



SMAP L4 Global 9 km EASE-Grid Surface and Root Zone Soil Moisture, Version 8:

3-hourly Analysis Update, 3-hourly Geophysical Data, and Land Model Constants

USER GUIDE

How to Cite These Data

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

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

FOR CURRENT INFORMATION, VISIT <https://nsidc.org/data/SPL4SMAU> (or [SPL4SMGP](#) or [SPL4SMLM](#))



National Snow and Ice Data Center

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This user guide applies to the following data sets:

[SMAP L4 Global 3-hourly 9 km EASE-Grid Surface and Root Zone Soil Moisture Geophysical Data \(SPL4SMGP\)](#)

[SMAP L4 Global 3-hourly 9 km EASE-Grid Surface and Root Zone Soil Moisture Analysis Update \(SPL4SMAU\)](#)

[SMAP L4 Global 9 km EASE-Grid Surface and Root Zone Soil Moisture Land Model Constants \(SPL4SMLM\)](#)

1 DATA DESCRIPTION

1.1 Summary

SMAP Level-4 (L4) surface and root zone soil moisture (L4_SM) data are provided in three products:

- SMAP L4 Global 3-hourly 9 km EASE-Grid Surface and Root Zone Soil Moisture Geophysical Data (SPL4SMGP, DOI: 10.5067/T5RUATAQREF8). This product is a series of 3-hourly time average geophysical land surface fields that are output by the L4_SM algorithm. It is likely of primary interest to most users.
- SMAP L4 Global 3-hourly 9 km EASE-Grid Surface and Root Zone Soil Moisture Analysis Update (SPL4SMAU, DOI: 10.5067/02LGW4DGJYRX). This product provides diagnostics from the land surface analysis updates. It 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.
- SMAP L4 Global 9 km EASE-Grid Surface and Root Zone Soil Moisture Land Model Constants (SPL4SMLM, DOI: 10.5067/PXQIBL2ALDZD). This product provides static (time-invariant) land surface model constants that will be needed by some users for further interpretation of the geophysical land surface fields. This product consists of only one granule (file) per L4_SM data product version (as defined by a distinct Science Version ID).

For each product, SMAP L-band brightness temperature data from descending and ascending half-orbit satellite passes (approximately 6:00 a.m. and 6:00 p.m. local solar time, respectively) are assimilated into a land surface model that is gridded using an Earth-fixed, global cylindrical 9 km Equal-Area Scalable Earth Grid, Version 2.0 (EASE-Grid 2.0) projection.

1.2 Parameters

SMAP L4_SM data include the following parameters:

- Surface soil moisture (0-5 cm vertical average)
- Root zone soil moisture (0-100 cm vertical average)
- Additional research products (not validated), including surface meteorological forcing variables, soil temperature, evapotranspiration, net radiation, and error estimates for select output fields that are produced internally by the SMAP Level-4 soil moisture algorithm

Soil moisture is output in volumetric units, in wetness (or relative saturation) units, and in percentile units (except surface soil moisture).

Parameters are further described in Section 3 of the Algorithm Theoretical Basis Document (ATBD) for this product (Reichle et al., 2014).

1.3 File Information

1.3.1 Format

Data are in HDF5 format.

Each HDF5 file contains file-level metadata. A separate metadata file with an `.xml` file extension is available from the National Snow and Ice Data Center (NSIDC) Distributed Active Archive Center (DAAC) with every HDF5 file; it contains essentially the same information as the file-level metadata. In addition, a Quality Assessment (QA) file with a `.qa` file extension is provided for every HDF5 file. QA files contain spatial statistics for each SMAP Level-4 soil moisture product, such as the global minimum, mean, and maximum of each data field.

For software and more information, including an HDF5 tutorial, visit the HDF Group's [HDF5](#) website.

1.3.2 File Contents

SMAP Level-4 soil moisture data consists of three main products:

- Geophysical Data (SPL4SMGP)
- Analysis Update Data (SPL4SMAU)
- Land Model Constants (SPL4SMLM)

For each 3-hour interval, there are two files: one geophysical file and one analysis update file. Land model constants are provided in a single file per science version. Science Version IDs (such as Vv8010) are included in all file names and are defined in the **Naming Convention** section of this User Guide.

1.3.2.1 Geophysical Data (SPL4SMGP)

The Geophysical Data (gph) product includes a series of 3-hourly time-averaged geophysical data fields from the assimilation system, such as surface and root zone soil moisture. The general contents of the gph granule file are shown in Figure 1.



Figure 1. Contents of a Geophysical Data file. For a complete list of file contents for the SMAP Level-4 soil moisture product, refer to the L4_SM Product Specification Document (Reichle et al., 2022).

1.3.2.2 Analysis Update (SPL4SMAU)

The Analysis Update (aup) product includes a series of 3-hourly instantaneous/snapshot files that contain the following:

- Analysis Data: Soil moisture and temperature analysis estimates, including error estimates
- Forecast Data: Land model predictions of brightness temperature, soil moisture, and soil temperature
- Observations Data: Assimilated SMAP brightness temperature observations and data assimilation diagnostics

Figure 2 shows the contents within an aup file.

