
**ESA Climate Change Initiative Plus - Soil Moisture**

# Product Specification Document (PSD)

## D1.2.1 Version 4.7

11 March 2020

Prepared by

**Earth Observation Data Centre for Water Resources Monitoring (EODC) GmbH**

eodc

in cooperation with

**TU Wien, VanderSat, CESBIO, ETH Zürich**

TU WIEN GEO

CESBIO

ETH zürich

This document forms the deliverable D1.2.1 Product Specification Document (PSD) and was compiled for the ESA Climate Change Initiative Plus Soil Moisture Project (ESRIN Contract No: 4000126684/19/I-NB contract subject "ESA CCI+ Phase 1 New R&D on CCI ECVS Soil Moisture"). For more information on the CCI programme of the European Space Agency (ESA) see http://www.esa-cci.org/.

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|---|---|
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**Document Change Record:** For any clarifications please contact Wouter Dorigo. (Wouter.Dorigo@geo.tuwien.ac.at).

## Project Partners

| | |
| --- | --- |
| **Prime Contractor and project management** | **EODC,** Earth Observation Data Centre for Water Resources Monitoring (Austria) |
| **Earth Observation Partners** | **TU Wien**, Vienna University of Technology (Austria)<br>**VanderSat**, The Netherlands<br>**CESBIO**, France |
| **Climate Research Partners** | **ETH**, Institute for Atmospheric and Climate Science, (Switzerland) |

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## Definitions, acronyms and abbreviations

| | |
| --- | --- |
| **AMI-WS** | Active Microwave Instrument – Windscat (ERS 1 and ERS 2) |
| **AMSR2** | Advanced Microwave Scanning Radiometer 2 |
| **AMSR-E** | Advanced Microwave Scanning Radiometer-Earth Observing System |
| **ASCAT** | Advanced Scatterometer (Metop) |
| **ATBD** | Algorithm Theoretical Basis Document |
| **CCI** | Climate Change Initiative |
| **CDF** | Cumulative Distribution Function |
| **CECR** | Comprehensive Error Characterization Report |
| **CF** | Climate Forecast |
| **DGG** | Discrete Global Grid |
| **ECMWF** | European Centre for Medium Range Weather Forecasting |
| **ECV** | Essential Climate Variable |
| **ERA-40** | ECMWF ReAnalysis 40 data set |
| **ESA** | European Space Agency |
| **FAO** | Food and Agriculture Organization of the United Nations |
| **GCMD** | Global Change Master Directory (NASA) |
| **GLDAS** | Global Land Data Assimilation System |
| **GLWD** | Global Lakes and Wetlands Database |
| **GRIB** | Grided Binary format |
| **GSFC** | Goddard Space Flight Center (NASA) |
| **HDF** | Hierarchical Data Format |
| **IIASA** | Interational Institute for Applied Systems Analysis |
| **ISSCAS** | Chinese Academy of Sciences |
| **ISRIC** | International Soil Reference and Information Centre (World Soil Information) |
| **JRC** | Joint Research Centre of the European Commission |
| **LPRM** | Land Parameter Retrieval model |
| **NaN** | Not A Number |
| **NASA** | National Aeronautics and Space Administration |
| **NetCDF** | Network Common Data Form |
| **PSD** | Product Specification Document |
| **PVP** | Product Validation Plan |
| **SM** | Soil Moisture |
| **SSMV** | Surface Soil Moisture Volumetric |
| **SMMR** | Scanning Multichannel Microwave Radiometer |
| **SMOS** | Soil Moisture and Ocean Salinity |

| | |
|---|---|
| **SNR** | Signal to noise ratio |
| **SSM/I** | Special Sensor Microwave Imager |
| **TC** | Triple Collocation |
| **TMI** | TRMM Microwave Imager |
| **USGS** | United States Geological Survey |
| **UTC** | Coordinated Universal Time |
| **VOD** | Vegetation Optical Depth |
| **VUA** | Vrije Universiteit Amsterdam |
| **WACMOS** | Water Cycle Multimission Observation Strategy |
| **WARP** | soil Water Retrieval Package |
| **WindSat** | WindSat Spaceborne Polarimetric Microwave Radiometer |

## *Processing Levels*[1]

*Table 1 Processing Level Codes for Remotely Sensed Data Sets*

| **Level** | **<ProcessingLevel> Code** | **Description** | **Based on Source** |
|---|---|---|---|
| **Level 0** | L0 | Unprocessed instrument and payload data at full resolution. | GHRSST |
| **Level 1A** | L1A | Reconstructed unprocessed instrument data at full resolution, time referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters, computed and appended, but not applied, to L0 data. | GHRSST |
| **Level 1B** | L1B | Level 1A data that have been processed to sensor units. | GHRSST |
| **Level 1C** | L1C | Level 1B data that have been further processed, e.g. by correcting radiances or by mapping onto a spatial grid, prior to deriving geophysical variables from the data. | SMOS data products definition |
| **Level 2** | L2 | Retrieved environmental variables at the same resolution and location as the Level 1 source. | CEOS handbook[2] |
| **Level 2Pre-processed** | L2P | Geophysical variables derived from Level 1 source data at the same resolution and location as the Level 1 data, typically in a satellite projection with geographic information.These data form the fundamental basis for higher-level CCI products. | GHRSST |
| **Level 3** | L3 | Level 2 variables mapped on a defined grid with reduced requirements for ancillary data. Three types of L3 products are defined: | GHRSST |
| | L3U | Uncollated (L3U): L2 data granules remapped to a space grid without combining any observations from overlapping orbits. | |
| | L3C | Collated (L3C): Observations combined from a single instrument into a space-time grid. | |
| | L3S | Super-collated(L3S): observations combined from multiple instruments into a space-time grid. | |
| **Level 4** | L4 | Data sets created from the analysis of lower level data that result in gridded, gap-free products. | GHRSST |

[1] Extracted from [RD-4]
[2] http://wiki.ieee-earth.org/@api/deki/files/7/=Handbook_0802.pdf

# 1 Introduction

The document provides technical support to the ESA CCI Soil Moisture dataset (product version 04.7). The document provides the technical specifications relating to the formating and content of the soil moisture product data files. The ESA CCI SM v04.7 product consists of three surface soil moisture data sets: The "ACTIVE Product" and the "PASSIVE Product" were created by using scatterometer and radiometer soil moisture products, respectively; The "COMBINED Product" is a blended product based on both scatterometer and radiometer products. Data files are provided as NetCDF-4 classic format and comprise global merged surface soil moisture datasets at daily temporal resolution. The data set spans 40 years covering the period from November 1978 to December 2019.

The theoretical and algorithmic base of the product is described in [RD-1], and reported by (Wagner et al. 2012). The SNR (signal-to-noise-ratio) merging algorithm introduced for the first time in version 4.0 of this product is described in (Gruber et al. 2017) and Gruber et al. (2019). An overview of all known errors of the soil moisture datasets is provided in [RD-2] and in (Dorigo et al. 2017). Further documentation relating to the product, and reference documents are provided in Section 2.2 and can be found on the CCI Soil Moisture project web site (http://www.esa-soilmoisture-cci.org).

The location and full access details to the product are provided to users after completion and verification of a user registration form. Users can register to access the product from the User Registration form on the CCI Soil Moisture website[3], as noted in Section 5.1.

The product is provided in a format that currently complies with the minimum standard format requirements as detailed by the CCI data standards working group (DSWG) [RD-4]. For this reason ESA CCI SM v04.7 is provided in NetCDF-4 classic format and is also compliant with the NetCDF Climate and Forecasting group best practice[4] [RD-5].

## 1.1 Purpose of the document

This Product Specification Document (PSD) relates to the ESA CCI Surface Soil Moisture (SM) product version 04.7.

The document provides the specific definition of the following:

- geophysical parameters provided
- structure and format of the product
- annotation data sets

[3]http://www.esa-soilmoisture-cci.org/dataregistration
[4]http://cf-pcmdi.llnl.gov/documents/cf-conventions/latest-cf-conventions-document-1

- quality flags / indicators
- product grid and projection
- ancillary data used

The document further clarifies data usage restrictions, and provides full data citation to be used in all reporting on product usage.

The product specifications provided in this document will be the base specification for all future ESA CCI SM product versions, noting the product specification will be expected to evolve following the good practices resulting from the CCI data standards working group (DSWG).

### 1.2 Targeted audience

This document targets the following audience

- Users of the ESA CCI SM data product
- System Engineers for the ESA CCI SM product
- Other CCI ECV projects

## 2 Documents

### 2.1 Applicable documents

The documents outlined here detail the scope and focus for the work that is reported in this document.

[AD-1] ESA Climate Change Initiative Plus Soil Moisture Project (ESRIN Contract No: 4000126684/19/I-NB contract subject ”ESA CCI+ Phase 1 New R&D on CCI ECVS Soil Moisture”).

[AD-2] ESA Climate Change Initiative Plus, Statement of Work, European Space Agency, ESA_CCI-EOPS-PRGM-SOW-18-0118.

[AD-3] Technical Proposal (Part 3) in response to ESA Climate Change Initiative Plus AO/1-9322.18/I-NB , Vienna University of Technology.

### 2.2 Reference documents

This section provides a list of reference documents upon which this document is either based, or are required to be referenced by the reader in order to obtain the full information intended by the authors.

[RD-1] ATBD, Algorithm Theoretical Baseline Document, D2.1 Version 04.7, 20 February 2020. ESA Climate Change Initiative Plus Soil Moisture Project, http://www.esa-soilmoisture-cci.org

[RD-2] CECR, Comprehensive Error Characterisation Report, Version 0.6, 21 April 2015, ESA Climate Change Initiative Phase 2 Soil Moisture Project, http://www.esa-soilmoisture-cci.org/sites/default/files/documents/public/Deliverables/CCI2_Soil_Moisture_D2.2.0_CECR_v0.6.pdf

[RD-3] PVP, Product Validation Plan, Version 1.1, 30th August 2012, ESA Climate Change Initiative Phase 1 Soil Moisture Project, http://www.esa-soilmoisture-cci.org/sites/default/files/documents/public/Deliverables/20120830_CCI_Soil_Moisture_D2.1_PVP_v.1.1.pdf

[RD-4] ESA, Guidelines for Data Producers - Climate Change Initiative Phase 1, CCI-PRGM-EOPS-TN-13-0009, Issue 1, Revision 1, Victoria Bennett and Sarah James, 24/05/2013

[RD-5] NetCDF Climate and Forecast (CF) Metadata Conventions: Version 1.6, 5 December, 2011, Brian Eaton, Jonathan Gregory, Bob Drach, Karl Taylor, and Steve Hankin

### 2.3 Bibliography

A complete bibliographic list, detailing scientific text or publications that support arguments or statements made within the current document is provided in Section 7.

