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EUMETSAT Satellite Application Facility on Support to Operational Hydrology and Water Management http://h-saf.eumetsat.int/



Product User Manual (PUM)

Metop ASCAT Surface Soil Moisture Climate Data Record v5 12.5 km (H115) and Extension (H116)



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Revision History

Revision	Date	Author(s)	Description
0.1	2019/12/04	S. Hahn	First release, based on previous ASCAT SSM
			CDR PUM. Revising sections 3 and 4. Added
			section 5.

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List of Acronyms

ASAR Advanced Synthetic Aperture Radar (on Envisat)

ASAR GM ASAR Global Monitoring

ASCAT Advanced Scatterometer

ATBD Algorithm Theoretical Baseline Document

BUFR Binary Universal Form for the Representation of meteorological data

DORIS Doppler Orbitography and Radiopositioning Integrated by Satellite (on Envisat)

ECMWF European Centre for Medium-range Weather Forecasts

Envisat Environmental Satellite

ERS European Remote-sensing Satellite (1 and 2)

ESA European Space Agency

EUM Short for EUMETSAT

EUMETCast EUMETSAT's Broadcast System for Environment Data

EUMETSAT European Organisation for the Exploitation of Meteorological Satellites

FTP File Transfer Protocol

H SAF SAF on Support to Operational Hydrology and Water Management

Météo France National Meteorological Service of France

Metop Meteorological Operational Platform

NRT Near Real-Time

NWP Near Weather Prediction

PRD Product Requirements Document

PUM Product User Manual

PVR Product Validation Report

SAF Satellite Application Facility

SAR Synthetic Aperture Radar

SRTM Shuttle Radar Topography Mission

SZF Sigma Zero Full resolution

SZO Sigma Zero Operational (25 km spatial sampling)



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SZR Sigma Zero Research (12.5 km spatial sampling)

TU Wien Technische Universität Wien (Vienna University of Technology)

WARP Soil Water Retrieval Package

WARP H WARP Hydrology

WARP NRT WARP Near Real-Time

ZAMG Zentralanstalt für Meteorologie und Geodynamic (National Meteorological Service of Austria)



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1. Executive summary

The Product User Manual (PUM) describes the Metop ASCAT Surface Soil Moisture (SSM) Climate Data Record (CDR) v5 12.5 km (H115) and extension (H116). A general introduction of the purpose of the document followed by related surface soil moisture products are describe in section 2. The product categories (CDR and offline) and previously released CDR products are discussed in section 3.1, followed by a product description of the Metop ASCAT SSM CDR v5 in section 4. References to technical reports and journal articles are summarized at the end of the document.

The Metop ASCAT SSM CDR products are consistent data records based on the latest version of the EUMETSAT H SAF TU Wien soil moisture retrieval algorithm described in the Algorithm Theoretical Baseline Document (ATBD) [2]. In order to provide a consistent extension to the CDR, offline SSM products are generated until a new CDR supersedes the previous CDR. A validation of the present Metop ASCAT SSM CDR can be found in the Product Validation Report (PVR) [3].

2. Introduction

2.1. Purpose of the document

The Product User Manual (PUM) is intended to provide a description of the main product characteristics, parameters, format and availability. Although reasonably self-standing, the PUM's rely on other documents for further details. Specifically:

- Algorithm Theoretical Baseline Document (ATBD) [2], for extensive details on the algorithms, only highlighted here.
- Product Validation Report (PVR) [4], for full recount of the validation activity, both the evolution and the latest results.

2.2. Targeted audience

This document mainly targets:

• Users of the remotely sensed soil moisture data sets.

2.3. Related products

Various soil moisture products with different timeliness (e.g. NRT, offline, data records), spatial resolution (1-50 km), format (e.g. time series, swath orbit geometry) and the representation of the water content in various soil layer (e.g. surface, root-zone), are generated on a regular basis and distributed to users by H SAF. A list of all available soil moisture products, as well as other H SAF products (such as precipitation or snow) can be found on the H SAF website http://h-saf.eumetsat.int/.



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3. Climate Data Record and Extension

SAF products are categorized according to their availability and timeliness. Three main product categories exist: Near Real-Time (NRT), Climate Data Record (CDR) and Offline products. Each SAF product belongs to a certain category and is tagged with a product status. The status reflects the scientific maturity and operational readiness of the product. Each product will go through a pre-defined review-cycle depending on its product category.

3.1. Product category and status

The Metop ASCAT Surface Soil Moisture (SSM) Climate Data Record (CDR) products are consistent data sets and belong to the group of Thematic Climate Data Records (TCDR). A TCDR typically represents a geophysical variable associated with GCOS Essential Climate Variables based on a Fundamental Climate Data Record (FCDR). A FCDR is considered to be a single sensor type re-calibrated and inter-satellite calibrated Level 1 data set, such as the ASCAT Level 1b backscatter FCDR. The product stages of a CDR is given in the following listing:

- In development: product is under development and not available to users
- Demonstration: product is delivered to users without any commitment on the quality and availability
- Released: product that is made available to users, satisfying largely the applicable requirements, with documented characteristics, validations results and limitations

It is foreseen to process a new SSM CDR each year based on the latest version of the EU-METSAT H SAF TU Wien soil moisture retrieval algorithm. Hence, depending on the version of the algorithm and the version of the Metop ASCAT Level 1b backscatter data, the soil moisture values for each CDR can be different. In addition, each CDR is based on empirical model parameters computed as part of the soil moisture retrieval algorithm and therefore yet another reason why each SSM CDR is unique.

The Metop ASCAT Surface Soil Moisture (SSM) Climate Data Record (CDR) Extension products represent continuations of the Metop ASCAT SSM CDR products. A CDR is a self-contained data set, i.e. it cannot be manipulate retrospectively or updated. This is the reason why the SSM CDR Extension data sets are offline products, since they can be generated continuously without the previously mentioned limitations of a CDR. Technically, an offline product is the same as a NRT product, although not as punctual. Offline products are typically updated on a weekly, monthly or yearly basis. In order to nominate an offline (or NRT) product an extension of a CDR, it is important to use the same version of algorithm, software and input data to be able to produce a compliant and consistent continuation. The processing of an offline product is maintained until a new CDR is released, which will supersede the previous CDR and its extension. The product stages of an offline product is given in the following listing:

- In development: product is under development and not available to users
- Demonstration: product is delivered to users without any commitment on the quality and availability

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Table 3.1: List of available Metop ASCAT SSM CDR products.

CDR	Satellite	ATBD	PVR	Temporal coverage
H25 [5]	Metop-A	[6]	[7]	2007 - 01 - 01 - 2014 - 12 - 31
H109 [8]	Metop-A/B	[9]	[10]	$2007\hbox{-}01\hbox{-}01 - 2015\hbox{-}12\hbox{-}31$
H111 [11]	Metop-A/B	[9]	[12]	$2007\hbox{-}01\hbox{-}01 - 2016\hbox{-}12\hbox{-}31$
H113 [13]	Metop-A/B	[14]	[15]	$2007\hbox{-}01\hbox{-}01 - 2017\hbox{-}12\hbox{-}31$
H115 [16]	Metop-A/B	[2]	[3]	2007-01-01 - 2018-12-31

Table 3.2: List of available Metop ASCAT SSM CDR Extension products.