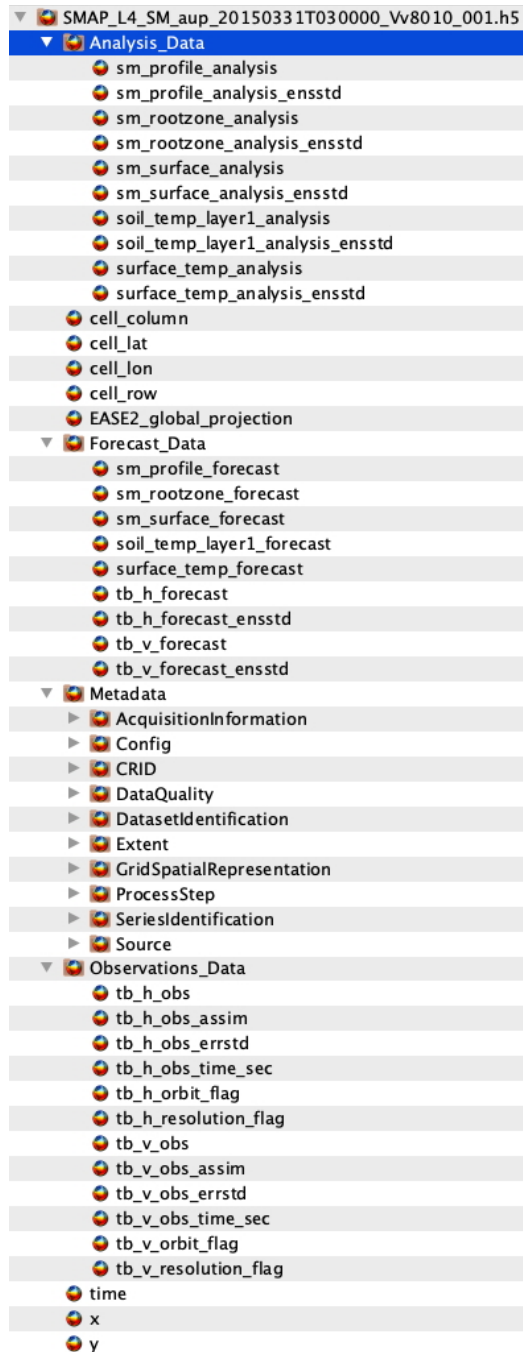


Figure 2. Contents of an Analysis Update Data file. For a complete list of file contents for the SMAP Level-4 soil moisture product, refer to the L4_SM Product Specification Document (Reichle et al., 2022).

1.3.2.3 Land Model Constants (SPL4SMLM)

The Land Model Constants (1mc) product includes static land surface model constants that provide further interpretation of the geophysical land surface fields. Figure 3 shows the contents within an 1mc file.



Figure 3. Contents of a Land Model Constants Data file. For a complete list of file contents for the SMAP Level-4 soil moisture product refer to the L4_SM Product Specification Document (Reichle et al., 2022).

All global data fields have dimensions of 1624 rows and 3856 columns (6,262,144 pixels per array).

1.3.3 Metadata Fields

Each product also contains metadata that describe the full content of each file. For a description of all metadata fields for this product, refer to the L4_SM Product Specification Document (Reichle et al., 2022).

1.3.4 Naming Convention

Files are named according to the following convention:

SMAP_L4_SM_pid_yyyymmddThhmmss_VLMmmm_NNN.[ext]

For example:

SMAP_L4_SM_gph_20150331T013000_Vv8010_001.h5

Table 1 describes the variables within a file name:

