

Doc.No: HSAF/CDOP3/PUM/ Issue/Revision: 0.2 Date: 2022/03/02 Page: 1/33

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 v7 12.5 km (H119) and Extension (H120)



## **Revision History**

Revision	Date	Author(s)	Description
0.1	2021/05/28	TU Wien	First draft based on H115 PUM. Update graph-
			ics and product description.
0.2	2022/03/02	TU Wien	Fixed typos, updated sections 1, 2 and updated
			figures 4.1, 4.3.

## How to cite this document

H SAF, Product User Manual (PUM) Metop ASCAT Surface Soil Moisture Climate Data Record v7 12.5 km sampling (H119) and Extension (H120), v0.2, 2022. [1]



## **Table of Contents**

Lis	t of Acronyms	5
1.	Executive summary	7
2.	Introduction           2.1. Purpose of the document	<b>7</b> 7 7 7
3.	Climate Data Record and Extension         3.1. Product category and status	<b>8</b> 8 9
4.	Metop ASCAT Surface Soil Moisture CDR v7 12.5 km         4.1. Lineage         4.2. Parameters         4.2.1. Soil moisture         4.2.2. Geo-location and satellite parameters         4.2.3. Flags         4.2.4. Auxiliary information         4.3. Spatial resolution and sampling         4.4. Temporal resolution and sampling         4.5. Application, limitation and caveats         4.6. Validation         4.7. File format	<ol> <li>9</li> <li>10</li> <li>11</li> <li>12</li> <li>13</li> <li>16</li> <li>16</li> <li>16</li> <li>17</li> <li>19</li> </ol>
5.	Product download, terms and condition         5.1. Acknowledgment and citation         5.2. User feedback and support         5.3. Downstream services	<b>26</b> 26 27 27
6.	References	27
Ар	pendices	31
Α.	Introduction to H SAF	31
В.	Purpose of the H SAF	31
C.	Products / Deliveries of the H SAF	32
D.	System Overview	33



## List of Tables

9.1	List of available Motor ACCAT SCM CDD meduate	0
J.1.	List of available Metop ASCAT SSM CDR products	9
3.2.	List of available Metop ASCAT SSM CDR Extension products	9
4.1.	Overview of soil moisture parameters	2
4.2.	Overview of geo-location and satellite parameters	.3
4.3.	Product flags	.3
4.4.	Surface state flag meaning	.4
4.5.	Confidence flag meaning 1	.4
4.6.	Processing flag meaning	5
4.7.	Correction flag meaning	5
4.8.	Overview of auxiliary parameters	6

# List of Figures

4.1.	Mean surface soil moisture from Metop ASCAT SSM CDR v7 for the period	
	2007-2020 globally (a) and for the committed area only (b)	11
4.2.	Number of ASCAT observations within 24 hours for one (a), two (b) and three	
	(c) Metop satellites	18
4.3.	Map showing the committed product area	19
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.	20
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	21
4.6.	Example of surface soil moisture time series from various SSM CDR	22
A.1.	Conceptual scheme of the EUMETSAT Application Ground Segment	31
A.2.	Current composition of the EUMETSAT SAF Network.	32



## 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
- $\ensuremath{\mathsf{EUM}}$  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
- $\boldsymbol{\mathsf{NRT}}$  Near Real-Time
- **NWP** Near Weather Prediction
- **PRD** Product Requirements Document
- **PUM** Product User Manual
- $\ensuremath{\mathsf{PVR}}$  Product Validation Report
- **SAF** Satellite Application Facility
- **SAR** Synthetic Aperture Radar
- ${\sf SRTM}$ Shuttle Radar Topography Mission
- ${\sf SZF}$ Sigma Zero Full resolution
- **SZO** Sigma Zero Operational (25 km spatial sampling)



- **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
- $\ensuremath{\mathsf{WARP}}\xspace$  NRT WARP Near Real-Time
- **ZAMG** Zentralanstalt für Meteorologie und Geodynamic (National Meteorological Service of Austria)



## 1. Executive summary

The Product User Manual (PUM) describes the Metop ASCAT Surface Soil Moisture (SSM) Climate Data Record (CDR) v7 12.5 km (H119) [2] and extension (H120) [3]. A general introduction of the purpose of this document and a section identifying related surface soil moisture products are described 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 v7 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) [4]. 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) [5].

## 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) [4], for extensive details on the algorithms, only highlighted here.
- Product Validation Report (PVR) [5], for a 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 layers (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/.



## 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), Data Record (DR) 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 selfcontained data set, i.e. it cannot be manipulated 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 timely. 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



- 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 level of maturity 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.

		-		•
CDR	Satellite	ATBD	PVR	Temporal coverage
H25 [6]	Metop-A	[7]	[8]	2007-01-01 - 2014-12-31
H109 [ <mark>9</mark> ]	Metop-A,-B	[10]	[11]	2007-01-01 - 2015-12-31
H111 [12]	Metop-A,-B	[10]	[13]	2007-01-01 - 2016-12-31
H113 [14]	Metop-A,-B	[15]	[16]	2007-01-01 - 2017-12-31
H115 [ <b>17</b> ]	Metop-A,-B	[18]	[19]	2007-01-01 - 2018-12-31
H119 [2]	Metop-A,-B,-C	[4]	[5]	2007-01-01 - 2020-12-31

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

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

Extension	CDR	Temporal coverage
H108 [20]	H25	2015-01-01 - 2015-06-30
H110 [21]	H109	2016-01-01 - 2016-07-31
H112 [22]	H111	2017-01-01 - 2017-11-01
H114 [23]	H113	2018-01-01 - 2018-12-31
H116 [24]	H115	2019 - 01 - 01 - 2021 - 12 - 31
H120 [ <b>3</b> ]	H119	2021-01-01 - ongoing

## 4. Metop ASCAT Surface Soil Moisture CDR v7 12.5 km

#### 4.1. Lineage

The Metop ASCAT Surface Soil Moisture (SSM) Climate Data Record (CDR) v7 12.5 km product (H119) is based on Metop-A, -B, -C 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) [25] is used and combined with archived Metop-A Level 1b NRT product from 2014-04-01 until 2020-12-31 [26]. In case of Metop-B (2013-01-01 until 2020-12-31) and Metop-C (2019-04-01 until 2020-12-31), the Level 1b NRT product has been used [26]. The empirical model parameters generated during the retrieval of surface soil moisture have been derived from Metop-A, -B and -C together. Further input data sets used to generate the Metop ASCAT SSM CDR v7 are the Köppen Geiger Climate Classification [27] and land surface temperature from ERA5 [28].

The EUMETSAT H SAF TU Wien soil moisture retrieval algorithm [4], [29], [30] 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 2007-2020 derived from Metop ASCAT SSM CDR v7 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 for the 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) [4]. The ASCAT Product Guide [31] 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 v6 (H115) [17].