Extension	CDR	Temporal coverage
H108 [17]	H25	2015-01-01 - 2015-06-30
H110 [18]	H109	2016-01-01 - 2016-07-31
H112 [19]	H111	2017-01-01 - 2017-11-01
H114 [20]	H113	2018-01-01 - 2018-12-31
H116 [21]	H115	2019-01-01 - ongoing

- Pre-operational: product with documented limitations that is able to satisfy the majority of applicable requirements
- Operational: product with documented limitations that largely satisfy the requirements and mature to be distribution to users
- Superseded: product that has been (pre-)operationally provided to users, which is no longer the case because the information of the same or superior quality and/or coverage is provided with another product
- Discontinued: product that has been previously (pre-)operationally provided to users but is not (pre-)operational anymore

3.2. Released products

It is recommended to use the latest released Metop ASCAT SSM CDR, which is based on the most recent version of the EUMETSAT H SAF TU Wien soil moisture retrieval algorithm. Table 3.1 and 3.2 shows all released Metop ASCAT SSM CDR products and extensions to users.

4. Metop ASCAT Surface Soil Moisture CDR v5 12.5 km

4.1. Lineage

The Metop ASCAT Surface Soil Moisture (SSM) Climate Data Record (CDR) v5 12.5 km product (H115) is based on Metop-A and Metop-B Level 1b backscatter products with 12.5 km spatial sampling. For the time period 2007-01-01 until 2014-03-30 the Metop-A Level 1b Fundamental Climate Data Record (FCDR) [22] is used and combined with archived Metop-A Level 1b NRT product from 2014-04-01 until 2018-12-31 [23]. In case of Metop-B, the Level 1b NRT product



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from 2013-01-01 until 2018-12-31 has been used [23]. The empirical model parameters generated during the retrieval of surface soil moisture have been derived from Metop-A and Metop-B together. Further input data sets used to generate the Metop ASCAT SSM CDR v5 are the Köppen Geiger Climate Classification [24] and land surface temperature from ERA5 [25].

The EUMETSAT H SAF TU Wien soil moisture retrieval algorithm [2], [26], [27] is used to derive relative surface soil moisture information and represents a physically based change detection method. Long-term backscatter measurements are used to model the incidence angle dependency of backscatter, which allows to normalize backscatter to a common reference incidence angle. The relative surface soil moisture estimates range between 0% (completely dry) and 100% (completely saturated and are derived by scaling the normalized backscatter between the lowest/highest backscatter values corresponding to the driest/wettest soil conditions. Soil moisture is represented in degree of saturation, but can be translated from relative (%) to absolute volumetric units (m^3m^{-3}) using porosity information (see Equation 1). Figure 4.1 shows mean surface soil moisture condition for 2007-2018 derived from Metop ASCAT SSM CDR v5 expressed in degree of saturation.

The retrieval algorithm is implemented in a Python software package called soil WAter Retrieval Package (WARP). In practice, the latest Metop ASCAT Level 1b Fundamental Climate Data Record (FCDR) and the latest operational Level 1b data are manually combined to a common Level 1 data set. Except surface temperature data (used for deriving the Surface State Flag (SSF) and a static climate classification map (used for the determination of the wet correction), no external data is required for the soil moisture retrieval. A detailed description of the retrieval algorithm together with a description of the derivation of the model parameters can be found in the Algorithm Theoretical Baseline Document (ATBD) [2]. The ASCAT Product Guide [28] contains an overview of the ASCAT instrument and product configuration.

The following changes have been introduced with respect to the previous Metop ASCAT SSM CDR (H113).

- Derivation of new empirical model parameters
- Soil temperature information using ERA5 [25]
- Add backscatter, backscatter noise, slope and slope noise to NetCDF file
- New data type of soil moisture and soil moisture noise in NetCDF file using scaling factor
- New static layer: sub-surface scattering probability

4.2. Parameters

The soil moisture CDR and offline products are composed of several parameters (geophysical parameters, flags, geo-location information, auxiliary parameters, etc.). The following subsections give an overview of all relevant parameters and flags.

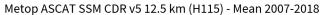
4.2.1. Soil moisture

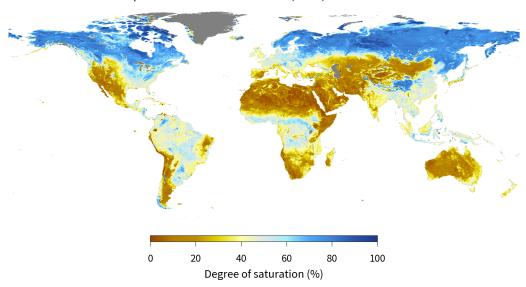
Soil moisture The soil moisture information provided in the Metop ASCAT SSM CDR product represents relative surface soil moisture (SM) of the topmost soil layer (< 5 cm). The soil moisture values are given in degree of saturation ranging from 0% (completely dry) to 100%

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(a)





(b)

Metop ASCAT SSM CDR v5 12.5 km (H115) - Mean 2007-2018

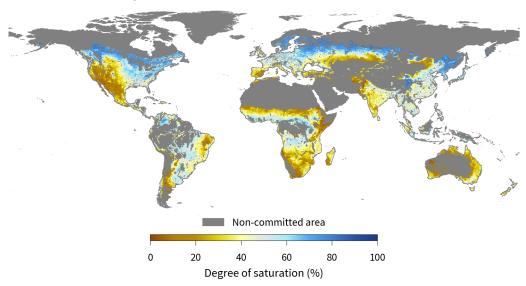


Figure 4.1: Mean surface soil moisture from Metop ASCAT SSM CDR v5 for the period 2007-2018 globally (a) and for the committed area only (b).



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Table 4.1: Overview of soil moisture parameters.

Name	Scaling factor	Units	Type	Byte size	NaN value
SM	10^{-2}	%	uint16	2	65535
SM_NOISE	10^{-2}	%	uint16	2	65535

(fully saturated). Degree of saturation expresses the water volume present in the soil relative to the pore volume and can be converted into (absolute) volumetric units m^3m^{-3} with the help of soil porosity information. If the exact amount of residual water content is also known, it can be used to adjust the absolute soil moisture content.

$$\Theta = \Theta_r + p \cdot \text{SM}/100 \tag{1}$$

where Θ is absolute soil moisture in m^3m^{-3} , p is porosity in m^3m^{-3} and Θ_r the residual water content in m^3m^{-3} . As it can be seen in Equation 1, the quality and representativness of soil porosity is important for the translation to absolute soil moisture content.