Table 1. File Naming Convention

Variable	Description									
SMAP	Indicates SMAP mission data									
L4_SM	Indicates specific product (L4: Level-4; SM: Soil Moisture)									
pid	<p>Product Identification (PID), where:</p> <table border="1"> <tr> <td>gph</td> <td>Geophysical Data</td> <td>The date/time corresponds to the center point of the 3-hourly time averaging interval. For example, T013000 corresponds to the time average from 00:00:00 UTC to 03:00:00 UTC on a given day.</td> </tr> <tr> <td>aup</td> <td>Analysis Update Data</td> <td>The date/time indicates the time of the analysis update. For example, T030000 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.</td> </tr> <tr> <td>lmc</td> <td>Land Surface Model Constants</td> <td>For the LMC product (time-invariant constants), which consists of only one file per Science Version, the date/time is 00000000T000000.</td> </tr> </table>	gph	Geophysical Data	The date/time corresponds to the center point of the 3-hourly time averaging interval. For example, T013000 corresponds to the time average from 00:00:00 UTC to 03:00:00 UTC on a given day.	aup	Analysis Update Data	The date/time indicates the time of the analysis update. For example, T030000 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.	lmc	Land Surface Model Constants	For the LMC product (time-invariant constants), which consists of only one file per Science Version, the date/time is 00000000T000000.
gph	Geophysical Data	The date/time corresponds to the center point of the 3-hourly time averaging interval. For example, T013000 corresponds to the time average from 00:00:00 UTC to 03:00:00 UTC on a given day.								
aup	Analysis Update Data	The date/time indicates the time of the analysis update. For example, T030000 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.								
lmc	Land Surface Model Constants	For the LMC product (time-invariant constants), which consists of only one file per Science Version, the date/time is 00000000T000000.								
yyymmddThhmmss	<p>Date/time in Coordinated Universal Time (UTC) of the data elements in the product, where:</p> <table border="1"> <tr> <td>yyymmdd</td> <td>4-digit year, 2-digit month, 2-digit day</td> </tr> <tr> <td>T</td> <td>Time (delineates the date from the time, i.e. yyymmddThhmmss)</td> </tr> <tr> <td>hhmmss</td> <td>2-digit hour, 2-digit minute, 2-digit second</td> </tr> </table> <p>See pid entries for details on the time of the data elements.</p>	yyymmdd	4-digit year, 2-digit month, 2-digit day	T	Time (delineates the date from the time, i.e. yyymmddThhmmss)	hhmmss	2-digit hour, 2-digit minute, 2-digit second			
yyymmdd	4-digit year, 2-digit month, 2-digit day									
T	Time (delineates the date from the time, i.e. yyymmddThhmmss)									
hhmmss	2-digit hour, 2-digit minute, 2-digit second									
VLMmmm	<p>Science Version ID (SVID), where:</p> <table border="1"> <tr> <td>V</td> <td>Version</td> </tr> <tr> <td>L</td> <td>Launch Indicator (v: Validated Data)</td> </tr> <tr> <td>M</td> <td>1-Digit SVID Major Version Number</td> </tr> <tr> <td>mmm</td> <td>3-Digit SVID Minor Version Number</td> </tr> </table> <p>Example: Vv8010 indicates a validated-quality data product with a version of 8.010. Refer to the SMAP Data Versions page for version information.</p>	V	Version	L	Launch Indicator (v: Validated Data)	M	1-Digit SVID Major Version Number	mmm	3-Digit SVID Minor Version Number	
V	Version									
L	Launch Indicator (v: Validated Data)									
M	1-Digit SVID Major Version Number									
mmm	3-Digit SVID Minor Version Number									

Variable	Description						
NNN	Number of times the file was generated under the same version for a particular date/time interval (e.g., 002 denotes 2nd time)						
. [ext]	File extensions include: <table border="1" data-bbox="456 367 837 508"> <tbody> <tr> <td>.h5</td> <td>HDF5 data file</td> </tr> <tr> <td>.qa</td> <td>Quality Assurance file</td> </tr> <tr> <td>.xml</td> <td>XML Metadata file</td> </tr> </tbody> </table>	.h5	HDF5 data file	.qa	Quality Assurance file	.xml	XML Metadata file
.h5	HDF5 data file						
.qa	Quality Assurance file						
.xml	XML Metadata file						

1.4 Spatial Information

1.4.1 Coverage

Coverage spans from 180°W to 180°E, and from approximately 85.044°N to 85.044°S. Coverage is for the global land surface excluding inland water and permanently frozen areas.

1.4.2 Resolution

The native spatial resolution of the SMAP radiometer footprint is approximately 36 km. Data are then assimilated into a land surface model that is gridded using the 9 km global EASE-Grid 2.0 projection.

1.4.3 Geolocation

These data are provided on the 9-km global cylindrical EASE-Grid 2.0 projection. Table 2 and Table 3 provide information for geolocating this data set. For more on EASE-Grid 2.0, refer to the [EASE Grids](#) website.

Table 2. Geolocation details for the EASE-Grid 2.0 projections used in this product

Geographic coordinate system	WGS 84
Projected coordinate system	EASE-Grid 2.0 Global
Longitude of true origin	0
Standard Parallel	30° N
Scale factor at longitude of true origin	N/A
Datum	WGS 84
Ellipsoid / spheroid	WGS 84
Units	meter

False easting	0
False northing	0
EPSG code	6933
PROJ4 string	+proj=cea +lon_0=0 +lat_ts=30 +x_0=0 +y_0=0 +ellps=WGS84 +towgs84=0,0,0,0,0,0,0 +units=m +no_defs
Reference	http://epsg.io/6933

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

Grid cell size (x, y pixel dimensions)	9,024.13 m (x) 9,024.13 m (y)
Number of columns	3856
Number of rows	1624
Geolocated lower left point in grid	85.044° S, 180.000° W
Nominal gridded resolution	9 km by 9 km
Grid rotation	N/A
ulxmap – x-axis map coordinate of the outer edge of the upper-left pixel	-17367530.45
ulymap – y-axis map coordinate of the outer edge of the upper-left pixel	7314540.83

1.5 Temporal Information

1.5.1 Coverage

Coverage spans from 31 March 2015 to present.

1.5.2 Satellite and Processing Events

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

[SMAP On-Orbit Events List for Instrument Data Users](#)

[Master List of Bad and Missing Data](#)

Significant gaps in coverage occurred between 19 June and 23 July 2019 and between 6 August and 20 September 2022 after the SMAP satellite went into Safe Mode. A brief description of the 2019 event and its impact on data quality is available in the [SMAP Post-Recovery Notice](#). The SMAP data acquired after the 2022 event were determined to be of high quality and consistent with the data acquired prior to the

event. Note, SPL4SM data are available during the 2019 and 2022 gaps in SMAP coverage, albeit based primarily on the modeling system and not on concomitant SMAP observations.

