

EUMETSAT Satellite Application Facility on  
Support to Operational Hydrology and Water Management  
<http://hsaf.meteoam.it/>



## Product validation report (PVR)

### H142

Soil Wetness Index in the roots region  
Data record extension

## Revision History

Revision	Date	Author(s)	Description
0.1	2024/04/25	David Fairbairn and Patricia de Rosnay	First version.

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## List of Acronyms

<b>ASAR</b>	Advanced Synthetic Aperture Radar (on Envisat)
<b>ASAR GM</b>	ASAR Global Monitoring
<b>ASCAT</b>	Advanced Scatterometer
<b>ATBD</b>	Algorithm Theoretical Baseline Document
<b>BUFR</b>	Binary Universal Form for the Representation of meteorological data
<b>DORIS</b>	Doppler Orbitography and Radiopositioning Integrated by Satellite (on Envisat)
<b>ECMWF</b>	European Centre for Medium-range Weather Forecasts
<b>ERS</b>	European Remote-sensing Satellite (1 and 2)
<b>ESA</b>	European Space Agency
<b>EUMETCast</b>	EUMETSAT's Broadcast System for Environment Data
<b>EUMETSAT</b>	European Organisation for the Exploitation of Meteorological Satellites
<b>FTP</b>	File Transfer Protocol
<b>HTESSEL</b>	Hydrology Tiled ECMWF Scheme of Surface Exchanges over Land
<b>H SAF</b>	SAF on Support to Operational Hydrology and Water Management
<b>LDAS</b>	Land Data Assimilation System
<b>Météo France</b>	National Meteorological Service of France
<b>Metop</b>	Meteorological Operational Platform
<b>NRT</b>	Near Real-Time
<b>NWP</b>	Numerical Weather Prediction
<b>PRD</b>	Product Requirements Document
<b>PUM</b>	Product User Manual
<b>PVR</b>	Product Validation Report
<b>SAF</b>	Satellite Application Facility
<b>SEKF</b>	Simplified Extended Kalman Filter
<b>SSM</b>	Surface soil moisture
<b>SWI</b>	Soil Wetness Index
<b>TU Wien</b>	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 Geodynamik (National Meteorological Service of Austria)

## 1. Executive summary

This document describes the validation of the H SAF scatterometer root zone soil moisture product data record extension (RZSM-DR-EXT-10/H142). The data record (RZSM-DR2019-10/H141) covers the period 1992-2018 and the H142 extension covers the period 2019-2021. After 2021 the H142 extension was discontinued. The validation of H142 is for the period overlapping with the operational review 13, from 1st June 2021 to 31st December 2021. An introduction (section 2) is followed by general overview of the H SAF root zone data record product (section 3). The product validation against in situ data is presented in section 4. Finally, the conclusion is given in section 5. Further information on the implementation of the processing chain and individual processing steps are available in the H141/H142 Algorithm Theoretical Basis Documents [1], and information on the product format can be found in the H141/H142 Product User Manual [1]. A comprehensive validation of the H141 data record against in situ measurements can be found in the product validation report [2]. Information about the H SAF consortium can be found in the Appendix.

## 2. Introduction

### 2.1. Purpose of the document

The Product Validation Report is intended to provide a description of the main product characteristics and validation results for RZSM-DR-EXT-10 (H142). The validation approach adopted for H142 will include the temporal correlation of the root zone soil moisture against in situ measurements from the International Soil Moisture Network [3] in Section 4. Only the top 3 layers of the root-zone are validated using in situ observations (0-100 cm depth), which correspond with the analyzed soil moisture layers in the SEKF data assimilation algorithm. The lack of in situ data below 100 cm depth means it is not feasible to validate the deepest layer between 100 and 289 cm depth. The validation period is from June 1st 2021 to December 31st 2021. During this period the H SAF ASCAT-B/C SSM products (H103/H105) were available for assimilation during the entire period. The ASCAT-A (H102) product was retired in November 2021, near the end of the validation period.

### 2.2. Targeted audience

This document mainly targets:

- Hydrology and water management experts
- Operational hydrology and Numerical Weather Prediction communities
- Users of remotely sensed soil moisture for a range of applications (e.g. climate modelling validation, trend analysis)

## 3. Introduction to the root-zone soil wetness index product (H142)

### 3.1. Principal of the product

The H142 production chain follows the same approach as the H141 data record. It uses a sequential Land Data Assimilation System (LDAS) based on a Simplified Extended Kalman Filter

(SEKF) method, as in [4]. The SEKF constitutes the central component of the H142 production chain. The H-TESSEL Land Surface Model is used to propagate in time and space the soil moisture information through the root zone, accounting for physiographic information (soil texture, orography), meteorological conditions and land surface processes such as soil evaporation and vegetation transpiration [5–7]. H142 is a root zone soil moisture product derived from Metop ASCAT surface soil moisture (SSM) observations. The retrieval approach relies on a sequential Land Data Assimilation System (LDAS) with 12-hour assimilation windows. The LDAS for H142 is implemented using an offline land data assimilation system. The atmospheric forcing comes from the ERA5 global atmospheric fields [8]. Figure 3.1 illustrates the H141 LDAS production suite. The H142 production suite is equivalent to H141, except that ASCAT-C is assimilated in addition to ASCAT-A and ASCAT-B. The H142 data record extension is available over the period 2019-2021 and has since been discontinued.