Soil moisture noise In addition to soil moisture, an estimation of the uncertainty is also provided in the SSM CDR and offline products. The soil moisture noise (SM_NOISE) is computed based on error propagation in the soil moisture retrieval algorithm. The uncertainty, i.e. SM_NOISE, is quantified in terms of the standard deviation and therefore also provided in degree of saturation (%). It is important to understand that not each error source is being described by the error model, e.g. the impact of frozen or snow covered soil are difficult to quantify. For these circumstance, additional information is needed on the soil state (see Product flags 4.2.3) in order to mask affected soil moisture measurements.

4.2.2. Geo-location and satellite parameters

Location ID The location id (LOCATION_ID) is a unique identifier for a single grid point (GP). It is also often referred to as Grid Point Index (GPI). The position of a grid point can be queried using the online DGG locator tool¹.

Row size The number of observations per grid point is indicated by the row size (ROW_SIZE) or, in other words, the length of the time series per grid point. This parameter is needed to extract the time series of a certain grid point.

Latitude The latitude (LATITUDE) position of the grid point in degrees north.

Longitude The longitude (LONGITUDE) position of the grid point in degrees east.

Time The time parameter (TIME) represents the time stamp for the measurements. It is defined as the fraction of days since $1900-01-01\ 00:00:00\ UTC$ (e.g. $1900-01-01\ 00:00:00\ UTC + 39081.2494791667 = 2007-01-01\ 05:59:15\ UTC$).

¹http://rs.geo.tuwien.ac.at/dv/dgg

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Table 4.2: Overview of geo-location and satellite parameters.

Name	Scaling factor	Units	Type	Byte size	NaN value
LOCATION_ID	-	-	int64	8	_
ROW_SIZE	-	-	int64	8	-
LATITUDE	-	Degrees North	float32	4	-
LONGITUDE	-	Degrees East	float32	4	-
TIME	-	Fraction of days	float64	8	-
DIR	-	-	int8	1	127
SAT_ID	-	-	int8	1	127

Orbit direction The orbit direction (DIR) indicates the movement of the spacecraft through the plane of reference. The ascending direction (DIR=0) represents a movement north through the plane of reference, and the descending (DIR=1) south through the plane of reference. Metop-A and Metop-B are flying in a sun-synchronous 29-day repeat cycle orbit with an equator crossing Local Solar Time (LST) of 09:30 a.m. and p.m. in descending and ascending nodes, respectively.

Satellite id The satellite id (SAT_ID) represents the sensor's platform identification (Metop-A=3, Metop-B=4, Metop-C=5).

4.2.3. Flags

The product flags indicate various conditions of interest advising the user on the quality and validity of the soil moisture observations. The flags provide an initial assistance on the usability and shall not prevent the usage of external data sets for masking soil moisture observations.

Table 4.3: Product flags.

Name	Scaling factor	Units	Type	Byte size	NaN value
SSF	-	-	int8	1	127
CONF_FLAG	-	-	uint8	1	255
CORR_FLAG	-	-	uint8	1	255
PROC_FLAG	-	-	uint8	1	255

Surface state flag The surface state flag (SSF) indicates the surface conditions: unknown, unfrozen, frozen, temporary (snow-)melting/water on the surface or permanent ice. The flag should be used to filter invalid soil moisture observations, since a screening has not been performed in advance. This way, users have full control of the masking and can decide on their own in a borderline case (e.g. during freeze/thaw transition periods). If land surface temperature data is available in the study area, it is recommended to combine this information with the SSF.

The retrieval of SSF is based on a logistic regression function and decision trees using temperature and backscatter data [29]. The SSF represents only the top soil layer and performs best during summer and winter periods. During transition periods and in areas with less frequent



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freezing the quality of the SSF deteriorates. In the latter case the relationship between negative temperature and backscatter can be no longer accurately modeled.

Table 4.4: Surface state flag meaning.

Flag value	Flag meaning
0	Unknown
1	Unfrozen
2	Frozen
3	Temporary (snow-)melting/water on the surface
4	Permanent ice
127	NaN

Confidence flag The confidence flag (CONF_FLAG) provides advise on the validity of the soil moisture observations. In case of problematic surface conditions (e.g. frozen soil, mountainous terrain, wetland) and/or high measurement uncertainty, the flag indicates unreliable soil moisture observations. The CONF_FLAG is provided as decimal number and needs to be converted into binary representation, in order to check which bit has been set. For example, CONF_FLAG=23 translates to 00010111 meaning that 1-3 bits and 5 bit are set.

The 1 bit is raised if SSF is set to 2, 3 or 4. The 2 bit is set in case of a high topographic complexity. The topographic complexity is computed as the normalized standard deviation of elevation using GTOPO30 data. The 3 bit indicates if fraction coverage of inundated and wetland areas derived from a combined analysis of the Global Lakes and Wetlands Database (GLWD) Level 3 product and the Global Self-consistent, Hierarchical, High-resolution Shoreline Database GSHHS (v1.5) is higher than 50%. The 4 bit is raised if soil moisture noise is higher than 50%. The 5 bit indicates if the sensitivity (i.e. the difference between wet and dry reference) is less than 1 dB. The 6 and 7 bit are reserved for future use. If all bits are set, the flag is invalid.

Table 4.5: Confidence flag meaning.

Bit	Meaning
1	Bad surface state flag
2	Topographic complexity $> 50\%$
3	Wetland $> 50\%$
4	Soil moisture noise $> 50\%$
5	Sensitivity of soil moisture $< 1 \text{ dB}$
6	Reserved for future use
7	Reserved for future use
1-8	NaN

Processing flag The processing flag (PROC_FLAG) explains the reason why a soil moisture value is set to Not a Number (NaN) in the product. The PROC_FLAG is provided as decimal number and needs to be converted into binary representation, in order to check which bit has been set.



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For example, PROC_FLAG=4 translates to 00000100 meaning that the 3 bit is set. The 1 and 2 bit indicate that soil moisture was out of bounds and the 3 bit show that either backscatter or the dry and wet reference are not valid. If all bits are set, the flag is invalid.

Table 4.6: Processing flag meaning.

Bit	Meaning
1	Original soil moisture lower than -25%
2	Original soil moisture larger than 125%
3	Backscatter is out of limits or dry/wet reference is not valid
4	Reserved for future use
5	Reserved for future use
6	Reserved for future use
7	Reserved for future use
1-8	NaN

Correction flag
The correction flag (CORR_FLAG) indicates that the soil moisture value has been modified. The CORR_FLAG is provided as decimal number and needs to be converted into binary representation, in order to check which bit has been set. For example, CORR_FLAG=1 translates to 00000001 meaning that the 1 bit is set. The 1 and 2 bit are raised if soil moisture was corrected to 0% or 100%, respectively. The 3 bit is raised when a wet correction was applied. In some regions truly saturated conditions are very rare due to the prevailing climate (e.g. deserts). Hence, a correction needs to be applied simulating wet conditions allowing to estimate a real or better wet reference. The application of the wet correction is based on an external climate data set [24], since scatterometer measurements alone are not sufficient to locate these regions. The wet correction is done in two steps: first the lowest level of the wet reference is set to -10 dB and subsequently, raised until a sensitivity (i.e. the minimum difference between the wet and dry backscatter reference) of at least 5 dB has been reached [30]. If all bits are set, the flag is invalid.

