SMAP L4 9 km EASE-Grid Surface and Root Zone Soil Moisture Land Model Constants, Version 3: 3-hourly Analysis Update, 3-hourly Geographical Data, and Land Model Constraints

USER GUIDE

How to Cite These Data

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

Reichle, R., G. De Lannoy, R. D. Koster, W. T. Crow, and J. S. Kimball. 2017. *SMAP L4 9 km EASE-Grid Surface and Root Zone Soil Moisture Analysis Update, Version 3*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: https://doi.org/10.5067/20ULJH6EZKFJ. [Date Accessed].

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Reichle, R., G. De Lannoy, R. D. Koster, W. T. Crow, and J. S. Kimball. 2017. *SMAP L4 9 km EASE-Grid Surface and Root Zone Soil Moisture Land Model Constants, Version 3*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/SPL4SMAU (or SPL4SMGP or SPL4SMLM)

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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 Analysis Update

SMAP L4 Global 3-hourly 9 km EASE-Grid Surface and Root Zone Soil Moisture Geophysical Data

SMAP L4 Global 9 km EASE-Grid Surface and Root Zone Soil Moisture Land Model Constants

1 DATA DESCRIPTION

1.1 Parameters

SMAP Level-4 soil moisture 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, evaporative fraction, 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). (Reichle et al. 2015a)

Refer to the Product Specification Document for details on all parameters. Parameters are further described in the Algorithm Theoretical Basis Document (ATBD) for this product.

1.2 File Contents

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

- Geophysical Data
- Analysis Update Data
- Land Model Constants

For each 3-hour interval, there are two files: one geophysical (gph) file and one analysis update (aup) file. Land model constants (lmc) are provided in a single file per Science Version. Science Version IDs (such as Vv2010) are included in all file names, and are defined in the File Naming Convention section.

1.2.1 Geophysical Data

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. Figure 1 shows a subset of the gph file contents.

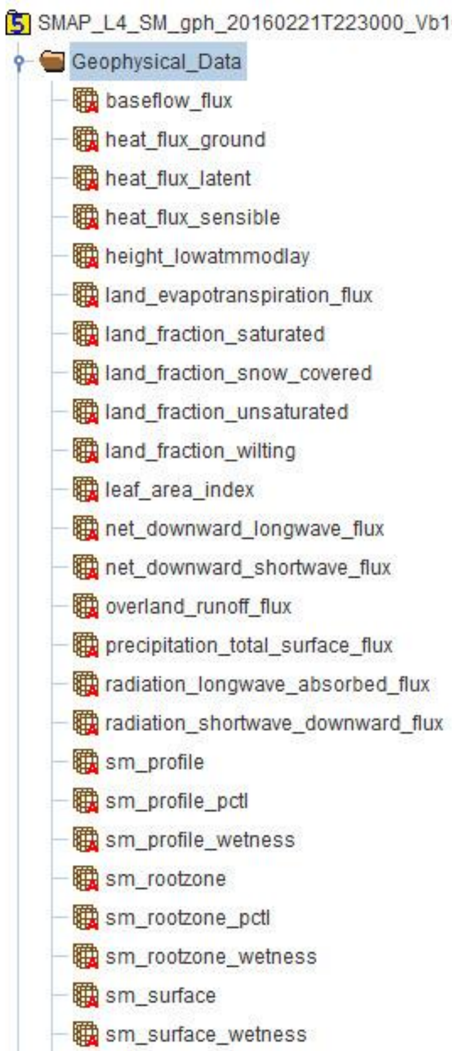

Figure 1. Subset of the Geophysical Data File Contents. For a complete list of file contents for the SMAP Level-4 soil moisture product, refer to the Product Specification Document.

1.2.2 Analysis Update Data

The Analysis Update Data (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 a subset of the aup file contents.

Figure 2. Subset of the Analysis Update Data File Contents. For a complete list of file contents for the SMAP Level-4 soil moisture product, refer to the Product Specification Document.

1.2.3 Land Model Constants

The Land Model Constants (lmc) product includes static land surface model constants that provide further interpretation of the geophysical land surface fields. Figure 3 shows a subset of the lmc file contents.

Figure 3. Subset of the Land Model Constants File Contents. For a complete list of file contents for the SMAP Level-4 soil moisture product, refer to the Product Specification Document.

1.3 Data Fields

Each file contains the main data groups summarized above. For a complete list and description of all data fields within these groups, refer to the Product Specification Document.

Most data element arrays are two dimensional with 1624 rows and 3856 columns.

