EUMETSAT Satellite Application Facility on
Support to Operational Hydrology and Water Management

Product User Manual (PUM) for product H35 – ESC-H

Effective snow cover by VIS/IR radiometry

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DOCUMENT CHANGE RECORD

Issue / Revision	Date	Description
1.0	02/06/2020	Baseline version prepared for ORR 2020
1.1	30/06/2020	Updated version which acknowledges RIDs dispositions
1.2	24/06/2021	Updated product acronyms
1.3	16/11/2022	Minor updates after PPS Cloud Mask implementation
1.4	19/07/2023	Updated version which acknowledges RIDs dispositions from delta-ORR

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1 Introduction

1.1 Purpose of the document

Product User Manuals are available for each (pre)-operational H SAF product, for open users, and also for demonstrational products, as necessary for *beta-users*.

Each PUM contains:

- Product introduction: principle of sensing, Satellites utilized, Instrument(s) description, Highlights of the algorithm, Architecture of the products generation chain, Product coverage and appearance;
- Main product operational characteristics: Horizontal resolution and sampling, Observing cycle and time sampling, Timeliness;
- Overview of the product validation activity: Validation strategy, Global statistics, Product characterisation
- Basic information on product availability: Access modes, Description of the code, Description of the file structure

An annex also provides common information on Objectives and products, Evolution of H SAF products, User service and Guide to the Products User Manual.

Although reasonably self-standing, the PUM's rely on other documents for further details. Specifically:

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

These documents are structured as this PUM, i.e. one document for each product. They can be retrieved from the CNMCA site on HSAF web page at User Documents section.

Yearly Operations Reports can be found on the same site in the quality assessment section, where more information on yearly statistics and potentially newer validation results from the PVRs as well as information on hydrological validation experiments *(impact studies*).

1.2 Introduction to product ESC-H

1.2.1 Principle of sensing

Product ESC-H (*Effective snow cover by VIS/IR radiometry*) is based on multi-channel analysis of the AVHRR instrument onboard MetOp satellites. The AVHRR radiometer has an IFOV of 1.1 x 1.1 km^2 at nadir degrading to ~ 2 x 6 km^2 at the edge of the 2900 km cross-track swath. Computing fractional cover would in principle require segmenting the image in arrays of pixels (typically ~ 32 x 32) and counting those classifies as snow. This would lead to unacceptable product resolution. For H SAF, fractional cover is generated at pixel resolution, by exploiting the brightness intensity that is the convolution of the snow signal (highest) and the fraction of snow within the pixel ("effective" cover").

The retrieval algorithm is somewhat different for flat or forested area and for mountainous regions. ESC-H is generated in Finland by FMI and in Turkey by TSMS.

The ESC-H products from FMI and from TSMS both cover the Northern Hemisphere, but thereafter are merged at FMI by blending the information on flat/forested areas from the FMI product and that one on mountainous areas from the TSMS product, according to the mask shown in Figure 1.

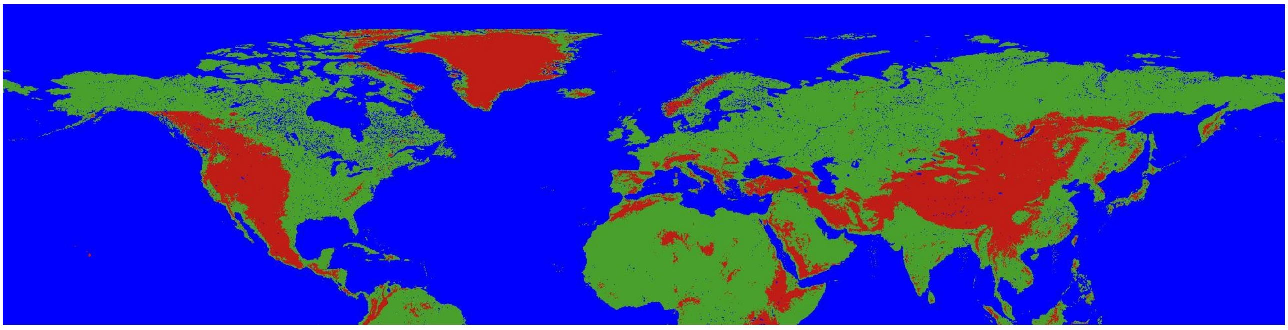


Figure 1. Mask flat/forested versus mountainous regions

For a single satellite pass, several areas in the scene would provide no useful measurements because of clouds. Therefore, the complex of passes is multi-temporally analysed to search for time instants of cloud-free conditions in a given time interval (e.g., 24 h). However, since short-wave channels play an essential role in the retrieval algorithm, the useful range of hours is in daylight.