1.5.3 Latencies

Please see the following FAQ: [What are the latencies for SMAP radiometer data sets?](#)

1.5.4 Resolution

Three basic time steps are involved in the generation of the Level-4 soil moisture products, including:

1. The land model computational time step (7.5 minutes)
2. The Ensemble Kalman Filter (EnKF) analysis update time step (3 hours)
3. The reporting/output time step for the instantaneous and time-average geophysical fields that are stored in the data products (3 hours)

SMAP observations are assimilated in an EnKF analysis update step at the nearest 3-hourly analysis time such as 0z, 3z, ..., and 21z (where z indicates UTC). A broad variety of geophysical parameters are provided as 3-hourly averages between these update times. Moreover, instantaneous forecast and analysis soil moisture and temperature estimates are provided along with the assimilated observations. These snapshots are nominally for 0z, 3z, ..., or 21z.

2 DATA ACQUISITION AND PROCESSING

This section has been adapted from the Algorithm Theoretical Basis Document (ATBD) (Reichle et al. 2014). Additional documentation of the algorithm is provided by Reichle et al. 2017a, Reichle et al. 2017b, Reichle et al. 2019, Reichle and Liu 2021, and Reichle et al. 2023a.

2.1 Background

The primary SMAP measurements, land surface microwave emission at 1.41 GHz, are directly related to surface soil moisture (in the top 5 cm of the soil column). Several of the key applications targeted by SMAP, however, require knowledge of root zone soil moisture (defined here as soil moisture in the top 1 m of the soil column), which is not directly linked to SMAP observations. The foremost objective of the SMAP Level-4 Surface and Root Zone Soil Moisture (SPL4SM) products is to fill this gap and provide estimates of root zone soil moisture that are informed by, and consistent with, SMAP observations. Such estimates are obtained by merging SMAP observations with estimates from a land surface model in a soil moisture data assimilation system.

The land surface model component of the assimilation system is driven with observation-based surface meteorological forcing data, including precipitation, which is the most important driver for soil moisture. The model also encapsulates knowledge of key land surface processes, including the vertical transfer of soil moisture between the surface and root zone reservoirs. Finally, the assimilation system uses the land model to interpolate and extrapolate SMAP observations in time and in space. The SPL4SM products thus provide a comprehensive and consistent picture of land surface hydrological conditions based on SMAP observations and complementary information from a variety of sources. The assimilation algorithm considers the respective uncertainties of each component and, if properly calibrated, yields a product that is superior to both satellite and land model data. Error estimates for the SPL4SM products are generated as a by-product of the data assimilation system.

2.2 Instrumentation

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

2.3 Acquisition

SMAP Level-4 soil moisture products are derived from the following primary input data sets:

- SMAP L1C Radiometer Half-Orbit 36 km EASE-Grid Brightness Temperatures (SPL1CTB) [Version 6](#) (a.k.a. “R19” in the Level 1 Composite Release Identifier classification). See the [SMAP Data Versions](#) page for more details.
- [Goddard Earth Observing System \(GEOS\)](#) Forward Processing (FP) global, 0.25-degree, hourly surface meteorology from observation-constrained global weather model analysis
- NOAA Climate Prediction Center "Unified" ([CPCU](#)) global, 0.5 degree, daily, gauge-based precipitation data
- NASA Integrated Multi-satellitE Retrievals for the Global Precipitation Measurement mission ([IMERG](#)) quasi-global, 0.1-degree, ½-hourly, satellite- and gauge-based ([IMERG-Final](#)) and satellite-only ([IMERG-Late](#)) precipitation data (Version 07). The corresponding [monthly IMERG-Final](#) product is also used.

Utilizing the data assimilation algorithm discussed below, input data sources are used with the SMAP Level-4 soil moisture model to provide enhanced estimates of surface soil moisture, root zone soil moisture, and related geophysical variables (Reichle et al. 2017a, Reichle et al. 2017b, Reichle et al. 2019, Reichle and Liu 2021, Reichle et al. 2023a).

2.4 Derivation Techniques and Algorithms

The SPL4SM science algorithm consists of two key processing elements:

- GEOS Catchment land surface and microwave radiative transfer model
- GEOS ensemble-based land data assimilation algorithm

The GEOS Catchment land surface and microwave radiative transfer model is a numerical description of the water and energy transport processes at the land-atmosphere interface, augmented with a model that describes the land surface microwave radiative transfer (refer to section 4.1.1 of the ATBD: Reichle et al., 2014). The GEOS Ensemble-Based Land Data Assimilation System is the tool used to merge SMAP observations with estimates from the land model as it is driven with observation-based surface meteorological forcing data.

The SMAP Level-4 soil moisture algorithm, described in detail in the ATBD, includes a soil moisture analysis based on the ensemble Kalman filter (EnKF) and a rule-based freeze/thaw analysis. However, data users should note that for Validated Version 8 data, the algorithm ingests only the SPL1CTB radiometer brightness temperatures, contrary to the planned use of downscaled brightness temperatures from the SPL2SMAP product and of landscape freeze-thaw state retrievals from the SPL2SMA product. The latter two products—SPL2SMAP and SPL2SMA—are based on radar observations and are only available for the period from 13 April 2015 through 07 July 2015 due to an anomaly that caused the premature failure of the SMAP L-band radar. Neither of these two radar-based products is assimilated in the SMAP Level-4 soil moisture algorithm.