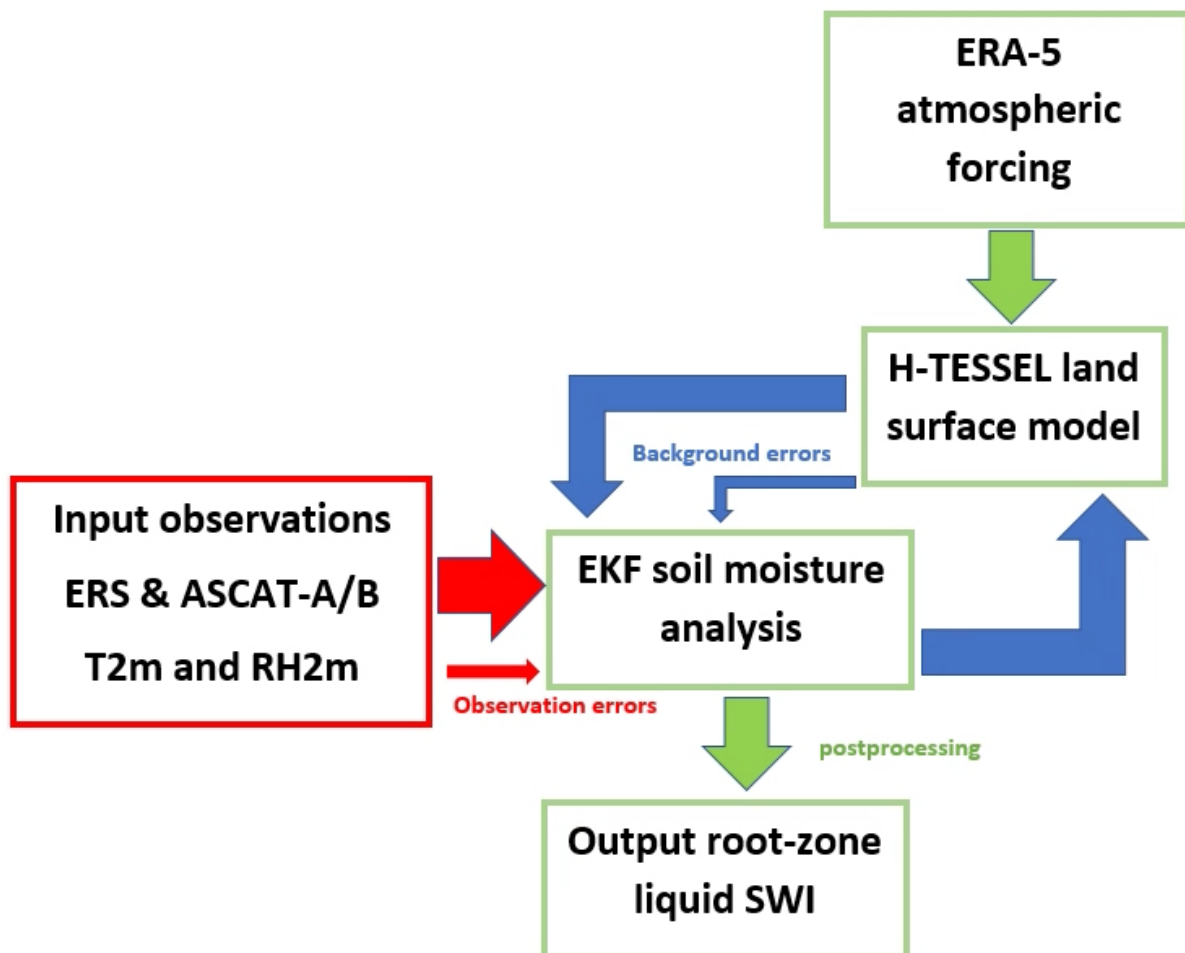


Figure 3.1: Illustration of the H141 root zone soil moisture production chain based on ERS-1/2 and ASCAT-A/B satellite derived surface soil moisture data assimilation.



### 3.2. Main characteristics

H142 is an offline data record extension, which is valid at 00UTC over the period 2019-2021. H142 is produced at a horizontal resolution of about 10km on four vertical layers in the soil: surface to 7 cm, 7 cm to 28 cm, 28 cm to 100 cm, and 100 cm to 289 cm. H142 relies on a data assimilation approach that propagates the information in time and space (on the vertical dimension in the root zone). Therefore, it allows a global update of the root zone soil moisture states using SSM derived from the aforementioned ASCAT products. The H142 root-zone soil moisture product is expressed as a liquid soil wetness index, with units between 0 (zero soil moisture) and 1 (saturation), representing the lower and upper soil moisture limits. After data assimilation, a post-processing step is required to convert the volumetric soil moisture analysis into the soil wetness index. It is computed using the soil texture (as defined by the FAO/United Nations Educational, Scientific and Cultural Organization (UNESCO) Digital Soil Map of the world [9]), the saturated soil moisture, and the fraction of liquid water content (the fraction of water that is not frozen) on each grid point and each soil layer. Having the units of H142 as a liquid soil wetness index is consistent with all the other ASCAT soil moisture products that are available for the surface (e.g. H141 and H26). Furthermore, it is relevant to various applications and can be combined with different hydrological models (e.g. [10]).

## 4. Validation against in situ data

### 4.1. Introduction

Several authors have demonstrated that in situ soil moisture measurements could be used to validate model and remotely-sensed SM at different scales (e.g. [11–13]). The high spatial variability of in situ SM used for validation as well as SM data set specific characteristics suggests that the Pearson correlation coefficient (R) should be the main score to be evaluated. Supportive scores are the Root Mean Square Difference (RMSD), Mean Error (or bias, ME), and the Standard Deviation (SD). Table 4.1 demonstrates the accuracy requirements for the RZSM, which follow the same requirements as for H141. Cases with significant levels of correlations (p-value < 0.05) are considered only as discussed in section 4.3. Data from 6 networks in the ISMN are considered for the validation. Three networks are located in the US: NRCS-SCAN (Natural Resources Conservation Service - Soil Climate Analysis Network), USCRN (U.S. Climate Reference Network) and NRCS-SNOTEL (short for Snow Telemetry) [14,15]. The SMOSMANIA (Soil Moisture Observing System Meteorological Automatic Network Integrated Application) network [16,17] is located over southwest France. The TERENO (Network of Terrestrial Environmental Observatories in Germany) network [18] is located in northwest Germany. Additionally, the REMEDHUS network in Spain [19] is employed to validate the surface layer. Despite this geographical extent limitation, these networks sample a large diversity of soil and vegetation types. They cover most of the soil texture and vegetation types (forest, crops, natural fallow, bare soil) in plains, mountainous, and coastal areas. More information about the networks is given in Section 4.2.

Table 4.1: Pearson correlation coefficient performance requirements for H141 and H142 [R]

Unit	Threshold	Target	Optimal
Dimensionless	0.5	0.65	0.8

## 4.2. In situ data

This study makes use of in situ soil moisture measurements obtained through the International Soil Moisture Network (ISMN <sup>1</sup>, [3, 20]), a data hosting centre where globally-available ground-based soil moisture measurements are collected, harmonized and made available to users. The performance of H142 is estimated by comparing it with in situ observations from 6 in situ networks in the US and Europe. A description of each network is given below together with the total number of stations used after quality control screening.