Table 4.7: Correction flag meaning.

Bit	Meaning
1	Original soil moisture between -25% and 0%, but set to 0%
2	Original soil moisture between 100% and 125% . but set to 100%
3	Wet correction applied
4	Reserved for future use
5	Reserved for future use
6	Reserved for future use
7	Reserved for future use
1-8	NaN



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Table 4.8: Overview of auxiliary parameters.

Name	Scaling factor	Units	Type	Byte size	NaN value
SIGMA40	10^{-2}	dB	int16	2	32767
SIGMA40_NOISE	10^{-2}	dB	uint16	2	65535
SLOPE40	10^{-3}	dB/degree	int16	2	32767
SLOPE40_NOISE	10^{-5}	dB/degree	uint16	2	65535

4.2.4. Auxiliary information

Backscatter at 40 degree Backscatter normalized to an incidence angle of 40 degree (in dB) (SIGMA40). Backscatter at 40 degree is scaled between the dry and wet backscatter reference in order to compute surface soil moisture information [2].

Backscatter at 40 degree noise An estimation of uncertainty of backscatter at 40 degree incidence angle (in dB) (SIGMA40_NOISE) based on propagation of uncertainty.

Slope at 40 degree The first derivative of the relationship between incidence angle and backscatter at 40 degree (in dB/degree) (SLOPE40). The slope parameter is used for the incidence angle normalization of backscatter and for the computation of the dry and wet backscatter reference.

Slope at 40 degree noise An estimation of uncertainty of slope at 40 degree incidence angle (in dB/degree) (SLOPE40_NOISE) based on propagation of uncertainty.

4.3. Spatial resolution and sampling

The spatial resolution of the Metop ASCAT SSM CDR and extension products is 25-34 km \times 25-34 km and defined by the spatial resolution of the Level 1b input product. A trade-off between spatial resolution and radiometric accuracy was necessary in the processing of the Level 1b product by applying a variable filter width. Thus, the spatial resolution of the Level 1b ranges from 25 km in the near swath to 34 km in the far swath. M ore information on the Level 1b averaging and processing can be found in the ASCAT product guide [28].

The spatial sampling is defined by the WARP 5 grid, which represents a Discrete Global Grid (DGG) with a fixed spacing of 12.5 km in longitudinal and latitudinal direction. The WARP 5 grid consists of 3264391 grid points, but only 839826 gird points are over land and can possibly contain data. The location of the grid points are stored in an auxiliary file available on the H SAF FTP (TUW_WARP5_grid_info_<version>.nc). An interactive tool, the so-called DGG Point Locator² can be used to search for specific grid points.

4.4. Temporal resolution and sampling

The temporal resolution of the Metop ASCAT SSM CDR and extension products represents instantaneous observations. No temporal filtering or averaging has been applied to the surface

²http://rs.geo.tuwien.ac.at/dv/dgg



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soil moisture estimates, i.e. the time stamp from the original Level 1 observation remains unchanged.

The temporal sampling is defined by the number of Metop satellites and latitude. The following Figure 4.2 shows exemplary the coverage of ASCAT for one, two and three Metop satellites within 24 hours.

4.5. Application, limitation and caveats

The soil moisture retrieval algorithm is most suited under following conditions: (i) low to moderate vegetation regimes, (ii) unfrozen and no snow, (iii) low to moderate topographic variations and (iv) no wetlands and coastal areas. Still, the Metop ASCAT SSM CDR product is globally available for all grid points over land. Therefore, users have to decide about masking inaccurate soil moisture values using the enclosed advisory and quality flags (see section 4.2.3), as well as their expert knowledge about the study area. Users are also advised to use the best and most accurate auxiliary data available improving the filtering and masking procedure. As soon as, dense forest, snow cover, frozen soil, open water or topographic complex area are dominating the instrument footprint, the retrieval of soil moisture becomes inaccurate or even impossible. Furthermore, it is important to understand that the error model is not able to describe all error sources, specifically frozen soil, snow and wetland. In such cases, the noise estimation is not reliable.

Depending on the application of the Metop ASCAT SSM CDR product users can decide themselves about the flags and thresholds used in the procedure of filtering and masking inaccurate soil moisture values, e.g. [31], [32]. More details and the influence of the different error sources are discussed in the Algorithm Theoretical Baseline Document (ATBD) [2].

4.6. Validation

The Metop ASCAT SSM CDR v5 has been validated using the Noah GLDAS data set [33] and the ESA CCI passive soil moisture data set (v4.5). As described in the Product Validation Report (PVR) [3], after quality checking and masking the SSM CDR, a temporal and spatial matching has been carried out. The following flags and thresholds have been used to mask inaccurate soil moisture: (i) soil temperature $< 4^{\circ}$ Celsius, (ii) snow water equivalent (SWE) $< 0 \text{ kg m}^{-2}$ and (iii) surface state flag (SSF) > 1. The Pearson Correlation Coefficient and the Signal-to-Noise Ratio (SNR) (using Triple Collocation) were computed as quality benchmarks between the collocated data sets.

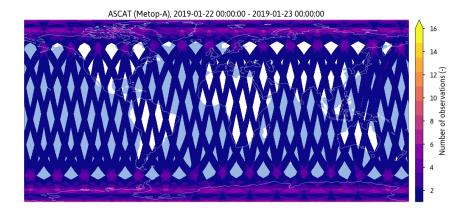
The validation has been performed globally, but the evaluation mainly targets the so-called committed area. This area represents a restricted geographical region with high confidence in the successful retrieval of surface soil moisture and is limited to: (i) low and moderate vegetation regimes, (ii) unfrozen and no snow cover, (iii) low to moderate topographic variations, as well as (iv) no wetlands and coastal areas (see Figure 4.3). More information about the products requirements can be found in the Product Requirements Document (PRD) [34]).

The validation results indicate an acceptable performance for the committed product area (see Figure 4.4). On a global scale, a lower performance of the Metop ASCAT SSM CDR v5 can be found in areas with low soil moisture dynamics (e.g. deserts) or at higher latitudes. In the latter case, frozen soil and snow cover are the main reason why many measurements needs to be masked. Therefore, in these regions only summer months can be used for validation.