SMAP SPL1CTB data are required for the L4_SM algorithm. Aside from SMAP observations, the data assimilation system requires initialization, parameter, and forcing inputs for the Catchment land surface model, as well as input error parameters for the ensemble-based data assimilation system. Details regarding the ancillary data requirements are described in Section 4.1.3 of the ATBD (Reichle et al., 2014). Depending on the time and location, the precipitation observations used to correct the GEOS precipitation estimates are obtained from the CPCU gauge-based product, the NASA [IMERG](#) satellite- and gauge-based (IMERG-Final) product, or the [IMERG](#) satellite-only (IMERG-Late) data product (Reichle et al. 2017a, Reichle et al. 2017b, Reichle et al. 2019, Reichle and Liu 2021, Reichle et al. 2023a).

For more information on each portion of the algorithm processing flow, refer to the ATBD (Reichle et al., 2014). The remainder of this section discusses the new features and changes in the SPL4SM Version 8 algorithm relative to Version 7.

2.4.1 Land Surface Modeling and Assimilation System Updates for Version 8

The precipitation observations used outside of North America and the high latitudes are now from Version 07 of the IMERG products. Precipitation rates from the IMERG-Final half-hourly product for a given month are used only where they are consistent with the rates of the IMERG-Final monthly product. In this case, the (hourly) L4_SM precipitation forcing is corrected to match the IMERG-Final daily total precipitation. When the IMERG-Final half-hourly data are inconsistent with the corresponding IMERG-Final monthly data, which is typically the case for solid precipitation (snowfall), the L4_SM precipitation forcing is corrected to match only the IMERG-Final monthly total precipitation.

The L-band microwave radiative transfer model (mwRTM) also underwent several updates:

- The mwRTM now uses the Mironov soil mixing approach, replacing the Wang & Schmugge model used in earlier L4_SM versions.
- The mwRTM now uses updated values of the L-band scattering albedo, soil roughness, and vegetation opacity climatology obtained from Version 6 of the SMAP Level-2 dual-channel soil moisture retrieval product ([SPL2SMP_E](#)).
- The mwRTM now uses updated values of the polarization mixing parameters of the rough surface reflectivity, matching those of the [SPL2SMP_E](#) product.

In addition, the Catchment land surface model has been updated to use climatological snow albedo values based on observations from the NASA Moderate Resolution Imaging Spectroradiometer, replacing the look-up table parameterization of earlier L4_SM versions.

The assimilated brightness temperatures are now taken only from Version 6 (“R19”) of the SPL1CTB product. The brightness temperature scaling parameters in the L4_SM algorithm have also been updated and are now based on nine years of SMAP observations and model simulations (April 2015 – March 2024).

Lastly, two bug fixes were implemented. The first corrects excessive precipitation rates that occasionally appeared along certain longitudes in North America in earlier versions of L4_SM. The second fixes an error in the ancillary soil data that misclassified a small region in Argentina as peat.

Note: Because of the changes and updates made for Version 8, it is recommended that users do NOT combine data output from earlier SMAP L4 versions with this new version.

2.5 Processing

SMAP L4_SM data are generated by the [NASA Global Modeling and Assimilation Office \(GMAO\)](#) located at the [NASA Goddard Space Flight Center \(GSFC\)](#), using the High-End Computing Facilities at the [NASA Center for Climate Simulation \(NCCS\)](#), also located at GSFC in Greenbelt, Maryland.

2.6 Quality, Errors, and Limitations

2.6.1 Quality Overview

SMAP products provide multiple means to assess quality. Uncertainty measures and file-level metadata that provide quality information are provided within each product. For details, refer to the L4_SM Product Specification Document (Reichle et al., 2022).

Level-4 surface and root zone soil moisture estimates are validated to a Root Mean Square Error (RMSE) requirement of $0.04 \text{ m}^3/\text{m}^3$ 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 $5 \text{ kg}/\text{m}^2$. 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.

For in-depth details regarding the quality of these data, refer to Version 7 of the SMAP Project Assessment Report (Reichle et al., 2023b).

2.6.2 Quality Control

Quality control is also an integral part of the soil moisture assimilation system. Two kinds of quality control (QC) measures are applied. The first set of QC steps is based on the flags that are provided with the SMAP observations. Only SMAP brightness temperature data that have favorable flags for soil moisture estimation are assimilated, such as acceptably low vegetation density, no rain, no snow cover, no frozen ground, no RFI, sufficient distance from open water, etc.

The second set of QC steps are additional rules that exclude SMAP observations from assimilation in the EnKF soil moisture update whenever the land surface model indicates that (1) heavy rain is falling, (2) the soil is frozen, or (3) the ground is fully or partly covered with snow. The assimilation system will typically provide some weight to the model background and thus buffers the impact of anomalous observations that are not caught in the flagging process.

For more quality control information, refer to the ATBD of the SPL4SM products (Reichle et al., 2014).