The NRCS-SCAN network [14] is a comprehensive, USA-wide soil moisture and climate information system designed to provide data to support natural resource assessments and conservation activities with a focus on agricultural areas in the USA. The observing network is used to monitor soil temperature and soil moisture at several depths, soil water level, air temperature, relative humidity, solar radiation, wind, precipitation and barometric pressure amongst other variables. NRCS-SCAN data have been used for various studies ranging from global climate modelling to agricultural studies. The vegetation cover at these sites consists of either natural fallow or short grass. Data are collected by a dielectric constant measuring device and typically measurements are made at 5, 10, 20, 50 and 100 cm. After the quality control checks, a sample of 115 out of 207 stations was used in the validation.

The U.S. Climate Reference Network National from the Oceanic and Atmospheric Administration's National Climatic Data Center (USCRN NOAA's NCDC) consists of stations developed, deployed, managed, and maintained by the National Oceanic and Atmospheric Administration (NOAA) in the contiguous United States for the express purpose of detecting the national signal of climate change [15]. The USCRN network is spread across many parts of the USA, from North to South and West to East (network map available on the ISMN website). USCRN sites sample a variety of natural environments in addition to agricultural settings that predominate in some networks. The main objective of USCRN is to provide climate-science-quality measurements of air temperature and surface conditions. The stations in the network were designed to be extensible to other missions and in 2011, the USCRN team completed at each station in the contiguous United States the installation of triplicate-configuration soil moisture and soil temperature probes at 5, 10, 20, 50, and 100 cm. After the quality control checks, a sample of 90 out of 112 stations was used in the validation.

The Natural Resources Conservation Service (NRCS) installs, operates and maintains an extensive, automated system called SNOTEL (short for Snow Telemetry, [14, 15]). The SNOTEL is designed to collect snowpack and related climatic data in the Western U.S. and Alaska. Most of the stations also measure soil moisture and are located in high altitudes. Data are collected by a dielectric constant measuring device and typically measurements are made at 5, 20 and 50 cm. After the quality control checks, a sample of 263 out of 346 stations was used in the validation.

The SMOSMANIA project is a long-term data acquisition effort of soil moisture observations in Southwestern France [16, 17]. Soil moisture profile measurements at 12 automated weather stations of Météo-France from the RADOME network (Réseau d'Acquisition de Données d'Observations Météorologiques Étendu), have been obtained since January 2007 at four different depths (5, 10, 20 and 30 cm) with 12 minutes time steps. Stations span from the Mediterranean Sea to the Atlantic Ocean. The soil moisture measurements (in units of  $\text{m}^3\text{m}^{-3}$ ) are derived from capacitance probes: ThetaProbe ML2X of Delta-T Devices. Data was kindly

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<sup>1</sup><https://ismn.geo.tuwien.ac.at/en/>

provided by J.-C. Calvet from Meteo-France in the framework of the H SAF project. After the quality control checks, a sample of 20 out of 21 stations was used in the validation.

The REMEDHUS is located in the central sector of the Duero basin in Spain. Each station has been equipped with capacitance probes (Stevens Hydraprobe) installed horizontally at a depth of 5 cm. Analysis of soil samples were carried out to verify the capacitances probes and to assess soil properties at each station [21]. After the quality control checks, a sample of 16 out of 18 stations was used in the validation.

Finally, the TERENO observations are located in the Eifel/Lower Rhine Valley in Germany [18]. Each station is equipped with capacitance probes (Stevens Hydraprobe) installed at depths of 5, 10 and 50 cm. After the quality control checks, 1 out of 4 stations was used in the validation.

### 4.3. In situ data preparation and metrics

Observations of soil moisture closest to the analysis time ( $\pm 30$  minutes) are compared with the H142 soil moisture using the nearest neighbour approach. The rescaled in situ observations at the highest depth are used for the validation of the H142 surface layer (0-7 cm). The root-zone in situ soil moisture observations are approximated using a vertical average of the in situ measurements in the first metre of soil, with weights that are proportional to the spacing of the sensor depths (as in [22]). The REMEDHUS network is only used to validate the surface layer of H142, since deeper observations are not available from this network. For the SMOSMANIA (TERENO) networks, the deepest observations at 30 (50) cm are assumed to represent the depth 30-100 cm (50-100 cm). The rescaled root-zone in situ observations are then used to validate the average H142 root-zone soil wetness index (0-100 cm). H142 is an index between 0 and 1 while in situ measurements of soil moisture are in  $\text{m}^3\text{m}^{-3}$ . To enable a fair comparison, it is then necessary to rescale the data. The 90% confidence interval was chosen to define the upper and lower values to exclude any abnormal outliers due to instrument noise using the following equations (as in [12, 23]):

$$\begin{aligned}\text{Int}^+ &= \mu_{\text{in-situ}} + 1.64\sigma_{\text{in-situ}} \\ \text{Int}^- &= \mu_{\text{in-situ}} - 1.64\sigma_{\text{in-situ}},\end{aligned}\tag{1}$$

where  $\text{Int}^+$  and  $\text{Int}^-$  are the upper and lower limits of the 90% confidence interval (i.e. 5th and 95th percentiles) calculated over the June to December 2021 period. Then the SWI is obtained using:

$$\text{SWI} = \frac{\text{SM} - \text{Int}^-}{\text{Int}^+ - \text{Int}^-},\tag{2}$$

where SM stands for Soil Moisture (in volumetric units). It is assumed that the H142 data set does not have such a problem with outliers and is rescaled using the maximum and the minimum values of each individual times series considering the whole validation time period.

The comparison between the observation data and the H142 product is performed according to the following statistical scores:

- Mean difference (or Bias)
- Pearson Correlation coefficient (R)
- Anomaly correlation coefficient (Ranom)

- Root Mean Square Difference (RMSD). In situ data contain errors (instrumental and representativeness) so they are not considered as ‘true’ soil moisture. This is underlined here by using the RMS Difference terminology instead of RMS Error.
- p-value, a measure of the correlation significance should be calculated as well. It indicates the significance of the test, the 95% confidence interval should be used; configurations where the p-value is below 0.05 (i.e. the correlation is not a coincidence) have to be retained. This process has probably removed some good stations too (e.g., in areas where the model might not realistically represent soil moisture). However it also ensures that stations with non-significant R values can be considered suspect and are excluded from the computation of the network average metrics. It is commonly used for soil moisture validation activities against in situ as well as against model data sets [24,25].

