from 18:00:00 UTC to 21:00:00 UTC on December 25, 2014. The file represents the second time an L4_SM "gph" product was generated for the date and time interval in question:

`SMAP_L4_SM_gph_20141225T193000_Vv3030_002.h5`

The name of the QA product that assesses the output of the above L4_SM "gph" granule would be:

`SMAP_L4_SM_gph_20141225T193000_Vv3030_002.qa`

4.4 L4_SM Data Product Metadata

As mentioned in section 4.1.2, the metadata elements in the L4_SM data product appear in two forms. One form appears in two specific HDF Attributes within the Metadata Group. The content of the first of these two HDF Attributes is the complete set of series metadata. The series metadata apply to all L4_SM files in a SMAP mission version. The content of the second HDF Attribute is the complete set of dataset metadata. The dataset metadata are specific to each product file. Combined, these two Attributes represent all of the metadata that apply to the associated L4_SM product. The content of these Attributes 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. Each of these groups contain a set of HDF5 Attributes. Each HDF5 Attribute 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 19115-1 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 carats <>.

The final column of Table 8 indicates the L4_SM file Collections in which the metadata appear. If metadata appear in a Collection, they will appear in every granule (file) of the Collection. Metadata values may differ between the "gph" and the "aup" Collections. For example, metadata entries for "Extent/rangeBeginningDateTime" and "Extent/rangeEndDateTime" will differ for the data product elements in the "gph" (which represent time averages) and the data product elements of the "aup" Collection (which represent instantaneous or snapshot data), and it will not be present in the "lmc" Collection (which represents time-invariant model constants).

Table 8: Granule level metadata in the L4_SM data product.

ISO Major Class	SMAP HDF5 Metadata SubGroup	Subgroup/Attribute in SMAP HDF5	Valid Values	Collec-tion
DQ_DataQuality	DataQuality/TBH	Scope	`tb_h_forecast`	aup
		CompletenessOmission/evaluationMethodType	directInternal	
		CompletenessOmission/measureDescription	Percent of land grid cells (excluding inland water and permanent ice) that lack H-polarized model forecast Tb data relative to the total number of land grid cells that fall within the global domain (excluding inland water and permanent ice). Model forecast Tb is only computed where SMAP Tb observations are ingested.	
		CompletenessOmission/nameOfMeasure	Percent of Missing Data	
		CompletenessOmission/value	*<A measure between 0 and 100>*	
		CompletenessOmission/unitOfMeasure	Percent	
		DomainConsistency/evaluationMethodType	directInternal	
		DomainConsistency/measureDescription	Percent of geophysical data that fall within a predefined acceptable range of measure.	
		DomainConsistency/nameOfMeasure	Percent of geophysical data that are within the acceptable range.	
		DomainConsistency/value	*<A measure between 0 and 100>*	
		DomainConsistency/unitOfMeasure	Percent	

	DataQuality/TBV	Scope	`tb_v_forecast`	aup
		CompletenessOmission/evaluationMethodType	directInternal	
		CompletenessOmission/measureDescription	Percent of land grid cells (excluding inland water and permanent ice) that lack V-polarized model forecast Tb data relative to the total number of land grid cells that fall within the global domain (excluding inland water and permanent ice). Model forecast Tb is only computed where SMAP Tb observations are ingested.	
		CompletenessOmission/nameOfMeasure	Percent of Missing Data	
		CompletenessOmission/value	*<A measure between 0 and 100>*	
		CompletenessOmission/unitOfMeasure	Percent	
		DomainConsistency/evaluationMethodType	directInternal	
		DomainConsistency/measureDescription	Percent of geophysical data that fall within a predefined acceptable range of measure.	
		DomainConsistency/nameOfMeasure	Percent of geophysical data that are within the acceptable range.	
		DomainConsistency/value	*<A measure between 0 and 100>*	
		DomainConsistency/unitOfMeasure	Percent	

	DataQuality/SM	Scope	`sm_rootzone`	gph
		CompletenessOmission/evaluationMethodType	directInternal	
		CompletenessOmission/measureDescription	Percent of land grid cells (excluding inland water and permanent ice) that lack root zone soil moisture data relative to the total number of land grid cells that fall within the global domain (excluding inland water and permanent ice).	
		CompletenessOmission/nameOfMeasure	Percent of Missing Data	
		CompletenessOmission/value	*<A measure between 0 and 100>*	
		CompletenessOmission/unitOfMeasure	Percent	
		DomainConsistency/evaluationMethodType	directInternal	
		DomainConsistency/measureDescription	Percent of geophysical data that fall within a predefined acceptable range of measure.	
		DomainConsistency/nameOfMeasure	Percent of geophysical data that are within the acceptable range.	
		DomainConsistency/value	*<A measure between 0 and 100>*	
		DomainConsistency/unitOfMeasure	Percent	

EX_Extent	Extent	description	Global land excluding inland water and permanent ice.	gph, aup, lmc (except time range)
		westBoundLongitude	-180 degrees	
		eastBoundLongitude	180 degrees	
		southBoundLatitude	- 85.0445664 degrees	
		northBoundLatitude	85.0445664 degrees	
		rangeBeginningDateTime	*<Time stamp that indicates the initial time element in the product.>*	
		rangeEndingDateTime	*<Time stamp that indicates the final time of data in the product.>*	

LI_Lineage/LE_ProcessStep	ProcessStep	processor	Soil Moisture Active Passive (SMAP) Mission Science Data System (SDS) Operations Facility	gph, aup, lmc
		stepDateTime	*<A date time stamp that specifies when the processing of the data product took place.>*	
		processDescription	Assimilates Level 1 and Level 2 SMAP data into a global land surface model to generate spatially complete and temporally continuous estimates of soil moisture and associated land surface conditions.	
		documentation	*<Document title.>*	
		documentDate	*<Document release/publication date (ccyy-mm-dd).>*	
		documentVersion	*<Document version identifier.>*	
		identifier	L4_SM_SPS	
		runTimeParameters	*<Specify any run time parameters if they were used.>*	
		SWVersionID	*<A software version identifier that runs from 001 to 999>*	
		softwareDate	*<A date stamp that specifies when software used to generate this product was released.>*	
		softwareTitle	Level 4 Surface and Root Zone Soil Moisture SPS	
		timeVariableEpoch	J2000	
		epochJulianDate	2451545.00	
		epochUTCDate	2000-01-01T11:58:55.816Z	
		ATBDTitle	Soil Moisture Active Passive (SMAP) Level 4 Surface and Root Zone Soil Moisture (L4_SM) Algorithm Theoretical Basis Document (ATBD)	

		ATBDDate	*<Time stamp that specifies the release date of the ATBD>*	
		ATBDVersion	*<Latest ATBD version number.>*	
		algorithmDescription	The L4_SM algorithm is a customized, off-line (land-only) version of the ensemble-based NASA GEOS-5 land data assimilation system. It merges SMAP observations with estimates from a land surface model that is driven with observations-based precipitation forcing.	
		algorithmVersionID	*<An algorithm version identifier that runs from 001 to 999>*	
LI_Lineage/LE_Source	Source/L1C_TB	description	The SMAP Level 1C Brightness Temperature product, which contains the assimilated SMAP radiometer brightness temperatures on 36 km EASE-Grid 2.0.	aup
		fileName	*<Complete file name(s) of the input data product(s).>*	
		creationDate	*<Date stamp(s) of the input data product(s).>*	
		version	*<The SMAP Composite Release ID(s) of the input data product(s).>*	
		identifier	SPL1CTB	
		DOI	*<Digital object identifier(s) of the input data product(s), if available.>*	

	Source/L2_SM_AP	description	The SMAP Level 2 Active/Passive Soil Moisture product which contains assimilated SMAP radiometer brightness temperatures downscaled to 9 km EASE-Grid 2.0 through combination with SMAP radar backscatter observations.	aup
		fileName	*<Complete file name(s) of the input data product.>*	
		creationDate	*<Date stamp(s) of the input data product(s).>*	
		version	*<The SMAP Composite Release ID(s) of the input data product(s).>*	
		identifier	SPL2SMAP	
		DOI	*<Digital object identifier(s) of the input data product(s), if available.>*	
	Source/L2_SM_A	description	The SMAP Level 2 Active Soil Moisture product which contains the assimilated SMAP radar-based freeze-thaw indicator.	aup
		fileName	*<Complete file name(s) of the input data product.>*	
		creationDate	*<Date stamp(s) of the input data product(s).>*	
		version	*<The SMAP Composite Release ID(s) of the input data product(s).>*	
		identifier	SPL2SMA	
		DOI	*<Digital object identifier(s) of the input data product(s), if available.>*	

	Source/GEOS5_lfo	description	The surface meteorological data from the NASA GEOS-5 system that are used to force the land surface model component of the L4_SM algorithm.	gph
		fileName	*<Complete file name(s) of the input data product.>*	
		creationDate	*<Date stamp(s) of the input data product(s).>*	
		version	*<Version ID(s) of the input data product(s).>*	
		identifier	*<Short name(s) of the input data product(s).>*	
		DOI	*<Digital object identifier(s) of the input data product(s), if available.>*	
	Source/GEOS5_lfo_corr	description	The observation-corrected surface meteorological data from the NASA GEOS-5 system. Precipitation corrected using the gauge-based NOAA Climate Prediction Center Unified precipitation product.	gph
		fileName	*<Complete file name(s) of the input data product.>*	
		creationDate	*<Date stamp(s) of the input data product(s).>*	
		version	*<Version ID(s) of the input data product(s).>*	
		identifier	*<Short name(s) of the input data product(s).>*	
		DOI	*<Digital object identifier(s) of the input data product(s), if available.>*	

DS_Dataset/MD_DataIdentification	DataSetIdentification	creationDate	*<Date when the L4_SM data product file was created>*	gph, aup, lmc
		VersionID	*<SMAP Science Version ID associated with this data product – See section 4.3 of the L4_SM Product Specification Document.>*	
		CompositeReleaseID	*<SMAP Composite Release ID (CRID) associated with this data product. The CRID is the Science Version ID with a four-digit appendix. – See section 4.3 of the L4_SM Product Specification Document.>*	
		ECSVersionID	*<Three-character string that identifies the type of ECS data stream and, for the operational streams, reflects the major science version of the product, for example:* *"001" = first operational processing stream;* *"002" = second operational processing stream (supersedes first stream after major algorithm update and includes reprocessing);* *"003" = third operational processing stream (supersedes second stream…);* *"199" = candidate operational stream (a.k.a. OASIS or parallel processing stream)* *>*	
		UUID	*<Universally Unique identifier (36-character string)>*	
		fileName	*<Name of the L4_SM output data file.>*	
		originatorOrganizationName	NASA Global Modeling and Assimilation Office, Goddard Space Flight Center, Greenbelt, Maryland, USA	
		longName	SMAP Level 4 Surface and Root Zone Soil Moisture <*Collection ID*> Collection	
		shortName	*<ECS Short Name>*	
		SMAPShortName	L4_SM_<*Collection ID*>	

		abstract	The SMAP L4_SM data product provides global, 3-hourly surface and root zone soil moisture at 9 km resolution. The L4_SM data product consists of three Collections of data granules (or files): the geophysical data Collection (shortName=SPL4SMGP), the analysis update data Collection (shortName=SPL4SMAU), and the land model constants data Collection (shortName=SPL4SMLM).	
		characterSet	utf8	
		credit	The software that generates the L4_SM data product and the data system that automates its production were designed and implemented at the NASA Global Modeling and Assimilation Office, Goddard Space Flight Center, Greenbelt, Maryland, USA.	
		language	eng	
		purpose	The SMAP L4_SM data product provides spatially and temporally complete surface and root zone soil moisture information for science and applications users.	
		status	"on-going" ("completed" after final reprocessing)	
		topicCategoryCode	geoscientificInformation	
		QACreationDate	*<The generation date of the QA product that accompanies the L4_SM data granule.>*	
		QAFileName	*<The name of QA product.>*	
		QAAbstract	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.	