- Derivation of new empirical model parameters
- Add Metop-C ASCAT Level 1b product
- Introducing spatially-variable cross-over angles [32]
- Increasing threshold of masking backscatter observations affected by water bodies during resampling

#### 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.





Figure 4.1: Mean surface soil moisture from Metop ASCAT SSM CDR v7 for the period 2007-2020 globally (a) and for the committed area only (b).

#### 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% (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  $\Theta$  is absolute soil moisture in  $m^3m^{-3}$ , p is porosity in  $m^3m^{-3}$  and  $\Theta_r$  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.

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

#### 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 tool<sup>1</sup>.

**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).

<sup>&</sup>lt;sup>1</sup>https://dgg.geo.tuwien.ac.at/



**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 satellites 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, -B=4, -C=5).

				· P ··· ··· · · · · · · ·	
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

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

#### 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.

	iable	1.0. 1 10.	auce mag		
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

Table 4.3: Product flags.

**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 [33]. 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



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.
10010 1.1.	Sarrace	00000	11005	mooning.

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.



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	$6 \cdot Pr$	ocessing	flag	meaning
тарис ч.	.0. I I	occosing	mag	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 [27], 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 [34]. 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



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

Table 4.8: Overview of auxiliary parameters.

#### 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 [4].

**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. More information on the Level 1b averaging and processing can be found in the ASCAT product guide [31].

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 Locator<sup>2</sup> 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

 $<sup>^{2}</sup>$  https://dgg.geo.tuwien.ac.at/



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. [35], [36]. More details and the influence of the different error sources are discussed in the Algorithm Theoretical Baseline Document (ATBD) [4].

#### 4.6. Validation

The Metop ASCAT SSM CDR v7 has been validated using the Noah GLDAS data set [37] and the ESA CCI passive soil moisture data set (v4.5). As described in the Product Validation Report (PVR) [5], 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 kg m<sup>-2</sup> 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) [38]).

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 v7 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.



Doc.No: HSAF/CDOP3/PUM/ Issue/Revision: 0.2 Date: 2022/03/02 Page: 18/33

(a)



(b)



(c)



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





Figure 4.3: Map showing the committed product area.

More detailed information about the validation can be found in the Product Validation Report (PVR) [5].

#### 4.7. File format

The CDR and offline products are provided in NetCDF and follow the Climate and Forecast (CF) Metadata Conventions v1.6 [39]. 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  $5^{\circ} \times 5^{\circ}$  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 table between grid point index (GPI) and cell number, longitude and latitude is provided 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 [39]. 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 the grid point time series. The time series i comprises the following data elements:

row\_start(i) to row\_start(i) + row\_size(i)-1

where

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

The variable **row\_size** is the count variable containing the length of each time series feature along with an attribute named *sample\_dimension* which holds the name of the sample dimension (*obs* in this case). The auxiliary location parameters **lat** and **lon** are GPI variables.





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.