The RMSD represents the relative error of the soil moisture dynamical range. As H142 is an index, it has no units. It is possible to obtain an estimate of the error of the liquid root zone soil moisture retrieval in  $\text{m}^3\text{m}^{-3}$  by multiplication between the RMSD and the observed dynamical range ( $\text{obs}_{\text{max}} - \text{obs}_{\text{min}}$ ). Usually, soil moisture time series show a strong seasonal pattern that could artificially increase the perceived agreement between satellite and in situ observations in terms of CC. Therefore, to avoid seasonal effects, time series of anomalies from a moving monthly average are also calculated [12]. The difference to the mean is calculated for a sliding window of five weeks (if there are at least five measurements in this period), and the difference is scaled to the standard deviation. For each SM estimate at day (i), a period F is defined, with  $F=[i-17, i+17]$  (corresponding to a 5-week window). If at least five measurements are available in this period of time, the average SM value and the standard deviation are calculated. The Anomaly (dimensionless) is then given by:

$$\text{Ano}(i) = \frac{\text{SM}(i) - \text{SM}(F)}{\text{stdev}(\text{SM}(F))}. \quad (3)$$

The anomaly transformation is used only to compute the Ranom scores. All the other metrics (ME, R, RMSD) are computed using the H142 time series without the anomaly transformation.

More often than not, soil moisture is measured along with soil temperature. In line with the validation of the data record product (H141), the quality of the H142 extension product is assessed for all weather conditions, except when the soil temperature is below  $+4^\circ\text{C}$ . In addition, the 95% statistical significance intervals of the Ranom are calculated using a Fisher-Z transform (as in [26]). Note that the effective sampling size in the calculation of the confidence intervals is reduced by accounting for the temporal auto-correlation ([26] gives details).

#### 4.4. Validation results

Firstly, maps are presented in Figure 4.1 showing the locations of the stations in each network used in the validation. On the maps, the average R over the entire validation period for H142 is shown for the surface SWI layer for each station. Recall that the performance requirements for the correlation coefficients are listed in Table 4.1. While there is evidently some spatial variability in the performance across all 6 networks, most of the stations demonstrate R values above the target requirement ( $\text{CC} > 0.65$ ). Similarly spatially distributed R scores were found for the root-zone (not shown).

Figure 4.2 illustrates a time series for the surface SM and the root-zone SM for a mid-latitude station in the SMOSMANIA network in France. At this latitude, SM exhibits significant seasonal-scale variability, with normally drier conditions in summer and wetter conditions during the winter. The surface SM variability is largely driven by the short-term atmospheric forcing e.g. precipitation events. The root-zone SM has a longer memory than the surface SM and the annual cycle should be more distinct. It is evident in Figure 4.2 that the soil moisture annual cycle as well as its short term variability is well represented in both layers i.e. most peaks and troughs. H142 is represented for the validation period from June 1st 2021 until December 31st 2021 (after which H142 was discontinued).

Spatially averaged results of the H142 surface soil wetness validation against the in situ measurements for each network are reported in Table 4.2. On average, the R scores are above the target performance of 0.65 for both layers. The Ranom scores are generally lower than the R scores, which is expected because the autocorrelation in the annual SM cycle is reflected in the CC, but not in the ACC. Nevertheless, the Ranom scores generally reach the threshold requirement of 0.50. The estimated surface SWI volumetric RMSDs are reasonable ( $\approx 0.06 \text{ m}^3\text{m}^{-3}$ ) and the biases are much smaller than the RMSDs. The root-zone SWI scores are given at the bottom of Table 4.2. Overall, the root-zone SWI performs slightly better than the surface SWI in terms of the R/Ranom and has a substantially smaller average RMSD. This is expected because the root-zone SWI is less sensitive to random errors in the atmospheric forcing than the surface SWI. Note that there are generally fewer stations used to validate the root-zone SWI than the surface SWI, since measurements across all the root-zone depths are needed to construct the root-zone layer and measurements are discarded if data is missing or if the temperature is below  $4^\circ\text{C}$ .

Table 4.2: Mean scores for the H142 surface (top) and root-zone (bottom) SWI layers against in situ measurements from the SCAN, USCRN, SNOTEL, SMOSMANIA, REMEDHUS and TERENO networks.

Surface SM scores				
Network (N stations)	R	Ranom	RMSD ( $\text{m}^3\text{m}^{-3}$ )	Bias ( $\text{m}^3\text{m}^{-3}$ )
SCAN (115)	0.62	0.50	0.06	0.00
USCRN (90)	0.64	0.53	0.05	0.00
SNOTEL (263)	0.64	0.49	0.06	-0.02
SMOSMANIA (20)	0.76	0.69	0.05	0.03
REMEDHUS (16)	0.78	0.52	0.05	0.01
TERENO (1)	0.61	0.39	0.08	0.06
Average	0.65	0.51	0.06	-0.01
Root-zone SM scores				
Network (N stations)	R	Ranom	RMSD ( $\text{m}^3\text{m}^{-3}$ )	Bias ( $\text{m}^3\text{m}^{-3}$ )
SCAN (86)	0.55	0.52	0.03	0.00
USCRN (77)	0.65	0.55	0.03	0.00
SNOTEL (238)	0.71	0.56	0.04	0.00
SMOSMANIA (15)	0.76	0.65	0.04	0.00
TERENO (1)	0.74	0.56	0.02	0.02
Average	0.67	0.55	0.04	0.00

Table 4.3 reports statistical scores for the H142 surface SWI at a seasonal scale. R values