DS_Series/MD_DataIdentification	SeriesIdentification	revisionDate	*<Date and time of the software release that was used to generate this data product.>*	gph, aup, lmc
		VersionID	*<SMAP Science Version ID associated with this data product – See section 4.3 of the L4_SM Product Specification Document.>*	
		CompositeReleaseID	*<SMAP Composite Release ID (CRID) associated with this data product. The CRID is the Science Version ID with a four-digit appendix. – See section 4.3 of the L4_SM Product Specification Document.>*	
		ECSVersionID	*<Three-character string that identifies the type of ECS data stream and, for the operational streams, reflects the major science version of the product, for example:* *"001" = first operational processing stream;* *"002" = second operational processing stream (supersedes first stream after major algorithm update and includes reprocessing);* *"003" = third operational processing stream (supersedes second stream…);* *"199" = candidate operational stream (a.k.a. OASIS or parallel processing stream)* >	
		longName	SMAP Level 4 Surface and Root Zone Soil Moisture <*Collection ID*> Collection	
		shortName	< *ECS Short Name*>	
		identifier_product_DOI	<*digital object identifier*>	
		resourceProviderOrganizationName	National Aeronautics and Space Administration	

		abstract	The SMAP L4_SM data product provides global, 3-hourly surface and root zone soil moisture at 9 km resolution. The L4_SM data product consists of three Collections of data granules (or files): the geophysical data Collection (shortName=SPL4SMGP), the analysis update data Collection (shortName=SPL4SMAU), and the land model constants data Collection (shortName=SPL4SMLM).	
		characterSet	utf8	
		credit	The software that generates the L4_SM data product and the data system that automates its production were designed and implemented at the NASA Global Modeling and Assimilation Office, Goddard Space Flight Center, Greenbelt, Maryland, USA.	
		language	Eng	
		purpose	The SMAP L4_SM data product provides spatially and temporally complete surface and root zone soil moisture information for science and applications users.	
		status	"on-going" ("completed" after final reprocessing)	
		topicCategoryCode	geoscientificInformation	
		pointOfContact	National Snow and Ice Data Center, Boulder, Colorado, USA.	
		PSDPublicationDate	*<Date of publication of the Product Specification Document>*	
		PSDEdition	*<Edition identifier for the Product Specification Document>*	
		PSDTtitle	Soil Moisture Active Passive Mission Level 4 Surface and Root Zone Soil Moisture (L4_SM) Product Specification Document	

		SMAPShortName	L4_SM_<*Collection_ID*>	
		mission	Soil Moisture Active Passive (SMAP)	
		maintenanceAndUpdateFrequency	asNeeded	
		maintenanceDate	<*Specifies a date when the next update to this product might be anticipated.*>	
		format	HDF5	
		formatVersion	<*HDF5 version number*>	
MD_GridSpatialRepresentation	GridSpatialRepresentation	Latitude/dimensionSize	1624	gph, aup, lmc
		Latitude/resolution	9 km on average	
		Longitude/dimensionSize	3856	
		Longitude/resolution	9 km on average	

MD_AcquisitionInformation	AcquisitionInformation	platform/antennaRotationRate	*<Antenna rotation rate in rpm>*	gph, aup
		platformDocument/publicationDate	*<The date of publication of the document that describes the SMAP platform, if available to the general public.>*	
		platformDocument/edition	*<The edition of publication of the document that describes the SMAP platform, if available to the general public.>*	
		platformDocument/title	*<The title of the publication of the document that describes the SMAP platform, if available to the general public.>*	
		platform/description	The SMAP observatory houses an L-band radiometer that operates at 1.4 GHz and an L-band radar that operates at 1.26-1.29 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.	
		platform/identifier	SMAP	
		radarDocument/publicationDate	*<The date of publication of the document that describes the SMAP radar instrument, if available to the general public.>*	
		radarDocument/edition	*<The edition of publication of the document that describes the SMAP radar instrument, if available to the general public.>*	
		radarDocument/title	*<The title of the publication of the document that describes the SMAP radar instrument, if available to the general public.>*	
		radar/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.	

		radar/identifier	SMAP SAR	
		radar/type	L-band Synthetic Aperture Radar	
		radiometerDocument/publicationDate	*<The date of publication of the document that describes the SMAP radiometer instrument, if available to the general public.>*	
		radiometerDocument/edition	*<The edition of publication of the document that describes the SMAP radiometer instrument, if available to the general public.>*	
		radiometerDocument/title	*<The title of the publication of the document that describes the SMAP radiometer instrument, if available to the general public.>*	
		radiometer/description	The SMAP L-band Radiometer records V-pol, H-pol, 3rd and 4th Stokes brightness temperatures at 40 km resolution at 4.3 Megatbits per second with accuracies of 1.3 Kelvin or better.	
		radiometer/identifier	SMAP RAD	
		radiometer/type	L-band Radiometer	

4.5 Data Structure

This section lists the names, types, shapes, valid minimum values, valid maximum values, and units of the L4_SM data elements for the Geophysical Data Group (section 4.5.1), the Observations Data Group (section 4.5.2), the Forecast Data Group (section 4.5.3), the Analysis Data Group (section 4.5.4), and the LandModelConstants Data Group (section 4.5.5).

Further descriptions of all L4_SM data elements are provided in Table 14 in section 4.6.

As shown in Figure 7, the granules of the "gph" file Collection contain the Geophysical Data Group, the granules of the "aup" file Collection contain the Observations, Forecast, and Analysis Data Groups, and the (single) granule of the "lmc" file Collection contains the LandModelConstants Data Group.

The spatial coordinate Datasets (EASE2_global_projection, latitude, longitude, x coordinates, y coordinates, row index, and column index) are the same for these five Data Groups and are stored in the HDF5 root Data Group (section 2.2.2). All the HDF5 Datasets within the five Data Groups have LatCell_LonCell_Array shape. The LatCell_LonCell_Array shape describes a two-dimensional array, where each array element represents a specific grid cell in the 9 km global cylindrical EASE-Grid 2.0 as specified by the `cell_lat` and `cell_lon` arrays. For example, array element `surface_temp`(234,789) in the Geophysical Data Group represents the land surface temperature of the grid cell located at `cell_lat`(234,789) and `cell_lon`(234,789), where `cell_row`(234,789)=234 and `cell_column` (234,789)=789.

The *EASE2_global_projection* HDF5 Dataset contains attributes describing the parameters of the cylindrical 9 km Earth-fixed EASE-Grid 2.0 projection and defines the mapping from latitude/longitude to grid-native coordinates, following CF (Climate and Forecast) metadata conventions. The *x* and *y* HDF5 Datasets contain grid-native coordinate values from the cylindrical 9 km Earth-fixed EASE-Grid 2.0 projection. The *grid_mapping = EASE2_global_projection* attribute in all HDF5 Datasets signals that its grid-native coordinate system is defined in the *EASE2_global_projection* Dataset. The *standard_name = projection_x_coordinate* and *standard_name = projection_y_coordinate* attributes in the *x* and *y* HDF5 Datasets associate them as the grid-native coordinates of the projection, following CF metadata conventions. The dimension scales in all HDF5 Datasets associates the dimensions of that Dataset with the grid-native coordinates of the *x* and *y* Datasets. Dimension scales provide an additional (non-CF specific) way to associate the grid-native coordinate HDF5 Datasets with other Dataset dimensions in HDF5.

4.5.1 Geophysical Data Group

The Geophysical Data Group contains elements that specify time-average geophysical data (including soil moisture, soil temperature, and land surface fluxes) along with spatial coordinate information. The Geophysical Data Group is stored in the “gph” file Collection (Figure 7). All of the product elements in the Geophysical Data Group are stored in a single HDF5 Group named “/Geophysical_Data”. A distinct HDF5 Dataset stores each data element. The name of each Dataset object matches the data element that it stores. Table 9 lists all of the elements in the Geophysical Data Group.

Table 9: The Geophysical Data Group.