Doc.No: HSAF/CDOP3/PUM/ Issue/Revision: 0.2 Date: 2022/03/02 Page: 21/33

•	53 2589 °	52 2588	51 2587	50 2586	852 619 40 25.05	•	48 2584 117 117	47 2583	•	0 0 0	45 2581	44 2580	43 2579	0 0 2578	•	41 2577 • •	40 2576	39 2575	0 0 7574	0	37 2573 %8 0	36 2572	35 2571	34 2570	8	0 0	32 2568	31 2567	30 2566	622 B40	COC2 C20	28 2564	27 2563	26 2562	25 2561	0 0 24 2560	0	23 2559 ° °	222 2558 e e	21 2557	20 2556	• 921
•	2517 25	2516 25	2515 25	2514 25	005	N.	2512 25	2511 25	0 00	22 0122	2509 25	2508 25	2507 25	0 2506.25	۰	2505 25	2504 25	2503 25	0 25035	0	2501 25	2500 25	2499 25	2498 25	780	C7 / 647	2496 25	2495 25	2494 25	0 0000	1 316 1	2492 25	2491 25	2490 25	2489 25	0 2488.25	0	2487 25	2486 25	2485 25	2484 25	•
•	445 2481	444 2480	443 2479	442 2478	06 HS	105 268	440 2476 1025 246	439 2475	16	438 24/4 •	437 2473	436 2472	435 2471	07470	•	433 2469	432 2468	431 2467	342 2466	-	429 2465	428 2464	427 2463	<sup>36</sup> 3/2 426 2462	0	1047 074	424 2460	423 2459	422 2458	*	1547 T74	420 2456	419 2455	418 2454	417 2453	0 0 016 2452	•	415 2451	414 2450	413 2449	412 2448	• 09
•	3 2409 2	2 2408 2	1 2407 2	0 2406 2	0 2405 2	366	8 2404 2	7 2403 2	439	6 2402 2	5 2401 2	4 2400 2	3 2399 2	0 0 0	2115	1 2397 2	0 2396 2	9 2395 2	212 0	3 0	7 2393 2	6 2392 2	5 2391 2	4 2390 2	0	7 6367 5	2 2388 2	1 2387 2	0 2386 2	11 255	2 C362 5	8 2384 2	7 2383 2	6 2382 2	5 2381 2	0 0 0	0	3 2379 2	2 2378 2	1 2377 2	0 2376 2	• <u>101</u>
0	2337 237	2336 237	2335 237	2334 237	909 93 91 930	40.0	2332 236	2331 236	1105	052 0255 11 AL	2329 236	2328 236	2327 236	0 255 235	2	2325 236	2324 236	2323 235	0 232	0	2321 235	2320 235	2319 235	2318 235	1807 75	CE1 / LE1	2316 235 1741 173	2315 235	2314 235	01 201	100 95	2312 234	2311 234	2310 234	2309 234	0 216 234	0	2307 234	2306 234	2305 234	2304 234	• 142
•	55 2301	54 2300	3 2299	52 2298	00 908 11 2307	1001	50 2296 36 1193	59 2295	56 1768	62 2294	2293	6 2292	5 2291	as o	•	6 2289	52 2288	1 2287	345 00 2786	0 10	19 2285 1 105	18 2284	7 2283	45 2282	1688	1877 6	14 2280 35 1737	13 2279	12 2278	210 21	0 0	0 2276	89 2275	88 2274	87 2273	0 0 0	0	85 2271 : • •	M 2270	3 2269	12 2268	• 132
۰	2229 222	2228 226	22 222	2226 226	2225 270	1079	2224 220	2223 223	1354 13	5 222 2222	2221222	2220 22	2219 22	2718 27	*	2217 22	2216 22 <sup>5</sup>	2215 22	E 897	1000	2213 222	2212 22	221122	2210 222	1868 19	577 5077	2208 224	2207 224	2206 222	0	-77 S077	2204 222	2203 223	2202 223	2201 22	° 0000	0	0 0	2198 22	2197 22	2196 22	• 8
•	57 2193	56 2192	55 2191	54 2190	507 909 5.2 2160	078 2078	52 2188 1% 11%	51 2187	356 1355 Fo 2005	212 OC	49 2185 515 1090	48 2184	47 2183	46 2182	843 756	45 2181	44 2180	43 2179	A01 2178	911 IN	41 2177	40 2176	39 2175	65 427 38 2174	80 3274	1311 108	36 2172	35 2171	34 2170	0 191	0 0 69T7 55	32 2168	31 2167	30 2166	29 2165	0 0 28 2164	0	27 2163	26 2162	25 2161	24 2160	120 12
•	2121 21	2120 21	2119 21	2118 21	2117 21	1000	2116 21	2115 21	1357	1 2012	12 2113 21	2112 21	2111 21	2110 21	1513	2109 21	2108 21	2107 21	0 00 0	1 2121	2105 21	2104 21	2103 21	2102 21	•	1 017	2100 21	2099 21	2098 21	•	7 607	2096 21	2095 21	2094 21	2093 21	° 000	•	2091 21	0602	2089 21	2088 21	• 11 10
0	2085	048 2084	047 2083	046 2082	206 019 1005 2001	1082 1071	044 2080	043 2079	1951 1951	3441 JU01	041 2077 1589	040 2076	039 2075	NUL NUL	1825 1718	037 2073 1867 1414	036 2072	035 2071	905 2070	107 001	033 2069 108 1125	032 2068	031 2067	030 2066	0	5007 670	028 2064	027 2063	026 2062	0 IC	1907 570	024 2060	023 2059	022 2058	021 2057	0 00 0 CU	0	019 2055	018 2054	017 2053	016 2052	• 102
•	7 2013 2	6 2012 2	5 2011 2	4 2010 2	102 0	8.00E 9.	2 2008 2	1 2007 2	6 1357	0 2006 2	9 2005 2	8 2004 2	7 2003 2	8 1738 6 2007 2	1852	5 2001 2	4 2000 2	3 1999 2	A 894 7	1 100 CT 7	1 1997 2	0 1996 2	9 1995 2	8 1994 2	0	0 0 0	6 1992 2 0 0	5 1991 2	4 1990 2	0 0001	0 0 0 0	2 1988 2	1 1987 2	0 1986 2	9 1985 2	0 0	•	7 1983 2	6 1982 2	5 1981 2	4 1980 2	a2 100
•	1941 197	1940 197 197	1939 197	1938 197	906 X	1061	1156 197	1935 197	1358 135	101 101	1933 196	195 196	1931 196	1740 174	1683 170	1929 196 371	1928 196	195 196	0 20	0	1925 196 0	1924 196	195	0 192	0	661 1261	020 195	1919 195	0 195	0 100	61 / 161 0	0 195	1915 195	1914 195	913 194	0 101	•	0 194	0101	1909 194	1908	• 8
0	59 1905 12 19	58 1904	57 1903	56 1902	07 906 1001	CI8 1607	54 1900	1899	56 1350	22 1898	1897	50 1896	591895	1894	88 1852	57 1893 01 108	56 1892	1681 55	ett	0 0	53 1889 : 0 0	52 1888	51 1887	0 1886	0	0 1881	18 1884 0 0	17 1883	0 0 16 1882	0	1881 0	14 1880 : 0 0	13 1879	12 1878	1 1877	0 0	0	39 1875 : 0 0	38 1874 : 0 0	37 1873	36 1872	• 8
•	1833 18	1832 18	1831 181	1830 184	1070 106	1078	11828 18	1827 18(	1 1930	1625 18	1825 18	1824 184	1823 185	1 871	1623 13	1821 18 967 18	1820 18:	1819 18	1 0 1	01 01 01	1817 18.	1816 18	1815 181	1814 185	0	91 0 1919	1812 18 0	1811 184	1810 184	0	0 18	1808 18	1807 18	1806 184	1805 184	0	°	1803 18 °	1802 18	1801 18.	1800 181	• 22