## 3 Specification of the products

### 3.1 Geophysical Parameters

The ACTIVE product is the output of merging scatterometer-based soil moisture data, which were derived from AMI-WS and ASCAT (Metop-A and Metop-B). The PASSIVE product merges data from SMMR, SSM/I, TMI, AMSR-E, WindSat, AMSR2, and SMOS. The COMBINED product merges all these 10 active and passive data sets. . The merging algorithm of the here described product version v04.7 is a temporal extension of the dataset based on the algorithm v04.4, which is described in detail in (Gruber et al. 2017; see also Dorigo et al. 2017; Liu et al. 2012; Liu et al. 2011; Wagner 2012).The homogenized and merged products present surface soil moisture with a global coverage and a spatial resolution of 0.25°, and a temporal resolution of 1 day with a reference time at 0:00 UTC. The soil moisture data for the PASSIVE and the

COMBINED product are provided in volumetric units [$m^3m^{-3}$], while the ACTIVE soil moisture data are expressed in percent of saturation [%].

## 3.2 Product Data Volume

The ESA CCI SM product version 04.7 is provided as global daily images, in NetCDF-4 classic file format and covers the period (yyyy-mm-dd) 1978-11-01 to 2019-12-31 for the PASSIVE and COMBINED products. The ACTIVE product covers the period from 1991-08-05 to 2019-12-31. Table 2 gives an overview of all three products.

*Table 2 Temporal coverage and volume size of the products.*

| Product | Coverage dates | Number of files (days) | Volume size |
|---|---|---|---|
| ACTIVE | 19910805 – 20191231 | 10376 | 7.78 GB |
| PASSIVE | 19781101 – 20191231 | 15036 | 11.50 GB |
| COMBINED | 19781101 – 20191231 | 15036 | 14.10 GB |
| Total | N/A | 40448 | 33.50 GB |

## 3.3 Structure and format of the product

### *3.3.1 Data file format and file naming*

The file format used for storing the data is NetCDF-4 classic. All (NetCDF) files follow the NetCDF Climate and Forecast (CF) Metadata Conventions version 1.6. The NetCDF soil moisture data files are stored in folders for each year with one file per day. The following file naming convention, based on available CCI ECV standards [RD-4], form 2, is applied:

```
ESACCI-<CCI Project>-<Processing Level>-<Data Type>-<Product String>[-<Additional
Segregator>]-<Indicative Date>[<Indicative Time>]-fv<File version>.nc
```

**<CCI Project>**

Following the filenameing convention of CCI data standards working group (DSWG) [RD-4] the name of this project is SOILMOISTURE.

**<Processing Level>**

The processing level for the ESA CCI SM products is "**L3S"** (super-collated), where observations from multiple instruments are combined into a space-time grid.

**<Data Type>**

The data type for the ACTIVE product is "**SSMS"** (surface soil moisture degree of saturation absolute), and for the PASSIVE and COMBINED product it is "**SSMV"** (surface soil moisture volumetric absolute).

**<Product String>**

The product string for the ACTIVE product is defined as "**ACTIVE**", for the PASSIVE product it is "**PASSIVE**", and "**COMBINED**" for the COMBINED product.

**<Additional Segregator>**

Additional segregator not used and not defined.

**<Indicative date and time>**

This field indicates the date and time for soil moisture data that are stored in the NetCDF file. The format is YYYYMMDDHHmmSS, where YYYY is the four digit year, MM is the two digit month form 01 to 12, DD is the two digit day of the month from 01 to 31, HH the two digit hour from 00 to 23, mm the two digit minute from 00 to 59, and SS the two digit second from 00 to 59. All times relate to UTC.

**fv<file version>**

The file version number in form xy.z provides information relating the version of the file format that has been used to provide the product. In the global NetCDF header of each data file the product version number specifies the version of the current product. Since product version 02.1 the file version and the product version number are the same.

### *3.3.2 NetCDF file structure*

#### *3.3.2.1 Global NetCDF Attributes*

The Global NetCDF attributes are described in Table 3 for the ACTIVE, Table 4 for the PASSIVE, and Table 5 for the COMBINED product. The Global Attributes are provided for two reasons. The attributes "**title**" and "**product version**" provide the minimum usage information about

the data, whilst the remaining attributes starting with the "**summary**" attribute provide product discovery metadata for harvesting into catalogues and data federations. Because the global NetCDF attributes slightly differ between each of the three products in some points, we present the complete list of attributes.

In general, the Global Attributes will be static and not vary between files for the same file version containing the same product version, with the exception of those attributes whose content is noted by a variable; denoted as <variable>. Explicitly the following attributes will vary for every file within a product: "**history**" (updating creation date), "**tracking id**", "**filename**" and "**date created**", and between the three products, in addition to the latter, "**title**" (product title), "**source**", "**time_coverage_start**", "**time_coverage_duration**", "**platform**", and "**sensor.**"

*Table 3 Global NetCDF Attributes for the ACTIVE product*

| Global Attribute Name | Content |
|---|---|
| title | ESA CCI Surface Soil Moisture merged ACTIVE Product |
| institution | Technische Universität Wien (AUT), Transmissivity B.V. / VanderSat B.V. Noordwijk (NL) |
| contact | cci_sm_contact@eodc.eu |
| source | WARP 5.5R1.1/AMI-WS/ERS12 Level 2 Soil Moisture; WARP 5.4R1.0/AMI-WS/ERS2 Level 2 Soil Moisture; H115: Metop ASCAT Surface Soil Moisture Climate Data Record v5 12.5 km sampling, DOI: 10.15770/EUM_SAF_H_0006; H116: Metop ASCAT Surface Soil Moisture Climate Data Record v5 Extension 12.5 km sampling; Metop ASCAT Surface Soil Moisture Climate Data Record v5 12.5 km sampling, DOI: 10.15770/EUM_SAF_H_0006; H116: Metop ASCAT Surface Soil Moisture Climate Data Record v5 Extension 12.5 km sampling. |
| platform | ERS-1, ERS-2, METOP-A, Metop-B |
| sensor | AMI-WS, ASCAT-A, ASCAT-B |
| references | http://www.esa-soilmoisture-cci.org<br>Liu, Y.Y., Dorigo, W.A., Parinussa, R.M., de Jeu, R.A.M. , Wagner, W., McCabe, M.F., Evans, J.P., van Dijk, A.I.J.M. (2012). Trend-preserving blending of passive and active microwave soil moisture retrievals, Remote Sensing of Environment, 123, 280-297, doi: 10.1016/j.rse.2012.03.014.<br>Liu, Y.Y., Parinussa, R.M., Dorigo, W.A., De Jeu, R.A.M., Wagner, W., van Dijk, A.I.J.M., McCabe, M.F., & Evans, J.P. (2011). Developing an improved soil moisture |

| Global Attribute Name | Content |
|---|---|
| | dataset by blending passive and active microwave satellite based retrievals. Hydrology and Earth System Sciences, 15, 425-436.<br><br>Wagner, W., W. Dorigo, R. de Jeu, D. Fernandez, J. Benveniste, E. Haas, M. Ertl (2012). Fusion of active and passive microwave observations to create an Essential Climate Variable data record on soil moisture. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume I-7, 2012. XXII ISPRS Congress, 25 August - 01 September 2012, Melbourne, Australia.<br><br>Gruber, A., Dorigo, W. Crow, W., & Wagner, W. (2017). Triple collocation-based merging of satellite soil moisture retrievals. IEEE Transactions on Geoscience and Remote Sensing, 1-13.<br><br>Dorigo, W.A., Wagner, W., Albergel, C., Albrecht, F., Balsamo, G., Brocca, L., Chung, D., Ertl, M., Forkel, M., Gruber, A., Haas, E., Hamer, P. D., Hirschi, M., Ikonen, J., de Jeu, R., Kidd, R., Lahoz, W., Liu, Y. Y.,Miralles, D., Mistelbauer, T., Nicolai-Shaw, N., Parinussa, R., Pratola, C., Reimer, C., van der Schalie, R., Seneviratne, S. I. Smolander, T., Lecomte, P. (2017). ESA CCI Soil Moisture for improved Earth system understanding: State-of-the art and future directions, Remote Sensing of Environment. https://doi.org/10.1016/j.rse.2017.07.001. |
| product_version | 04.7 |
| id | <filename> |
| tracking_id | <xxxxxxxx-yyyy-zzzz-nnnn-mmmmmmmmmmmm> a UUID (Universal Unique Identifier) value |
| conventions | CF-1.6 |
| standard_name_vocabulary | NetCDF Climate and Forecast (CF) Metadata Convention |
| summary | The data set was produced with funding of the ESA CCI Soil Moisture and FP7-Earth2Observe projects. |
| keywords | Soil Moisture/Water Content |
| naming_authority | TU Wien |
| keywords_vocabulary | NASA Global Change Master Directory (GCMD) Science Keywords |
| cdm_data_type | Grid |
| comment | These data were produced as part of the ESA CCI Soil Moisture and FP7-Earth2Observe projects. Contract No. 4000112226/14/I-NB and GA No. 603608. |
| history | 2020-01-20 12:00:00 - product produced |

| Global Attribute Name | Content |
|---|---|
| date_created | <file creation date> |
| creator_name | Department of Geodesy and Geoinformation, Technische Universität Wien (TU Wien) |
| creator_url | http://rs.geo.tuwien.ac.at |
| creator_email | cci_sm_developer@eodc.eu |
| project | Climate Change Initiative – European Space Agency |
| license | data use is free and open for all registered users |
| time_coverage_start | 19910805T000000Z |
| time_coverage_ed | 20191231T235959Z |
| time_coverage_duration | P28Y |
| time_coverage_resolution | P1D |
| geospatial_lat_min | -90.0 |
| geospatial_lat_max | 90.0 |
| geospatial_lon_min | -180.0 |
| geospatial_lon_max | 180.0 |
| geospatial_vertical_min | 0.0 |
| geospatial_vertical_max | 0.0 |
| geospatial_lat_units | degrees_north |
| geospatial_lon_units | degrees_east |
| geospatial_lat_resolution | 0.25 degree |
| geospatial_lon_resolution | 0.25 degree |
| spatial_resolution | 25km |