Element Name	Type	Shape	Valid_Min	Valid_Max	Units
EASE2_global_projection$	String	n/a	n/a	n/a	n/a
x$	Float64	LonCell_Array	-17367531	17367531	meters
y$	Float64	LatCell_Array	-7342231	7342231	meters
cell_lat$	Float32	LatCell_LonCell_Array	-90.0	90.0	degrees
cell_lon$	Float32	LatCell_LonCell_Array	-180.0	179.999	degrees
cell_row$	Unsigned32	LatCell_LonCell_Array	0	1623	dimensionless
cell_column$	Unsigned32	LatCell_LonCell_Array	0	3855	dimensionless
sm_surface	Float32	LatCell_LonCell_Array	0.0	0.9	$m^3 m^{-3}$
sm_rootzone	Float32	LatCell_LonCell_Array	0.0	0.9	$m^3 m^{-3}$
sm_profile	Float32	LatCell_LonCell_Array	0.0	0.9	$m^3 m^{-3}$
sm_surface_wetness	Float32	LatCell_LonCell_Array	0.0	1.0	dimensionless
sm_rootzone_wetness	Float32	LatCell_LonCell_Array	0.0	1.0	dimensionless

Element Name	Type	Shape	Valid_Min	Valid_Max	Units
sm_profile_wetness	Float32	LatCell_LonCell_Array	0.0	1.0	dimensionless
surface_temp	Float32	LatCell_LonCell_Array	180.0	350.0	K
soil_temp_layer1	Float32	LatCell_LonCell_Array	210.0	340.0	K
soil_temp_layer2	Float32	LatCell_LonCell_Array	210.0	330.0	K
soil_temp_layer3	Float32	LatCell_LonCell_Array	215.0	325.0	K
soil_temp_layer4	Float32	LatCell_LonCell_Array	220.0	325.0	K
soil_temp_layer5	Float32	LatCell_LonCell_Array	225.0	325.0	K
soil_temp_layer6	Float32	LatCell_LonCell_Array	230.0	320.0	K
snow_mass	Float32	LatCell_LonCell_Array	0.0	10000.0	kg m^{-2}
snow_depth	Float32	LatCell_LonCell_Array	0.0	50.0	m
land_evapotranspiration_flux	Float32	LatCell_LonCell_Array	-0.001	0.001	kg m^{-2} s^{-1}
overland_runoff_flux	Float32	LatCell_LonCell_Array	0.0	0.05	kg m^{-2} s^{-1}
baseflow_flux	Float32	LatCell_LonCell_Array	0.0	0.01	kg m^{-2} s^{-1}
snow_melt_flux	Float32	LatCell_LonCell_Array	0.0	0.05	kg m^{-2} s^{-1}
soil_water_infiltration_flux	Float32	LatCell_LonCell_Array	0.0	0.05	kg m^{-2} s^{-1}
land_fraction_saturated	Float32	LatCell_LonCell_Array	0.0	1.0	dimensionless
land_fraction_unsaturated	Float32	LatCell_LonCell_Array	0.0	1.0	dimensionless

Element Name	Type	Shape	Valid_Min	Valid_Max	Units
land_fraction_wilting	Float32	LatCell_LonCell_Array	0.0	1.0	dimensionless
land_fraction_snow_covered	Float32	LatCell_LonCell_Array	0.0	1.0	dimensionless
heat_flux_sensible	Float32	LatCell_LonCell_Array	-2500.0	3000.0	$W\ m^{-2}$
heat_flux_latent	Float32	LatCell_LonCell_Array	-2500.0	3000.0	$W\ m^{-2}$
heat_flux_ground	Float32	LatCell_LonCell_Array	-1000.0	1000.0	$W\ m^{-2}$
net_downward_shortwave_flux	Float32	LatCell_LonCell_Array	0.0	1365.0	$W\ m^{-2}$
net_downward_longwave_flux	Float32	LatCell_LonCell_Array	-1000.0	200.0	$W\ m^{-2}$
radiation_shortwave_downward_flux	Float32	LatCell_LonCell_Array	0.0	1500.0	$W\ m^{-2}$
radiation_longwave_absorbed_flux	Float32	LatCell_LonCell_Array	35.0	800.0	$W\ m^{-2}$
precipitation_total_surface_flux	Float32	LatCell_LonCell_Array	0.0	0.05	$kg\ m^{-2}\ s^{-1}$
snowfall_surface_flux	Float32	LatCell_LonCell_Array	0.0	0.05	$kg\ m^{-2}\ s^{-1}$
surface_pressure	Float32	LatCell_LonCell_Array	40000.0	110000.0	Pa
height_lowatmmodlay	Float32	LatCell_LonCell_Array	40.0	80.0	m
temp_lowatmmodlay	Float32	LatCell_LonCell_Array	180.0	350.0	K
specific_humidity_lowatmmodlay	Float32	LatCell_LonCell_Array	0.0	0.4	$kg\ kg^{-1}$
windspeed_lowatmmodlay	Float32	LatCell_LonCell_Array	-60.0	60.0	$m\ s^{-1}$
vegetation_greenness_fraction	Float32	LatCell_LonCell_Array	0.0	1.0	dimensionless

Element Name	Type	Shape	Valid_Min	Valid_Max	Units
leaf_area_index	Float32	LatCell_LonCell_Array	0.0	10.0	m^2 m^{-2}
sm_rootzone_pctl	Float32	LatCell_LonCell_Array	0.0	100.0	percent
sm_profile_pctl	Float32	LatCell_LonCell_Array	0.0	100.0	percent
depth_to_water_table_from_surface_in_peat	Float32	LatCell_LonCell_Array	-5.0	0.15	m
free_surface_water_on_peat_flux	Float32	LatCell_LonCell_Array	-0.001	0.001	kg m^{-2} s^{-1}
mwrtm_vegopacity	Float32	LatCell_LonCell_Array	0.0	2.5	dimensionless

[$]The spatial coordinate Datasets are stored in the HDF5 root Data Group (section 2.2.2).

4.5.2 Observations Data Group

The Observations Data Group provides information about the assimilated SMAP observations along with time and space coordinate information. The Observations Data Group is stored in the "aup" file Collection (Figure 7). All of the product elements in the Observations Data Group are stored in a single HDF5 Group named "/Observations_Data". A distinct HDF5 Dataset stores each data element. The name of each Dataset object matches the data element that it stores. Table 10 lists all of the elements in the Observations Data Group.

Output is only stored at times and locations for which input SMAP Level 1 or Level 2 data are ingested. (Model forecast brightness temperatures are also provided for times and locations with SMAP observations that pass quality control but cannot be assimilated for lack of brightness temperature scaling parameters.) If more than one overpass occurs for a given grid cell within the assimilation time window, the Level 1 or Level 2 observations from all overpasses within the analysis update time window are averaged.

Time stamps for H-polarization and V-polarization observations are provided in the elements `tb_h_obs_time_sec` and `tb_v_obs_time_sec`, respectively. If observations from more than one overpass time at the same location (grid cell) are assimilated, the observation time stamps reflect the average over the spacecraft overpass times. Furthermore, the elements `tb_h_orbit_flag` and `tb_v_orbit_flag` indicate whether the observation is exclusively from ascending orbits (orbit_flag=1), exclusively from descending orbits (orbit_flag=2), or from an average over ascending and descending orbits (orbit_flag=0). The latter case may occur at very high latitudes.

Observed brightness temperatures that originate from 36 km L1C_TB files are posted at 9 km here for convenience (as average over fore and aft brightness temperatures that appear in the L1C_TB product). The elements `tb_h_resolution_flag` and `tb_v_resolution_flag` can be used to identify whether the brightness temperatures originate from the 36 km L1C_TB product or from the 9 km L2_SM_AP product.

Table 10: The Observations Data Group.

Element Name	Type	Shape	Valid_Min	Valid_Max	Units
EASE2_global_projection$	String	n/a	n/a	n/a	n/a
x$	Float64	LonCell_Array	-17367531	17367531	meters

Element Name	Type	Shape	Valid_Min	Valid_Max	Units
y$	Float64	LatCell_Array	-7342231	7342231	meters
cell_lat$	Float32	LatCell_LonCell_Array	-90.0	90.0	degrees
cell_lon$	Float32	LatCell_LonCell_Array	-180.0	179.999	degrees
cell_row$	Unsigned32	LatCell_LonCell_Array	0	1623	dimensionless
cell_column$	Unsigned32	LatCell_LonCell_Array	0	3855	dimensionless
tb_h_obs_time_sec	Float64	LatCell_LonCell_Array	465156000	946000000	s
tb_v_obs_time_sec	Float64	LatCell_LonCell_Array	465156000	946000000	s
tb_h_resolution_flag	Unsigned32	LatCell_LonCell_Array	1	2	dimensionless
tb_v_resolution_flag	Unsigned32	LatCell_LonCell_Array	1	2	dimensionless
tb_h_orbit_flag	Unsigned32	LatCell_LonCell_Array	0	2	dimensionless
tb_v_orbit_flag	Unsigned32	LatCell_LonCell_Array	0	2	dimensionless
tb_h_obs	Float32	LatCell_LonCell_Array	100.0	350.0	K
tb_v_obs	Float32	LatCell_LonCell_Array	100.0	350.0	K
tb_h_obs_assim	Float32	LatCell_LonCell_Array	100.0	350.0	K
tb_v_obs_assim	Float32	LatCell_LonCell_Array	100.0	350.0	K
tb_h_obs_errstd	Float32	LatCell_LonCell_Array	0.0	50.0	K
tb_v_obs_errstd	Float32	LatCell_LonCell_Array	0.0	50.0	K

$The spatial coordinate Datasets are stored in the HDF5 root Data Group (section 2.2.2).

4.5.3 Forecast Data Group

The Forecast Data Group is the land model equivalent of the Observations Data Group, that is, the Forecast Data Group provides the land surface model's predictions of the assimilated observations. These forecasts (or observations predictions) are based on propagating the land surface model forward in time from the previous analysis time step. The Forecast Data Group does *not* contain a medium-range (5-day) forecast of land surface conditions.

The Forecast Data Group is stored in the "aup" file Collection (Figure 7). All of the product elements in the Forecast Data Group data are stored in a single HDF5 Group called "/Forecast_Data". A distinct HDF5 Dataset stores each data element. The name of each Dataset object matches the data element that it stores. Table 11 lists all of the elements in the Forecast Data Group.

The soil moisture and temperature values are snapshots (instantaneous data). The resolution of the brightness temperature values in the Forecast Data Group is given by the elements `tb_h_resolution_flag` and `tb_v_resolution_flag` in the Observations Data Group.

Brightness temperature output is only stored at times and locations for which input SMAP Level 1 or Level 2 brightness temperature data are ingested.

Model forecast brightness temperatures that correspond to 36 km observations from the L1C_TB product are aggregated from 9 km to 36 km and then posted at 9 km for convenience. The elements `tb_h_resolution_flag` and `tb_v_resolution_flag` in the Observation Data Group indicate whether the model forecast brightness temperature for a given grid cell corresponds to a 36 km observation from the L1C_TB product or to a 9 km observation from the L2_SM_AP product.

Table 11: The Forecast Data Group.