0	1797	760 1796	59 1795	58 1794	57 1702	1079	192 1792	1621 25	157	AU 1/90	753 1789 993 1591	52 1788	1787	50 1786	262 839	749 1785 0 0	48 1784	47 1783	0 0 46 1782	0	745 1781 0 0	44 1780	43 1779	42 1778	0	0 0	740 1776 0 0	39 1775	38 1774	0 0	3/ T//3	36 1772	1771 257	34 1770	33 1769	32 1768	0 0	731 1767 0 0	730 1766	229 1765	28 1764	- 23
0	1725 17 m	1724 17	1723 17	1722 17	1731	E BLODE	1720 17	1719 17	1350		1717 17	1716 17	1715 17	1714 17	1691	1713 17	1712 17	1711 17	0 121		1709 17	1708 17	1707 17	0 1706 17	8	1 10	1704 17	1703 17	1702 17	0		1700 17	1699 17	1698 17	1697 17	0 1	0	1695 17	1694 17	1693 17	1692 17	• 8
•	653 1689 44 u	652 1688 * an	651 1687	650 1686	900 900 900 900 900 900 900 900 900 900	1007 1081	1194 1191	647 1683	1513 128	260 1082 301 mct	645 1681 1986 1241	644 1680	643 1679	101 101	1810 1811	641 1677 1869 170	640 1676	639 1675	N2 8191	201	637 1673 0 21	636 1672	635 1671	634 1670	18.00	1181 (	632 1668 197 0	631 1667	630 1666	0	679 C	628 1664	627 1663	626 1662	625 1661	0 1660	0	623 1659	622 1658	621 1657	620 1656	• 8
•	1 1617 1	0 1616 1	9 1615 1	8 1614 1	7 1612 1	1 IOH	6 1612 1 4 1195	S 1611 1	1353	1 1010	3 1609 1	2 1608 1	1 1607 1	1111 0	2 1851	9 1605 1 8 1534	8 1604 1	7 1603 1	1 500 1 5	1 1988	5 1601 1 2 778	4 1600 1	3 1599 1	2 1598 1	\$	1 /651 1	0 1596 1	9 1595 1	8 1594 1	•	0 0	6 1592 1	5 1591 1	4 1590 1	3 1589 1	0 0	•	1 1587 1	0 1586 1	9 1585 1	8 1584 1	
•	1545 158 w	1544 158	1543 157	1542 157	908 X	1079 101	11540 157	1539 157	1306 19	VCI 850	1510 157	1536 157	1535 157	115 1157	1852 15	1809 100	1012 156	1531 156	1944 194 1530 156	1996 202	1529 156	1528 156	1527 156	1912 191 1526 156	1869 14	9CT CZCI	1224 156	1523 155	197 1522 155	•	CCT 1751	LS20 155 °	1519 155	1518 155	" IS17 155	0	•	1515 155 °	1514 155	I513 154	1512 154	• 8
•	73 1509	72 1508	11 1507	70 1506	07 907	1080	58 1504 30 1194	57 1503	56 1554	20 I 20Z	1501 St	54 1500	1499	1408	50 1852	1497	50 1496	59 1495	1404	1007 10	57 1493 67 1959	56 1492	1491	12 1912 54 1490	00 1860	50 1927	52 1488 38 1739	51 1487	50 1486	0 100 F	0 1480	18 1484	17 1483	16 1482	1481	0 0	0	13 1479 : 0 0	12 1478	11 1477	10 1476	22 30
•	1437 14	1436 14	1435 14	1434 14	3 05	и	1432 14	1431 14	1356 1	1430 14	1429 14	1428 14	1427 14	1476 141	1852 15	1425 14	1424 14	1423 14	21 2161 1A7 7A1	1988 X	1421 14 1953 14	1420 14	1419 14	1418 14	1870 15	141/141	1416 14 1679 11	1415 14	1414 14	*		1412 14	1411 14	1410 14	1409 14	0 1408 14	•	1407 14	1406 14	1405 14	1404 14	• 8
•	65 1401 76 200	64 1400	63 1399	62 1398	744 905	1001	60 1396 007 1192	59 1395	355 1357	1221 1234	57 1393 224 979	56 1392	55 1391	739 1757 5.4 1390	854 1852	133 1389 870 1869	52 1388 915 1915	51 1387	996 1999 SAD 1386	1007 POD	49 1385 461 1917	48 1384	47 1383	0 1050 46 1382	0 1439	1351 0	44 1380	43 1379	42 1378	0	at 13//	40 1376	39 1375	38 1374	37 1373	0 0 36 1377	•	35 1371 0 0	34 1370	133 1369 0 0	32 1368	• •
•	1329 13	1328 13	1327 13	1326 13	1225 13	2	1324 13	1323 13	1379	1922	1321 13	1320 13	1319 13	1318 1	1872	1317 13	1316 13	1315 13	1214 12	8	1313 13	1312 13	1311 13	0 13	•		1308 13	1307 13	1306 13	•	1302 1301	1304 13	1303 13	1302 13	1301 13	0 13 1300 13	•	1299 13	1298 13	1297 13	1296 13	• •
•	257 1293	256 1292	255 1291	254 1290	241 10 25.2 1.200	-11	252 1288	251 1287	8 102	121 811	249 1285	248 1284	247 1283	1711 BUT	1854 1821	245 1281 1870 184	244 1280	243 1279	X61 102	100 214	241 1277	240 1276	239 1275	238 1274	•	131 F73	236 1272	235 1271	234 1270	•	597 T793	232 1268	231 1267	230 1266	229 1265	0 0 0	•	227 1263	226 1262	225 1261	224 1260	• 9
•	5 1221 1	4 1220 1	3 1219 1	2 1218 1	1 1217 1	•	0 1216 1	9 1215 1	•	8 1214	7 1213 1	6 1212 1	5 1211 1	1 210 1	1852	3 1209 1	2 1208 1	1 1207 1	2 1204		9 1205 1	8 1204 1	7 1203 1	6 1202 1	•		4 1200 1	3 1199 1	2 1198 1	•		0 1196 1	9 1195 1	8 1194 1	7 1193 1	0 0	•	0 0	4 1190 1	3 1189 1 0 0	2 1188 1	
•	1149 118	1148 118	1147 118	1146 118	307 35	۰	1144 118 °	1143 117	•	×11 2011	1141 117	1140 117	711 6611	0 11	•	0 21137 1117	1136 117	1135 117	0	•	01133 116	1132 116	1131 116	° 1130 116	•	91 671	1128 116	1127 116	° 1126 116	•		1124 116	1123 115	1122 115	121 115	° 1150	•	811 9111	0 0	1117 115	1116 115	•
•	77 1113	76 1112	75 1111	74 1110	0 23	•	72 1108 • •	71 1107	•		59 1105	58 1104	57 1103	6 1102	•	6 1101	54 1100	23 1099	0 1000	0 0	5 1097	50 1096	59 1095	1 0 58 1094	•	0 T033	56 1092 0 0	1601 55	54 1090	0 0001 C	0 1087	52 1088 • •	51 1087	50 1086	<sup>3 1085</sup>	0 0	•	47 1083 ° °	46 1082	1081	14 1080	- 2-
•	1041 10	1040 10	1039 10	1038 10	23	•	1036 10	1035 10	•	1034 10	1033 10	1032 10	1031 10	° 1030 10	۰	01 0201	1028 10	1027 10	0 10	0	1025 10 542	1024 10	1023 10	1022 10	8	01 701	1020 10	1019 10	1018 10	•		1016 10	1015 10	1014 10	1013 10	° 101 01	•	1011 10	1010 10	1009 10	1008 10	• 57 57
•	969 1005 414 418	968 1004 605	967 1003	966 1002	376 200 26.0 1001	21 15	964 1000 °	963 999	•	° °	997	966 996	, 995 995	0 0	•	993 • •	992	166 556	• •		989 989 989	352 988	981 987	1914 1914 350 986	1961	0821 0181	348 984 796 0	347 983	61 0 346 982	• •	182 0	980 • 980	943 979	942 978	91 977	o 0 040 076	* *	939 975	974	337 973	36 972	• 1