*Table 4 Global NetCDF Attributes for the PASSIVE product*

| Global Attribute Name | Content |
|---|---|
| title | ESA CCI Surface Soil Moisture merged PASSIVE Product |
| institution | Technische Universität Wien (AUT), Transmissivity B.V. / VanderSat B.V. Noordwijk (NL) |
| contact | cci_sm_contact@eodc.eu |
| source | LPRMv06/SMMR/Nimbus 7 L3 Surface Soil Moisture, Ancillary Params, and quality flags; LPRMv05/SSMI/F08, F11, F13 DMSP L3 Surface Soil Moisture, Ancillary Params, and quality flags; LPRMv06/TMI/TRMM L2 Surface Soil Moisture, Ancillary Params, and QC; LPRMv06/AMSR-E/Aqua L2B Surface Soil Moisture, Ancillary Params, and QC; LPRMv06/WINDSAT/CORIOLIS L2 Surface Soil Moisture, Ancillary Params, and QC; LPRMv06/AMSR2/GCOM-W1 L3 Surface Soil Moisture, Ancillary Params; LPRMv06/SMOS/MIRAS L3 Surface Soil Moisture, CATDS Level 3 Brightness Temperatures (L3TB) version 300 RE03 & RE04 |
| platform | Nimbus 7, DMSP, TRMM, AQUA, Coriolis, GCOM-W1, MIRAS |
| sensor | SMMR, SSM/I, TMI, AMSR-E, WindSat, AMSR2, SMOS |
| references | http://www.esa-soilmoisture-cci.org<br><br>Liu, Y.Y., Dorigo, W.A., Parinussa, R.M., de Jeu, R.A.M. , Wagner, W., McCabe, M.F., Evans, J.P., van Dijk, A.I.J.M. (2012). Trend-preserving blending of passive and active microwave soil moisture retrievals, Remote Sensing of Environment, 123, 280-297, doi: 10.1016/j.rse.2012.03.014.<br><br>Liu, Y.Y., Parinussa, R.M., Dorigo, W.A., De Jeu, R.A.M., Wagner, W., van Dijk, A.I.J.M., McCabe, M.F., & Evans, J.P. (2011). Developing an improved soil moisture dataset by blending passive and active microwave satellite based retrievals. Hydrology and Earth System Sciences, 15, 425-436.<br><br>Wagner, W., W. Dorigo, R. de Jeu, D. Fernandez, J. Benveniste, E. Haas, M. Ertl (2012). Fusion of active and passive microwave observations to create an Essential Climate Variable data record on soil moisture. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume I-7, 2012. XXII ISPRS Congress, 25 August - 01 September 2012, Melbourne, Australia.<br><br>Gruber, A., Dorigo, W. Crow, W., & Wagner, W. (2017). Triple collocation-based merging of satellite soil moisture retrievals. IEEE Transactions on Geoscience and Remote Sensing, 1-13. |

| Global Attribute Name | Content |
|---|---|
| | Dorigo, W.A., Wagner, W., Albergel, C., Albrecht, F., Balsamo, G., Brocca, L., Chung, D., Ertl, M., Forkel, M., Gruber, A., Haas, E., Hamer, P. D., Hirschi, M., Ikonen, J., de Jeu, R., Kidd, R., Lahoz, W., Liu, Y. Y.,Miralles, D., Mistelbauer, T., Nicolai-Shaw, N., Parinussa, R., Pratola, C., Reimer, C., van der Schalie, R., Seneviratne, S. I. Smolander, T., Lecomte, P. (2017). ESA CCI Soil Moisture for improved Earth system understanding: State-of-the art and future directions, Remote Sensing of Environment. https://doi.org/10.1016/j.rse.2017.07.001. |
| product_version | 04.7 |
| id | <filename> |
| tracking_id | <xxxxxxxx-yyyy-zzzz-nnnn-mmmmmmmmmmmm> a UUID (Universal Unique Identifier) value |
| conventions | CF-1.6 |
| standard_name_vocabulary | NetCDF Climate and Forecast (CF) Metadata Convention |
| summary | These data were produced as part of the ESA CCI Soil Moisture and FP7-Earth2Observe projects. |
| keywords | Soil Moisture/Water Content |
| naming_authority | TU Wien |
| keywords_vocabulary | NASA Global Change Master Directory (GCMD) Science Keywords |
| cdm_data_type | Grid |
| comment | These data were produced as part of the ESA CCI Soil Moisture and FP7-Earth2Observe projects. Contract No. 4000112226/14/I-NB and GA No. 603608. |
| history | 2020-01-20 12:00:00 - product produced |
| date_created | <file creation date> |
| creator_name | Department of Geodesy and Geoinformation, Technische Universität Wien (TU Wien) |
| creator_url | http://rs.geo.tuwien.ac.at |
| creator_email | cci_sm_developer@eodc.eu |
| project | Climate Change Initiative – European Space Agency |
| license | data use is free and open for all registered users |
| time_coverage_start | 19781101T000000Z |

| Global Attribute Name | Content |
|---|---|
| time_coverage_end | 20191231T235959Z |
| time_coverage_duration | P41Y |
| time_coverage_resolution | P1D |
| geospatial_lat_min | -90.0 |
| geospatial_lat_max | 90.0 |
| geospatial_lon_min | -180.0 |
| geospatial_lon_max | 180.0 |
| geospatial_vertical_min | 0.0 |
| geospatial_vertical_max | 0.0 |
| geospatial_lat_units | degrees_north |
| geospatial_lon_units | degrees_east |
| geospatial_lat_resolution | 0.25 degree |
| geospatial_lon_resolution | 0.25 degree |
| spatial_resolution | 25km |

*Table 5 Global NetCDF Attributes for the COMBINED product*

| Global Attribute Name | Content |
|---|---|
| Title | ESA CCI Surface Soil Moisture COMBINED active+passive Product |
| institution | Technische Universität Wien (AUT), Transmissivity B.V. / VanderSat B.V. Noordwijk (NL) |
| contact | cci_sm_contact@eodc.eu |
| source | WARP 5.5R1.1/AMI-WS/ERS12 Level 2 Soil Moisture; WARP 5.4R1.0/AMI-WS/ERS2 Level 2 Soil Moisture; H115: Metop ASCAT Surface Soil Moisture Climate Data Record v5 12.5 km sampling, DOI: 10.15770/EUM_SAF_H_0006; H116: Metop ASCAT Surface Soil Moisture Climate Data Record v5 Extension 12.5 km sampling; H115: Metop ASCAT Surface Soil Moisture Climate Data Record v5 12.5 km sampling, DOI: 10.15770/EUM_SAF_H_0006; H116: Metop ASCAT Surface Soil Moisture Climate Data Record v5 Extension 12.5 km sampling; LPRMv06/SMMR/Nimbus 7 L3 Surface Soil Moisture, Ancillary Params, and quality flags; LPRMv05/SSMI/F08, F11, F13 DMSP L3 Surface Soil Moisture, Ancillary |

| Global Attribute Name | Content |
|---|---|
| | Params, and quality flags; LPRMv06/TMI/TRMM L2 Surface Soil Moisture, Ancillary Params, and QC; LPRMv06/AMSR-E/Aqua L2B Surface Soil Moisture, Ancillary Params, and QC; LPRMv06/WINDSAT/CORIOLIS L2 Surface Soil Moisture, Ancillary Params, and QC; LPRMv06/AMSR2/GCOM-W1 L3 Surface Soil Moisture, Ancillary Params; LPRMv06/SMOS/MIRAS L3 Surface Soil Moisture, CATDS Level 3 Brightness Temperatures (L3TB) version 300 RE03 & RE04 |
| platform | Nimbus 7, DMSP, TRMM, AQUA, Coriolis, GCOM-W1, MIRAS; ERS-1, ERS-2, METOP-A, METOP-B |
| sensor | SMMR, SSM/I, TMI, AMSR-E, WindSat, AMSR2, SMOS; AMI-WS, ASCAT-A, ASCAT-B |
| references | http://www.esa-soilmoisture-cci.org<br><br>Liu, Y.Y., Dorigo, W.A., Parinussa, R.M., de Jeu, R.A.M. , Wagner, W., McCabe, M.F., Evans, J.P., van Dijk, A.I.J.M. (2012). Trend-preserving blending of passive and active microwave soil moisture retrievals, Remote Sensing of Environment, 123, 280-297, doi: 10.1016/j.rse.2012.03.014.<br><br>Liu, Y.Y., Parinussa, R.M., Dorigo, W.A., De Jeu, R.A.M., Wagner, W., van Dijk, A.I.J.M., McCabe, M.F., & Evans, J.P. (2011). Developing an improved soil moisture dataset by blending passive and active microwave satellite based retrievals. Hydrology and Earth System Sciences, 15, 425-436.<br><br>Wagner, W., W. Dorigo, R. de Jeu, D. Fernandez, J. Benveniste, E. Haas, M. Ertl (2012). Fusion of active and passive microwave observations to create an Essential Climate Variable data record on soil moisture. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume I-7, 2012. XXII ISPRS Congress, 25 August - 01 September 2012, Melbourne, Australia.<br><br>Gruber, A., Dorigo, W. Crow, W., & Wagner, W. (2017). Triple collocation-based merging of satellite soil moisture retrievals. IEEE Transactions on Geoscience and Remote Sensing, 1-13.<br><br>Dorigo, W.A., Wagner, W., Albergel, C., Albrecht, F., Balsamo, G., Brocca, L., Chung, D., Ertl, M., Forkel, M., Gruber, A., Haas, E., Hamer, P. D., Hirschi, M., Ikonen, J., de Jeu, R., Kidd, R., Lahoz, W., Liu, Y. Y.,Miralles, D., Mistelbauer, T., Nicolai-Shaw, N., Parinussa, R., Pratola, C., Reimer, C., van der Schalie, R., Seneviratne, S. I. Smolander, T., Lecomte, P. (2017). ESA CCI Soil Moisture for improved Earth system understanding: State-of-the art and future directions, Remote Sensing of Environment. https://doi.org/10.1016/j.rse.2017.07.001. |