Element Name	Type	Shape	Valid_Min	Valid_Max	Units
EASE2_global_projection[$]	String	n/a	n/a	n/a	n/a
x[$]	Float64	LonCell_Array	-17367531	17367531	meters
y[$]	Float64	LatCell_Array	-7342231	7342231	meters
cell_lat[$]	Float32	LatCell_LonCell_Array	-90.0	90.0	degrees
cell_lon[$]	Float32	LatCell_LonCell_Array	-180.0	179.999	degrees
cell_row[$]	Unsigned32	LatCell_LonCell_Array	0	1623	dimensionless
cell_column[$]	Unsigned32	LatCell_LonCell_Array	0	3855	dimensionless
tb_h_forecast	Float32	LatCell_LonCell_Array	100.0	350.0	K
tb_v_forecast	Float32	LatCell_LonCell_Array	100.0	350.0	K
tb_h_forecast_ensstd	Float32	LatCell_LonCell_Array	0.0	50.0	K
tb_v_forecast_ensstd	Float32	LatCell_LonCell_Array	0.0	50.0	K
sm_surface_forecast	Float32	LatCell_LonCell_Array	0.0	0.9	$m^3 m^{-3}$
sm_rootzone_forecast	Float32	LatCell_LonCell_Array	0.0	0.9	$m^3 m^{-3}$
sm_profile_forecast	Float32	LatCell_LonCell_Array	0.0	0.9	$m^3 m^{-3}$
surface_temp_forecast	Float32	LatCell_LonCell_Array	180.0	350.0	K
soil_temp_layer1_forecast	Float32	LatCell_LonCell_Array	210.0	340.0	K

[$]The spatial coordinate Datasets are stored in the HDF5 root Data Group (section 2.2.2).

4.5.4 Analysis Data Group

The Analysis Data Group contains soil moisture and temperature estimates after the ensemble Kalman filter analysis update, along with their corresponding uncertainty estimates. The Analysis Data Group is stored in the "aup" file Collection (Figure 7). All of the product elements in the Analysis Data Group data are stored in a single HDF5 Group called "/Analysis_Data". A distinct HDF5 Dataset stores each data element. The name of each Dataset object matches the data element that it stores. Table 12 lists all of the elements in the Analysis Data Group.

The soil moisture and temperature values in the Analysis Data Group are snapshots (instantaneous data).

Table 12: The Analysis Data Group.

Element Name	Type	Shape	Valid_Min	Valid_Max	Units
EASE2_global_projection$	String	n/a	n/a	n/a	n/a
x$	Float64	LonCell_Array	-17367531	17367531	meters
y$	Float64	LatCell_Array	-7342231	7342231	meters
cell_lat$	Float32	LatCell_LonCell_Array	-90.0	90.0	degrees
cell_lon$	Float32	LatCell_LonCell_Array	-180.0	179.999	degrees
cell_row$	Unsigned32	LatCell_LonCell_Array	0	1623	dimensionless
cell_column$	Unsigned32	LatCell_LonCell_Array	0	3855	dimensionless
sm_surface_analysis	Float32	LatCell_LonCell_Array	0.0	0.9	$m^3 m^{-3}$
sm_rootzone_analysis	Float32	LatCell_LonCell_Array	0.0	0.9	$m^3 m^{-3}$

Element Name	Type	Shape	Valid_Min	Valid_Max	Units
sm_profile_analysis	Float32	LatCell_LonCell_Array	0.0	0.9	$m^3 m^{-3}$
surface_temp_analysis	Float32	LatCell_LonCell_Array	180.0	350.0	K
soil_temp_layer1_analysis	Float32	LatCell_LonCell_Array	210.0	340.0	K
sm_surface_analysis_ensstd	Float32	LatCell_LonCell_Array	0.0	1.0	$m^3 m^{-3}$
sm_rootzone_analysis_ensstd	Float32	LatCell_LonCell_Array	0.0	1.0	$m^3 m^{-3}$
sm_profile_analysis_ensstd	Float32	LatCell_LonCell_Array	0.0	1.0	$m^3 m^{-3}$
surface_temp_analysis_ensstd	Float32	LatCell_LonCell_Array	0.0	50.0	K
soil_temp_layer1_analysis_ensstd	Float32	LatCell_LonCell_Array	0.0	50.0	K

[$]The spatial coordinate Datasets are stored in the HDF5 root Data Group (section 2.2.2).

4.5.5 LandModelConstants Data Group

The LandModelConstants Data Group contains elements that specify *static* (or time-invariant) parameters (or constants) of the Catchment land surface model (CLSM) and its associated L-band microwave radiative transfer model (MWRTM) along with spatial coordinate information. As shown in Figure 7, the LandModelConstants Data Group is stored in the “lmc” file Collection which, due to the time-invariant nature of the file contents, consists of only one granule (file) per data product version (as identified by a distinct Science Version ID, section 4.3).

The LandModelConstants Data Group is motivated by the model-based nature of the L4_SM data product that requires more detailed information on land model constants than can be provided without ambiguity in the metadata. For example, metadata elements such as “minimumVerticalExtent” and “maximumVerticalExtent” would be confusing in connection with the layer-based land surface modeling approach of the Catchment model, where different layers are used for soil moisture and for soil temperature, and where some layer thicknesses vary horizontally. Moreover, the “lmc” file Collection and LandModelConstants Data Group parsimoniously facilitate the dissemination, as part of the L4_SM Data Product, of static ancillary data such as wilting point or porosity that many users will need to work with the elements of the Geophysical Data Group.

All of the product elements in the LandModelConstants Data Group are stored in a single HDF5 Group named “/LandModelConstants_Data”. A distinct HDF5 Dataset stores each data element. The name of each Dataset object matches the data element that it stores. Table 13 lists all of the elements in the LandModelConstants Data Group. Note that some elements may be constants in space as well as in time but could become spatially varying in future versions of the data product.

Table 13: The LandModelConstants Data Group.

Element Name	Type	Shape	Valid_Min	Valid_Max	Units
EASE2_global_projection[$]	String	n/a	n/a	n/a	n/a
x[$]	Float64	LonCell_Array	-17367531	17367531	meters
y[$]	Float64	LatCell_Array	-7342231	7342231	meters
cell_lat[$]	Float32	LatCell_LonCell_Array	-90.0	90.0	degrees
cell_lon[$]	Float32	LatCell_LonCell_Array	-180.0	179.999	degrees
cell_row[$]	Unsigned32	LatCell_LonCell_Array	0	1623	dimensionless
cell_column[$]	Unsigned32	LatCell_LonCell_Array	0	3855	dimensionless
cell_land_fraction	Float32	LatCell_LonCell_Array	0.0	1.0	dimensionless
cell_elevation	Float32	LatCell_LonCell_Array	-500.0	6000.0	m
clsm_dzsf	Float32	LatCell_LonCell_Array	0.05	0.05	m
clsm_dzrz	Float32	LatCell_LonCell_Array	1.0	1.0	m
clsm_dzpr	Float32	LatCell_LonCell_Array	1.33	10.0	m
clsm_dztsurf	Float32	LatCell_LonCell_Array	0.0	0.05	m
clsm_dzgt1	Float32	LatCell_LonCell_Array	0.0988	0.0988	m
clsm_dzgt2	Float32	LatCell_LonCell_Array	0.1952	0.1952	m
clsm_dzgt3	Float32	LatCell_LonCell_Array	0.3859	0.3859	m
clsm_dzgt4	Float32	LatCell_LonCell_Array	0.7626	0.7626	m

Element Name	Type	Shape	Valid_Min	Valid_Max	Units
clsm_dzgt5	Float32	LatCell_LonCell_Array	1.5071	1.5071	m
clsm_dzgt6	Float32	LatCell_LonCell_Array	10.0	10.0	m
clsm_poros	Float32	LatCell_LonCell_Array	0.3	0.93	$m^3 m^{-3}$
clsm_wp	Float32	LatCell_LonCell_Array	0.001	0.35	$m^3 m^{-3}$
clsm_cdcr1	Float32	LatCell_LonCell_Array	30.0	3200.0	kg m^{-2}
clsm_cdcr2	Float32	LatCell_LonCell_Array	200.0	6000.0	kg m^{-2}
clsm_veghght	Float32	LatCell_LonCell_Array	0.0	60.0	m
mwrtm_vegcls	Unsigned32	LatCell_LonCell_Array	1	16	dimensionless
mwrtm_soilcls	Unsigned32	LatCell_LonCell_Array	1	253	dimensionless
mwrtm_sand	Float32	LatCell_LonCell_Array	0.0	1.0	dimensionless
mwrtm_clay	Float32	LatCell_LonCell_Array	0.0	1.0	dimensionless
mwrtm_poros	Float32	LatCell_LonCell_Array	0.3	0.93	$m^3 m^{-3}$
mwrtm_wangwt	Float32	LatCell_LonCell_Array	0.1	0.4	$m^3 m^{-3}$
mwrtm_wangwp	Float32	LatCell_LonCell_Array	0.0	0.4	$m^3 m^{-3}$
mwrtm_rghhmin	Float32	LatCell_LonCell_Array	0.0	10.0	dimensionless
mwrtm_rghhmax	Float32	LatCell_LonCell_Array	0.0	10.0	dimensionless
mwrtm_rghwmin	Float32	LatCell_LonCell_Array	0.1	0.4	$m^3 m^{-3}$

Element Name	Type	Shape	Valid_Min	Valid_Max	Units
mwrtm_rghwmax	Float32	LatCell_LonCell_Array	0.3	0.93	$m^3 m^{-3}$
mwrtm_rghnrh	Float32	LatCell_LonCell_Array	0.0	1.75	dimensionless
mwrtm_rghnrv	Float32	LatCell_LonCell_Array	-1.0	2.0	dimensionless
mwrtm_rghpolmix	Float32	LatCell_LonCell_Array	0.0	0.0	dimensionless
mwrtm_omega	Float32	LatCell_LonCell_Array	0.0	0.3	dimensionless
mwrtm_bh	Float32	LatCell_LonCell_Array	0.0	0.7	dimensionless
mwrtm_bv	Float32	LatCell_LonCell_Array	-0.15	0.85	dimensionless
mwrtm_lewt	Float32	LatCell_LonCell_Array	0.0	2.0	$kg\ m^{-2}$

[$]The spatial coordinate Datasets are stored in the HDF5 root Data Group (section 2.2.2).