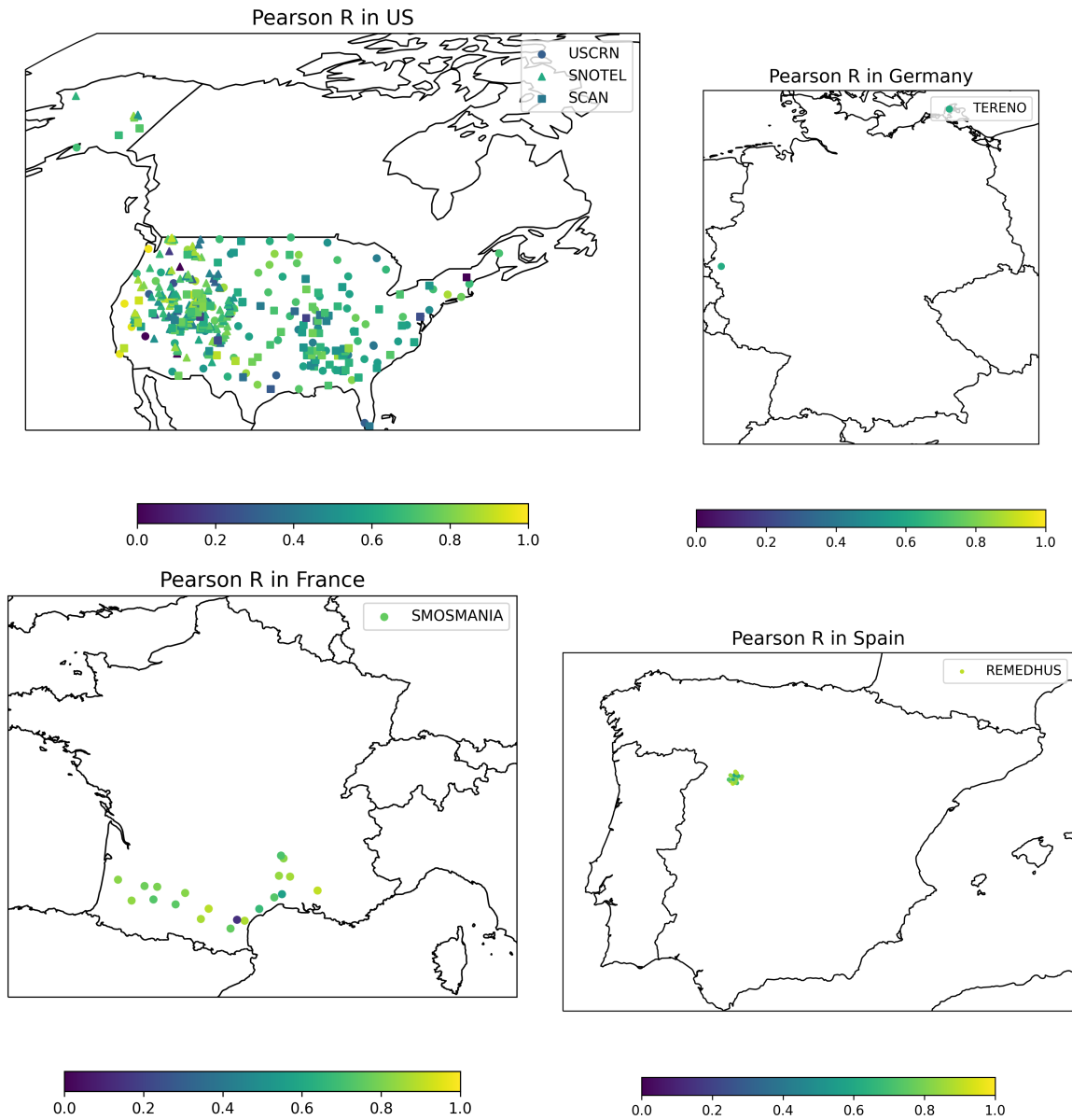


Figure 4.1: Locations of the stations of the US (top-left), German (top-right), French (bottom-left), and Spanish (bottom-right) networks used in the validation. Also shown is the correlation coefficient averaged over the period for each station.

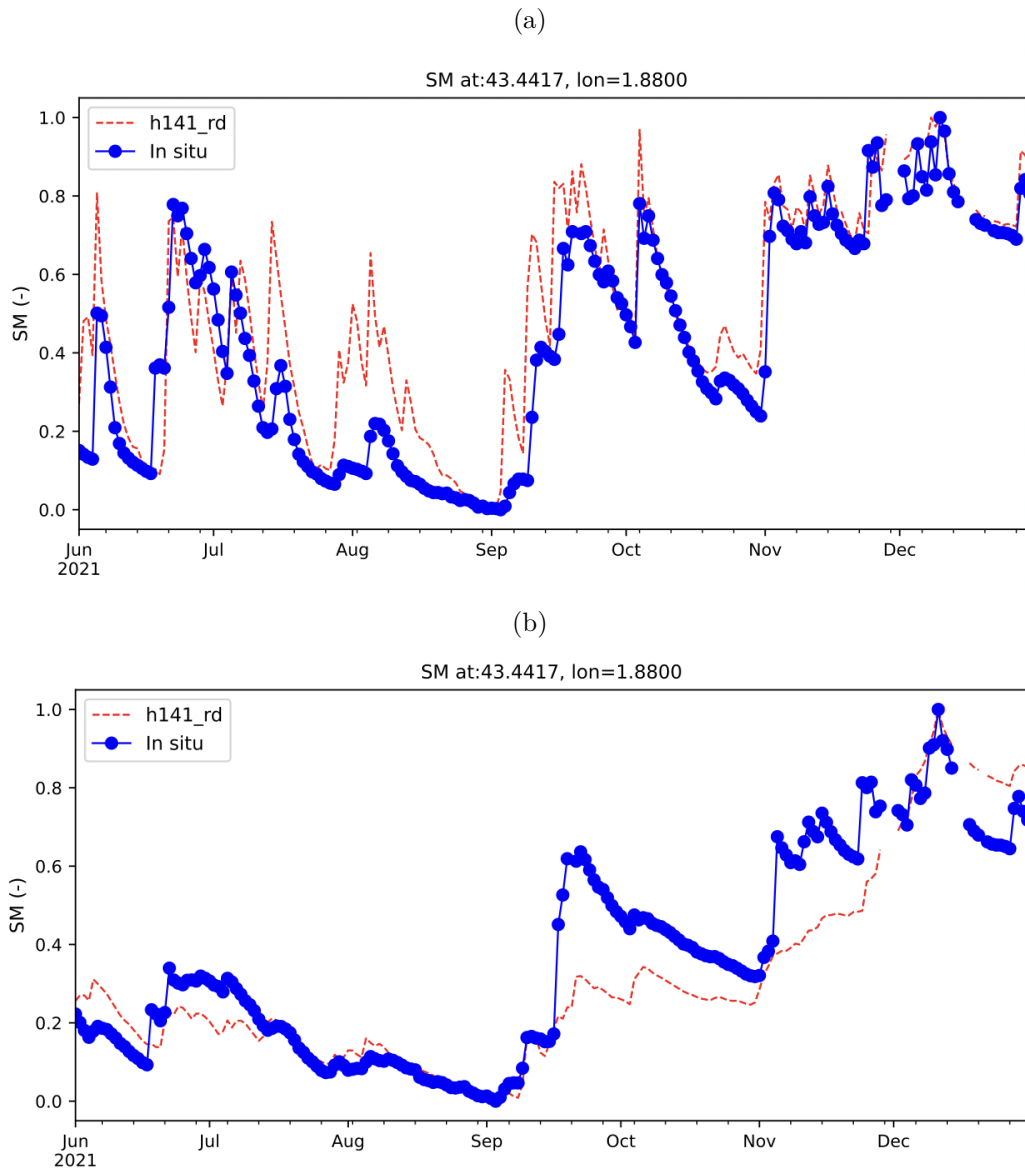


Figure 4.2: Illustration of soil moisture products time series for a station belonging to the SMOS-MANIA network for a) Surface SM and b) Root-zone SM. The in situ data are in blue and H142 is in red.



are, on average, above the threshold (0.50) and targeted (0.65) values for all seasons. Note that the validation period does not include spring and only one month of winter (December 2021) is included. The root-zone SWI seasonal scores are given in Table 4.4, which demonstrate slightly improved scores relative to the surface.