| Global Attribute Name | Content |
|---|---|
| product_version | 04.7 |
| id | <filename> |
| tracking_id | <xxxxxxxx-yyyy-zzzz-nnnn-mmmmmmmmmmmm> a UUID (Universal Unique Identifier) value |
| conventions | CF-1.6 |
| standard_name_vocabulary | NetCDF Climate and Forecast (CF) Metadata Convention |
| summary | These data were produced as part of the ESA CCI Soil Moisture and FP7-Earth2Observe projects. |
| keywords | Soil Moisture/Water Content |
| naming_authority | TU Wien |
| keywords_vocabulary | NASA Global Change Master Directory (GCMD) Science Keywords |
| cdm_data_type | Grid |
| comment | These data were produced as part of the ESA CCI Soil Moisture and FP7-Earth2Observe projects. Contract No. 4000112226/14/I-NB and GA No. 603608. |
| history | 2020-01-20 12:00:00 - product produced |
| date_created | <file creation date> |
| creator_name | Department of Geodesy and Geoinformation Technische Universität Wien (TU Wien) |
| creator_url | http://rs.geo.tuwien.ac.at |
| creator_email | cci_sm_developer@eodc.eu |
| project | Climate Change Initiative – European Space Agency |
| license | data use is free and open for all registered users |
| time_coverage_start | 19781101T000000Z |
| time_coverage_ed | 20191231T235959Z |
| time_coverage_duration | P41Y |
| time_coverage_resolution | P1D |
| geospatial_lat_min | -90.0 |
| geospatial_lat_max | 90.0 |

| Global Attribute Name | Content |
|---|---|
| geospatial_lon_min | -180.0 |
| geospatial_lon_max | 180.0 |
| geospatial_vertical_min | 0.0 |
| geospatial_vertical_max | 0.0 |
| geospatial_lat_units | degrees_north |
| geospatial_lon_units | degrees_east |
| geospatial_lat_resolution | 0.25 degree |
| geospatial_lon_resolution | 0.25 degree |
| spatial_resolution | 25km |

### *3.3.2.2 NetCDF Data File Variables and Attributes*

**lon**

*Table 6 Attribute Table for Variable lon*

| NetCDF Attribute | Description |
|---|---|
| standard_name | longitude |
| units | degrees_east |
| valid_range | [-180.0, 180.0] |
| _CoordinateAxisType | Lon |

**lat**

*Table 7 Attribute Table for Variable Lat*

| NetCDF Attribute | Description |
|---|---|
| standard_name | latitude |
| units | degrees_north |
| valid_range | [-90.0, 90.0] |
| _CoordinateAxisType | Lat |

**time**

*Table 8 Attribute Table for Variable time (reference time). The type of this variable is double.*

| NetCDF Attribute | Description |
|---|---|
| standard_name | Time |
| units | days since 1970-01-01 00:00:00 UTC |
| calendar | Standard |
| _CoordinateAxisType | Time |

**sm** (ACTIVE product)

*Table 9 Attribute Table for Variable sm for the ACTIVE product*

| NetCDF Attribute | Description |
|---|---|
| long_name | Percent of Saturation Soil Moisture |
| units | percent |
| _CoordinateAxes | lat lon time |
| _FillValue | -9999.0 (NaN); type: float32 (4 bytes) |

**sm** (PASSIVE and COMBINED product)

*Table 10 Attribute Table for Variable sm for the PASSIVE and COMBINED products*

| NetCDF Attribute | Description |
|---|---|
| long_name | Volumetric Soil Moisture |
| units | $m^3m^{-3}$ |
| _CoordinateAxes | lat lon time |
| _FillValue | -9999.0 (NaN); type: float32 (4 bytes) |

**sm_uncertainty** (ACTIVE product)

*Table 11 Attribute Table for Variable sm_uncertainty*

| NetCDF Attribute | Description |
|---|---|
| long_name | Percent of Saturation Soil Moisture Uncertainty |
| Units | percent |
| _CoordinateAxes | lat lon time |
| _FillValue | -9999.0 (NaN); type: float32 (4 bytes) |

**sm_uncertainty** (PASSIVE and COMBINED product)

*Table 12 Attribute Table for Variable sm_uncertainty for the PASSIVE and COMBINED products*

| NetCDF Attribute | Description |
|---|---|
| long_name | Volumetric Soil Moisture Uncertainty |
| Units | m3 m-3 |
| _CoordinateAxes | lat lon time |
| _FillValue | -9999.0 (NaN); type: float32 (4 bytes) |

**dnflag**

*Table 13 Attribute Table for Variable dnflag*

| NetCDF Attribute | Description |
|---|---|
| long_name | Day / Night Flag |
| flag_values | [0, 1, 2, 3] |
| flag_meanings | 0 = NaN<br>1 = day<br>2 = night<br>3 = combination of day and night |
| _CoordinateAxes | lat lon time |
| _FillValue | 0 (NaN); type: signed byte |

## flag

*Table 14 Attribute Table for Variable flag*

| NetCDF Attribute | Description |
|---|---|
| long_name | Flag |
| flag_values | [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49. 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 127] |
| flag_meanings | **0 = no data inconsistency detected**<br>**1 = snow coverage or temperature below zero**<br>**2 = dense vegetation**<br>3 = combination of flag values 1 and 2<br>**4 = others - no convergence in the model thus no valid sm estimates**<br>5 = combination of flag values 1 and 4<br>6 = combination of flag value 2 and 4<br>7 = combination of flag values 1, 2, and 4<br>**8 = soil moisture value exceeds physical boundary**<br>9 = combination of flag values 1, and 8<br>10 = combination of flag values 2, and 8<br>11 = combination of flag values 1, 2, and 8<br>12 = combination of flag values 4, and 8<br>13 = combination of flag values 1, 4, and8<br>14 = combination of flag values 2, 4, 8<br>15 = combination of flag values 1, 2, 4, and 8<br>**16 = weight of measurement below threshold / data set deemed unreliable**<br>17 = combination of flag values 1 and 16<br>18 = combination of flag values 2 and 16<br>19 = combination of flag values 1 and 2 and 16<br>20 = combination of flag values 4 and 16<br>21 = combination of flag values 1 and 4 and 16<br>22 = combination of flag values 2 and 4 and 16<br>23 = combination of flag values 1 and 2 and 4 and 16<br>24 = combination of flag values 8 and 16<br>25 = combination of flag values 1 and 8 and 16<br>26 = combination of flag values 2 and 8 and 16<br>27 = combination of flag values 1 and 2 and 8 and 16<br>28 = combination of flag values 4 and 8 and 16<br>29 = combination of flag values 1 and 4 and 8 and 16<br>30 = combination of flag values 2 and 4 and 8 and 16<br>31 = combination of flag values 1 and 2 and 4 and 8 and 16<br>**32 = all datasets deemed unreliable**<br>33 = combination of flag values 1 and 32<br>34 = combination of flag values 2 and 32<br>35 = combination of flag values 1 and 2 and 32<br>36 = combination of flag values 4 and 32<br>37 = combination of flag values 1 and 4 and 32<br>38 = combination of flag values 2 and 4 and 32<br>39 = combination of flag values 1 and 2 and 4 and 32<br>40 = combination of flag values 8 and 32<br>41 = combination of flag values 1 and 8 and 32<br>42 = combination of flag values 2 and 8 and 32<br>43 = combination of flag values 1 and 2 and 8 and 32<br>44 = combination of flag values 4 and 8 and 32<br>45 = combination of flag values 1 and 4 and 8 and 32<br>46 = combination of flag values 2 and 4 and 8 and 32<br>47 = combination of flag values 1 and 2 and 4 and 8 and 32<br>48 = combination of flag values 16 and 32<br>49 = combination of flag values 1 and 16 and 32<br>50 = combination of flag values 2 and 16 and 32<br>51 = combination of flag values 1 and 2 and 16 and 32<br>52 = combination of flag values 4 and 16 and 32<br>53 = combination of flag values 1 and 4 and 16 and 32 |

| | |
|---|---|
| | 54 = combination of flag values 2 and 4 and 16 and 32<br>55 = combination of flag values 1 and 2 and 4 and 16 and 32<br>56 = combination of flag values 8 and 16 and 32<br>57 = combination of flag values 1 and 8 and 16 and 32<br>58 = combination of flag values 2 and 8 and 16 and 32<br>59 = combination of flag values 1 and 2 and 8 and 16 and 32<br>60 = combination of flag values 4 and 8 and 16 and 32<br>61 = combination of flag values 1 and 4 and 8 and 16 and 32<br>62 = combination of flag values 2 and 4 and 8 and 16 and 32<br>63 = combination of flag values 1 and 2 and 4 and 8 and 16 and 32 |
| _CoordinateAxes | lat lon time |
| _FillValue | 127 (NaN); type: signed byte |