1.2.2 Status of satellites and instruments

The current status of MetOp satellites is shown in Table 1, that also records the status of satellites carrying MODIS (EOS Terra and Aqua), that is used to support the computation of forest transmissivity.

Table 1. Current status of NOAA and MetOp satellites (as of March 2023)

Satellite	Launch	End of service	Height	LST or inclin.	Status	Instrument used in H SAF
MetOp-A	19 Oct 2006	expected 2011	817 km	09:31 d	Retired	AVHRR/3
MetOp-B	17 Sep 2012	expected 2019	817 km	09:31 d	Operational	AVHRR/3
MetOp-C	7 Nov 2018	expected 2024	817 km	09:31 d	Operational	AVHRR/3
EOS-Terra	18 Dec 1999	expected 2010	705 km	10:30 d	Operational	MODIS
EOS-Aqua	4 May 2002	expected 2010	705 km	13:30 a	Operational	MODIS

Next two tables collect, respectively, the main features of the AVHRR/3 instrument and the main features of MODIS.

Table 2. Main features of AVHRR/3

AVHRR/3	Advanced Very High Resolution Radiometer / 3
Satellites	**TIROS-N, NOAA 6 to 14, NOAA-15, NOAA-16, NOAA-17, NOAA-18, NOAA-19, MetOp-A, MetOp-B, MetOp-C**
Status	**Operational** - Utilisation period: 1978 to ~ 2014 on NOAA, 2006 to ~ 2024 on MetOp
Mission	Multi-purpose imagery
Instrument type	Multi-purpose imaging VIS/IR radiometer - 6 channels (channel 1.6 and 3.7 alternative)
Scanning technique	Cross-track: 2048 pixel of 800 m s.s.p., swath 2900 km - Along-track: six 1.1-km lines/s
Coverage/cycle	Global coverage twice/day (IR) or once/day (VIS)
Resolution (s.s.p.)	1.1 km IFOV
Resources	Mass: 33 kg - Power: 27 W - Data rate: 621.3 kbps

Central wavelength	Spectral interval	Radiometric accuracy (NEΔT or SNR)
0.630 µm	0.58 - 0.68 µm	9 @ 0.5 % albedo
0.862 µm	0.725 - 1.00 µm	9 @ 0.5 % albedo
1.61 µm	1.58 - 1.64 µm	20 @ 0.5 % albedo
3.74 µm	3.55 - 3.93 µm	0.12 K @ 300 K
10.80 µm	10.3 - 11.3 µm	0.12 K @ 300 K
12.00 µm	11.5 - 12.5 µm	0.12 K @ 300 K

Table 3. Main features of MODIS

MODIS	**Moderate-resolution Imaging Spectro-radiometer**
Satellites	**EOS-Terra, EOS-Aqua**
Status	**Operational** - Utilised in the period 1999 to ~ 2010
Mission	Multi-purpose imagery
Instrument type	Multi-purpose imaging VIS/IR radiometer - 36-channel VIS/IR spectro-radiometer
Scanning technique	Swath 2230 km. Whiskbroom scanning: a strip of 19.7 km width along-track is cross-track scanned every 2.956 s. The strip includes 16 parallel lines sampled by 2048 pixel of 1000 m s.s.p., or 32 parallel lines sampled by 4096 pixel of 500 m s.s.p., or 64 parallel lines sampled by 8192 pixel of 250 m s.s.p.
Coverage/cycle	Global coverage nearly twice/day (long-wave channels) or once/day (short-wave channels)
Resolution (s.s.p.)	IFOV: 0.25 km (two channels), 0.5 km (5 channels), 1.0 km (29 channels) – See table
Resources	Mass: 250 kg - Power: 225 W - Data rate: 6.2 Mbps