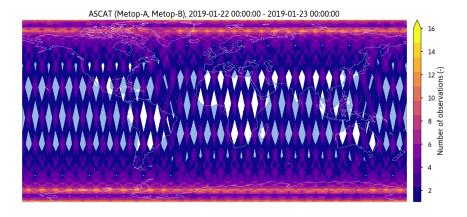
 $\begin{array}{l} {\rm Doc. No:\ HSAF/CDOP3/PUM/} \\ {\rm Issue/Revision:\ 0.1} \end{array}$

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(a)



(b)



(c)

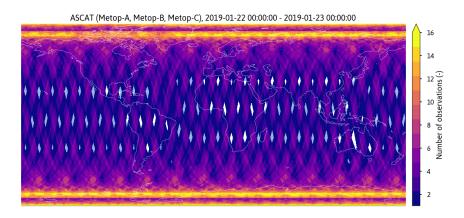


Figure 4.2: Number of ASCAT observations within 24 hours for one (a), two (b) and three (c) Metop satellites.

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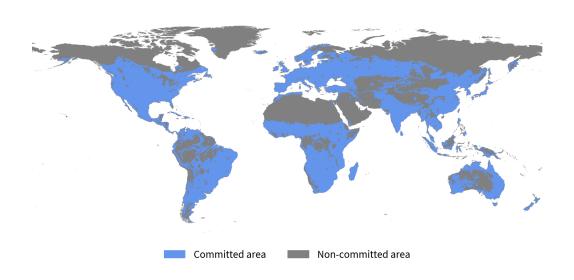


Figure 4.3: Map showing the committed product area.

More detailed information about the validation can be found in the Product Validation Report (PVR) [3].

4.7. File format

The CDR and offline products are provided in NetCDF and follow the Climate and Forecast (CF) Metadata Conventions v1.6 [35]. The time series representation of the CDR and offline products is organized in cells. A cell contains a number of grid points stored as NetCDF file (<hsaf_identifier>_<cell_nr>.nc). This way, the two extreme cases will be avoided: (i) one file per grid point and (ii) one file for all grid points. A cell is defined as 5° × 5° and contains up to 2000 grid points. The cell number and the number of grid points per cell are shown in Figure 4.5. A look-up between grid point index (GPI) and cell number, longitude and latitude can be found in an auxiliary file (TUW_WARP5_grid_info_<version>.nc) available on the H SAF FTP.

The time series are stored in the contiguous ragged array representation defined by the NetCDF Climate and Forecast (CF) Metadata Conventions [35]. The time series parameters (like SM and SM_NOISE) are associated with the coordinate values time(obs), lat(i) and lon(i), where i indicates which grid point time series. The time series i comprises the following data elements:

where

$$row_start(i) = 0$$
 if $i = 0$

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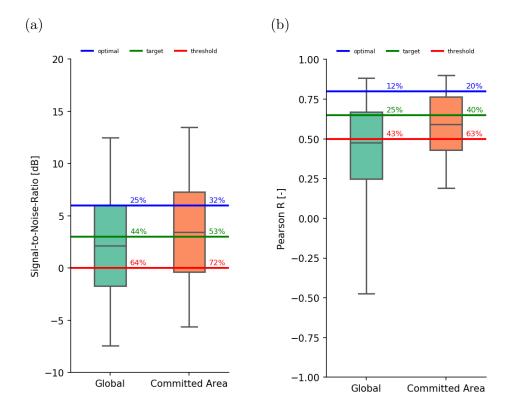


Figure 4.4: The boxplots indicate the distribution of the quality benchmarks globally and just for the committed area. A percentage of locations exceeding each of the three thresholds is indicated as well.

The variable row_size is the count variable containing the length of each time series feature. It is identified by having an attribute with name $sample_dimension$ whose value is name of the sample dimension (obs in this case). The auxiliary location parameters lat and lon are GPI variables.

An example of the NetCDF variables is shown in the Listing 4.1. The NetCDF can be read using the ascat³ Python package or older versions of the pytesmo⁴ Python package. The following Figure 4.6 shows a time series example.