## freqbandID

*Table 15 Attribute Table for Variable freqbandID*

<table>
<tr><th>NetCDF Attribute</th><th>Description</th></tr>
<tr><td>long_name</td><td>Frequency Band Identification</td></tr>
<tr><td>flag_values</td><td>[0, 1, 2, 3, 4, 8, 9, 10, 11, 16, 17, 18, 19, 24, 25, 26, 27, 32, 33, 34, 35, 64, 65, 66, 67, 72, 73, 74, 75, 80, 81, 82, 83, 128, 130]</td></tr>
<tr><td>flag_meanings</td><td>Flag values and their meaning
<table>
<tr><th>Value</th><th>Meaning</th><th>Value</th><th>Meaning</th><th>Value</th><th>Meaning</th></tr>
<tr><td>0</td><td>NaN</td><td>19</td><td>L14+C53+C69</td><td>67</td><td>L14+C53+X107</td></tr>
<tr><td>1</td><td>L14</td><td>24</td><td>C68+C69</td><td>72</td><td>C68+X107</td></tr>
<tr><td>2</td><td>C53</td><td>25</td><td>L14+C68+C69</td><td>73</td><td>L14+C68+X107</td></tr>
<tr><td>3</td><td>L14+C53</td><td>26</td><td>C53+C68+C69</td><td>74</td><td>C53+C68+X107</td></tr>
<tr><td>4</td><td>C66</td><td>27</td><td>L14+C53+C68+C69</td><td>75</td><td>L14+C53+C68+X107</td></tr>
<tr><td>8</td><td>C68</td><td>32</td><td>C73</td><td>80</td><td>C69+X107</td></tr>
<tr><td>9</td><td>L14+C68</td><td>33</td><td>L14+C73</td><td>81</td><td>L14+C69+X107</td></tr>
<tr><td>10</td><td>C53+C68</td><td>34</td><td>C53+C73</td><td>82</td><td>C53+C69+X107</td></tr>
<tr><td>11</td><td>L14+C53+C68</td><td>35</td><td>L14+C53+C73</td><td>83</td><td>L14+C53+C69+X107</td></tr>
<tr><td>16</td><td>C69</td><td>64</td><td>X107</td><td>128</td><td>K194</td></tr>
<tr><td>17</td><td>L14+C69</td><td>65</td><td>L14+X107</td><td>130</td><td>C53+K194</td></tr>
<tr><td>18</td><td>C53+C69</td><td>66</td><td>C53+X107</td><td></td><td></td></tr>
</table>
List of major codes and the corresponding frequency bands
<table>
<tr><th>Binary</th><th>Decimal</th><th>Frequency [GHz]</th><th>BandID</th></tr>
<tr><td>00000000</td><td>0</td><td>NaN</td><td>N/A</td></tr>
<tr><td>00000001</td><td>1</td><td>1.4</td><td>L14</td></tr>
<tr><td>00000010</td><td>2</td><td>5.3 / 5.255</td><td>C53</td></tr>
<tr><td>00000100</td><td>4</td><td>6.6</td><td>C66</td></tr>
<tr><td>00001000</td><td>8</td><td>6.8</td><td>C68</td></tr>
<tr><td>00010000</td><td>16</td><td>6.9 / 6.93</td><td>C69</td></tr>
<tr><td>00100000</td><td>32</td><td>7.3</td><td>C73</td></tr>
<tr><td>01000000</td><td>64</td><td>10.65 / 10.7</td><td>X107</td></tr>
<tr><td>10000000</td><td>128</td><td>19.35 / 19.4</td><td>K194</td></tr>
</table>
Sensors and their operating frequencies:
<table>
<tr><th>Sensor</th><th>Operating Frequency [GHz]</th></tr>
<tr><td>SMMR</td><td>6.6 / 10.7</td></tr>
<tr><td>SSM/I</td><td>19.35</td></tr>
<tr><td>TMI</td><td>10.65</td></tr>
<tr><td>AMSR-E</td><td>6.93 / 10.65</td></tr>
<tr><td>AMSR2</td><td>6.93 / 7.3 / 10.65</td></tr>
<tr><td>WindSat</td><td>6.8 / 10.7</td></tr>
<tr><td>SMOS</td><td>1.4</td></tr>
<tr><td>AMI-WS</td><td>5.3</td></tr>
<tr><td>ASCAT-A/B</td><td>5.255</td></tr>
</table></td></tr>
<tr><td>_CoordinateAxes</td><td>lat lon time</td></tr>
<tr><td>_FillValue</td><td>0 (NaN); type: signed integer</td></tr>
</table>

### mode

*Table 16 Attribute Table for Variable mode*

| NetCDF Attribute | Description |
|---|---|
| long_name | Satellite Mode |
| flag_values | [0, 1, 2, 3] |
| flag_meanings | 0 = NaN<br>1 = ascending<br>2 = descending<br>3 = combination of ascending and descending |
| _CoordinateAxes | lat lon time |
| _FillValue | 0 (NaN); type: signed byte |

### sensor

*Table 17 Attribute Table for Variable sensor*

| NetCDF Attribute | Description |
|---|---|
| long_name | Sensor |
| flag_values | [0, 1, 2, 4, 8, 16, 24, 32, 64, 72, 80, 88, 96, 128, 130, 132, 136, 256, 264, 272, 280, 288, 320, 328, 336, 344, 352, 512, 544, 576, 608, 768, 800, 832, 864] |
| flag_meanings | |
| _CoordinateAxes | lat lon time |
| _FillValue | 0 (NaN); type: signed integer |

| Value | Sensor Combination | Value | Sensor Combination |
|---|---|---|---|
| 0 | NaN | 264 | AMSRE+ASCATA |
| 1 | SMMR | 272 | WindSat+ASCATA |
| 2 | SSMI | 280 | AMSRE+WindSat+ASCATA |
| 4 | TMI | 288 | AMSR2+ASCATA |
| 8 | AMSRE | 320 | SMOS+ASCATA |
| 16 | WindSat | 328 | AMSRE+SMOS+ASCATA |
| 24 | AMSRE+WindSat | 336 | WindSat+SMOS+ASCATA |
| 32 | AMSR2 | 344 | AMSRE+WindSat+SMOS+ASCATA |
| 64 | SMOS | 352 | AMSR2+SMOS+ASCATA |
| 72 | AMSRE+SMOS | 512 | ASCATB |
| 80 | WindSat+SMOS | 544 | AMSR2+ASCATB |
| 88 | AMSRE+WindSat+SMOS | 576 | SMOS+ASCATB |
| 96 | AMSR2+SMOS | 608 | AMSR2+SMOS+ASCATB |
| 128 | AMIWS | 768 | ASCATA+ASCATB |
| 130 | SSMI+AMIWS | 800 | AMSR2+ASCATA+ASCATB |
| 132 | TMI+AMIWS | 832 | SMOS+ASCATA+ASCATB |
| 136 | ASMRE+AMIWS | 864 | AMSR2+SMOS+ASCATA+ASCATB |
| 256 | ASCATA | | |

**t0**

*Table 18 Attribute Table for Variable t0*

| NetCDF Attribute | Description |
|---|---|
| long_name | Observation Time Stamp |
| units | days since 1970-01-01 00:00:00 UTC |
| valid_range | <individual decimal numbers depending on observation timestamp> |
| _CoordinateAxes | lat lon time |
| _FillValue | -9999.0; type: double |

## 3.4 Description of data set variables

### *3.4.1 sm*

The "sm" parameter holds the surface soil moisture estimates are generated by blending passive and active microwave soil moisture retrieval sin a weighted average fashion with the weights being proportional to the signal-to-noise ratio (SNR) of the data sets. SNRs are estimated using triple collocation (TC) analysis. In areas where no TC based SNR estimates are available, SNRs are derived from a polynomial regression between the SNRs in areas where TC based estimates are available, and the Vegetation Optical Depth (VOD) at the corresponding locations [RD-1]. The data are provided in percentage of saturation [%] units for the ACTIVE product, and volumetric [$m^3m^{-3}$] units for the PASSIVE and COMBINED products.

### *3.4.2 sm_uncertainty*

The merging of soil moisture data from different sensors requires a harmonization of the data. The data need to be brought into a common climatology by running them through several scaling procedures performing the cumulative distribution function (CDF-) matching technique. The provided "sm_uncertainty" parameter represents the error standard deviation of the data sets (in the respective climatology of the dataset), estimated through triple collocation (TC) analysis, which are used to calculate the relative weighting of the data sets. In periods where TC cannot be applied, or in cases where the TC-based error standard deviation estimates do not converge, sm_uncertainty is set to NaN. The unit of sm_uncertainty for the ACTIVE product is percentage of saturation [%]. For the PASSIVE and the COMBINED product the unit is volumetric soil moisture [$m^3m^{-3}$].. On days where only measurements of one single data set are available, sm_uncertainty represents their error standard deviation as obtained from TC analysis. On days where two or more data sets are

merged, sm_uncertainties represents the estimated error standard deviation of the merged soil moisture measurements, obtained by propagating the TC-based error standard deviation estimates of the contributing data sets through the merging algorithm using a standard error propagation scheme. sm_uncertainty values exceeding the maximum value of 100 (ACTIVE) or 1 (PASSIVE and COMBINED) are set to the maximum value respectively. Table 19 lists the availability of the soil moisture uncertainty information for each product.

*Table 19 sm_uncertainty data provided in the ESA CCI SM Products*

| Product | Time Period |
|---|---|
| ACTIVE | 1991-08-05 to 2019-12-31 |
| PASSIVE | 1987-07-09 to 2019-12-31 |
| COMBINED | 1987-07-09 to 2019-12-31 |

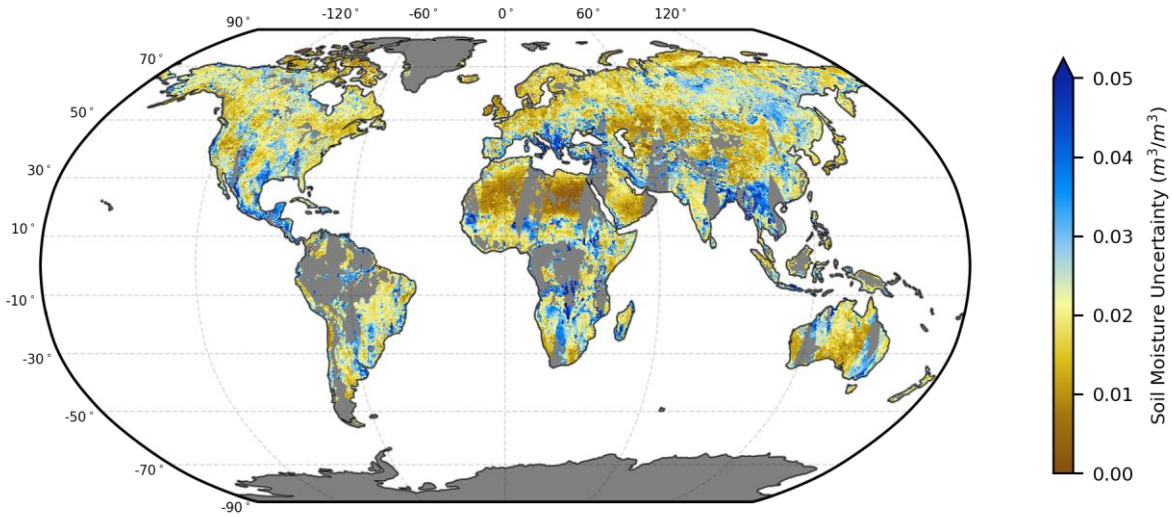


*Figure 1: sm_uncertainty for the day 2019-07-01 from the COMBINED ESA CCI SM product (v04.7).*

### *3.4.3 dnflag*

The Day or Night Flag gives information, whether the observation(s) occurred at local day (1) or night (2) time. A value of 3 indicates that the data is a result of merging satellite microwave data observed during day as well as during night time. In cases where the information cannot be determined the value is set to 0 (zero).