4.5.6 Quality Assurance Files

Each "gph", "aup", and "lmc" granule is processed into a corresponding Quality Assurance file that contains statistical information about the data in the granule. Excerpts from sample Quality Assurance files are provided in Figures 8-11. These samples are from science version Vv3030. Note that the numerical values of all parameters may change in future versions as ancillary land model parameters, forcing data, and assimilated SMAP observations are updated to newer versions. These changes include updates to the land mask, which may change the number of land grid cells on the 9 km EASEv2 grid.

```
Quality Assessment for SMAP L4_SM Granule <SMAP_L4_SM_gph_20170704T133000_Vv3030_001.h5>
Number of L4_SM EASEv2  9 km land grid cells =  1653157

=========================================================================================================================================
Geophysical variables
=========================================================================================================================================
Fieldname                                           ,Units (*1)      ,    Mean (*2), Std-dev (*2),          Min,           Max,   N (*3)
-----------------------------------------------------------------------------------------------------------------------------------------
[...]
precipitation_total_surface_flux                    ,[kg m-2 s-1]    ,  3.4572e-05,  1.7271e-04,  0.0000e+00,  1.2137e-02,  1653157
sm_surface_wetness                                  ,[dimensionless] ,      0.5047,      0.2611,      0.0211,      0.9995,  1653157
sm_profile_wetness                                  ,[dimensionless] ,      0.5362,      0.2560,      0.0263,      0.9997,  1653157
snow_depth                                          ,[m]             ,      0.0066,      0.0442,      0.0000,      9.2912,  1653157
height_lowatmmodlay                                 ,[m]             ,     65.6781,      2.2384,     57.2290,     71.0493,  1653157
baseflow_flux                                       ,[kg m-2 s-1]    ,  7.7118e-07,  3.1598e-06,  0.0000e+00,  1.7647e-04,  1653157
sm_profile_pctl                                     ,[percent]       ,     58.2959,     30.0859,      0.0000,    100.0000,   798005
land_fraction_saturated                             ,[dimensionless] ,      0.1811,      0.1899,      0.0000,      0.9824,  1653157
snowfall_surface_flux                               ,[kg m-2 s-1]    ,  9.0436e-07,  1.9352e-05,  0.0000e+00,  2.7695e-03,  1653157
land_fraction_unsaturated                           ,[dimensionless] ,      0.5272,      0.3087,      0.0000,      1.0000,  1653157
sm_rootzone_wetness                                 ,[dimensionless] ,      0.5066,      0.2534,      0.0202,      1.0000,  1653157
leaf_area_index                                     ,[m2 m-2]        ,      1.4577,      1.4520,      0.0001,      6.4551,  1653157
radiation_shortwave_downward_flux                   ,[W m-2]         ,    307.8340,    272.4104,      0.0000,   1019.8970,  1653157
sm_surface                                          ,[m3 m-3]        ,      0.2304,      0.1393,      0.0084,      0.7972,  1653157
soil_temp_layer1                                    ,[K]             ,    295.9064,     10.8385,    258.3926,    334.0488,  1653157
[...]
-----------------------------------------------------------------------------------------------------------------------------------------
See SMAP L4_SM Data Products Specification Document for additional information.

(*1) Units are valid for all statistics except N [dimensionless].
(*2) Mean and std-dev statistics are weighted by the land fraction of each grid cell.
(*3) N is the number of 9 km EASEv2 grid cells that contribute to the statistics.
```

Figure 8: Excerpt from a Quality Assurance file for the "gph" Collection.

```
Quality Assessment for SMAP L4_SM Granule <SMAP_L4_SM_aup_20170704T120000_Vv3030_001.h5>
Number of L4_SM EASEv2  9 km land grid cells =  1653157
Number of L4_SM EASEv2 36 km land grid cells =  110772

=======================================================================================================================================
Brightness temperatures ("EnKF observation space")
=======================================================================================================================================
Fieldname (*1)                                    ,Units (*2)      ,    Mean (*3), Std-dev (*3),          Min,          Max,   N (*4)
---------------------------------------------------------------------------------------------------------------------------------------
tb_h_obs_36km                                     ,[K]             ,     242.2302,      31.8695,     101.4803,     287.7057,    14434
tb_h_obs_36km_A                                   ,[K]             ,     244.5651,      31.8693,     102.0187,     287.7057,     8113
tb_h_obs_36km_D                                   ,[K]             ,     239.4435,      31.4308,     101.4803,     275.9212,     6215
tb_h_obs_09km                                     ,[K]             ,   -9999.0000,   -9999.0000,   -9999.0000,   -9999.0000,        0
[...]
tb_h_obs_assim_36km                               ,[K]             ,     253.5229,      21.1498,     148.6156,     292.2878,     8958
tb_h_obs_assim_36km_A                             ,[K]             ,     254.8204,      19.4051,     158.1511,     292.2878,     5359
tb_h_obs_assim_36km_D                             ,[K]             ,     251.5871,      23.3797,     148.6156,     280.6068,     3599
tb_h_obs_assim_09km                               ,[K]             ,   -9999.0000,   -9999.0000,   -9999.0000,   -9999.0000,        0
[...]
tb_h_forecast_36km                                ,[K]             ,     254.0992,      20.9207,     141.9996,     290.9957,     8958
[...]
tb_h_obs_errstd_36km                              ,[K]             ,       4.0000,       0.0000,       4.0000,       4.0000,     8958
[...]
tb_h_forecast_ensstd_36km                         ,[K]             ,       1.7231,       1.6583,       0.0000,       8.9166,     8958
[...]
tb_h_obs_assim_minus_forecast_36km                ,[K]             ,      -0.5763,       5.7085,     -41.2212,      55.2532,     8958
tb_h_norm_obs_assim_minus_forecast_36km           ,[K K-1]         ,      -0.1161,       1.2719,      -9.3198,      12.9328,     8958
[...]
---------------------------------------------------------------------------------------------------------------------------------------
See SMAP L4_SM Data Products Specification Document for additional information.

(*1) Fieldnames that contain "_h" and "_v" are for H-polarization and V-polarization brightness temperature (Tb) data, respectively.
     "tb_h_obs" and "tb_v_obs" are observed Tbs obtained from SMAP L1C_TB and L2_SM_AP files after quality control based on
     information from the same files.
     "tb_h_obs_assim" and "tb_v_obs_assim" are observed Tbs that were assimilated in the L4_SM system after land model-based
     quality control and climatological adjustment (scaling).
     Fieldnames that contain "_36km" or "_09km" provide statistics for Tbs from SMAP L1C_TB files or L2_SM_AP files, respectively,
     and corresponding model Tbs.
     Fieldnames that contain "_A" or "_D" provide statistics that are masked to Tbs from ascending or descending orbits, respectively.
     Some observations at very high latitudes may have resulted from averaging over both ascending and descending orbits.
     Only descending orbits are available for 9 km Tb observations from SMAP L2_SM_AP files.
     Fieldnames that contain "norm_obs_assim_minus_forecast" provide statistics for normalized Tb innovations, defined as
     (tb_obs_assim - tb_forecast)/sqrt(tb_obs_errstd^2 + tb_forecast_ensstd^2).
(*2) Units are valid for all statistics except N [dimensionless].
(*3) Mean and std-dev statistics are weighted by the land fraction in each grid cell.
(*4) N is the number of EASEv2 grid cells that contribute to the statistics.
     For fieldnames containing "_36km" and "_09km", N is the number of contributing 36 km and 9 km EASEv2 grid cells, respectively.
```

Figure 9: Excerpt from the Brightness Temperature section of a Quality Assurance file for the “aup” Collection.

```
Quality Assessment for SMAP L4_SM Granule <SMAP_L4_SM_aup_20170704T120000_Vv3030_001.h5>
Number of L4_SM EASEv2  9 km land grid cells =  1653157
Number of L4_SM EASEv2 36 km land grid cells =  110772

========================================================================================================================
Brightness temperatures ("EnKF observation space")
========================================================================================================================
Fieldname (*1)                                   ,Units (*2)      ,    Mean (*3), Std-dev (*3),         Min,          Max,   N (*4)
------------------------------------------------------------------------------------------------------------------------
sm_surface_forecast                              ,[m3 m-3]        ,       0.2306,       0.1392,       0.0070,       0.7972, 1653157
sm_surface_forecast_masked                       ,[m3 m-3]        ,       0.2827,       0.1573,       0.0174,       0.7942,  228934
sm_rootzone_forecast                             ,[m3 m-3]        ,       0.2323,       0.1394,       0.0080,       0.8000, 1653157
sm_rootzone_forecast_masked                      ,[m3 m-3]        ,       0.2884,       0.1577,       0.0139,       0.8000,  228934
[...]
soil_temp_layer1_forecast                        ,[K]             ,     295.8402,      10.8371,     258.3886,     333.6759, 1653157
soil_temp_layer1_forecast_masked                 ,[K]             ,     296.8747,      10.9028,     273.1600,     331.0134,  228934
sm_surface_analysis                              ,[m3 m-3]        ,       0.2307,       0.1392,       0.0070,       0.7972, 1653157
sm_surface_analysis_masked                       ,[m3 m-3]        ,       0.2831,       0.1568,       0.0075,       0.7946,  228934
sm_rootzone_analysis                             ,[m3 m-3]        ,       0.2324,       0.1394,       0.0080,       0.8000, 1653157
sm_rootzone_analysis_masked                      ,[m3 m-3]        ,       0.2884,       0.1577,       0.0138,       0.8000,  228934
[...]
soil_temp_layer1_analysis                        ,[K]             ,     295.8168,      10.7960,     258.3886,     333.6759, 1653157
soil_temp_layer1_analysis_masked                 ,[K]             ,     296.7080,      10.6232,     273.1600,     330.7287,  228934
sm_surface_analysis_ensstd                       ,[m3 m-3]        ,       0.0164,       0.0078,       0.0000,       0.1373, 1653157
sm_surface_analysis_ensstd_masked                ,[m3 m-3]        ,       0.0132,       0.0058,       0.0005,       0.1030,  228934
sm_rootzone_analysis_ensstd                      ,[m3 m-3]        ,       0.0094,       0.0068,       0.0000,       0.1015, 1653157
sm_rootzone_analysis_ensstd_masked               ,[m3 m-3]        ,       0.0099,       0.0065,       0.0000,       0.0904,  228934
[...]
surface_temp_analysis_ensstd                     ,[K]             ,       1.5872,       1.6476,       0.0000,      11.6638, 1653157
surface_temp_analysis_ensstd_masked              ,[K]             ,       1.0570,       1.0559,       0.0000,      10.8728,  228934
soil_temp_layer1_analysis_ensstd                 ,[K]             ,       1.0124,       0.9610,       0.0000,       8.2390, 1653157
soil_temp_layer1_analysis_ensstd_masked          ,[K]             ,       0.8917,       0.8594,       0.0000,       7.2119,  228934
analysis_minus_forecast_sm_surface               ,[m3 m-3]        ,   6.0491e-05,   2.4766e-03,  -1.0357e-01,   1.0209e-01, 1653157
analysis_minus_forecast_sm_surface_masked        ,[m3 m-3]        ,   4.3131e-04,   6.6011e-03,  -1.0357e-01,   1.0209e-01,  228934
analysis_minus_forecast_sm_rootzone              ,[m3 m-3]        ,   7.6791e-06,   1.1881e-03,  -5.8098e-02,   5.9791e-02, 1653157
analysis_minus_forecast_sm_rootzone_masked       ,[m3 m-3]        ,   5.4753e-05,   3.1721e-03,  -5.8098e-02,   5.9791e-02,  228934
[...]
analysis_minus_forecast_soil_temp_layer1         ,[K]             ,  -2.3378e-02,   3.4993e-01,  -1.2408e+01,   5.9231e+00, 1653157
analysis_minus_forecast_soil_temp_layer1_masked  ,[K]             ,  -1.6669e-01,   9.2153e-01,  -1.2408e+01,   5.9231e+00,  228934
------------------------------------------------------------------------------------------------------------------------
See SMAP L4_SM Data Products Specification Document for additional information.

(*5) For fieldnames ending in "_masked", statistics are masked to areas with non-zero increments, where zero is defined to be within
     +/-10e-5 [dimensionless] for soil moisture variables and +/-10e-3 [K] for temperature variables.
     Fieldnames starting with "analysis_minus_forecast" provide statistics for analysis increments.
(*6) Units are valid for all statistics except N [dimensionless].
(*7) Mean and std-dev statistics are weighted by the land fraction of each grid cell.
(*8) N is the number of 9 km EASEv2 grid cells that contribute to the statistics._
```