³https://github.com/TUW-GEO/ascat

⁴https://github.com/TUW-GEO/pytesmo



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2591	2590	5289	1588	17.6	2367	2586	2585	2584	111	° 2583	2582	2581	2580	2579	2578	2577	2576	2575	2574	2573	2572	2571	2570	2569	0 0 0	2567	2566	2565	2564	\$563	2562	2561	2560	2559	2558	2557	3556
2555	2554 2	2553 2	2552 2	69 133		2550 2	2549 2	12			2546 2	2545 2	2544 2580	2543 2	2542	2541	2540 2	2539 2	2538	2537 2	2536 2	2535 2	2534 2	2533 2	2532 2	2531 2	2530 2	2529 2	2528 2	2527 2563	2526 2	2525 2	2524 2	2523 2	2522	2521 255	25.20
2519	2518	2517	2516	S		2514	2513	2512	200	0 0	2510	2509	2508	2507	2506	2505	2504	2503	2502	2501	2500	2499	2498	2497	2496	2495	2494	2493	2492	2491	2490	2489	2488	2487	2486	2485	2404
2483	2482	2481	2480	2	788 771	442 2478 834 907	2477	2476	346		2474	2473	2472	2471	2470	2469	2468	2467	2466	2465	2464	2463	2462	2461	2460	2459	2458	2457	2456	2455	2454	2453	2416 2452	2415 2451 2487	2414 2450	2413 2449	3440
2447	2446	2445	2444	200	2 SE	2442	2441 247	2440	100	2439	2438	2437	2436	2435	2434	2433	2432	2431	2430	2429	2428	2427	2426	2425	2424	2423	2422	2421	2420	2419	2418	2417	2416	2415	2414	2413	0.000
2411	2410	2409	2408	338	240/	2406	2405	2404	\$	2403	2402	2401	2400	2399	2398	2397	2396	2395	2394	2393	2392	2391	2390	2389	2388	2387	2386	2385	2384	2383	2382	2381	2380	2379	2342 2378	2377	2376
2375	2374	2373	2372	483	702	2370	2369	2368	"	2367	2366	2365	2364	2363	2362	2361	2360	2359	2358	2357	2356	2355	2354	2353	2352	2351	2350	2349	2348	2347	2346	2345	2344	2343	2342	2341	23.40
2339	2338	2337	2336	9 5	253 21	2334	2333	2332	1001	2331	2330	2329	2328	2327	2326	2325	2324	2323	2322	2321	2320	2319	2318	2317	2316	2315	2314	2313	2312	2311	2310	2309	2308	2307	2306	2305	2304
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2231	2230	2229	2228	905	777 TII	2226	2225	2224	1193	1354	2222	2221	2220	2219	2218	2217	2216	2215	2214	2213	2212	2211	2210	2209	2208	2207	2206	2205	2204	2203	2202	2201	2200	2199	2198	2197	2106
2195	2194	2193	2612	528	707	2190	2189	2188	110	2187	2186	2185	2184	2183	2182	2181	2180	2179	2178	2177	2176	2175	2174	2173	2172	2171	2170	2133 2169	2168	2167	2130 2166	2165	2164	2163	2162	2161	2160
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1907	1906	1905	1904	085	270	1902	1901	1900	311	1899	1898	1897	1896	1895	1894	1893	1892	1891	1890	1889	1888	1887	1886	1885	1884	1883	1882	1881	1880	1879	1878	1877	1876	1875	1874	1873	1872
1871	1870	1869	1868	8	700	1866	1865	1864	1911	1556	1862	1861	1860	1859	1858	1857	1856	1855	1854	1853	1852	1851	1850	1849	1848	1847	1846	1845	1844	1843	1842	1841	1840	1839	1838	1837	1836
1835	1834	1833	1832	9	700	1830	1829	1828	310	1827	1826	1825	1824	1823	1822	1821	1820	1819	1818	1817	1816	1815	1814	1813	1812	1811	1810	1809	1808	1807	1806	1805	1804	1803	1802	1801	1800
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1547	1546	1545	1544	103		1542	1541	1540	311	1539	1538	1537	1536	1535	1534	1533	1532	1531	1530	1529	1528	1527	1526	1525	1524	1523	1522	1521	1520	0 0	1518	1517	1516	1515	1514	1513	1512
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1439	1438	1437		3	1430	31434	1433	1432	611	188	1430	1429	1428	1427	1426	1425 187	1424	1423	1422	1421	1420	1415	1418	1417	1416	1415	1414	1413	1412	1411	1410	1409	1408	1407	1406	3 1405	140
1403	1402	5 1401	12	0	9	1398	1397	1396	110	1395	1394	1393	1392	1391	1390	1389	1388	1387	1386	1385	3 1384 XII	1383	1382	1381	1380	1379	1378	1377	1376	1375	1374	1373	1372	1371	1370	1369	1369
1367	1366	13	1364	0		1362	1361	1360	108	1359	1358	1357	1356	1355	1354	1353	1352	1351	1350	1349	1348	1347	1346	1345	1344	1343	1342	1341	1340	1339	1338	1337	1336	1335	1334	1297 1333 0 0	1332
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9 1295	8 1294	7 1293	6 1292			1290	3 1285	178	F.	7 102	0 1286	9 128	8 128	7 128	5 128	5 128;	1280	3 1279	2 1278	7721	0 1276	9 1275	8 1274	7 1273	6 1272	1271	1270	3 1269	2 1268	1267	0 1266	9 1265	8 1264	7 1263	6 1262	5 1261	1260
1259	1258	1257	1256	*		1254	1253	1252	100	125	1250	1245	1248	1247	1246	1245	1244	1243	1242	1241	1240	1239	1238	1237	1236	1235	1234	1233	1232	1231	1230	1229	1228	1227	1226	1225	1224
1223	1222	1221	12	22		1218	1217	12			1214	1213	1212	1211	1210	1209	1208	1207	1206	1205	1204	1203	1202	1201	1200	1199	1198	, ,	1196	1195	1194	1193	1192	1191	1190	1189	1186
1187	1186	1185	-			1182	1181	188			1178	7711	1176	1175 1	1174	1173	2711	117	1170	1169	1168	1167	1166	1165	1164	1163	1162	1161	1160	1159	1158	1157	1156	1155	1118 1154	1153	1150
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9 1115	117	1113			N.	1110	3 1109	1108			1106	9 1105	1104	1103	1102	1101	1100	1099	2 1098	1097	1096	1095	3 1094	1093	1092	1001	1000	1089	1088	1087	1086	3 1085	3 1084	7 1083	1082	1081	1080
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971	970	696	01	88 5	796	9966	0.	9 8			962	961	96	929	858	957	926	955	954	953	95,	101	956	3 948	948	947	946	945	944	943	942	941	940	939	938	937	986
	934	933	932	8	2 12	930	929	826		726	926	925	3 924	923	922	921	920	919	918 1934	201	916	161 6	917	913	912	116 5	910	906	906	907	906	900	96 °	903	902	901	900
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		7 753	110	8	0 8	4 750 14 878	3 74	2 74	3 .	2 2	24 24	74	244	743	6 742	27.8	_	3 739	73	67 % 262 %	5 73	9 73	8 734	7 733		6 731	4 730	9 729		727 0		-		11/1		5 721	720
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		1 177						6 172			4 170	3 169	2 168	1 167		9 165		7 163	6 162		9 160		2	1 157		9 155		7 153	6 152	5 151	4 150	3 149	2 148	1 147	-	9 145	144
7 143								0 136			8 134 °	7 133	96 132	95 131	130	3 129 0	2 128	1 127	0 126	9 125	8 124 0 0		6 122	85 121 ° °		3 119		111 °	0 116	79 115 °°°	78 114 ° °	7 113	76 112	111 8	4 110	73 109	77 108
71 107 ° °	0 106	69 105						64 100			62 98	61 97		59 95	58 94 °	57 93 0	56 92 0	55 91 0	54 0 0	53 89 0	52 88		98 05 0			47 83 0 0		45 81 °	44 80 °	0 79	0 78	41 77	97 0	39 75	38 74	37 73	36 72
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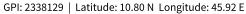
Figure 4.5: $5^{\circ} \times 5^{\circ}$ cell partitioning of the grid points. The upper number in each cell represents the cell number and the lower number the number of grid points in this cell.

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Listing 4.1: Example of NetCDF variables and dimension for H115 cell 28.

```
locations = 4;
        obs = UNLIMITED ; // (32833 currently)
variables:
        int64 row_size(locations);
                row_size:long_name = "number of observations at this location" ;
                row_size:sample_dimension = "obs" ;
        float lon(locations) ;
                lon:units = "degrees_east" ;
                lon:long_name = "location longitude";
                lon:standard_name = "longitude" ;
                lon:valid\_range = -180., 180.;
        float lat(locations) ;
                lat:units = "degrees_north" ;
                lat:long_name = "location latitude" ;
                lat:standard_name = "latitude" ;
                lat:valid_range = -90., 90. ;
       float alt(locations) ;
                alt:units = "m"
                alt:long_name = "vertical distance above the surface" ;
                alt:standard_name = "height" ;
                alt:axis = "Z" ;
                alt:positive = "up" ;
```



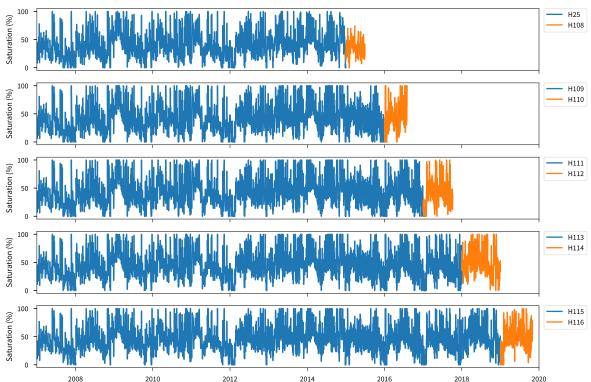


Figure 4.6: Example of surface soil moisture time series from various SSM CDR.



int64 location_id(locations);