Table 4.3: Mean seasonal scores for the H142 surface SWI layer against in situ measurements from all the networks. The summer, autumn, spring and winter seasons are represented by the periods June to August, September to November, March to May and December to February respectively. Also shown are the number of stations for each network and season (Summer/Autumn/Winter/Spring)

Network (N stations)	Score	Summer	Autumn	Winter	Spring
SCAN	Bias ( $\text{m}^3\text{m}^{-3}$ )	-0.01	0.01	0.01	N.A.
(92/102/41/0)	RMSD ( $\text{m}^3\text{m}^{-3}$ )	0.06	0.05	0.05	N.A.
	R (anomalies)	0.59 (0.54)	0.67 (0.57)	0.76 (0.73)	N.A.
USCRN	Bias ( $\text{m}^3\text{m}^{-3}$ )	0.00	0.01	N.A.	N.A.
(75/85/0/0)	RMSD ( $\text{m}^3\text{m}^{-3}$ )	0.05	0.05	N.A.	N.A.
	R (anomalies)	0.61 (0.56)	0.67 (0.60)	N.A.	N.A.
SNOTEL	Bias ( $\text{m}^3\text{m}^{-3}$ )	-0.02	-0.03	-0.01	N.A.
(220/201/6/0)	RMSD ( $\text{m}^3\text{m}^{-3}$ )	0.07	0.06	0.05	N.A.
	R (anomalies)	0.61 (0.52)	0.75 (0.57)	0.63 (0.64)	N.A.
SMOSMANIA	Bias ( $\text{m}^3\text{m}^{-3}$ )	0.03	0.05	0.03	N.A.
(19/18/8/0)	RMSD ( $\text{m}^3\text{m}^{-3}$ )	0.05	0.06	0.04	N.A.
	R (anomalies)	0.72 (0.68)	0.81 (0.77)	0.85 (0.76)	N.A.
REMEDHUS	Bias ( $\text{m}^3\text{m}^{-3}$ )	-0.03	0.02	0.01	N.A.
(8/16/1/0)	RMSD ( $\text{m}^3\text{m}^{-3}$ )	0.05	0.05	0.02	N.A.
	R (anomalies)	0.73 (0.36)	0.73 (0.73)	0.73 (0.63)	N.A.
TERENO	Bias ( $\text{m}^3\text{m}^{-3}$ )	0.05	N.A.	0.00	N.A.
(1/0/1/0)	RMSD ( $\text{m}^3\text{m}^{-3}$ )	0.07	N.A.	0.01	N.A.
	R (anomalies)	0.68 (0.47)	N.A.	0.83 (0.89)	N.A.

Figure 4.3 displays box plots of the distribution of the R values across all the stations for the US and SMOSMANIA networks. Note that the REMEDHUS network is not shown because it is only valid for the surface, whilst the TERENO network only has one station available over the period. Five metrics are included, namely the median, upper quartile, lower quartile, minimum and maximum values (excluding outliers more/less than  $3/2$  times the lower quartile). The left (right) hand side of Figure 4.3 shows box plots of the R for each network for the surface (root-zone) SM. For the US stations (labelled a-f), the interquartile range for the R spans between about 0.40 and 0.90 and the majority of stations are above the target accuracy requirement of 0.65. For the root-zone SM, more than 25% of stations exceed the optimum R value (0.8) for all of the networks. As expected, the anomaly correlations are generally lower than the correlations as the autocorrelations from the annual cycle are removed. Nevertheless, the median anomaly correlations consistently exceed the threshold requirement (0.50). The root-zone SWI correlations are generally slightly higher than the surface SWI correlations.

Figure 4.4 shows the Ranom and 95% confidence intervals for (a) the surface layer and (b) the root-zone layer for each network. The H142 Ranom scores are mainly above the threshold (0.50) for both the surface and root-zone layers. The large confidence intervals for SNOTEL are related to the lack of data available due to the frozen conditions over much of the period.