### 3.4.4 flag

Flag values are stored as signed bytes, and the default value (NaN) is 127. By reading the flag for the surface soil moisture data, the user gets information for that grid point. A “0” (zero) informs that the sm value for that grid point has been checked, but there was no inconsistency found. A flag value of “1” denotes, that the soil for that location is covered with snow or the temperature is below zero;“2” indicates that the observed location is covered by dense vegetation, ; “4” stands for undefined other cases, e.g. no convergence in the model, thus no valid soil moisture estimates; “8” denotes days that are masked because not all data sets have valid observations and those which do are deemed unreliable; and “16” denotes locations where all data sets are deemed unreliable. Please see Table 14 for the meaning of all other flag values.

### 3.4.5 freqbandID

The surface soil moisture data has its sources from multiple and different satellite sensors, which operate in various frequencies. The freqbandID values are representing the operating frequencies and comprise the combination of different frequency bands. Table 15 lists these combinations.

### 3.4.6 mode

The NetCDF variable mode stores the information of the sensor’s orbit direction. Ascending direction are denoted as 1, and descending orbit as 2. In cases where the orbit direction cannot be determined, the NaN value 0 (zero) is used. A value of 3 means that the merged data comprises both ascending and decending satellite modes (Table 16).

### 3.4.7 sensor

The values for sensor are stored as signed integer, with NaN as 0 (zero). These values indicate the satellite sensors that have been used for a specific grid point. Valid values range from 1 to 864. Table 17 lists all available sensor combinations.

### 3.4.8 t0

The original observation timestamp is stored within the NetCDF variable t0 (t-naught). Time values coming from two different sensors are averaged. Values of -9999.0 are used as NaN values. t0 data values are stored as number of “days since 1970-01-01 00:00:00 UTC” (Table 18).

### *3.4.9 time*

The reference timestamp of the day is saved in the “time” variable. The data values for the reference time are stored as number of “days since 1970-01-01 00:00:00 UTC” (Table 8).

## 3.5 Product Grid and Projection

The grid is a 0.25° x 0.25° longitude-latitude global array of points, based on the World Geodetic System 1984 (WGS 84) reference system. Its dimension is 1440 x 720, where the first dimension, X (longitude) is incrementing most rapidly West (-180°) to East (180°), and the second dimension, Y (latitude) is incrementing South (-90°) to North (90°). Grid edges are at multiple of quarter-degree values (e.g. 90, 89.75, 89.5, 89.25, …), and the grid centers are exactly between two grid edges:

First point center = (–89.875°S, –179.875°W) = Grid Point Index = 0

Second point center = (–89.875°S, –179.625°W) = Grid Point Index = 1

1441$^{st}$ point center = (–89.625°S, –179.875°W) = Grid Point Index = 1440

Last point center = (89.875°N, 179.875°E) = Grid Point Index = 1036799

In total, there are 1440 x 720 = 1036800 grid points, where 244243 points are land points. Figure 2 shows the land points that are used for the merged product.

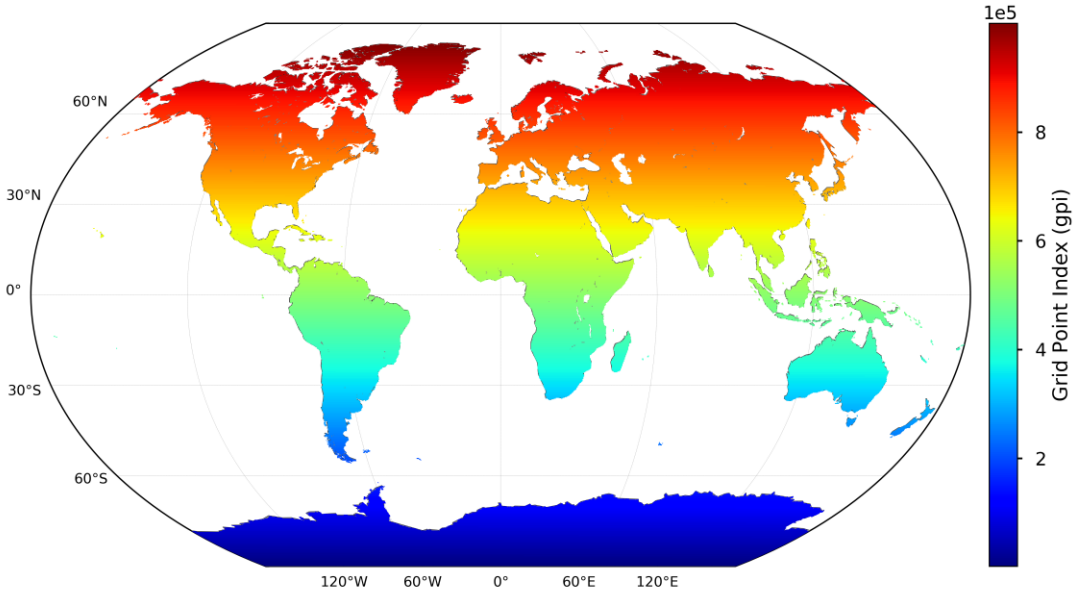


*Figure 2: Land mask used for the merged product. The 0.25° grid starts indexing from "lower left" to the "upper right". Note that not every grid points are available for all sensors, e.g. ASCAT retrievals are available between latitude degrees 80° and –60°.*

## 3.6 Ancillary data

The process of generating the soil moisture products involves the usage of various ancillary data sets which are described in the following subsections.

### *3.6.1 Global Land Data Assimilation System (GLDAS)*

The PASSIVE and ACTIVE products represent volumetric soil moisture ($m^3m^{-3}$) and degree of saturation (%), respectively. To combine these data, both products need to be adjusted to a common reference. The reference dataset requires global coverage with a spatial resolution and temporal interval that are comparable to both microwave products (i.e., approximately 25 km resolution and daily interval), a long time record, and reasonable surface soil moisture estimates for all land cover types (i.e., representative soil layer is not deeper than 10 cm). The GLDAS-2-Noah Land Surface Model L4 3 Hourly 0.25 x 0.25 degree soil moisture model data satisfies these requirements and is employed as the reference dataset. Both, the PASSIVE and ACTIVE, products were rescaled against the GLDAS-2-Noah (v2.1) data using the CDF matching technique. Furthermore, soil porosity data has been taken from the GLDAS-Noah dataset, and can be used in the conversion to volumetric soil moisture measurements. According to the author (Rodell et al. 2004) of the GLDAS-Noah data, this soil parameter has been derived from the 5’ resolution global soils dataset of Reynolds et al. (2000) by horizontally resampling to the 0.25° GLDAS grid and by linearly interpolating “to 0–2-, 2–150-, and 150–350-cm depths from the original 0–30- and 30–100-cm depths.” The methodolgy behind the use of both data sets is provided in [RD-1]

### *3.6.2 ASCAT Advisory Flag*

The following two ASCAT advisory flags (Scipal 2005) were used to mask out regions of frozen soils, or snow covered soils:

- **Probability of snow covered land**

  Derived from historic analysis of SSM/I (Special Sensor Microwave/Imager) snow cover data (averaged over the 9 years 1996-2004) and gives the probability for the occurrence of snow for any day of the year.

- **Probability of frozen land**

  Derived from historic analysis of modelled climate data (7 years 1995-2001 of ECMWF ERA-40 soil temperature) and gives the probability for the frozen soil/canopy conditions for each day of the year.

## 3.7 Ancillary data provided along with the ESA CCI SM v04.7 products

### *3.7.1 Land and Tropical forest Mask*

A common land mask is used for all ESA CCI SM v04.7 products and ancillary data. The land mask has been derived from the Global Self-consistent, Hierarchical, High-resolution Geography Database (GSHHG v2.2.2), (Wessel and Smith 1996). Lakes and rivers with areas less than 600 km$^2$ were not considered in the calculation of the land points (Figure 2). See section 3.5 for more detailed information on the used grid.

The Tropical forest mask (Figure 3) has been applied to all three ESA CCI SM products. The soil moisture and the soil moisture uncertainty values are set to NaN in these rainforest regions.

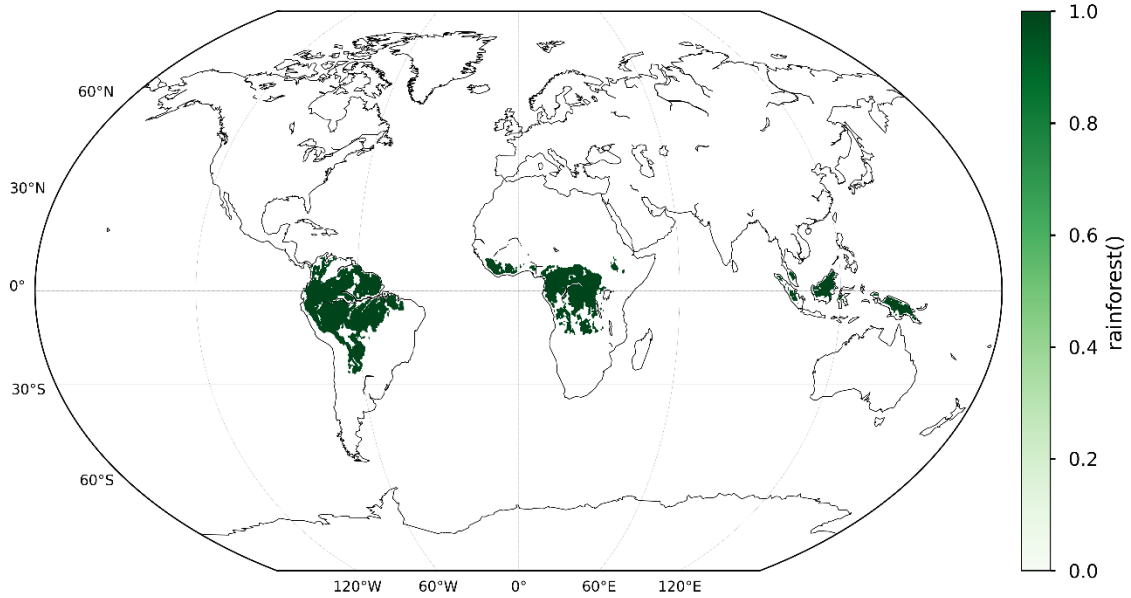


*Figure 3 Tropical forest Mask used applied to the ESA CCI SM v04.7 data. 1 (green) represents rainforest regions.*

### *3.7.2 Average Vegetation Optical Depth from AMSR-E*

Vegetation optical depth (VOD) estimated from AMSR-E with the VUA-NASA LPRM (v6) method are provided to give an indication of vegetation density. The provided global values represent the averaged VOD from 2002 to 2011 for C-band observations.