PUM ASCAT SSM CDR v5 12.5 km (H115) ASCAT SSM CDR v5 Extension 12.5 km (H116)

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```
string location_description(locations) ;
double time(obs);
        time:units = "days since 1900-01-01 \ 00:00:00";
        time:long_name = "time of measurement" ;
        time:standard_name = "time" ;
byte proc_flag(obs);
        proc_flag:long_name = "processing flag" ;
        proc_flag:name = "proc_flag" ;
        proc_flag:flag_meanings = "
           soil_moisture_set_to_nan_it_was_below_ -25
           soil_moisture_set_to_nan_it_was_above_125
           \verb|soil_moisture_set_to_nan_backscatter_not_usable|\\
           {\tt reserved\_for\_future\_use} \ {\tt reserved\_for\_future\_use}
           reserved_for_future_use reserved_for_future_use"
        proc_flag:flag_masks = 1b, 2b, 4b, 8b, 16b, 32b, 64b ;
        proc_flag:coordinates = "time lat lon" ;
        proc_flag:valid_range = 0b, 127b ;
short slope40(obs);
        slope40:scale_factor = 0.001f ;
        slope40:name = "slope40" ;
        slope40:coordinates = "time lat lon" ;
        slope40:valid\_range = -10000s, 10000s;
        slope40:long_name = "slope at 40 degree" ;
        slope40:units = "dB/degree";
        slope40:missing_value = 32767LL ;
byte conf_flag(obs);
        conf_flag:long_name = "confidence flag";
        conf_flag:name = "conf_flag" ;
        conf_flag:flag_meanings = "bad_surface_state_flag
           topographic_complexity_above_50perc wetland_above_50perc
           soil_moisture_noise_above_50perc
           \verb"sensitivity_to_soil_moisture_below_1dB"
           reserved_for_future_use reserved_for_future_use" ;
        conf_flag:flag_masks = 1b, 2b, 4b, 8b, 16b, 32b, 64b;
        conf_flag:coordinates = "time lat lon" ;
        conf_flag:valid_range = 0b, 127b ;
ushort slope40_noise(obs);
        slope40_noise:scale_factor = 1.e-05f ;
        slope40_noise:name = "slope40_noise" ;
        slope40_noise:coordinates = "time lat lon" ;
        slope40_noise:valid_range = OUS, 10000US;
        slope40_noise:long_name = "slope at 40 degree noise" ;
        slope40_noise:units = "dB/degree" ;
        slope40_noise:missing_value = 65535US ;
ushort sigma40_noise(obs);
        sigma40_noise:scale_factor = 0.01f ;
        sigma40_noise:name = "sigma40_noise" ;
        sigma40_noise:coordinates = "time lat lon" ;
        sigma40_noise:valid_range = OUS, 10000US;
        sigma40_noise:long_name = "backscatter at 40 degree noise" ;
        sigma40_noise:units = "dB" ;
        sigma40_noise:missing_value = 65535US ;
byte corr_flag(obs) ;
        corr_flag:long_name = "correction flag" ;
        corr_flag:name = "corr_flag" ;
        corr_flag:flag_meanings = "
```

PUM

ASCAT SSM CDR v5 12.5 km (H115) ASCAT SSM CDR v5 Extension 12.5 km (H116) Doc.No: HSAF/CDOP3/PUM/

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```
soil_moisture_set_to_0_it_was_between_0_and_-25
           soil_moisture_set_to_100_it_was_between_100_and_125
           wet_correction_applied reserved_for_future_use
           reserved_for_future_use reserved_for_future_use
           reserved_for_future_use" ;
        corr_flag:flag_masks = 1b, 2b, 4b, 8b, 16b, 32b, 64b ;
        corr_flag:coordinates = "time lat lon" ;
        corr_flag:valid_range = 0b, 127b ;
ushort sm(obs);
        sm:scale_factor = 0.01f ;
        sm:name = "sm";
        sm:coordinates = "time lat lon" ;
        sm:valid_range = OUS, 10000US;
        sm:long_name = "soil moisture" ;
        sm:units = "percentage" ;
        sm:missing_value = 65535US ;
byte sat_id(obs);
        sat_id:name = "sat_id" ;
        sat_id:flag_meanings = "ers-1, ers-2, metop-a, metop-b, metop-c"
        sat_id:coordinates = "time lat lon" ;
        sat_id:valid_range = 1b, 5b ;
        sat_id:long_name = "satellite id" ;
        sat_id:flag_values = 1b, 2b, 3b, 4b, 5b;
        sat_id:missing_value = 127b ;
byte ssf(obs);
        ssf:name = "ssf";
        ssf:flag_meanings = "unknown unfrozen frozen_temporary
           melting_water_on_the_surface permanent_ice" ;
        ssf:coordinates = "time lat lon" ;
        ssf:valid_range = 0b, 4b;
        ssf:long_name = "surface state flag" ;
        ssf:flag_values = 0b, 1b, 2b, 3b, 4b;
        ssf:missing_value = 127b;
short sigma40(obs) ;
        sigma40:scale_factor = 0.01f;
        sigma40:name = "sigma40";
        sigma40:coordinates = "time lat lon" ;
        sigma40:valid_range = -10000s, 10000s;
        sigma40:long_name = "backscatter at 40 degree";
        sigma40:units = "dB";
        sigma40:missing_value = 32767LL;
byte dir(obs);
        dir:name = "dir" ;
        dir:flag_meanings = "ascending descending" ;
        dir:coordinates = "time lat lon" ;
        dir:valid_range = 0b, 1b ;
        dir:long_name = "orbit direction" ;
        dir:flag_values = 0b, 1b ;
        dir:missing_value = 127b ;
ushort sm_noise(obs);
        sm_noise:scale_factor = 0.01f ;
        sm_noise:name = "sm_noise" ;
        sm_noise:coordinates = "time lat lon";
        sm_noise:valid_range = OUS, 10000US;
        sm_noise:long_name = "soil moisture noise" ;
        sm_noise:units = "percentage" ;
```