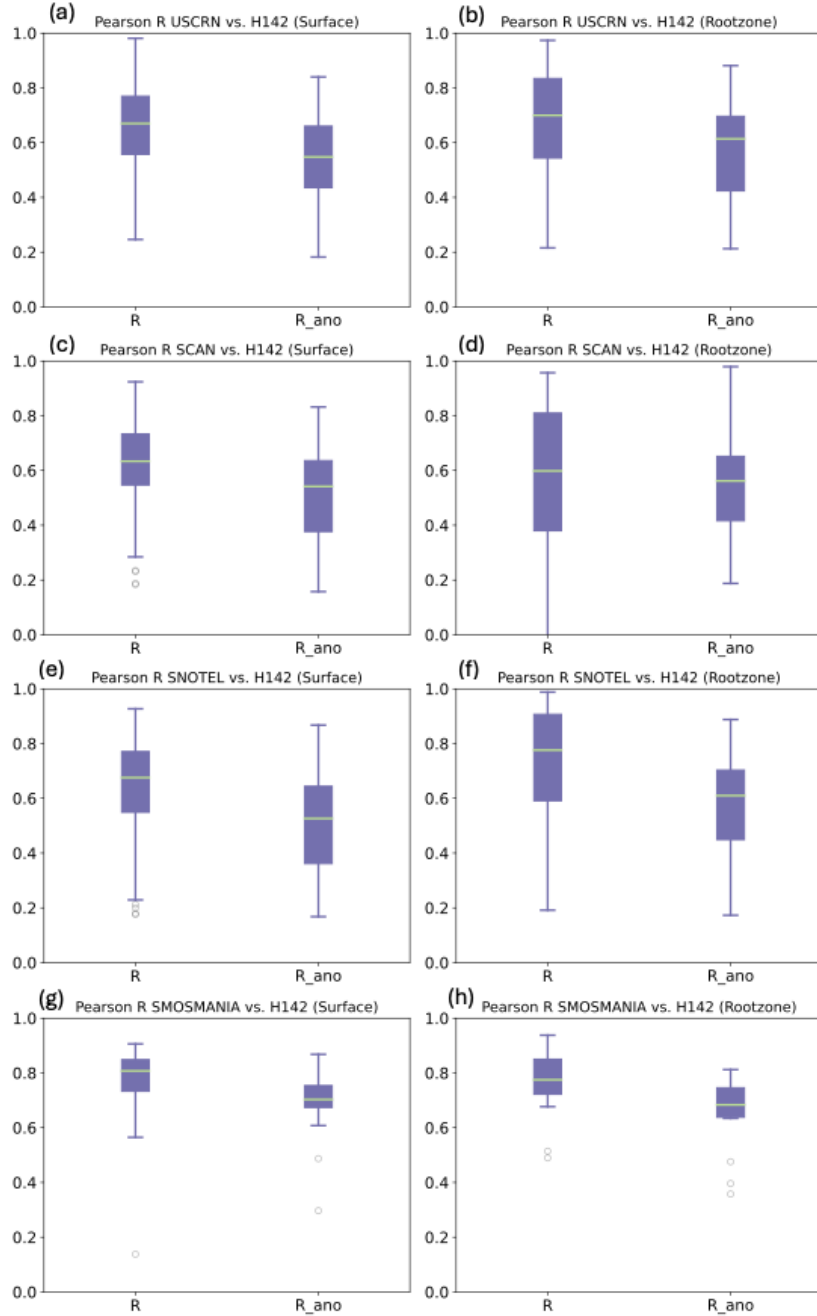


Figure 4.3: Box plots of correlation and anomaly correlation coefficients between in situ observations and H142 for June 2021 to December 2021. The surface SM scores are on the left and the root-zone SM scores are on the right.

Table 4.4: Same as Table 4.3 but for the root-zone SWI

Network (N stations)	Score	Summer	Autumn	Winter	Spring
SCAN	Bias ( $\text{m}^3\text{m}^{-3}$ )	0.00	0.00	0.01	N.A.
(74/79/37/0)	RMSD ( $\text{m}^3\text{m}^{-3}$ )	0.03	0.03	0.03	N.A.
	R (anomalies)	0.59 (0.55)	0.64 (0.60)	0.71 (0.71)	N.A.
USCRN	Bias ( $\text{m}^3\text{m}^{-3}$ )	0.00	0.00	N.A.	N.A.
(65/69/0/0)	RMSD ( $\text{m}^3\text{m}^{-3}$ )	0.03	0.04	N.A.	N.A.
	R (anomalies)	0.70 (0.55)	0.70 (0.61)	N.A.	N.A.
SNOTEL	Bias ( $\text{m}^3\text{m}^{-3}$ )	0.00	0.00	-0.02	N.A.
(221/196/3/0)	RMSD ( $\text{m}^3\text{m}^{-3}$ )	0.04	0.03	0.05	N.A.
	R (anomalies)	0.74 (0.57)	0.81 (0.61)	0.95 (0.95)	N.A.
SMOSMANIA	Bias ( $\text{m}^3\text{m}^{-3}$ )	0.00	-0.01	0.03	N.A.
(15/14/6/0)	RMSD ( $\text{m}^3\text{m}^{-3}$ )	0.03	0.04	0.04	N.A.
	R (anomalies)	0.64 (0.64)	0.81 (0.66)	0.61 (0.56)	N.A.
TERENO	Bias ( $\text{m}^3\text{m}^{-3}$ )	0.01	0.03	N.A.	N.A.
(1/1/0/0)	RMSD ( $\text{m}^3\text{m}^{-3}$ )	0.01	0.03	N.A.	N.A.
	R (anomalies)	0.96 (0.74)	0.30 (0.27)	N.A.	N.A.

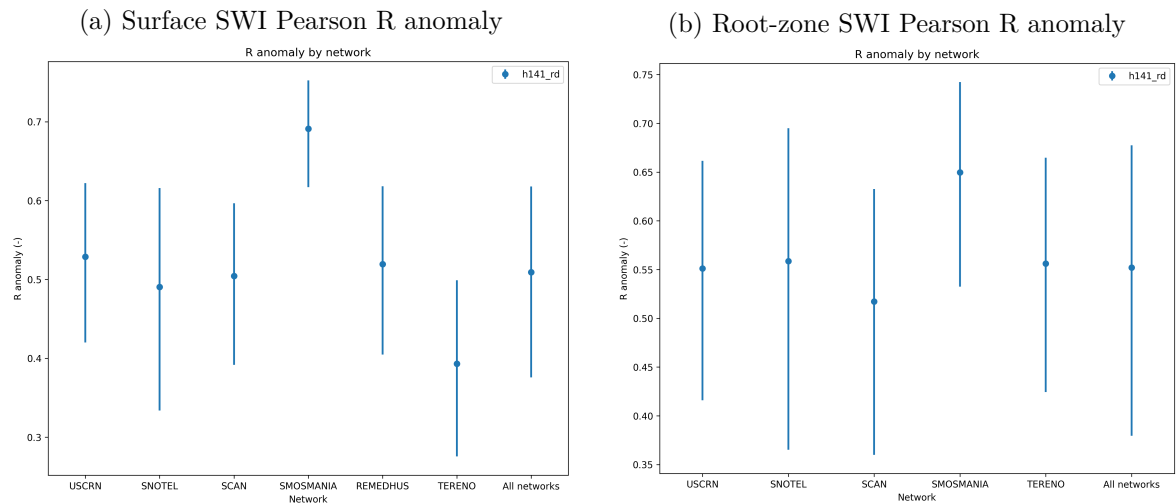


Figure 4.4: Pearson R anomalies for each network over the validation period. The left plot shows surface SWI scores and the right plot shows root-zone SWI scores.