1.4 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 Product Specification Document.

1.5 Format

Data are in HDF5 format. For software and more information, including an HDF5 tutorial, visit the HDF Group's HDF5 Web site.

1.6 File Naming Convention

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

```
SMAP_L4_SM_pid_yyyymmddThhmmss_VLMmmm_NNN.[ext]
```

For example:

```
SMAP_L4_SM_gph_20151015T133000_Vv2010_001.h5
```

Table 1. File Naming Conventions

<table>
<tr><th>Variable</th><th>Description</th></tr>
<tr><td>SMAP</td><td>Indicates SMAP mission data</td></tr>
<tr><td>L4_SM</td><td>Indicates specific product (L4: Level-4; SM: Soil Moisture)</td></tr>
<tr><td>pid</td><td>Product ID (PID), where:
<table>
<tr><th>Variable</th><th>Description of Data</th><th>Description of Date/Time for Product</th></tr>
<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></td></tr>
</table>

<table>
<tr><th>Variable</th><th>Description</th></tr>
<tr><td>yyyymmddThhmmss</td><td>Date/time in Universal Coordinated Time (UTC) of the data file, where:
<table>
<tr><td>yyyymmdd</td><td>4-digit year, 2-digit month, 2-digit day</td></tr>
<tr><td>T</td><td>Time (delineates the date from the time, i.e. yyyymmddThhmmss)</td></tr>
<tr><td>hhmmss</td><td>2-digit hour, 2-digit minute, 2-digit second</td></tr>
</table></td></tr>
<tr><td>VLMmmm</td><td>Science Version ID, where:
<table>
<tr><th>Variable</th><th>Description</th></tr>
<tr><td>V</td><td>Version (Not a variable; leading character will always be V)</td></tr>
<tr><td>L</td><td>Launch Indicator (v: Validated Data)</td></tr>
<tr><td>M</td><td>1-Digit Major Version Number</td></tr>
<tr><td>mmm</td><td>3-Digit Minor Version Number</td></tr>
</table>
Example: Vv2010 indicates a Validated-quality product with a version of 2.010. Refer to the SMAP Data Versions page for version information.</td></tr>
<tr><td>NNN</td><td>Product counter indicating the number of times the file was generated under the same Science Version ID for a particular date/time interval (002: 2nd time)</td></tr>
<tr><td>.[ext]</td><td>File extensions include:
<table>
<tr><td>.h5</td><td>HDF5 data file</td></tr>
<tr><td>.qa</td><td>Quality Assurance file</td></tr>
<tr><td>.xml</td><td>XML Metadata file</td></tr>
</table></td></tr>
</table>

1.7 File Size and Volume

Table 2 provides file sizes and daily volume estimates for each product.

Table 2. Approximate File Sizes and Total Volume for SMAP L4 Soil Moisture Products

Product	File Size	Total Volume
gph	135 MB	1.2 GB (Daily)
aup	86 MB	1.5 GB (Daily)
lmc	36 MB	36 MB*
* Not a daily product. LMC data are provided in a single file per Science Version.		

1.8 Spatial Coverage

Coverage spans from 180°W to 180°E, and from approximately 85.044°N to 85.044°S. The gap in coverage at both the North and South Pole, called a pole hole, has a radius of approximately 400 km. Coverage is for the global land surface excluding inland water and permanently frozen areas.

1.8.1 Spatial Resolution

The native spatial resolution of the radiometer footprint is approximately 40 km. Data are then assimilated into a land surface model that is gridded using the 9 km global EASE-Grid 2.0 projection.

1.9 Projection and Grid Description

1.9.1 EASE-Grid 2.0

These data are provided on the global cylindrical EASE-Grid 2.0 (Brodzik et al. 2012). Each grid cell has a nominal area of approximately 9 x 9 km2 regardless of longitude and latitude.

EASE-Grid 2.0 has a flexible formulation. By adjusting a single scaling parameter, a family of multi-resolution grids that nest within one another can be generated. The nesting can be adjusted so that smaller grid cells can be tessellated to form larger grid cells. Figure 2 shows a schematic of the nesting to a resolution of 3 km (4872 rows x 11568 columns on global coverage), 9 km (1624 rows x 3856 columns on global coverage) and 36 km (406 rows x 964 columns on global coverage).

This feature of perfect nesting provides SMAP data products with a convenient common projection for both high-resolution radar observations and low-resolution radiometer observations, as well as for their derived geophysical products.