•	2 933 10 10	932	931	930	221	•	328	1 927	000	976 0	925	3 924	923	0 00 0	•	5 921 5	920	616 8	118 0 010	M51 S	1017	916	915	1914	1969	11855	912	116 9	1 910	5 5	5°	806 °	6 a	906	° 305	° 8		003 003	5 902 9	106 0	800	• <sup>00</sup>
•	861 893	68 098	859 89	858 89	355 801	10	856 893	855 89	1131 35	55 °C	853 881	852 881	881 88	• US8	•	849 88	848 884	847 88	1932 100 RAK 82	1915 200	845 88: 1951 196	844 881	843 87	1914 191 842 871	1967 197	SHI 0581	840 871 1738 174	839 87	838 87	100 100	921 9/3 9/9	41 87	835 87	834 870	833 86	0 CE8		831 86	830 86	829 86	828 86	• 9
•	9 825 10 405	8 824	7 823	6 822	11 889 10 891	1066	14 820 1197	819	1357	102 B18	1 817	0 816	9 815	1 0 814 0	2	9 231	6 812	2 811	1942	1 2000 H	3 809	2 808	1 807	1910 0 806	1860	2 202 1851	8 804	7 803	35 1655 6 802	1501	102 SUL	14 800 50 1277	200	2 798	//7 E	° 296	0	9 795 • •	8 794 ° °	7 793 0 0	6 792	-70 -62
•	753 78	752 78	32 152	750 78	8 9/8 24 74	822 10	748 78	747 78	1356 13	140	745 78	744 78	743 77	140 F	100	147	740 77	739 77	1607 19 738 73	1 891 61 891	737 77 1963 19	736 77	735 77	101 19 734 77	-	26/ 26/ 26/	732 76	731 76	730 76	° ;	4 ° Q °	728 76	727 76	726 76	725 76	0 27 ACT	•	723 75	722 75	721 75	720 75	• -12
•	81 717	80 716 80 606	715	714	71 712	NN CO	712	75 711	1350	4 /10	73 709	72 708	102 12	11 11 11 11 11 11 11 11 11 11 11 11 11		59 705 13 216	58 704	57 703	9/ 10%	707	55 701 54 %	54 700	669	698 S2	•	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	50 696 •	59 692	694 58 694	° 5	• •	56 692 ° °	55 691 °	54 690	° 89	° ° °	, °	51 687	50 686 °	49 685 0 0	18 684	• <sup>10</sup>
•	645 6	644 6	643 6	642 6	21	Ste	640 6 1194 11	639 6	1356 1	9 A ANA	637 6	636 6	635 6	404 F	8	633 6 1656 1	632 6	631 6	• 12	8	629 6	628 6	627 6	° 626 6	•	۵ ۵	624 6	623 6	622 6	°Ę	9 79	620 620	619 6	618 6	617 6	616 G	•	615 6	614 6	613 6-	612 6	• - 90
•	573 609	572 608	571 607	570 606	706 016 200 6015	101 2101	568 604	567 603	100 100	200 002	565 601	564 600	563 599	245 548	1121 2380	561 597 002 1227	965 095 9	263 295	• • •	0	557 593 • •	556 592	222 591	6 60 6	•	690 °	552 588 • •	551 587	6 50 586	° 1	69°°	548 584 °	547 583 °	546 582	645 581	o 100	}° F°	543 579 e e	542 578 ° °	541 577	540 576	• • •
•	537	536	535	534	202	1070	532	231	1358	8	529 5	528	527	1 202	8	525	524	523	• • •		521 5	520	519	° 518	•	, ,	5 16 S	515 5	514 9	* :	77 ° 77	° 213	511	510	° 603	° 8	, } °	203 0	° 206	505	204	110 -105
•	465 50.	464 500	463 495	462 495	307 36 AG1 A07	1078 208	460 49	459 495	1356 135	458 49	457 49:	456 492	455 491	45.4 490	•	453 48:	452 481	451 48)	450 486	2 2	449 48	448 48	447 483	e 446 482	•	¥ ° ¥ °	444 48	443 475	442 475	•	4	440 471	439 47.	438 474	437 475	e 436 477	F -	435 47.	434 47	433 46	432 465	• - 115 -
•	3 429	428	1 427	0 426	00 475	79 2078	88 424 1114	17 423	1335	101 01	2 1111	4 420	3 419	0 0 0	•	81 417 • •	80 416	9 415	0 0 8 A1A	•	77 413 0 0	6 412	5 411	410	•	60 <del>4</del> 0	72 408 ° °	1 407	0 406	• •	60 <del>4</del> 0	6 404 •	57 403	6 402	5 401	° 007 0	•	6 0 0	52 398 ° °	51 397 0 0	0 396	-125 -12
•	357 35 °	356 39	355 39	354 39	35.3 30	1070 101	352 38	351 38	0 0 0	8 °	349 35	348 38	347 38	0 346 38	•	345 38	344 35	343 37	* CP2	i K	341 37	340 37	339 37	° 338 37		10 / 10 0	336 37	335 37	334 37	•	¥ .	332 36 °	331 36	330 36	329 36	0 35 365	5 3 7	327 36	326 36	325 36	324 36	• 5 = 130
•	85 321	84 320 26 16	83 319	\$2 318	21 217	-	80 316 ° °	79 315	•	·8 314	77 313	76 312	75 311	74 310	•	73 309 °	72 308	71 307	0 305	8 °	69 305 e 0	58 304	57 303	6 0 56 302	•	10F 0	64 300 °	53 299	62 298	0 10	20°	60 296 ° °	59 295 0 0	58 294	57 293	6 0 242	•	55 291 ° °	54 290 ° °	53 289	52 288	-140 -1
•	249 2	248 2	247 2	246 22	245 26	6	244 2	243 2:	•	242 2	241 2	240 2	239 2	738 73	•	237 2	236 2	235 25	0 22	5	233 2	232 21	231 24	230 26	•	, ,	228 2	227 24	226 26	•	9 °	224 2	223 2	222 2	221 22	220 24	0	219 2	218 2	217 2	216 2	50 =145
•	177 213 °	176 212	75 211	74 210	72 200	102 015	L72 208	171 207	0 00 0 00	° 508	169 205 e	168 204	67 203	6 0 0	51 19	201 201 285 291	164 200	63 199	0 0 CS	204 0	197 • •	160 196	195	58 194	•	64 / Y	192 0 0	191 231	64 190	•	69 P	L52 188 ° °	187	150 186	49 185	48 184	0	147 183 ° °	146 182 ° °	145 181 0 0	44 180	•
•	141 1	1 140 1	1 139 1	138 1	127 1	240	136	1 135 1	•	134	7 133 1	1 132 1	131	0 130	0	129	128 1	127 1	0 126		0 125 1	1 124 1	123 1	122 1	° 1	1 °	1 120 1	1 119 1	118 1	•	1	116 1	115 1	1 114 1	113 1	0 11 0	•	111 0	1110	109 1	108 1	165 -160
•	69 10 <sup>5</sup>	68 104	67 105	66 102	451 61.	141 225	64 101 310 481	63 95	•	74 °	16 I9 0	96 09	59 95	0 22	•	57 6 6	56 92	55 91	0 12	5 °	53 6	52 85	51 87	50 %	•	ió A °	48 8 2 8	47 83	46 82	•	xi ~ 4 °	44 o 19 o	43 75	42 78	41 77	0 40 A	2 0	39 75	38 74	37 72	36 72	• -170 -
•	8°°	32	5	8	51 2	°	387	27	• ;	ę °	22 9	24	3	° 6	°	<b>7</b> °	50	19	•	۹ °	17 0	16	15	o 41	•	¶°	51 °	Ħ	° 9	•	ρ o	80 °	N 0	9	° 5	• 4	• •	en o	2	<b>H</b> 0	•	•