Figure 10: Excerpt from the Geophysical Variables section of a Quality Assurance file for the "aup" Collection.

```
Quality Assessment for SMAP L4_SM Granule <SMAP_L4_SM_aup_20170704T120000_Vv3030_001.h5>
Number of L4_SM EASEv2  9 km land grid cells =  1653157
Number of L4_SM EASEv2 36 km land grid cells =  110772

[...]

=====================================================================================================================================
Geophysical variables ("EnKF state space")
=====================================================================================================================================
Fieldname (*5)                                   ,Units (*6)      ,    Mean (*7), Std-dev (*7),          Min,          Max,   N (*8)
-------------------------------------------------------------------------------------------------------------------------------------
cell_elevation                                   ,[m]             ,     614.6430,     783.2894,    -369.4832,    5948.0117,  1653157
cell_land_fraction                               ,[dimensionless] ,       0.9857,       0.0777,       0.0237,       1.0000,  1653157
[...]
clsm_dzpr                                        ,[m]             ,       2.0571,       0.9778,       1.3340,       8.9117,  1653157
clsm_dzrz                                        ,[m]             ,       1.0000,       0.0000,       1.0000,       1.0000,  1653157
clsm_dzsf                                        ,[m]             ,       0.0500,       0.0000,       0.0500,       0.0500,  1653157
clsm_dztsurf                                     ,[m]             ,       0.0048,       0.0147,       0.0000,       0.0500,  1653157
clsm_poros                                       ,[m3 m-3]        ,       0.4435,       0.0714,       0.3741,       0.8000,  1653157
clsm_wp                                          ,[m3 m-3]        ,       0.1137,       0.0664,       0.0043,       0.2531,  1653157
[...]
mwrtm_clay                                       ,[dimensionless] ,       0.2197,       0.1328,       0.0333,       0.5667,  1603509
mwrtm_lewt                                       ,[kg m-2]        ,       0.8909,       0.4940,       0.0000,       1.9000,  1603509
mwrtm_omega                                      ,[dimensionless] ,       0.1028,       0.0634,       0.0000,       0.3000,  1603509
mwrtm_poros                                      ,[m3 m-3]        ,       0.4507,       0.0674,       0.0000,       0.8000,  1603509
[...]
mwrtm_sand                                       ,[dimensionless] ,       0.5088,       0.2246,       0.0333,       0.9333,  1603509
mwrtm_soilcls                                    ,[dimensionless] ,   -9999.0000,   -9999.0000,       2.0000,     253.0000,  1603509
mwrtm_vegcls                                     ,[dimensionless] ,   -9999.0000,   -9999.0000,       1.0000,      16.0000,  1603509
mwrtm_wangwp                                     ,[m3 m-3]        ,       0.1118,       0.0662,       0.0000,       0.2531,  1603509
mwrtm_wangwt                                     ,[m3 m-3]        ,       0.2198,       0.0324,       0.1650,       0.2890,  1603509
-------------------------------------------------------------------------------------------------------------------------------------
See SMAP L4_SM Data Products Specification Document for additional information.

(*1) Units are valid for all statistics except N [dimensionless].
(*2) Mean and std-dev statistics are weighted by the land fraction of each grid cell.
(*3) N is the number of 9 km EASEv2 grid cells that contribute to the statistics.
```

Figure 11: Excerpt from a Quality Assurance file for the "lmc" Collection.

4.6 Element Definitions

Table 14 lists all L4_SM data product elements and their definitions in alphabetical order. All elements have shape LatCell_LonCell_Array and are of type Float32 unless otherwise indicated in the element Description. For information on valid minimum and maximum values refer to Tables 9-13.

Table 14: Data product element definitions.

Element Name (SMAP L4_SM)	GEOS-5 Name	Data Group	Description	Units
baseflow_flux	BASEFLOW	Geophysical	Baseflow	kg m^{-2} s^{-1}
cell_column	CELL_COLUMN_INDEX	*[All Data Groups]*$	The column index of each cell in the cylindrical 9 km Earth-fixed EASE-Grid 2.0. Type is Unsigned32.	Dimensionless
cell_elevation	CELL_ELEVATION	LandModel Constants	Mean elevation above sea level of land within each grid cell.	m
cell_land_fraction	FRLAND	LandModel Constants	Area fraction of land within each grid cell.	Dimensionless
cell_lat	LATITUDE	*[All Data Groups]*$	The geodetic latitude of the center of each cell in the cylindrical 9 km Earth-fixed EASE-Grid 2.0. Zero latitude represents the Equator. Positive latitudes represent locations North of the Equator. Negative latitudes represent locations South of the Equator.	Degrees

Element Name (SMAP L4_SM)	GEOS-5 Name	Data Group	Description	Units
cell_lon	LONGITUDE	[*All Data Groups*]$^{\$}$	The longitude of the center of each cell in the cylindrical 9 km Earth-fixed EASE-Grid 2.0. Zero longitude represents the Prime Meridian. Positive longitudes represent locations to the East of the Prime Meridian. Negative longitudes represent locations to the West of the Prime Meridian.	Degrees
cell_row	CELL_ROW_INDEX	[*All Data Groups*]$^{\$}$	The row index of each cell in the cylindrical 9 km Earth-fixed EASE-Grid 2.0. Type is Unsigned32.	Dimensionless
clsm_cdcr1	CLSM_CDCR1	LandModel Constants	Catchment model: Catchment deficit at which baseflow ceases	kg m^{-2}
clsm_cdcr2	CLSM_CDCR2	LandModel Constants	Catchment model: Maximum water holding capacity of land element	kg m^{-2}
clsm_dzgt1	CLSM_DZGT1	LandModel Constants	Catchment model: Thickness of soil heat diffusion model layer 1	m
clsm_dzgt2	CLSM_DZGT2	LandModel Constants	Catchment model: Thickness of soil heat diffusion model layer 2	m
clsm_dzgt3	CLSM_DZGT3	LandModel Constants	Catchment model: Thickness of soil heat diffusion model layer 3	m
clsm_dzgt4	CLSM_DZGT4	LandModel Constants	Catchment model: Thickness of soil heat diffusion model layer 4	m
clsm_dzgt5	CLSM_DZGT5	LandModel Constants	Catchment model: Thickness of soil heat diffusion model layer 5	m
clsm_dzgt6	CLSM_DZGT6	LandModel Constants	Catchment model: Thickness of soil heat diffusion model layer 6	m
clsm_dzpr	CLSM_DZPR	LandModel Constants	Catchment model: Thickness of profile soil moisture layer ("depth-to-bedrock" in the Catchment model)	m
clsm_dzrz	CLSM_DZRZ	LandModel Constants	Catchment model: Thickness of root zone soil moisture layer	m
clsm_dzsf	CLSM_DZSF	LandModel Constants	Catchment model: Thickness of surface soil moisture layer	m
clsm_dztsurf	CLSM_DZTSURF	LandModel Constants	Catchment model: Thickness of soil layer associated with `surface_temp`	m
clsm_poros	CLSM_POROS	LandModel Constants	Catchment model: Soil porosity	$m^3 m^{-3}$

Element Name (SMAP L4_SM)	GEOS-5 Name	Data Group	Description	Units
clsm_veghght	CLSM_VEGHGHT	LandModel Constants	Catchment model: Vegetation canopy height	m
clsm_wp	CLSM_WP	LandModel Constants	Catchment model: Soil wilting point	$m^3 m^{-3}$
depth_to_water_table_from_surface_in_peat	PEATCLSM_WATERLEVEL	Geophysical	Depth to water table from mean surface elevation in peatlands (positive above ground)	m
EASE2_global_projection	n/a	[All Data Groups]$	Defines the parameters of the cylindrical 9 km Earth-fixed EASE-Grid 2.0 projection and the mapping from latitude/longitude to grid-native coordinates. Type is string.	n/a
free_surface_water_on_peat_flux	PEATCLSM_FSWCHANGE	Geophysical	Change in free surface water storage on peatlands	$kg m^{-2} s^{-1}$
heat_flux_ground	GHLAND	Geophysical	Downward ground heat flux into layer 1 of soil heat diffusion model	$W m^{-2}$
heat_flux_latent	LHLAND	Geophysical	Latent heat flux from land*	$W m^{-2}$
heat_flux_sensible	SHLAND	Geophysical	Sensible heat flux from land*	$W m^{-2}$
height_lowatmmodlay	HLML	Geophysical	Center height of lowest atmospheric model layer	m
land_evapotranspiration_flux	EVLAND	Geophysical	Evapotranspiration from land*	$kg m^{-2} s^{-1}$
land_fraction_saturated	FRSAT	Geophysical	Fractional land area that is saturated and snow-free*	dimensionless
land_fraction_snow_covered	FRSNO	Geophysical	Fractional land area that is snow-covered*	dimensionless
land_fraction_unsaturated	FRUNSAT	Geophysical	Fractional land area that is unsaturated (but non-wilting) and snow-free*	dimensionless
land_fraction_wilting	FRWLT	Geophysical	Fractional land area that is wilting and snow-free*	dimensionless
leaf_area_index	LAI	Geophysical	Vegetation leaf area index	$m^2 m^{-2}$
mwrtm_bh	MWRTM_BH	LandModel Constants	Microwave radiative transfer model: H-pol. Vegetation b parameter	dimensionless
mwrtm_bv	MWRTM_BV	LandModel Constants	Microwave radiative transfer model: V-pol. Vegetation b parameter	dimensionless
mwrtm_clay	MWRTM_CLAY	LandModel Constants	Microwave radiative transfer model: Clay fraction	dimensionless