Central wavelength	**Bandwidth**	**Radiometric accuracy** (SNR or NEΔT at specified input spectral radiance	**IFOV at s.s.p.**
645 nm	50 nm	128 @ 21.8 W m^{-2} sr^{-1} μm^{-1}	250 m
858 nm	35 nm	201 @ 24.7 W m^{-2} sr^{-1} μm^{-1}	250 m
469 nm	20 nm	243 @ 35.3 W m^{-2} sr^{-1} μm^{-1}	500 m
555 nm	20 nm	228 @ 29.0 W m^{-2} sr^{-1} μm^{-1}	500 m
1240 nm	20 nm	74 @ 5.4 W m^{-2} sr^{-1} μm^{-1}	500 m
1640 nm	24 nm	275 @ 7.3 W m^{-2} sr^{-1} μm^{-1}	500 m
2130 nm	50 nm	110 @ 1.0 W m^{-2} sr^{-1} μm^{-1}	500 m
412 nm	15 nm	880 @ 44.9 W m^{-2} sr^{-1} μm^{-1}	1000 m
443 nm	10 nm	838 @ 41.9 W m^{-2} sr^{-1} μm^{-1}	1000 m
488 nm	10 nm	802 @ 32.1 W m^{-2} sr^{-1} μm^{-1}	1000 m
531 nm	10 nm	754 @ 27.9 W m^{-2} sr^{-1} μm^{-1}	1000 m
551 nm	10 nm	750 @ 21.0 W m^{-2} sr^{-1} μm^{-1}	1000 m
667 nm	10 nm	910 @ 9.5 W m^{-2} sr^{-1} μm^{-1}	1000 m
678 nm	10 nm	1087 @ 8.7 W m^{-2} sr^{-1} μm^{-1}	1000 m
748 nm	10 nm	586 @ 10.2 W m^{-2} sr^{-1} μm^{-1}	1000 m
870 nm	15 nm	516 @ 6.2 W m^{-2} sr^{-1} μm^{-1}	1000 m
905 nm	30 nm	167 @ 10.0 W m^{-2} sr^{-1} μm^{-1}	1000 m
936 nm	10 nm	57 @ 3.6 W m^{-2} sr^{-1} μm^{-1}	1000 m
940 nm	50 nm	250 @ 15.0 W m^{-2} sr^{-1} μm^{-1}	1000 m
1375 nm	30 nm	150 @ 6.0 W m^{-2} sr^{-1} μm^{-1}	1000 m
3.750 µm	0.180 µm	0.05 K @ 0.45 W m^{-2} sr^{-1} μm^{-1}	1000 m
3.959 µm	0.060 µm	2.00 K @ 2.38 W m^{-2} sr^{-1} μm^{-1}	1000 m
3.959 µm	0.060 µm	0.07 K @ 0.67 W m^{-2} sr^{-1} μm^{-1}	1000 m
4.050 µm	0.060 µm	0.07 K @ 0.79 W m^{-2} sr^{-1} μm^{-1}	1000 m
4.515 µm	0.165 µm	0.25 K @ 0.17 W m^{-2} sr^{-1} μm^{-1}	1000 m
4.515 µm	0.067 µm	0.25 K @ 0.59 W m^{-2} sr^{-1} μm^{-1}	1000 m
6.715 µm	0.360 µm	0.25 K @ 1.16 W m^{-2} sr^{-1} μm^{-1}	1000 m
7.325 µm	0.300 µm	0.25 K @ 2.18 W m^{-2} sr^{-1} μm^{-1}	1000 m
8.550 µm	0.300 µm	0.25 K @ 9.58 W m^{-2} sr^{-1} μm^{-1}	1000 m
9.730 µm	0.300 µm	0.25 K @ 3.69 W m^{-2} sr^{-1} μm^{-1}	1000 m
11.030 µm	0.500 µm	0.05 K @ 9.55 W m^{-2} sr^{-1} μm^{-1}	1000 m
12.020 µm	0.500 µm	0.05 K @ 8.94 W m^{-2} sr^{-1} μm^{-1}	1000 m
13.335 µm	0.300 µm	0.25 K @ 4.52 W m^{-2} sr^{-1} μm^{-1}	1000 m
13.635 µm	0.300 µm	0.25 K @ 3.76 W m^{-2} sr^{-1} μm^{-1}	1000 m
13.935 µm	0.300 µm	0.25 K @ 3.11 W m^{-2} sr^{-1} μm^{-1}	1000 m
14.235 µm	0.300 µm	0.35 K @ 2.08 W m^{-2} sr^{-1} μm^{-1}	1000 m