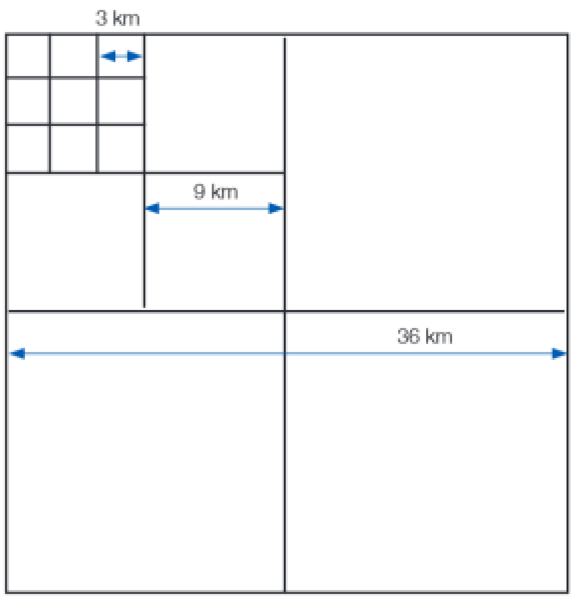

Figure 4. Perfect Nesting in EASE-Grid 2.0

For more on EASE-Grid 2.0, refer to the EASE-Grid 2.0 Format Description.

1.10 Temporal Coverage

Coverage is continuous and spans from 31 March 2015 to present.

1.10.1 Satellite and Processing Events

Due to instrument maneuvers, data downlink anomalies, data quality screening, and other factors, small gaps in the time series of the assimilated SMAP L1C brightness temperature observations (SPL1CTB) will occur. Refer to the SMAP On-Orbit Events List for Instrument Data Users page for details regarding these gaps. The SMAP Level-4 soil moisture products provided during those gaps rely on information from the SMAP observations assimilated prior to each gap, and on information from the land surface model.

1.10.2 Latencies

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

1.11 Temporal 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), and
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 (0z, 3z, ..., and 21z). 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 SOFTWARE AND TOOLS

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

3 DATA ACQUISITION AND PROCESSING

This section has been adapted from Reichle et al. (2014), the ATBD for this product.

3.1 Sensor or Instrument Description

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

3.2 Data Sources

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

- SMAP L1C Radiometer Half-Orbit 36 km EASE-Grid Brightness Temperatures, Version 3 (SPL1CTB)
- GEOS-5 Forward Processing (FP) Model Data from the NASA Global Modeling and Assimilation Office (GMAO): Daily surface meteorology from observation-constrained global model analysis; includes precipitation corrections using the NOAA Climate Prediction Center "Unified" global, 0.5 degree, daily gauge-based data product. (Reichle and Liu, 2014)

In addition, ancillary data sources used as input to calculating the SMAP Level-4 soil moisture products are obtained from the GMAO; these sources are listed in the ATBD. Precipitation observations that are used to correct the GMAO precipitation estimates are obtained from the NOAA Climate Prediction Center (Reichle and Liu, 2014).

3.3 Theory of Measurements

The primary SMAP measurements, land surface microwave emission at 1.41 GHz and radar backscatter at 1.26 GHz and 1.29 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) product 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 SMAP SPL4SM product thus provides 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 product are generated as a by-product of the data assimilation system.

The ATBD for this product provides a detailed description of the SMAP SPL4SM product, its algorithm, and how the product is validated.

3.4 Derivation Techniques and Algorithms

SMAP Level-4 soil moisture products are output from a variety of data sources. Utilizing the baseline data assimilation algorithm discussed below, input data sources are output from the SMAP Level-4 soil moisture model to provide enhanced estimates of surface soil moisture, root zone soil moisture, and related geophysical variables.

3.4.1 Baseline Algorithm

The SPL4SM science algorithm consists of two key processing elements:

1. GEOS-5 Catchment Land Surface and Microwave Radiative Transfer Model
2. GEOS-5 Ensemble-Based Land Data Assimilation Algorithm

The GEOS-5 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). The GEOS-5 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 baseline algorithm, described in detail in the ATBD, includes a soil moisture analysis based on the ensemble Kalman filter and a rule-based freeze/thaw analysis. However, data users should note that for Validated Version 2 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 was sufficiently mature in early 2016 to allow for calibration of the SMAP Level-4 soil moisture algorithm with these inputs in time for the Validated Version 2 release of SMAP Level-4 soil moisture products. Therefore, the decision to use only radiometer inputs (SPL1CTB) was made to ensure homogeneity in the Version 2 SMAP Level-4 soil moisture data record. The SMAP Project is considering the development and generation of a freeze/thaw data product using SMAP passive microwave observations. If an operational freeze/thaw product becomes available, the SMAP Level-4 soil moisture algorithm could be expanded to assimilate it, provided adequate resources are available.