2.6.3 Error Sources

The data assimilation system weighs the relative errors of the assimilated SMAP brightness temperatures and the land model forecasts. Estimates of the error of the assimilation product are dynamically determined as a by-product of this calculation. The usefulness of these error estimates depends on the

accuracy of the input error parameters and needs continual evaluation; refer to the ATBD, Section 4.2.4 (Reichle et al., 2014). The target accuracy of the assimilated brightness temperatures is discussed in the [SPL1CTB](#) product documentation (Chan et al., 2015). Error estimates of the land surface model and required input error parameters are discussed in the ATBD for the SPL4SM product (Reichle et al., 2014).

Each instantaneous land model field is accompanied by a corresponding instantaneous error field which is provided for select variables. The relevant outputs are listed in the [L4_SM Product Specification Document](#) (Reichle et al. 2022). Specifically, the error estimates are derived from the ensemble standard deviation of the analyzed fields. For soil moisture, the ensemble standard deviation is computed from the analysis ensemble in volumetric units (m³/m³). For temperatures, the ensemble standard deviation is provided in kelvins. These error estimates will vary in space and time.

More information about error sources is provided in Section 4.1.2 of the ATBD (Reichle et al., 2014). For more information on data product accuracy and its development over time, refer to Reichle et al., 2017a; Reichle et al., 2017b, Reichle et al., 2019, Reichle et al. 2021, Colliander et al. 2022, Reichle et al. 2023a, and the Version 7 Assessment Report (Reichle et al., 2023b).

3 VERSION HISTORY

Table 4 provides a brief overview of past quasi-annual updates to the Level 4 soil moisture products.

Table 4. Version History

Version	Release Date	Description of Changes
V1	Oct 2015	First public data release
V2	Apr 2016	Changes to this version include: <ul style="list-style-type: none"> • Transitioned to Validated-Stage 2. • Using updated SPL1CTB V3 validated data as input. • Minor bug fixes.
V3	Jul 2017	Changes to this version include: <ul style="list-style-type: none"> • SMAP observations are now assimilated in Eastern Europe, the Middle East, and East Asia due to expanded coverage of the brightness temperature scaling parameters. The latter are based on two years of SMAP Version 3 brightness temperature observations where the SMOS climatology is unavailable due to RFI. • An improved version of the model-only Nature Run (NRv4.1) simulation is used to derive the brightness temperature scaling parameters, the model soil moisture initial conditions, and the soil moisture climatology. • Minor bug fixes.

Version	Release Date	Description of Changes
V4	Jun 2018	<p>Changes to this version include:</p> <ul style="list-style-type: none"> • The land surface modeling system was revised in the following ways: <ul style="list-style-type: none"> - Improved input parameter data sets for land cover, topography, and vegetation height are based on more recent data sets. Land cover inputs were updated to the GlobCover2009 product, resulting in a slightly different land mask between Version 3 and Version 4. Topographic statistics now rely on observations from the Shuttle Radar Topography Mission. Finally, vegetation height inputs are derived from space-borne lidar measurements. - The model background precipitation forcing is rescaled to match the climatology of the Global Precipitation Climatology Project (v2.2), which results in substantial changes in the precipitation and soil moisture climatology in Africa and the high latitudes, where the gauge-based Climate Prediction Center Unified precipitation is not used. - SMAP Level-2 soil moisture retrievals and in situ soil moisture measurements from the Soil Climate Analysis Network and U.S. Climate Reference Network were used to calibrate a particular Catchment model parameter that governs the recharge of soil moisture from the model's root-zone excess reservoir into the surface excess reservoir. Specifically, the replenishment of soil moisture near the surface from below under non-equilibrium conditions was substantially reduced, which brings the model's surface soil moisture more in line with the SMAP Level-2 and in situ soil moisture. - Additional model changes include revisions to the parameters and parameterizations of the surface energy balance and the snow depletion curve. • The Version 4 brightness temperature scaling parameters are based on eight years of SMOS observations and three years of SMAP observations where the SMOS climatology is unavailable due to radio frequency interference. Note that the calibration of the assimilated SMAP brightness temperatures changed substantially from Version 3 to Version 4. • Analysis increments are no longer computed for the "catchment deficit" model prognostic variable in the Ensemble Kalman filter update step. • Minor bug fixes. • Added x and y coordinate variables [including arrays of EASE-Grid 2.0 coordinate values, Climate and Forecast (CF)-compliant metadata, and HDF-5 dimension scales] as well as an EASE-Grid 2.0 projection grid mapping variable. This augmentation of L4 soil moisture data files improves interoperability and user workflow via ArcGIS/QGIS, OPeNDAP, and programmatic access. Three new data fields accommodate this change: <i>EASE2_global_projection</i>, <i>x</i>, and <i>y</i>.
V5	Aug 2020	<p>Changes to this version include:</p> <ul style="list-style-type: none"> • The Level-4 soil moisture algorithm was recalibrated to work with the substantially changed calibration of the assimilated Level-1C brightness temperatures. • The brightness temperature scaling parameters in the updated Level-4 soil moisture algorithm are based on five years of SMAP observations (April 2015 – March 2020). • The land surface modeling system underpinning the updated Level-4 soil moisture algorithm was revised in the following ways: <ul style="list-style-type: none"> • Improved surface aerodynamic roughness length (<i>z0</i>) formulation, including the use of a stem area index and an increase in the minimum <i>z0</i> value. • Corrected an error in the fitting procedure used for one of the topography-related functions in the Catchment model, which potentially affected the simulation of soil moisture in about 2% of all land surface elements (De Lannoy et al. 2014). • Updated calibration of the microwave radiative transfer model parameters. • The updated Level-4 soil moisture algorithm includes major software upgrades, including full compliance with the Earth System Modeling Framework, a modular and extensible software design approach, for improved support of future science development. • Minor bug fixes.