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```
sm_noise:missing_value = 65535US ;
```

5. Product download, terms and condition

The soil moisture products are available via FTP. Download details are available after registering at the H SAF website http://h-saf.eumetsat.int/. If you need help, please contact the H SAF user helpdesk us_hsaf@meteoam.it.

All H SAF products are owned by EUMETSAT and the EUMETSAT SAF Data Policy applies⁵. The products are available for all users free of charge and users should recognize the respective roles of EUMETSAT, the H SAF Leading Entity and the H SAF Consortium when publishing results that are based on H SAF products. EUMETSAT's ownership and intellectual property rights into the SAF data and products is best safeguarded by simply displaying the words "© EUMETSAT" under each of the SAF data and products shown in a publication or website.

5.1. Acknowledgment and citation

The SSM CDR and Extension product should be cited (depending on the bibliography style) as follows:

H SAF (2019): ASCAT Surface Soil Moisture Climate Data Record v5 12.5 km sampling - Metop, EUMETSAT SAF on Support to Operational Hydrology and Water Management, DOI: 10.15770/EUM_SAF_H_0006. http://dx.doi.org/10.15770/EUM_SAF_H_0006

H SAF (2019): ASCAT Surface Soil Moisture Climate Data Record v5 Extension 12.5 km sampling - Metop, EUMETSAT SAF on Support to Operational Hydrology and Water Management. https://navigator.eumetsat.int/product/EO:EUM:DAT:METOP:H116

 $^{^5} https://www.eumetsat.int/website/home/AboutUs/WhoWeAre/LegalFramework/DataPolicy/index.html$



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5.2. User feedback and support

User feedback is warmly welcomed and encouraged. All questions and remarks concerning the product can be addressed to the H SAF user helpdesk us_hsaf@meteoam.it

5.3. Downstream services

The Metop ASCAT SSM CDR represents a base product for downstream services such as the Copernicus Global Land Service (CGLS)⁶ or the ESA Climate Change Initiative (CCI)⁷. In case of CGLS, Metop ASCAT SSM observations are translated into the Soil Water Index (SWI), which quantifies the soil moisture profile from surface conditions. It is based on an exponential filter and the assumption that over a large footprint only the relative dynamic range of the soil water content can be represented accurately, since the variability of soil characteristics can be very high [36]. In case of ESA CCI, Metop ASCAT SSM CDR is part of the ESA CCI active soil moisture data set, which represents a combination of soil moisture products based on active microwave instruments. The active product is further merged with a passive soil moisture product creating a combined long-term soil moisture data record [37]. The downstream services CGLS and ESA CCI provide their products at a different spatial and temporal sampling compared to the original Metop ASCAT SSM CDR product.

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⁶https://land.copernicus.eu/global/products/swi

⁷https://esa-soilmoisture-cci.org



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Appendices

A. Introduction to H SAF

H SAF is part of the distributed application ground segment of the "European Organization for the Exploitation of Meteorological Satellites (EUMETSAT)". The application ground segment consists of a Central Application Facilities located at EUMETSAT Headquarters, and a network of eight "Satellite Application Facilities (SAFs)", located and managed by EUMETSAT Member States and dedicated to development and operational activities to provide satellite-derived data to support specific user communities (see Figure A.1):

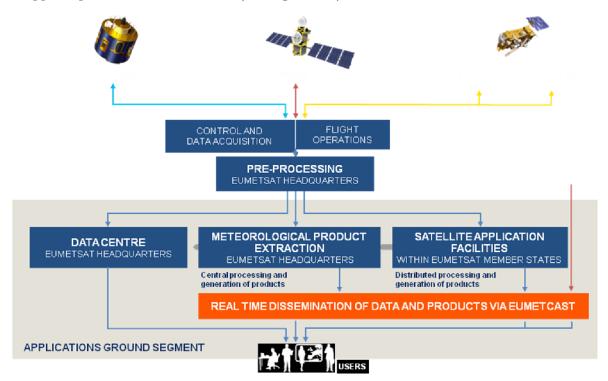


Figure A.1: Conceptual scheme of the EUMETSAT Application Ground Segment.

Figure A.2 here following depicts the composition of the EUMETSAT SAF network, with the indication of each SAF's specific theme and Leading Entity.

B. Purpose of the H SAF

The main objectives of H SAF are:

- a) to provide new satellite-derived products from existing and future satellites with sufficient time and space resolution to satisfy the needs of operational hydrology, by generating, centralizing, archiving and disseminating the identified products:
 - precipitation (liquid, solid, rate, accumulated);
 - soil moisture (at large-scale, at local-scale, at surface, in the roots region);

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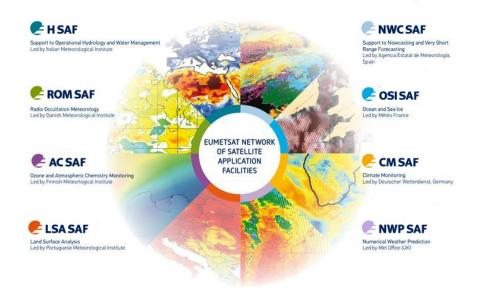


Figure A.2: Current composition of the EUMETSAT SAF Network.

- snow parameters (detection, cover, melting conditions, water equivalent);
- b) to perform independent validation of the usefulness of the products for fighting against floods, landslides, avalanches, and evaluating water resources; the activity includes:
 - downscaling/upscaling modelling from observed/predicted fields to basin level;
 - fusion of satellite-derived measurements with data from radar and raingauge networks;
 - assimilation of satellite-derived products in hydrological models;
 - assessment of the impact of the new satellite-derived products on hydrological applications.

C. Products / Deliveries of the H SAF

For the full list of the Operational products delivered by H SAF, and for details on their characteristics, please see H SAF website http://h-saf.eumetsat.int. All products are available via EUMETSAT data delivery service (EUMETCast⁸), or via ftp download; they are also published in the H SAF website⁹.

All intellectual property rights of the H SAF products belong to EUMETSAT. The use of these products is granted to every interested user, free of charge. If you wish to use these products, EUMETSAT's copyright credit must be shown by displaying the words "copyright (year) EUMETSAT" on each of the products used.

 $^{{}^{8}} http://www.eumetsat.int/website/home/Data/DataDelivery/EUMETCast/index.html$

⁹http://h-saf.eumetsat.int/



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D. System Overview

H SAF is lead by the Italian Air Force Meteorological Service (ITAF MET) and carried on by a consortium of 21 members from 11 countries (see website: http://h-saf.eumetsat.int/ for details) Following major areas can be distinguished within the H SAF system context:

- Product generation area
- Central Services area (for data archiving, dissemination, catalogue and any other centralized services)
- Validation services area which includes Quality Monitoring/Assessment and Hydrological Impact Validation.

Products generation area is composed of 5 processing centres physically deployed in 5 different countries; these are:

- for precipitation products: ITAF CNMCA (Italy)
- for soil moisture products: ZAMG (Austria), ECMWF (UK)
- for snow products: TSMS (Turkey), FMI (Finland)

Central area provides systems for archiving and dissemination; located at ITAF CNMCA (Italy), it is interfaced with the production area through a front-end, in charge of product collecting. A central archive is aimed to the maintenance of the H SAF products; it is also located at ITAF CNMCA.

Validation services provided by H SAF consists of:

- Hydrovalidation of the products using models (hydrological impact assessment);
- Product validation (Quality Assessment and Monitoring).

Both services are based on country-specific activities such as impact studies (for hydrological study) or product validation and value assessment. Hydrovalidation service is coordinated by IMWM (Poland), whilst Quality Assessment and Monitoring service is coordinated by DPC (Italy): The Services activities are performed by experts from the national meteorological and hydrological Institutes of Austria, Belgium, Bulgaria, Finland, France, Germany, Hungary, Italy, Poland, Slovakia, Turkey, and from ECMWF.