An example of the NetCDF variables is shown in Listing 1. The NetCDF can be read using the ascat<sup>3</sup> Python package or older versions of the pytesmo<sup>4</sup> Python package. The following Figure 4.6 shows a time series example.



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

<sup>&</sup>lt;sup>3</sup>https://github.com/TUW-GEO/ascat

 $<sup>^{4}</sup> https://github.com/TUW-GEO/pytesmo$ 



Listing 1: Example of NetCDF variables and dimension for cell 28. dimensions: locations = 436; obs = UNLIMITED ; // (6207877 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:standard\_name = "longitude" ; lon:long\_name = "location longitude" ; lon:units = "degrees\_east" ;  $lon:valid_range = -180., 180.;$ float lat(locations) ; lat:standard\_name = "latitude" ; lat:long\_name = "location latitude" ; lat:units = "degrees\_north" ; lat:valid\_range = -90., 90. ; float alt(locations) ; alt:standard\_name = "height" ; alt:long\_name = "vertical distance above the surface" ; alt:units = "m" ; alt:positive = "up" ; alt:axis = "Z" ; int64 location\_id(locations) ; string location\_description(locations) ; double time(obs) ; time:standard\_name = "time" ; time:long\_name = "time of measurement" ; time:units = "days since 1900-01-01 00:00:00" ; float sm(obs) ; sm:name = "sm" ; sm:coordinates = "time lat lon" ; sm:long\_name = "soil moisture" ; sm:units = "percentage" ; sm:scale\_factor = 0.01f ; sm:valid\_range = OUS, 10000US ; sm:missing\_value = 65535US ; float sm\_noise(obs) ; sm\_noise:name = "sm\_noise" ; sm\_noise:coordinates = "time lat lon" ; sm\_noise:long\_name = "soil moisture noise" ; sm\_noise:units = "percentage" ; sm\_noise:scale\_factor = 0.01f ; sm\_noise:valid\_range = OUS, 10000US ; sm\_noise:missing\_value = 65535US ; byte dir(obs) ; dir:name = "dir" ; dir:coordinates = "time lat lon" ; dir:long\_name = "orbit direction" ; dir:flag\_values = 0b, 1b ; dir:flag\_meanings = "ascending descending" ; dir:valid\_range = 0b, 1b ; dir:missing\_value = 127b ; byte ssf(obs) ; ssf:name = "ssf" ;



```
ssf:coordinates = "time lat lon" ;
        ssf:long_name = "surface state flag" ;
        ssf:flag_values = 0b, 1b, 2b, 3b, 4b ;
        ssf:flag_meanings = "unknown unfrozen frozen_temporary
           melting_water_on_the_surface permanent_ice" ;
        ssf:valid_range = 0b, 4b ;
        ssf:missing_value = 127b ;
byte sat_id(obs) ;
        sat_id:name = "sat_id" ;
        sat_id:coordinates = "time lat lon" ;
        sat_id:long_name = "satellite id" ;
        sat_id:flag_values = 1b, 2b, 3b, 4b, 5b ;
        sat_id:flag_meanings = "ers-1, ers-2, metop-a, metop-b, metop-c"
        sat_id:valid_range = 1b, 5b ;
        sat_id:missing_value = 127b ;
byte proc_flag(obs) ;
        proc_flag:name = "proc_flag" ;
        proc_flag:coordinates = "time lat lon" ;
        proc_flag:long_name = "processing flag" ;
        proc_flag:flag_masks = 1b, 2b, 4b, 8b, 16b, 32b, 64b ;
        proc_flag:flag_meanings = "
           soil_moisture_set_to_nan_it_was_below_-25
           soil_moisture_set_to_nan_it_was_above_125
           soil_moisture_set_to_nan_backscatter_not_usable
           soil_moisture_set_to_nan_model_parameter_not_usable
           reserved_for_future_use reserved_for_future_use
           reserved_for_future_use" ;
        proc_flag:valid_range = 0b, 127b ;
byte corr_flag(obs) ;
        corr_flag:name = "corr_flag" ;
        corr_flag:coordinates = "time lat lon" ;
        corr_flag:long_name = "correction flag" ;
        corr_flag:flag_masks = 1b, 2b, 4b, 8b, 16b, 32b, 64b ;
        corr_flag:flag_meanings = "
           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
           subsurface_scattering_correction_applied
           reserved_for_future_use reserved_for_future_use
           reserved_for_future_use" ;
        corr_flag:valid_range = 0b, 127b ;
byte conf_flag(obs) ;
        conf_flag:name = "conf_flag" ;
        conf_flag:coordinates = "time lat lon" ;
        conf_flag:long_name = "confidence flag" ;
        conf_flag:flag_masks = 1b, 2b, 4b, 8b, 16b, 32b, 64b ;
        conf_flag:flag_meanings = "bad_surface_state_flag
           topographic_complexity_above_50perc wetland_above_50perc
           soil_moisture_noise_above_50perc
           sensitivity_to_soil_moisture_below_1dB
           reserved_for_future_use reserved_for_future_use" ;
        conf_flag:valid_range = 0b, 127b ;
short slope40(obs) ;
        slope40:name = "slope40" ;
        slope40:coordinates = "time lat lon" ;
        slope40:long_name = "slope at 40 degree" ;
```



```
slope40:units = "dB/degree" ;
                slope40:scale_factor = 0.001f ;
                slope40:valid_range = -10000s, 10000s ;
                slope40:missing_value = 32767LL ;
       ushort slope40_noise(obs) ;
                slope40_noise:name = "slope40_noise" ;
                slope40_noise:coordinates = "time lat lon" ;
                slope40_noise:long_name = "slope at 40 degree noise" ;
                slope40_noise:units = "dB/degree" ;
                slope40_noise:scale_factor = 1.e-05f ;
                slope40_noise:valid_range = OUS, 10000US ;
                slope40_noise:missing_value = 65535US ;
        short sigma40(obs) ;
                sigma40:name = "sigma40" ;
                sigma40:coordinates = "time lat lon" ;
                sigma40:long_name = "backscatter at 40 degree" ;
                sigma40:units = "dB" ;
                sigma40:scale_factor = 0.01f ;
                sigma40:valid_range = -10000s, 10000s ;
                sigma40:missing_value = 32767LL ;
       ushort sigma40_noise(obs) ;
                sigma40_noise:name = "sigma40_noise" ;
                sigma40_noise:coordinates = "time lat lon" ;
                sigma40_noise:long_name = "backscatter at 40 degree noise" ;
                sigma40_noise:units = "dB" ;
                sigma40_noise:scale_factor = 0.01f ;
                sigma40_noise:valid_range = OUS, 10000US ;
                sigma40_noise:missing_value = 65535US ;
// global attributes:
                :id = "H119_0031.nc" ;
                :date_created = "2021-01-19 11:00:19";
                :featureType = "timeSeries" ;
                :platform = "Metop-A, Metop-B, Metop-C" ;
                :product_name = "Metop ASCAT Surface Soil Moisture Data Record
                   v7 12.5 km sampling";
                :software = "WARP v5.10.1" ;
                :source = "ASCAT Level 1b SZR" ;
                :project = "H SAF" ;
                :contact = "us_hsaf@meteoam.it" ;
                :geospatial_lon_resolution = "25-34 km" ;
                :geospatial_lon_sampling = "12.5 km";
                :geospatial_lat_resolution = "25-34 km"
                :geospatial_lat_sampling = "12.5 km" ;
                :created_with_software = "Python 3.6.10 and NetCDF 4.7.3" ;
                :uuid = "undefined" ;
                :institution = "TU Wien (Vienna University of Technology)";
                :creater_name = "TU Wien, Department of Geodesy and
                   Geoinformation (GEO)";
                :creater_url = "http://mrs.geo.tuwien.ac.at" ;
                :creater_email = "remote.sensing@geo.tuwien.ac.at" ;
                :cdm_data_type = "Time Series" ;
```