Element Name (SMAP L4_SM)	GEOS-5 Name	Data Group	Description	Units
mwrtm_lewt	MWRTM_LEWT	LandModel Constants	Microwave radiative transfer model: Parameter to transform leaf area index into vegetation water content	kg m^{-2}
mwrtm_omega	MWRTM_OMEGA	LandModel Constants	Microwave radiative transfer model: Scattering albedo	dimensionless
mwrtm_poros	MWRTM_POROS	LandModel Constants	Microwave radiative transfer model: Porosity	$m^3 m^{-3}$
mwrtm_rghhmax	MWRTM_RGHHMAX	LandModel Constants	Microwave radiative transfer model: Maximum microwave roughness parameter	dimensionless
mwrtm_rghhmin	MWRTM_RGHHMIN	LandModel Constants	Microwave radiative transfer model: Minimum microwave roughness parameter	dimensionless
mwrtm_rghwmax	MWRTM_RGHWMAX	LandModel Constants	Microwave radiative transfer model: Soil moisture value above which *minimum* microwave roughness parameter is used	dimensionless
mwrtm_rghwmin	MWRTM_RGHWMIN	LandModel Constants	Microwave radiative transfer model: Soil moisture value below which *maximum* microwave roughness parameter is used	dimensionless
mwrtm_rghnrh	MWRTM_RGHNRH	LandModel Constants	Microwave radiative transfer model: H-pol. Exponent for rough reflectivity parameterization	dimensionless
mwrtm_rghnrv	MWRTM_RGHNRV	LandModel Constants	Microwave radiative transfer model: V-pol. Exponent for rough reflectivity parameterization	dimensionless
mwrtm_rghpolmix	MWRTM_RGHPOLMIX	LandModel Constants	Microwave radiative transfer model: Polarization mixing parameter	dimensionless
mwrtm_sand	MWRTM_SAND	LandModel Constants	Microwave radiative transfer model: Sand fraction	dimensionless
mwrtm_soilcls	MWRTM_SOILCLS	LandModel Constants	Microwave radiative transfer model: Soil class. Type is Unsigned32.	dimensionless
mwrtm_vegcls	MWRTM_VEGCLS	LandModel Constants	Microwave radiative transfer model: Vegetation class. Type is Unsigned32.	dimensionless
mwrtm_vegopacity	MWRTM_VEGOPACITY	Geophysical	Microwave radiative transfer model: Vegetation opacity.	dimensionless

Element Name (SMAP L4_SM)	GEOS-5 Name	Data Group	Description	Units
mwrtm_wangwp	MWRTM_WANGWP	LandModel Constants	Microwave radiative transfer model: Wang dielectric model wilting point soil moisture	$m^3 m^{-3}$
mwrtm_wangwt	MWRTM_WANGWT	LandModel Constants	Microwave radiative transfer model: Wang dielectric model transition soil moisture	$m^3 m^{-3}$
net_downward_longwave_flux	LWLAND	Geophysical	Net downward longwave flux over land*	$W m^{-2}$
net_downward_shortwave_flux	SWLAND	Geophysical	Net downward shortwave flux over land*	$W m^{-2}$
overland_runoff_flux	RUNOFF	Geophysical	Overland (surface) runoff (including throughflow)*	$kg m^{-2} s^{-1}$
precipitation_total_surface_flux	PRECTOT	Geophysical	Total surface precipitation (incl. snow fall)	$kg m^{-2} s^{-1}$
radiation_longwave_absorbed_flux	LWGAB	Geophysical	Absorbed (downward) longwave radiation at the surface	$W m^{-2}$
radiation_shortwave_downward_flux	SWGDN	Geophysical	Downward shortwave flux incident on the surface	$W m^{-2}$
sm_profile	PRMC	Geophysical	Total profile soil moisture (0 cm to model bedrock depth).	$m^3 m^{-3}$
sm_profile_ analysis	PRMC_ANA	Analysis	Analysis total profile soil moisture (0 cm to model bedrock depth)	$m^3 m^{-3}$
sm_profile_ analysis_ensstd	PRMC_ANA_ENSSTD	Analysis	Uncertainty of analysis total profile soil moisture (0 cm to model bedrock depth; ensemble std-dev)	$m^3 m^{-3}$
sm_profile_ forecast	PRMC_FCST	Forecast	Catchment model forecast total profile soil moisture (0 cm to model bedrock depth)	$m^3 m^{-3}$
sm_profile_pctl	PRMC_PRCNTL	Geophysical	Total profile soil moisture (0 cm to model bedrock depth; percentile units).	percent
sm_profile_wetness	GWETPROF	Geophysical	Total profile soil wetness (0 cm to model bedrock depth; wetness units[&])	dimensionless
sm_rootzone	RZMC	Geophysical	Root zone soil moisture (0-100 cm)	$m^3 m^{-3}$
sm_rootzone_ analysis	RZMC_ANA	Analysis	Analysis root zone soil moisture (0-100 cm)	$m^3 m^{-3}$
sm_rootzone_ analysis_ensstd	RZMC_ANA_ENSSTD	Analysis	Uncertainty of analysis root zone soil moisture (0-100 cm; ensemble std-dev)	$m^3 m^{-3}$

Element Name (SMAP L4_SM)	GEOS-5 Name	Data Group	Description	Units
sm_rootzone_ forecast	RZMC_FCST	Forecast	Catchment model forecast root zone soil moisture (0-100 cm)	$m^3 m^{-3}$
sm_rootzone_pctl	RZMC_PRCNTL	Geophysical	Root zone soil moisture (0-100 cm; percentile units)	percent
sm_rootzone_wetness	GWETROOT	Geophysical	Root zone soil wetness (0-100 cm; wetness units[&])	dimensionless
sm_surface	SFMC	Geophysical	Top layer soil moisture (0-5 cm)	$m^3 m^{-3}$
sm_surface_ analysis	SFMC_ANA	Analysis	Analysis surface soil moisture (0-5 cm)	$m^3 m^{-3}$
sm_surface_ analysis_ensstd	SFMC_ANA_ENSSTD	Analysis	Uncertainty of analysis surface soil moisture (0-5 cm; ensemble std-dev)	$m^3 m^{-3}$
sm_surface_ forecast	SFMC_FCST	Forecast	Catchment model forecast surface soil moisture (0-5 cm)	$m^3 m^{-3}$
sm_surface_wetness	GWETTOP	Geophysical	Top layer soil wetness (0-5 cm; wetness units[&])	dimensionless
snow_depth	SNODP	Geophysical	Snow depth within snow-covered land fraction of grid cell*	m
snow_mass	SNOMAS	Geophysical	Average snow mass (or snow water equivalent) over land fraction of grid cell*	$kg\ m^{-2}$
snow_melt_flux	SNOMLT	Geophysical	Snowmelt*	$kg\ m^{-2}\ s^{-1}$
snowfall_surface_flux	PRECSNO	Geophysical	Surface snow fall	$kg\ m^{-2}\ s^{-1}$
soil_temp_layer1	TSOIL1	Geophysical	Soil temperature in layer 1 of soil heat diffusion model	K
soil_temp_layer1_analysis	TSOIL1_ANA	Analysis	Analysis soil temperature in layer 1 of soil heat diffusion model	K
soil_temp_layer1_analysis_ensstd	TSOIL1_ANA_ENSSTD	Analysis	Uncertainty of analysis soil temperature in layer 1 of soil heat diffusion model (ensemble std-dev)	K
soil_temp_layer1_forecast	TSOIL1_FCST	Forecast	Catchment model forecast soil temperature in layer 1 of soil heat diffusion model	K
soil_temp_layer2	TSOIL2	Geophysical	Soil temperature in layer 2 of soil heat diffusion model	K
soil_temp_layer3	TSOIL3	Geophysical	Soil temperature in layer 3 of soil heat diffusion model	K
soil_temp_layer4	TSOIL4	Geophysical	Soil temperature in layer 4 of soil heat diffusion model	K
soil_temp_layer5	TSOIL5	Geophysical	Soil temperature in layer 5 of soil heat diffusion model	K

Element Name (SMAP L4_SM)	GEOS-5 Name	Data Group	Description	Units
soil_temp_layer6	TSOIL6	Geophysical	Soil temperature in layer 6 of soil heat diffusion model	K
soil_water_infiltration_flux	QINFIL	Geophysical	Soil water infiltration rate	kg m^{-2} s^{-1}
specific_humidity_lowatmmodlay	QLML	Geophysical	Air specific humidity at center height of lowest atmospheric model layer	kg kg^{-1}
surface_pressure	PS	Geophysical	Surface pressure	Pa
surface_temp	TSURF	Geophysical	Mean land surface temperature (incl. snow-covered land area)*	K
surface_temp_analysis	TSURF_ANA	Analysis	Analysis surface temperature	K
surface_temp_analysis_ensstd	TSURF_ANA_ENSSTD	Analysis	Uncertainty of analysis surface temperature (ensemble std-dev)	K
surface_temp_forecast	TSURF_FCST	Forecast	Catchment model forecast surface temperature	K
tb_h_forecast‡	TBHCOMP_FCST	Forecast	Composite resolution Catchment model forecast 1.41 GHz H-pol brightness temperature#	K
tb_h_forecast_ ensstd‡	TBHCOMP_FCST_ ENSSTD	Forecast	Uncertainty (ensemble std-dev) of `tb_h_forecast`#	dimensionless
tb_h_obs‡	TBHCOMP_OBS	Observations	Composite resolution observed (L2_SM_AP or L1C_TB) H-pol brightness temperature, represented as the average of fore and aft observations from the SMAP antenna+	K
tb_h_obs_assim‡	TBHCOMP_OBS_ASSIM	Observations	Assimilated value after model-based quality control and climatological adjustment (scaling) `tb_h_obs`+ for consistency with the land model's seasonally varying mean brightness temperature climatology	dimensionless
tb_h_obs_errstd‡	TBHCOMP_OBS_ERRSTD	Observations	Observation error std-dev for `tb_h_obs_scaled`+	dimensionless
tb_h_obs_time_sec‡	TBHCOMP_OBS_TIME_SEC	Observations	Time values as counts of International System (SI) seconds based on the J2000 epoch in Ephemeris Time (ET). The J2000 epoch starting point is January 1, 2000 at 12:00 ET, which translates to January 1, 2000 at 11:58:55.816 Universal Coordinated Time (UTC). Type is Float64.	s