Version	Release Date	Description of Changes
V6	Nov 2021	<p>Changes to this version include:</p> <ul style="list-style-type: none"> • The climatology to which all L4_SM precipitation forcing inputs are rescaled is now based on the climatology of the NASA IMERG-Final (Version 06B) product. Where the IMERG climatology is not available (primarily poleward of 60°N latitude), L4_SM precipitation inputs are rescaled to the climatology of the Global Precipitation Climatology Project (GPCP) v2.3 product. • The L4_SM precipitation forcing outside of North America and the high latitudes is now corrected to match the daily totals from the NASA IMERG (Version 06B) product. As in Version 5, precipitation corrections based on CPCU data are used in North America. The latitude band for the linear tapering of the daily precipitation corrections is now 50-60°N/S. The IMERG-Final product, which is informed by satellite observations and monthly totals from precipitation gauges, was used during L4_SM reprocessing. Forward-processing of L4_SM uses the satellite-only IMERG-Late product, which is not informed by precipitation gauges. A change in the L4_SM Science Version ID indicates the switch from IMERG-Final to IMERG-Late inputs. • Minor change in a parameter related to the multiplicative, lognormal perturbations of precipitation and shortwave radiation forcing to reduce minor bias between perturbed and unperturbed forcing. • The brightness temperature scaling parameters in the updated Level-4 soil moisture algorithm are based on six years of SMAP observations (April 2015 – March 2021).
V7	Nov 2022	<p>Changes to this version include:</p> <ul style="list-style-type: none"> • The Catchment model now includes the PEATCLSM hydrology module for peatlands and uses an updated global map of peatland distribution. • Revised parameters are used in the L-band radiative transfer model that converts the simulated soil moisture and temperature estimates into Tb predictions for the radiance-based L4_SM analysis. Specifically, the L-band parameters for scattering albedo climatology, soil roughness climatology, and (seasonally-varying) vegetation opacity climatology are obtained from the SPL2SMP_E, Version 5, dual-channel retrieval product (April 2015 – March 2022). • The brightness temperature scaling parameters in the updated Level-4 soil moisture algorithm are based on seven years of SMAP observations and model simulations (April 2015 – March 2022). • For peatlands, the EnKF state vector now additionally includes the “catchment deficit” model prognostic variable.
	Nov 2023	<p>Change to this version include:</p> <ul style="list-style-type: none"> • Discontinues use of IMERG-Late precipitation because of data quality issues following the GPM orbit boost on 7-8 November 2023.

Version	Release Date	Description of Changes
V8	Apr 2025	<p>Changes to this version include:</p> <ul style="list-style-type: none"> • The precipitation observations used outside of North America and the high latitudes are from Version 07 of the NASA Integrated Multi-satellite Retrievals for the Global Precipitation Measurement mission (IMERG) products. Precipitation rates from the IMERG-Final half-hourly product for a given month are used only where they are consistent with the rates of the IMERG-Final monthly product. In this case, the (hourly) L4_SM precipitation forcing is corrected to match the IMERG-Final daily total precipitation. When the IMERG-Final half-hourly data are inconsistent with the corresponding IMERG-Final monthly data, which is typically the case for solid precipitation (snowfall), the L4_SM precipitation forcing is corrected to match only the IMERG-Final monthly total precipitation. • The L-band microwave radiative transfer model (mwRTM) was updated as follows: <ul style="list-style-type: none"> - The mwRTM uses the Mironov soil mixing approach, replacing the Wang & Schmusge model used in earlier L4_SM versions. - The mwRTM uses updated values of the L-band scattering albedo, soil roughness, and vegetation opacity climatology obtained from Version 6 of the SMAP Level-2 dual-channel soil moisture retrieval product (SPL2SMP_E). - The mwRTM uses updated values of the polarization mixing parameters of the rough surface reflectivity, matching those of the SPL2SMP_E product. • The Catchment land surface model now uses climatological snow albedo values based on observations from the NASA Moderate Resolution Imaging Spectroradiometer, replacing the look-up table parameterization of earlier L4_SM versions. • The assimilated brightness temperatures are now taken only from Version 6 (“R19”) of the SPL1CTB product. • The brightness temperature scaling parameters in the L4_SM algorithm are now based on nine years of SMAP observations and model simulations (April 2015 – March 2024). • Two bug fixes were implemented. The first corrects excessive precipitation rates that occasionally appeared along certain longitudes in North America in earlier versions of L4_SM. The second fixes an error in the ancillary soil data that misclassified a small region in Argentina as peat.