1.2.3 Highlights of the algorithm

The baseline algorithm for ESC-H processing is described in ATBD-35. Only essential elements are highlighted here. It is noted that for forested areas it is essential to take accurate forest transmissivity into account, whereas for the mountainous areas, this has little effect (few trees). For mountainous areas the sun zenith and azimuth angles, as well as direction of observation relative to these are more limiting factors.

The processing concepts for products ESC-H applied in Finland (FMI) and Turkey (METU) are somewhat different. Figure 2 and Figure 3 illustrate the flow chart of the ESC-H processing chain at FMI and TSMS, respectively.

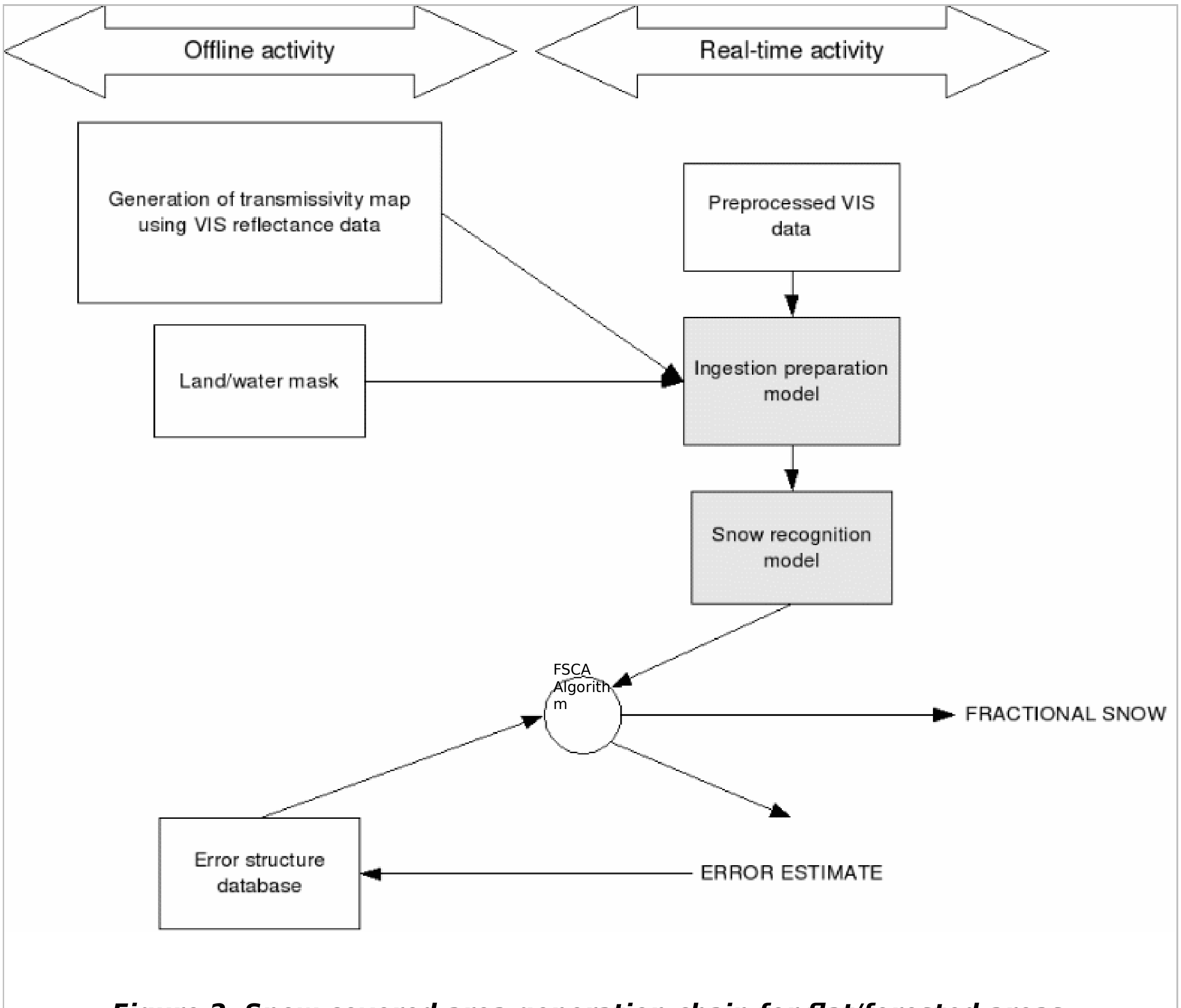


Figure 2. Snow covered area generation chain for flat/forested areas

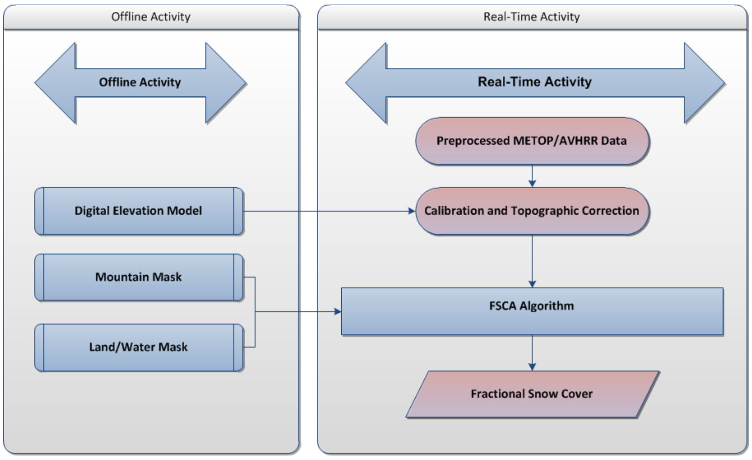


Figure 3. Snow covered area generation chain for mountainous areas

It is noted that the transmissivity map is essential input to the SCA-model, and has to be generated from reflectance data acquired at full dry snow cover conditions for each unit-area of the product. This is performed off-line by using MODIS.

For mountainous terrain three effects that caused by the topography can be listed: 1) Some areas receive exclusively diffuse irradiance due to cast shadows; 2) Shielding of the sky hemisphere reduces the diffuse irradiance; and 3) surrounding terrain reflects irradiance towards the observed ground area (Proy et al. 1989[1]). The shadowed areas become smaller on slopes facing the sun, while they increase on slopes oriented away from the sun.