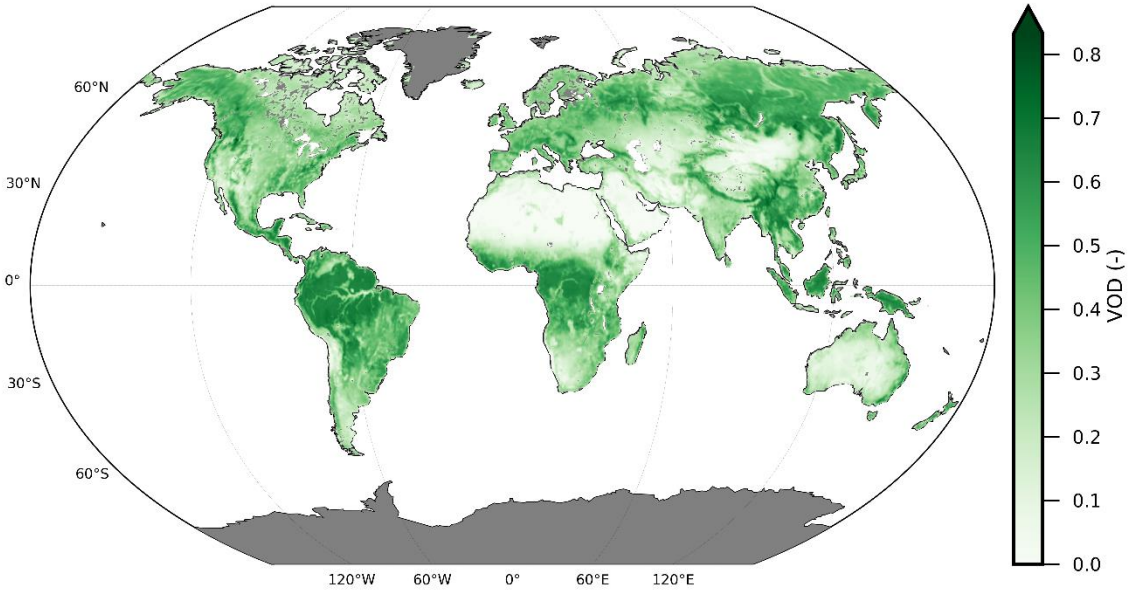


*Figure 4: AMSR-E average vegetation optical depth from 2002 to 2011 for band C (6.9 Ghz).*

### *3.7.3 Soil Porosity*

Global soil porosity information of the top layer (0-0.40 m depth) has been derived from the Harmonized World Soil Database (version 1.0) (FAO/IIASA/ISRIC/ISSCAS/JRC 2008) using the soil water characteristic estimates developed by Saxton and Rawls (Saxton 2006).

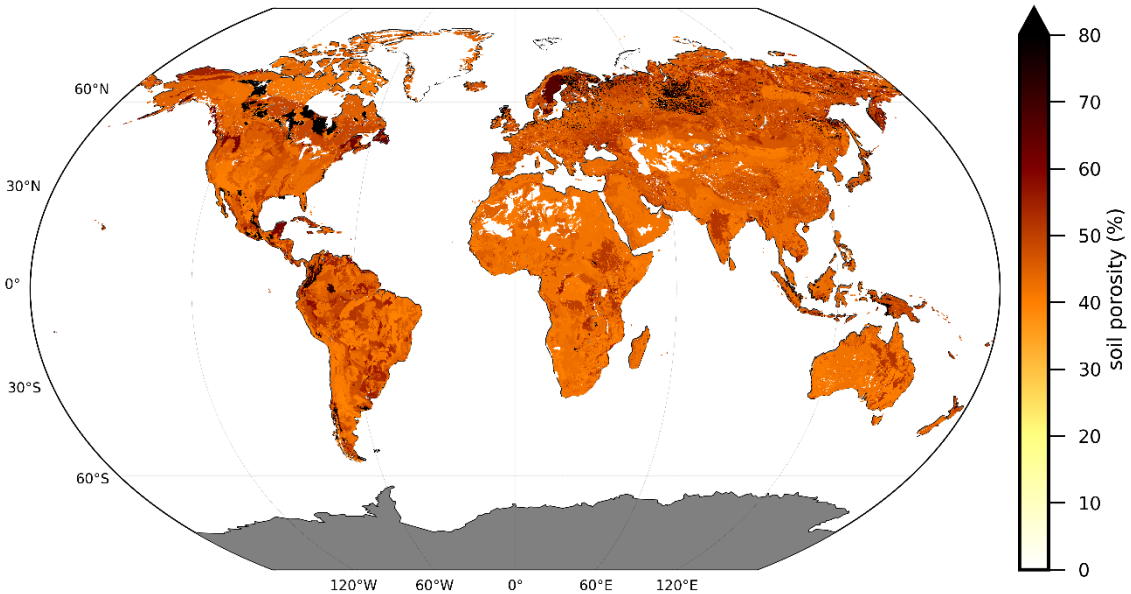


*Figure 5: Top soil porosity derived from the Harmonized World Soil Database.*

### *3.7.4 Topographic Complexity*

The topographic complexity is derived from the USGS 30-second Global Elevation Data (GTOPO30) (USGS 1996). Orginally, the elevation was calculated for the Discrete Global Grid (DGG) and normalized to values between 0 and 100. The conversion from DGG to the 0.25 degree grid, which is used for the ESA CCI SM products, is based on the nearest-neighbour search algorithm.

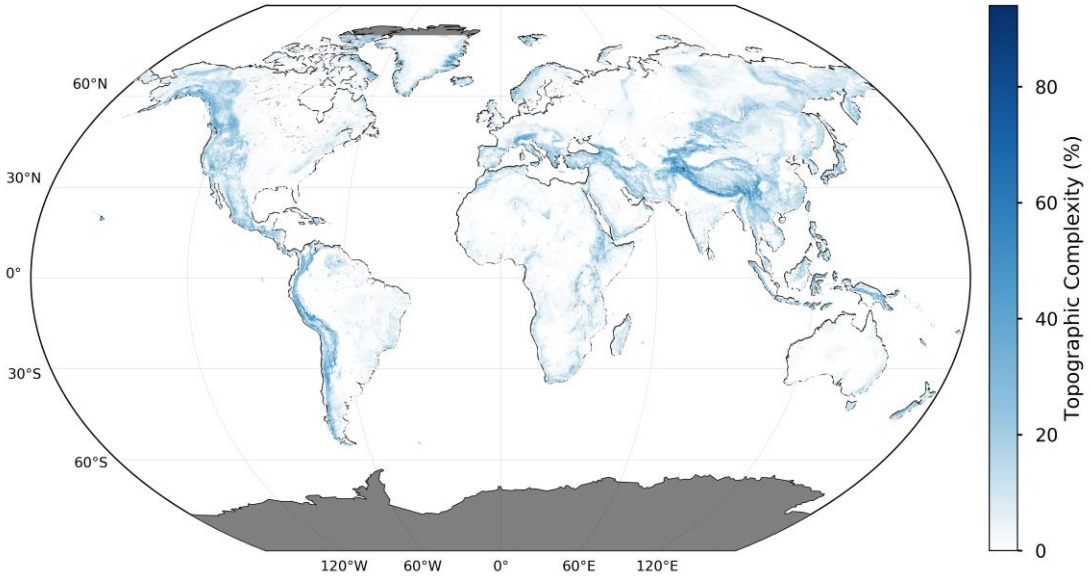


*Figure 6: Topographic complexity from the USGS 30-second Global Elevation Data (GTOPO30).*

### *3.7.5 Wetland fraction*

The open water fraction is defined as fraction coverage of areas with inundation potential. The inundation potential has been derived from the Global Lakes and Wetlands Database (GLWD) level 3 product, which includes several wetland and inundation types. Originally, the wetland fraction was calculated for the Discrete Global Grid (DGG). The conversion from DGG to the 0.25 degree grid, which is used for the ESA CCI SM products, is based on the nearest-neighbour search algorithm.

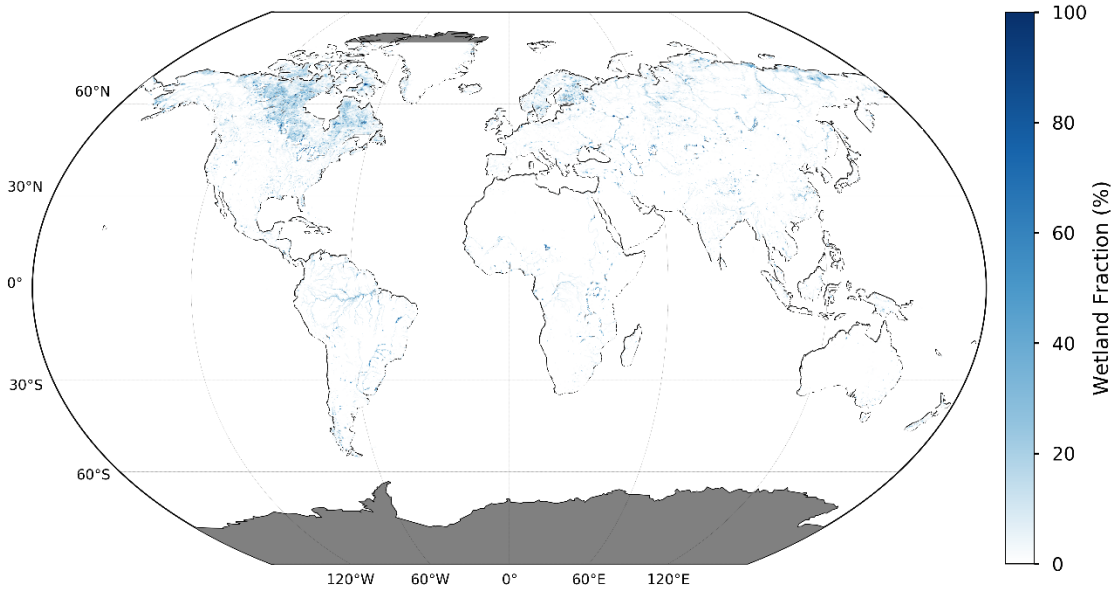


*Figure 7: Wetland fraction derived from the Global Lakes and Wetlands Database (GLWD).*

## 3.8 Blending time periods and used sensors

The following tables list for each predefined time period which sensors are considered in the SNR blending algorithm based on the triple collocation analysis.