For an in-depth description of the algorithm, refer to Section 4.1.2: Mathematical Description of the Algorithm in the ATBD for this product. For more information on data product accuracy, refer to the Validated Assessment Report from Reichle et al. 2016.

3.5 Processing Steps

SMAP Level-4 soil moisture data are generated by the 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.

SMAP SPL1CTB data are required for the baseline 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. These ancillary data requirements are unique to the SMAP Level-4 products and are described in detail in the ATBD, Section 4.1.3: Ancillary Data Requirements. The precipitation observations used to correct the GMAO precipitation estimates are obtained from the NOAA Climate Prediction Center (Reichle and Liu, 2014).

For more information on each portion of the algorithm processing flow, refer to the ATBD.

3.5.1 SMAP Nature Run

Note that an improved version of the model-only Nature Run (NRv4.1) simulation is used to derive brightness temperature scaling parameters, model soil moisture initial conditions, and the soil moisture climatology for Version 3 of SPL4SM products. For details regarding Nature Run (NRv4.1), refer to the Beta and Validated Reports listed in the Quality Assessment section of this document. Nature Run is the model-only simulation used to derive brightness temperature scaling parameters, model soil moisture initial conditions, and the soil moisture climatology used to generate soil moisture output in percentile units (sm_rootzone_pctl, sm_profile_pctl).

3.6 Error Sources

The data assimilation system weighs the relative errors of the assimilated lower-level product (such as radiance or retrieval) and the land model forecast. Estimates of the error of the assimilation product are dynamically determined as a by-product of this calculation. How useful these error estimates are depends on the accuracy of the input error parameters and needs to be determined through validation; refer to the ATBD, Section 4.2.4. The target accuracy of the assimilated brightness temperatures is discussed in the SPL1CTB product documentation. Error estimates of the land surface model and required input error parameters are discussed in the ATBD for this product.

Each instantaneous land model field is accompanied with a corresponding instantaneous error field which is provided for select variables. The relevant outputs are listed in the Product Specification Document for the SPL4SMAU product. 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 (m^3 m^{-3}). For temperatures, the ensemble standard deviation is provided in units of Kelvin. These error estimates will vary in space and time.

More information about error sources is provided in the ATBD under Section 4.1.2: Mathematical Description of the Algorithm. For more information on data product accuracy, refer to the Validated Assessment Report from Reichle et al. 2016.

3.7 Quality Assessment

For in-depth details regarding the quality of these Version 2 data, refer to the following reports:

Validated Assessment Report

Beta Assessment Report

3.7.1 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 Product Specification Document.

Each HDF5 file contains file-level metadata. A separate metadata file with an .xml file extension is also delivered to NSIDC DAAC with the 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 across the SMAP Level-4 soil moisture products, such as the global minimum, mean, and maximum of each data field.

Level-4 surface and root zone soil moisture estimates are validated to a Root Mean Square Error (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.

3.7.2 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. Note also that 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 Product Specification Document.

4 CONTACTS AND ACKNOWLEDGMENTS

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Brodzik, M. J., B. Billingsley, T. Haran, B. Raup, and M. H. Savoie. 2014. Correction: Brodzik, M. J. et al. EASE-Grid 2.0: Incremental but Significant Improvements for Earth-Gridded Data Sets. *ISPRS Int. J. Geo-Inf 2012*. 1(1):32-45 *ISPRS Int. J. Geo-Inf.* 3(3):1154-1156. http://dx.doi.org/10.3390/ijgi3031154.

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Reichle, R., G. J. M. De Lannoy, Q. Liu, J. V. Ardizzone, F. Chen, A. Colliander, A. Conaty, W. Crow, T. Jackson, J. Kimball, R. D. Koster, and E. Brent Smith. 2016. Soil Moisture Active Passive Mission L4_SM Data Product Assessment (Version 2 Validated Release). GMAO Office Note No. 12 (Version 1.0), 55 pp, NASA Goddard Space Flight Center, Greenbelt, MD, USA. (Reichle851.pdf, 3.2 MB).

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6 DOCUMENT INFORMATION

6.1 Publication Date

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6.2 Date Last Updated

18 February 2021