## 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 applies<sup>5</sup>. 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 (2021): ASCAT Surface Soil Moisture Climate Data Record v7 12.5 km sampling - Metop, EUMETSAT SAF on Support to Operational Hydrology and Water Management, DOI: 10.15770/EUM\_SAF\_H\_0007. http://dx.doi.org/10.15770/EUM\_SAF\_H\_0007

H SAF (2021): ASCAT Surface Soil Moisture Climate Data Record v7 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:H120

```
@misc{H119-SSM-CDR,
  author = {{H SAF}},
  title = {{Metop ASCAT Surface Soil Moisture
            Climate Data Record v7 12.5 km sampling (H119)}},
  year = 2021,
  note = {{EUMETSAT SAF on Support to Operational Hydrology
           and Water Management}},
  doi = {10.15770/EUM_SAF_H_0007},
  howpublished= {\url{http://dx.doi.org/10.15770/EUM_SAF_H_0007}}
}
@misc{H120-SSM-CDR,
  author = \{\{H SAF\}\},\
  title = {{Metop ASCAT Surface Soil Moisture
            Climate Data Record v7 Extension 12.5 km sampling (H120)}},
  year = 2021,
  note = {{EUMETSAT SAF on Support to Operational Hydrology
           and Water Management}}
  howpublished= {\url{https://navigator.eumetsat.int/product/
```

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



EO:EUM:DAT:METOP:H120}}

}

#### 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)<sup>6</sup> or the ESA Climate Change Initiative (CCI)<sup>7</sup>. 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 [40]. 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 [41]. 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.

## 6. References

- [1] H SAF, Product User Manual (PUM) Metop ASCAT Surface Soil Moisture Climate Data Record v7 12.5 km sampling (H119) and Extension (H120), v0.2, 2022.
- H SAF, Metop ASCAT Surface Soil Moisture Climate Data Record v7 12.5 km sampling (H119), http://dx.doi.org/10.15770/EUM\_SAF\_H\_0007, EUMETSAT SAF on Support to Operational Hydrology and Water Management, 2021. DOI: 10.15770/EUM\_SAF\_H\_ 0007.
- [3] H SAF, ASCAT Surface Soil Moisture Climate Data Record v7 Extension 12.5 km sampling
   Metop (H120), https://navigator.eumetsat.int/product/EO:EUM:DAT:METOP:H120,
   EUMETSAT SAF on Support to Operational Hydrology and Water Management, 2021.
- [4] H SAF, Algorithm Theoretical Baseline Document (ATBD) Metop ASCAT Surface Soil Moisture Climate Data Record v7 12.5 km sampling (H119) and Extension (H120), v0.1, 2021.
- [5] H SAF, Product Validation Report (PVR) Metop ASCAT Surface Soil Moisture Climate Data Record v7 12.5 km sampling (H119) and Extension (H120), v1.1, 2022.
- [6] H SAF, ASCAT Surface Soil Moisture CDR2014 time series 12.5 km sampling Metop (H25), http://dx.doi.org/10.15770/EUM\_SAF\_H\_0001, EUMETSAT SAF on Support to Operational Hydrology and Water Management, 2017. DOI: 10.15770/EUM\_SAF\_H\_ 0001.

<sup>&</sup>lt;sup>6</sup>https://land.copernicus.eu/global/products/swi

<sup>&</sup>lt;sup>7</sup>https://esa-soilmoisture-cci.org



- [7] H SAF, Algorithm Theoretical Baseline Document (ATBD) Soil Moisture Data Records, Metop ASCAT Soil Moisture Time Series, v0.4, 2016.
- [8] H SAF, Product Validation Report (PVR) Metop ASCAT Surface Soil Moisture Climate Data Record DR2014 12.5 km sampling (H25) and Extension (H108), v0.1, 2015.
- [9] H SAF, ASCAT Surface Soil Moisture CDR2015 time series 12.5 km sampling Metop (H109), http://dx.doi.org/10.15770/EUM\_SAF\_H\_0002, EUMETSAT SAF on Support to Operational Hydrology and Water Management, 2017. DOI: 10.15770/EUM\_SAF\_H\_ 0002.
- [10] H SAF, Algorithm Theoretical Baseline Document (ATBD) Soil Moisture Data Records, Metop ASCAT Soil Moisture Time Series, v0.5, 2017.
- [11] H SAF, Product Validation Report (PVR) Metop ASCAT Surface Soil Moisture Climate Data Record DR2015 12.5 km sampling (H109) and Extension (H110), v0.1, 2016.
- [12] H SAF, ASCAT Surface Soil Moisture CDR2016 time series 12.5 km sampling Metop (H111), http://dx.doi.org/10.15770/EUM\_SAF\_H\_0004, EUMETSAT SAF on Support to Operational Hydrology and Water Management, 2017. DOI: 10.15770/EUM\_SAF\_H\_ 0004.
- [13] H SAF, Product Validation Report (PVR) Metop ASCAT Surface Soil Moisture Climate Data Record DR2016 12.5 km sampling (H111) and Extension (H112), v0.1, 2017.
- [14] H SAF, ASCAT Surface Soil Moisture CDR2017 time series 12.5 km sampling Metop (H113), http://dx.doi.org/10.15770/EUM\_SAF\_H\_0005, EUMETSAT SAF on Support to Operational Hydrology and Water Management, 2018. DOI: 10.15770/EUM\_SAF\_H\_ 0005.
- [15] H SAF, Algorithm Theoretical Baseline Document (ATBD) Soil Moisture Data Records, Metop ASCAT Soil Moisture Time Series, v0.7, 2018.
- [16] H SAF, Product Validation Report (PVR) Metop ASCAT Surface Soil Moisture Climate Data Record DR2017 12.5 km sampling (H113) and Extension (H114), v0.3, 2018.
- [17] H SAF, Metop ASCAT Surface Soil Moisture Climate Data Record v5 12.5 km sampling (H115), http://dx.doi.org/10.15770/EUM\_SAF\_H\_0006, EUMETSAT SAF on Support to Operational Hydrology and Water Management, 2019. DOI: 10.15770/EUM\_SAF\_H\_ 0006.
- [18] H SAF, Algorithm Theoretical Baseline Document (ATBD) Metop ASCAT Surface Soil Moisture Climate Data Record v5 12.5 km sampling (H115) and Extension (H116), v0.1, 2019.
- [19] H SAF, Product Validation Report (PVR) Metop ASCAT Surface Soil Moisture Climate Data Record v5 12.5 km sampling (H115) and Extension (H116), v0.3, 2019.
- H SAF, ASCAT Surface Soil Moisture CDR2014-EXT time series 12.5 km sampling -Metop (H108), https://navigator.eumetsat.int/product/EO:EUM:DAT:METOP:H108, EUMETSAT SAF on Support to Operational Hydrology and Water Management, 2017.
- H SAF, ASCAT Surface Soil Moisture CDR2015-EXT time series 12.5 km sampling -Metop (H110), https://navigator.eumetsat.int/product/EO:EUM:DAT:METOP:H110, EUMETSAT SAF on Support to Operational Hydrology and Water Management, 2017.