### *3.8.1 ACTIVE Product*

*Table 20 SNR blending period for the ACTIVE Product*

| Sensors | Time Period |
|---|---|
| AMI-WS | 1991-08-05 to 2006-12-31 |
| ASCAT-A | 2007-01-01 to 2012-11-05 |
| ASCAT-A & ASCAT-B | 2012-11-06 to 2019-12-31 |

### *3.8.2 PASSIVE Product*

*Table 21 SNR blending period for the PASSIVE Product. *The [SSM/I, TMI, SSM/I] period is latitudinally divided into [90S, 37S] and [90N, 37N] for SSM/I, and the region inbetween for TMI.*

| Sensors | Time Period |
|---|---|
| SMMR | 1978-11-01 to 1987-07-08 |
| SSM/I | 1987-07-09 to 1997-12-31 |
| [SSM/I, TMI, SSM/I]* | 1998-01-01 to 2002-06-18 |
| AMSR-E | 2002-06-19 to 2007-09-30 |
| AMSR-E & WindSat | 2007-10-01 to 2010-01-14 |
| AMSR-E & WindSat & SMOS | 2010-01-15 to 2011-10-04 |
| WindSat & SMOS | 2011-10-05 to 2012-06-30 |
| SMOS & AMSR2 | 2012-07-01 to 2019-12-31 |

### *3.8.3 COMBINED Product*

*Table 22 SNR blending period for the PASSIVE Product. *The [SSM/I, TMI, SSM/I] period is latitudinally divided into [90S, 37S] and [90N, 37N] for SSM/I, and the region inbetween for TMI.*

| Sensors (Active / Passive) | Time Period |
|---|---|
| SMMR | 1978-11-01 to 1987-07-08 |
| SSM/I | 1987-07-09 to 1991-08-04 |
| AMI-WS & SSMI | 1991-08-05 to 1997-12-31 |
| AMI-WS & [SSM/I, TMI, SSM/I]* | 1998-01-01 to 2002-06-18 |
| AMI-WS & AMSRE | 2002-06-19 to 2006-12-31 |
| ASCAT-A & AMSRE | 2007-01-01 to 2007-09-30 |
| ASCAT-A & AMSRE & WindSat | 2007-10-01 to 2010-01-14 |
| ASCAT-A & AMSRE & WindSat & SMOS | 2010-01-15 to 2011-10-04 |
| ASCAT-A & WindSat & SMOS | 2011-10-05 to 2012-06-30 |
| ASCAT-A & ASCAT-B & SMOS & AMSR2 | 2012-07-01 to 2019-12-31 |

# 4 Example NetCDF file

An example of the NetCDF product is shown in the following figures. The viewer used within this example is Panoply[5]. Panoply is a cross-platform application which plots geo-gridded arrays from NetCDF, HDF and GRIB datasets.

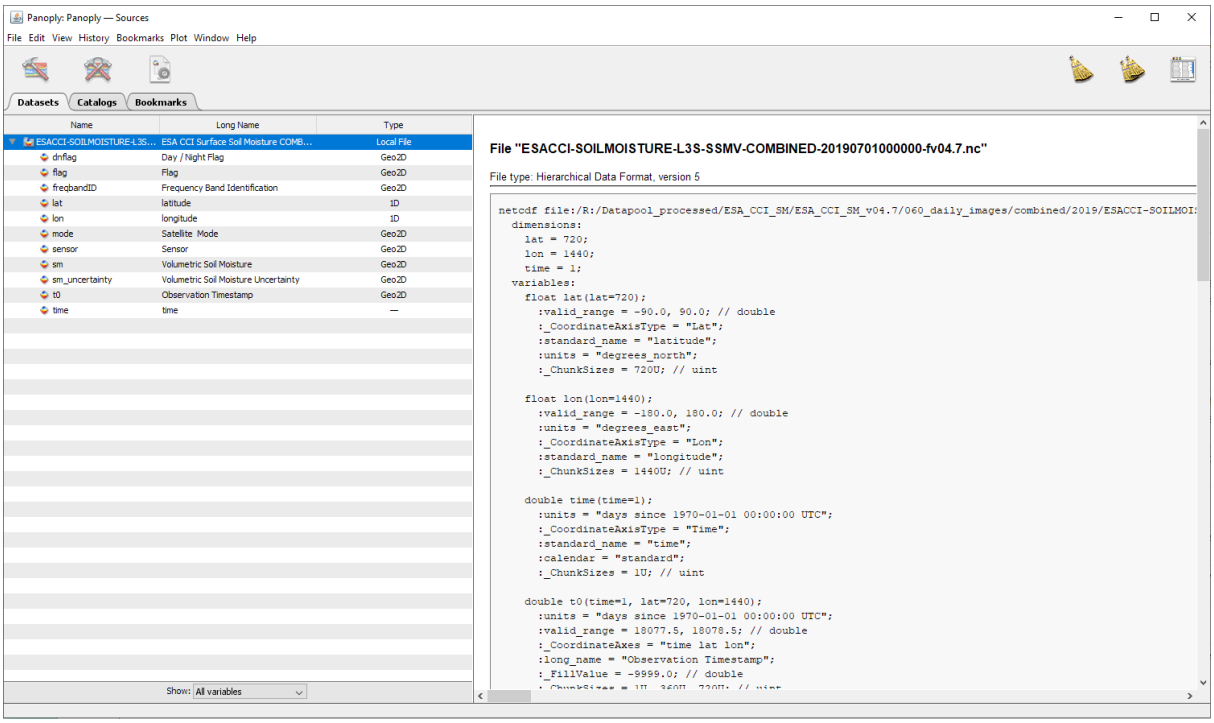


*Figure 8 NetCDF Global Attributes for an example ESA CCI SM file (v04.7 COMBINED for date 2019-07-01) (file opened in Panoply).*

[5] Panoply netCDF, HDF and GRIB Data Viewer: http://www.giss.nasa.gov/tools/panoply

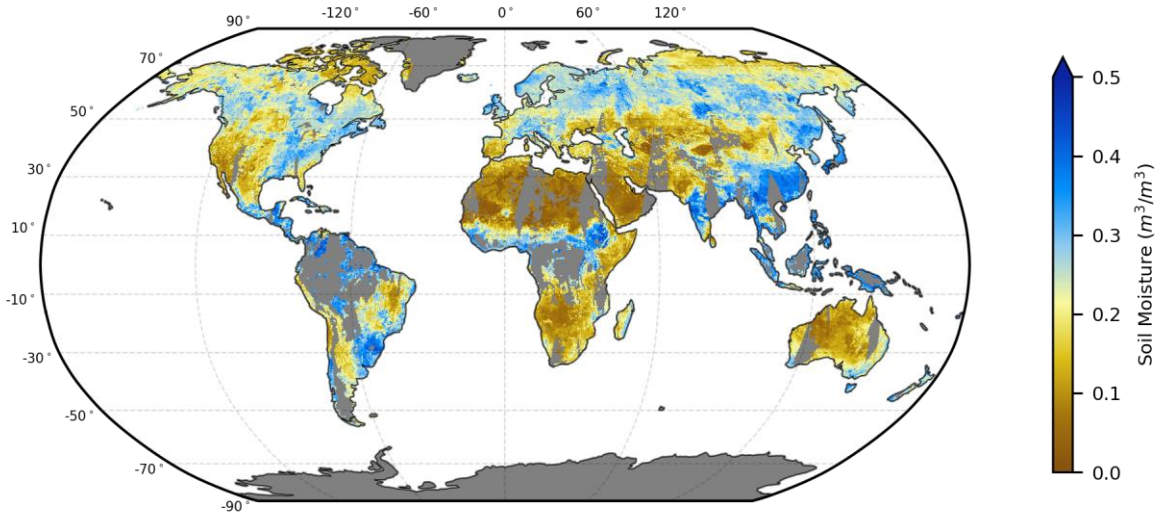


*Figure 9: Soil moisture (sm) for the day 2019-07-01 from the COMBINED ESA CCI SM product (v04.7).*

# 5 Data Usage and Limitations

## 5.1 Free Use

The ACTIVE, PASSIVE, and the COMBINED products are freely available after completion of a simple registration form. The use of the product is free and open for all registered users. User Registration can be found at http://www.esa-soilmoisture-cci.org/dataregistration.

## 5.2 No onward distribution

The use of the downloaded data is restricted to the user and the associated organisation, no onward distribution is permitted. This is in the best interest of both the individual data providers and the potential users as unrestricted copying of the original data by multiple, independent users may lead to errors in the data.

Full data citation must be adhered to for all data usage.

# 6 Data Citation

The data set should be cited using the complete references as follows:

1. Gruber, A., Scanlon, T., van der Schalie, R., Wagner, W., Dorigo, W. (2019). Evolution of the ESA CCI Soil Moisture Climate Data Records and their underlying merging methodology. Earth System Science Data 11, 717-739, https://doi.org/10.5194/essd-11-717-2019
2. Gruber, A., Dorigo, W. Crow, W., & Wagner, W. (2017). Triple collocation-based merging of satellite soil moisture retrievals. IEEE Transactions on Geoscience and Remote Sensing, 1-13. https://doi.org/10.1109/TGRS.2017.2734070.
3. Dorigo, W.A., Wagner, W., Albergel, C., Albrecht, F., Balsamo, G., Brocca, L., Chung, D., Ertl, M., Forkel, M., Gruber, A., Haas, E., Hamer, P. D., Hirschi, M., Ikonen, J., de Jeu, R., Kidd, R., Lahoz, W., Liu, Y. Y.,Miralles, D., Mistelbauer, T., Nicolai-Shaw, N., Parinussa, R., Pratola, C., Reimer, C., van der Schalie, R., Seneviratne, S. I. Smolander, T., Lecomte, P. (2017). ESA CCI Soil Moisture for improved Earth system understanding: State-of-the art and future directions, Remote Sensing of Environment. https://doi.org/10.1016/j.rse.2017.07.001.

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Data Record on Soil Moisture. *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences, I-7*, 315--321

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