4 RELATED DATA SETS

[SMAP Data at NSIDC | Overview](#)

5 RELATED WEBSITES

[SMAP at NASA JPL](#)

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7 REFERENCES

Chan, S., E. Njoku, A. Colliander. 2015. SMAP Algorithm Theoretical Basis Document (ATBD) Level-1C Radiometer Data Product (L1C_TB). SMAP Project, Jet Propulsion Laboratory, Pasadena, CA. (see [PDF](#))

Colliander, A., R.H. Reichle, W.T. Crow, M.H. Cosh, F. Chen, S. Chan, ... S.H. Yueh (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. <http://doi.org/10.1109/JSTARS.2021.3124743>

De Lannoy, G. J. M., Koster, R. D., Reichle, R. H., Mahanama, S. P. P., and Liu, Q. (2014). An updated treatment of soil texture and associated hydraulic properties in a global land modeling system. *Journal of Advances in Modeling Earth Systems*, 6(4), 957–979. <http://doi.org/10.1002/2014ms000330>

Huffman, G.J., E.F. Stocker, D.T. Bolvin, E.J. Nelkin, Jackson Tan (2023). GPM IMERG Final Precipitation L3 Half Hourly 0.1 degree x 0.1 degree V07, Greenbelt, MD, Goddard Earth Sciences Data and Information Services Center (GES DISC). <https://doi.org/10.5067/GPM/IMERG/3B-HH/07>

Huffman, G.J., E.F. Stocker, D.T. Bolvin, E.J. Nelkin, Jackson Tan (2023), GPM IMERG Final Precipitation L3 1 month 0.1 degree x 0.1 degree V07, Greenbelt, MD, Goddard Earth Sciences Data and Information Services Center (GES DISC). <https://doi.org/10.5067/GPM/IMERG/3B-MONTH/07>

Huffman, G.J., E.F. Stocker, D.T. Bolvin, E.J. Nelkin, Jackson Tan (2024), GPM IMERG Late Precipitation L3 Half Hourly 0.1 degree x 0.1 degree V07, Greenbelt, MD, Goddard Earth Sciences Data and Information Services Center (GES DISC). <https://doi.org/10.5067/GPM/IMERG/3B-HH-L/07>

Reichle, R., R. Koster, G. De Lannoy, W. Crow, and J. Kimball (2014). SMAP Algorithm Theoretical Basis Document: Level 4 Surface and Root Zone Soil Moisture (L4_SM) Data Product. SMAP Project, JPL D-66483, Jet Propulsion Laboratory, Pasadena, CA, USA. (see [PDF](#))

Reichle, R. H., G. J. De Lannoy, Q. Liu, J. V. Ardizzone, A. Colliander, A. Conaty, et al. (2017a). Assessment of the SMAP Level-4 Surface and Root-Zone Soil Moisture Product Using In Situ Measurements. *Journal of Hydrometeorology*, 18(10), 2621–2645. <http://doi.org/10.1175/JHM-D-17-0063.1>

Reichle, R. H., G. J. De Lannoy, Q. Liu, R. D. Koster, J. S. Kimball, W. T. Crow, et al. (2017b). Global Assessment of the SMAP Level-4 Surface and Root-Zone Soil Moisture Product Using Assimilation Diagnostics. *Journal of Hydrometeorology*, 18(12): 3217–3237. <http://doi.org/10.1175/JHM-D-17-0130.1>

Reichle, R. H., Q. Liu, R. D. Koster, W. T. Crow, G. J. M. De Lannoy, J. S. Kimball, et al. (2019). Version 4 of the SMAP Level - 4 Soil Moisture Algorithm and Data Product. *Journal of Advances in Modeling Earth Systems*, 11(10), 3106–3130. <http://doi.org/10.1029/2019MS001729>

Reichle, R. H., Q. Liu, J. V. Ardizzone, W. T. Crow, G. J. M. De Lannoy, J. Dong, ... R. D. Koster (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. <http://doi.org/10.1175/JHM-D-20-0217.1>

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. (see [PDF](#))

Reichle, R., R. A. Lucchesi, J. V. Ardizzone, G. Kim, E. B. Smith, and B. H. Weiss (2022). SMAP Mission Level 4 Surface and Root Zone Soil Moisture (L4_SM) Product Specification Document. GMAO Office Note No. 10 (Version 1.6), NASA Goddard Space Flight Center, Greenbelt, MD, USA, 84 pp. (see [PDF](#))

Reichle, R. H., Q. Liu, J. V. Ardizzone, W. T. Crow, G. J. M. De Lannoy, J. S. Kimball, and R. D. Koster (2023a). IMERG Precipitation Improves the SMAP Level-4 Soil Moisture Product, *Journal of Hydrometeorology*, 24, 1699-1723. <https://doi.org/10.1175/JHM-D-23-0063.1>.

Reichle, R. H., Q. Liu, J. V. Ardizzone, M. Bechtold, W. T. Crow, G. J. M. De Lannoy, J. S. Kimball and R. D. Koster (2023b). Soil Moisture Active Passive (SMAP) Project Assessment Report for Version 7 of the L4_SM Data Product. NASA/TM-2023-104606, Vol. 64, National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland, USA, 91 pp. (see [PDF](#))

8 DOCUMENT INFORMATION

8.1 Publication Date

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8.2 Date Last Updated

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