- [22] H SAF, ASCAT Surface Soil Moisture CDR2015-EXT time series 12.5 km sampling -Metop (H112), https://navigator.eumetsat.int/product/EO:EUM:DAT:METOP:H112, EUMETSAT SAF on Support to Operational Hydrology and Water Management, 2017.
- [23] H SAF, ASCAT Surface Soil Moisture CDR2015-EXT time series 12.5 km sampling -Metop (H114), https://navigator.eumetsat.int/product/EO:EUM:DAT:METOP:H114, EUMETSAT SAF on Support to Operational Hydrology and Water Management, 2018.
- [24] H SAF, ASCAT Surface Soil Moisture Climate Data Record v5 Extension 12.5 km sampling
   Metop (H116), https://navigator.eumetsat.int/product/EO:EUM:DAT:METOP:H116,
   EUMETSAT SAF on Support to Operational Hydrology and Water Management, 2019.
- [25] EUMETSAT, ASCAT Level 1 SZR Climate Data Record Release 2 Metop, http://dx. doi.org/10.15770/EUM\_SEC\_CLM\_0043, European Organisation for the Exploitation of Meteorological Satellites, 2014. DOI: 10.15770/EUM\_SEC\_CLM\_0043.
- [26] EUMETSAT, ASCAT GDS Level 1 Sigma0 resampled at 12.5 km Swath Grid Metop, https://navigator.eumetsat.int/product/EO:EUM:DAT:METOP:ASCSZR1B, European Organisation for the Exploitation of Meteorological Satellites, 2009.
- [27] Peel, M. C., Finlayson, B. L., and McMahon, T. A., "Updated world map of the Köppen-Geiger climate classification," en, *Hydrology and Earth System Sciences*, vol. 11, no. 5, pp. 1633–1644, Oct. 2007. DOI: 10.5194/hess-11-1633-2007.
- [28] Copernicus Climate Change Service (C3S), ERA5: Fifth generation of ECMWF atmospheric reanalyses of the global climate. Copernicus Climate Change Service Climate Data Store (CDS), Date of access 2019-02-10.
- [29] Wagner, W., Lemoine, G., and Rott, H., "A method for estimating soil moisture from ERS scatterometer and soil data," *Remote Sensing of Environment*, vol. 70, no. 2, pp. 191–207, Nov. 1999. DOI: 10.1016/s0034-4257(99)00036-x.
- [30] Naeimi, V., "Model improvements and error characterization for global ERS and METOP scatterometer soil moisture data," PhD dissertation, Ph.D. dissertation, Vienna University of Technology, Austria, 2009.
- [31] ASCAT Product Guide, v5, 2015.
- [32] Hahn, S., Wagner, W., Steele-Dunne, S. C., Vreugdenhil, M., and Melzer, T., "Improving ASCAT soil moisture retrievals with an enhanced spatially variable vegetation parameterization," *IEEE Transactions on Geoscience and Remote Sensing*, pp. 1–16, 2020. DOI: 10.1109/tgrs.2020.3041340.
- [33] Naeimi, V., Paulik, C., Bartsch, A., Wagner, W., Kidd, R., Park, S.-E., Elger, K., and Boike, J., "ASCAT Surface State Flag (SSF): Extracting Information on Surface Freeze/Thaw Conditions From Backscatter Data Using an Empirical Threshold-Analysis Algorithm," *IEEE Transactions on Geoscience and Remote Sensing*, 2012. DOI: 10.1109/TGRS.2011. 2177667.
- [34] Naeimi, V., Scipal, K., Bartalis, Z., Hasenauer, S., and Wagner, W., "An improved soil moisture retrieval algorithm for ERS and METOP scatterometer observations," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 47, no. 7, pp. 1999–2013, 2009. DOI: 10.1109/TGRS.2008.2011617.



- [35] Wagner, W., Hahn, S., Kidd, R., Melzer, T., Bartalis, Z., Hasenauer, S., Figa-Saldaña, J., de Rosnay, P., Jann, A., Schneider, S., Komma, J., Kubu, G., Brugger, K., Aubrecht, C., Züger, J., Gangkofner, U., Kienberger, S., Brocca, L., Wang, Y., Blöschl, G., Eitzinger, J., Steinnocher, K., Zeil, P., and Rubel, F., "The ASCAT Soil Moisture Product: A Review of its Specifications, Validation Results, and Emerging Applications," *Meteorologische Zeitschrift*, vol. 22, no. 1, pp. 5–33, Feb. 2013. DOI: 10.1127/0941-2948/2013/0399.
- [36] Brocca, L., Crow, W. T., Ciabatta, L., Massari, C., Rosnay, P. de, Enenkel, M., Hahn, S., Amarnath, G., Camici, S., Tarpanelli, A., and Wagner, W., "A review of the applications of ASCAT soil moisture products," *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 10, no. 5, pp. 2285–2306, May 2017. DOI: 10.1109/ jstars.2017.2651140.
- [37] Rodell, M., GLDAS Noah Land Surface Model L4 3 hourly 0.25 x 0.25 degree, Version 2.1, https://disc.sci.gsfc.nasa.gov/datacollection/GLDAS\_NOAH025\_3H\_2.1.html, Accessed: 01-March-2019, 2016. DOI: 10.5067/E7TYRXPJKWOQ.
- [38] H SAF, Product Requirements Document (PRD), v0.1, 2017.
- [39] Eaton, B., Gregory, J., Drach, B., Taylor, K., and Steve, H., "NetCDF Climate and Forecast (CF) Metadata Conventions," Tech. Rep. version 1.6, 2011.
- [40] Albergel, C., Rüdiger, C., Pellarin, T., Calvet, J.-C., Fritz, N., Froissard, F., Suquia, D., Petitpa, A., Piguet, B., and Martin, E., "From near-surface to root-zone soil moisture using an exponential filter: An assessment of the method based on in-situ observations and model simulations," *Hydrology and Earth System Sciences*, vol. 12, no. 6, pp. 1323– 1337, Dec. 2008. DOI: 10.5194/hess-12-1323-2008.
- [41] Gruber, A., Scanlon, T., Schalie, R. van der, Wagner, W., and Dorigo, W., "Evolution of the ESA CCI soil moisture climate data records and their underlying merging methodology," *Earth System Science Data*, vol. 11, no. 2, pp. 717–739, May 2019. DOI: 10.5194/essd-11-717-2019.



# 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);





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 (EUMETCast<sup>8</sup>), or via ftp download; they are also published in the H SAF website<sup>9</sup>.

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.

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

<sup>&</sup>lt;sup>9</sup>http://h-saf.eumetsat.int/



## 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.