Element Name (SMAP L4_SM)	GEOS-5 Name	Data Group	Description	Units
tb_h_orbit_flag‡	TBHCOMP_ORBFLAG	Observations	Flag indicating the orbit direction of H-pol brightness temperature composite fields (`tb_h_obs`, `tb_h_forecast`, etc.): 0=average over ascending and descending orbits, 1=ascending orbits only, 2=descending orbits only. Type is Unsigned32.	n/a
tb_h_resolution_flag‡	TBHCOMP_RESFLAG	Observations	Flag indicating the effective resolution of H-pol brightness temperature composite fields (`tb_h_obs`, `tb_h_forecast`, etc.): 1=36 km, 2=9 km. Type is Unsigned32.	n/a
tb_v_forecast‡	TBVCOMP_FCST	Forecast	Composite resolution Catchment model forecast 1.41 GHz V-pol brightness temperature#	K
tb_v_forecast_ensstd‡	TBVCOMP_FCST_ENSSTD	Forecast	Uncertainty (ensemble std-dev) of `tb_v_forecast`#	dimensionless
tb_v_obs‡	TBVCOMP_OBS	Observations	Composite resolution observed (L2_SM_AP or L1C_TB) V-pol brightness temperature, represented as the average of fore and aft observations from the SMAP antenna+	K
tb_v_obs_assim‡	TBVCOMP_OBS_ASSIM	Observations	Assimilated value after model-based quality control and climatological adjustment (scaling) of `tb_v_obs`+ for consistency with the land model's seasonally varying mean brightness temperature climatology	dimensionless
tb_v_obs_errstd‡	TBVCOMP_OBS_ERRSTD	Observations	Observation error std-dev for `tb_v_obs_scaled`+	dimensionless
tb_v_obs_time_sec‡	TBVCOMP_OBS_TIME_SEC	Observations	Time values as counts of International System (SI) seconds based on the J2000 epoch in Ephemeris Time (ET). The J2000 epoch starting point is January 1, 2000 at 12:00 ET, which translates to January 1, 2000 at 11:58:55.816 Universal Coordinated Time (UTC). Type is Float64.	s

Element Name (SMAP L4_SM)	GEOS-5 Name	Data Group	Description	Units
tb_v_orbit_flag‡	TBVCOMP_ORBFLAG	Observations	Flag indicating the orbit direction of V-pol brightness temperature composite fields (`tb_v_obs, tb_v_forecast`, etc.): 0=average over ascending and descending orbits, 1=ascending orbits only, 2=descending orbits only. Type is Unsigned32.	n/a
tb_v_resolution_flag‡	TBVCOMP_RESFLAG	Observations	Flag indicating the effective resolution of V-pol brightness temperature composite fields (`tb_v_obs, tb_v_forecast` , etc.): 1=36 km, 2=9 km. Type is Unsigned32.	n/a
temp_lowatmmodlay	TLML	Geophysical	Air temperature at center height of lowest atmospheric model layer	K
vegetation_greenness_fraction	GRN	Geophysical	Vegetation “greenness” or fraction of transpiring leaves averaged over the land area* of the grid cell.	dimensionless
windspeed_lowatmmodlay	SPEEDLML	Geophysical	Surface wind speed at center height of lowest atmospheric model layer	$m\ s^{-1}$
x	n/a	[*All Data Groups*]$	The x coordinate values from the cylindrical 9 km Earth-fixed EASE-Grid 2.0 projection.	m
y	n/a	[*All Data Groups*]$	The y coordinate values from the cylindrical 9 km Earth-fixed EASE-Grid 2.0 projection.	m

$The spatial coordinate Datasets are stored in the HDF5 root Data Group (section 2.2.2).
*Excluding areas of open water and permanent ice.
‡Output is only stored at times and locations for which input SMAP Level 1 or Level 2 data are ingested. If more than one overpass occurs for a given grid cell within the assimilation time window, output represents average over all overpass times. Brightness temperatures are at the top of the vegetation, excluding contributions from atmospheric, galactic and cosmic radiation.
+Observed brightness temperatures that originate from 36 km L1C_TB files are posted at 9 km here for convenience (as average over the fore and aft brightness temperatures, which are stored separately in the L1C_TB product).
#Model forecast brightness temperatures that correspond to 36 km observations from the L1C_TB product are aggregated from 9 km to 36 km and then posted at 9 km for convenience.
&Soil wetness units (dimensionless) vary between 0 and 1, indicating relative saturation between completely dry conditions and completely saturated conditions, respectively. See also Appendix E.

5 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
AOS	Acquisition of Signal
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
ESH	EDOS Service Header
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
GEOS-5	Goddard Earth Observing System, version 5
GHA	Greenwich Hour Angle
GHz	gigahertz
GLOSIM	Global Simulation
GMAO	Global 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
LDAS	Land Data Assimilation System
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 Product
n/a	not applicable
OCO	Orbiting Carbon Observatory
OEF	Orbit Events File
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 sqaure
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
T_b	Brightness Temperature
TBC	To Be Confirmed
TBD	To Be Determined
TBR	To Be Resolved
TBS	To Be Specified
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

6 APPENDIX B – SHAPES IN THE L4_SM DATA PRODUCT

Table 15 lists all of the Shapes that appear in the L4_SM data product. The table also lists the rank, the nominal dimensions and the maximum dimensions for each Shape in the L4_SM data product.

The naming convention for shape names places the dimension where consecutive indices represent contiguous storage positions last. The naming convention thus conforms to index representation in the C language.

On the other hand, since a large contingent of the SMAP science community programs are in Fortran, index order of arrays in this document conforms to the Fortran standard. Thus, in array dimension representation, the dimension where consecutive indices represent contiguous storage appears first.

Table 15: Shapes in the SMAP L4_SM data product.

Shape	Rank	Nominal Product Dimensions	Maximum Product Dimensions
LonCell_Array	1	(3856)	(3856)
LatCell_Array	1	(1624)	(1624)
LatCell_LonCell_Array	2	(3856, 1624)	(3856, 1624)

7 APPENDIX C – L4_SM DIMENSIONS

Table 16 lists all of the Dimensions that are used by data elements in the L4_SM data product. The name of each Dimension matches the name given in the Dimension column below. The table also lists the anticipated nominal value and the maximum value for each dimension that appears in the L4_SM data product.

Table 16: Dimensions in the SMAP L4_SM data product.

Dimension	Nominal Size	Maximum Size
Latitude	1624	1624
Longitude	3856	3856

8 APPENDIX D – L4_SM UNITS

Table 17 lists the units that are used by the L4_SM data product elements. The SMAP implementation of HDF5 stores unit information for each data element in local metadata. The first column in the Table 17 identifies units that apply to data in the L4_SM data product. The second column lists the Common Symbol used to represent the unit. The third column lists the matching Label that appears in the local metadata in the L4_SM data product.

Soil moisture output from the Catchment land surface model is provided in "volumetric units" (m^3 m^{-3}), "wetness units" (dimensionless), and "percentile units" (percent).

Volumetric soil moisture units (m^3 m^{-3}) specify the volume of (liquid or frozen) soil water per total (bulk) soil volume, with a minimum possible value of zero and a maximum possible value given by the soil porosity `clsm_poros`.

Soil wetness units (dimensionless) vary between 0 and 1 (dimensionless) and indicate relative saturation between completely dry conditions and completely saturated conditions, respectively. Soil wetness units can be converted to volumetric soil moisture units through multiplication with the soil porosity `clsm_poros`.

Soil moisture output in percentile units (percent) is only provided for root zone and profile soil moisture. Percentiles are based on a multi-year soil moisture climatology that resolves the seasonal cycle. For example, the soil moisture value for November 5, 2014 at a given location may be much drier than the long-term average soil moisture for this date and location. The soil moisture value in question would then be reflected by a percentile value in the low percent range. Percentile units are not provided (that is, set to fill values or no-data-values) if the multi-year soil moisture variability for a given time-of-year and location falls below a threshold of 0.05 (in wetness units).

All land model constants that are related to soil moisture are provided in volumetric soil moisture units (m^3 m^{-3}), including soil porosity (`clsm_poros`), wilting point (`clsm_wp`), and select microwave radiative transfer parameters (`mwrtm_wangwt`, `mwrtm_wangwp`, `mwrtm_rghwmin`, `mwrtm_rghwmax`).

Table 17: Units in the SMAP L4_SM data product.

Unit	Common Symbol	L4_SM Label	Typical Use
counts	Counts	counts	number of elements in a set
degrees	degrees	degrees	angular measure
dimensionless	n/a	dimensionless	dimensionless quantity
Gigahertz	GHz	GHz	frequency measure
Megabytes	Mbytes	Mbytes	computer storage units
meters	m	m	distance measure
kilometers	km	km	distance measure
percent	%	percent	per hundred
seconds	s	sec	time measure
revolutions per minute	rpm	rpm	rotational measure
degrees Celsius	°C	degrees_Celsius	temperature measure
Kelvin	K	Kelvin	temperature measure
Pascal	Pa	Pa	pressure measure
kilograms per kilogram	$kg\ kg^{-1}$	kg kg-1	mass per mass measure
meters per second	$m\ s^{-1}$	m s-1	velocity measure
meters squared per meters squared	$m^2\ m^{-2}$	m2 m-2	area per area measure
meters cubed per meters cubed	$m^3\ m^{-3}$	m3 m-3	volume per volume measure
kilograms per meters squared	$kg\ m^{-2}$	kg m-2	mass storage per area measure
kilograms per meters squared per second	$kg\ m^{-2}\ s^{-1}$	kg m-2 s-1	mass flux measure
Watts per meters squared	$W\ m^{-2}$	W m-2	energy flux measure