## 5. Conclusion

The RZSM-ASCAT-NRT-10km (H142) product has been validated using the temporal correlation of the root zone (0-1 m) against sparse in situ measurements from the International Soil Moisture Network [3]. The in situ measurements from 6 networks belonging to the ISMN were employed, namely SCAN, USCRN and SNOTEL in the USA, SMOSMANIA in southwest France, REMEDHUS in Spain and TERENO in Germany. Averaged over the period June to December 2021, the correlation coefficient (Pearson R) meets the target HSAF performance requirements ( $R > 0.65$ ) for the surface and root-zone SWI for all the networks. As expected, the anomaly correlation coefficients (Ranom) demonstrate generally lower values than the R on average since the autocorrelation from the annual soil moisture cycle is reflected in the R but not in the Ranom. Nevertheless, for the surface and root-zone SWI, the Ranom meets the threshold requirement ( $> 0.50$ ). The best performances are found in the SMOSMANIA network (Ranom exceeding 0.65), with an example site capturing well the seasonal cycle and precipitation events in the in situ observations. The most uncertainty (largest confidence intervals) is found over the SNOTEL network in the US, which is affected by frozen conditions over many stations. Overall the validation results for H142 data record extension meet the performance requirements for the original data record (H141).

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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):

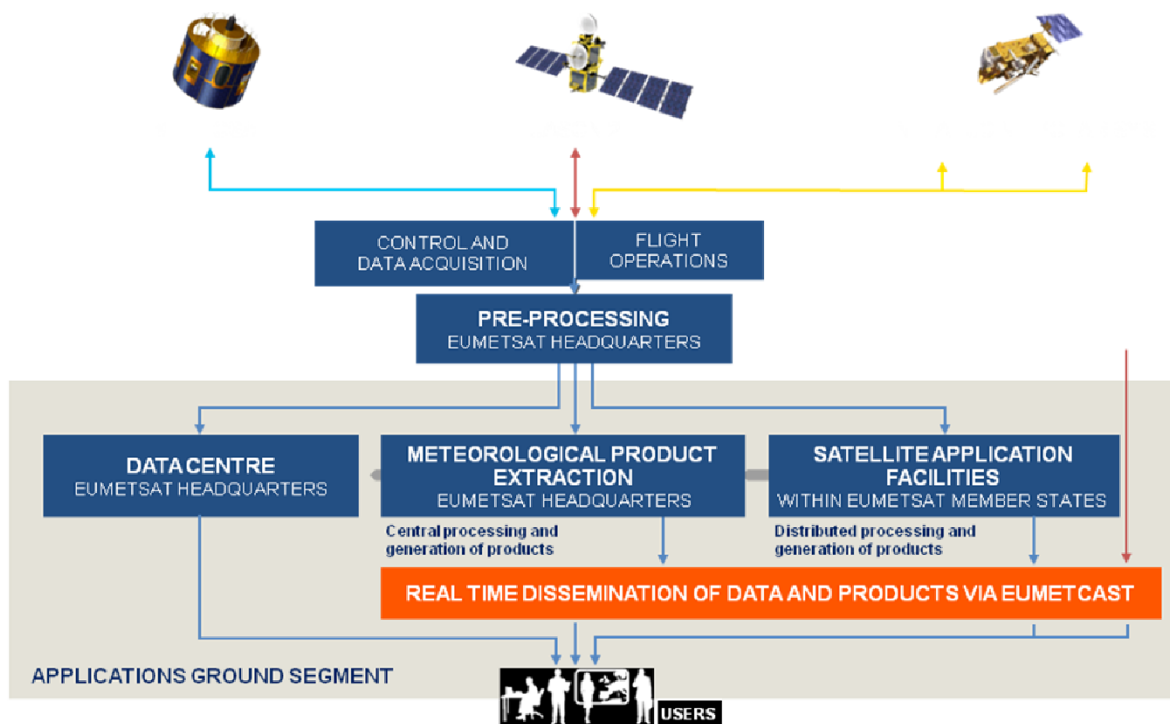


Figure A.1: Conceptual scheme of the EUMETSAT Application Ground Segment.

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);

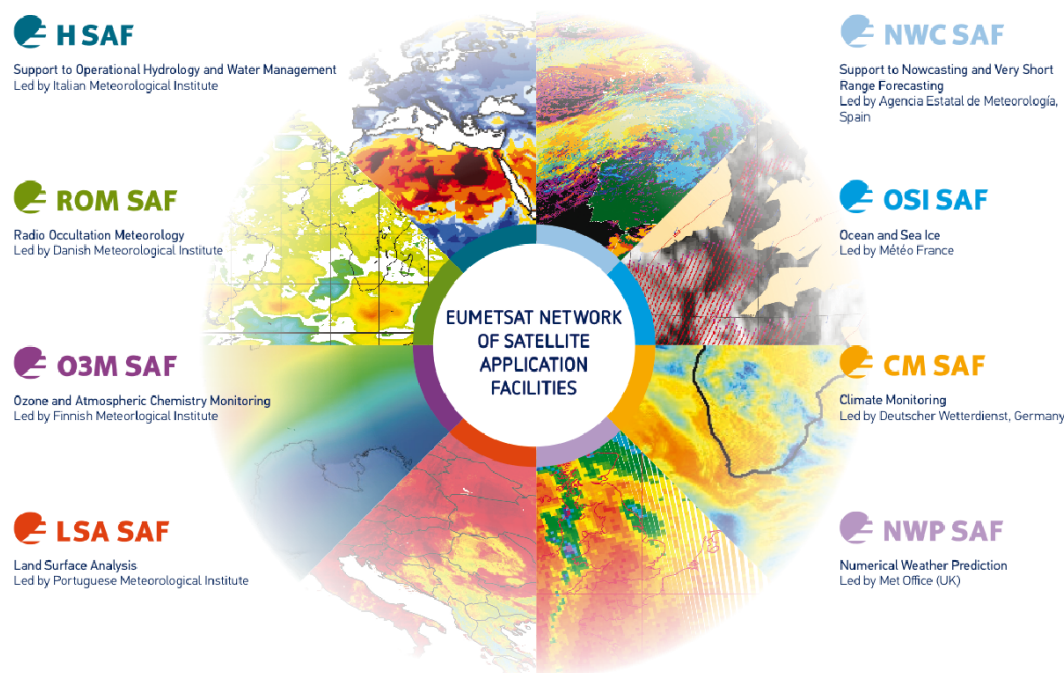


Figure A.2: Current composition of the EUMETSAT SAF Network.

- 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 [hsaf.meteoam.it](http://hsaf.meteoam.it). All products are available via EUMETSAT data delivery service (EUMETCast<sup>1</sup>), or via ftp download; they are also published in the H SAF website<sup>2</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>1</sup><http://www.eumetsat.int/website/home/Data/DataDelivery/EUMETCast/index.html>

<sup>2</sup><http://hsaf.meteoam.it>



## 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: [hsaf.meteoam.it](http://hsaf.meteoam.it) 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.