Several methods have been developed so far with the purpose of removing terrain effects from the measured pixel radiance. Widely used methods are the Lambertian cosine correction, the statistical-empirical correction, the C-correction and the Minnaert correction (Vikhmar et al. 2004[2]; Riano et al. 2003[3]). The general approach of these methods is to normalize the observed radiance from inclined surfaces (L_T) to flat (horizontal) surfaces (L_H) by modelling the local incidence angle to the terrain surface *cos*(i) for each pixel. θ_i is defined as the angle between the surface normal and the solar beam (cf. Figure 4). Using information about the solar position at the acquisition time for the satellite image and the local terrain relief, it can be calculated for a pixel by the following formula (Smith et al. 1980[4]):

$$\cos(i) = \cos(\theta_i)\cos(\theta_p) + \sin(\theta_i)\sin(\theta_p)\cos(\varphi_o - \varphi_a) \quad (1)$$

[1] Proy C., D. Tanre and P.Y. Deschamps, 1989: “Evaluation of topographic effects in remotely sensed data”. *Reomete Sensing of Environment*, 30, 21-32.

[2] Vikhamar D., R. Solberg and K. Seidel, 2004: “Reflectance Modeling of Snow-covered forests in hilly terrain” . *Photogrametric Engineering and Remote Sensing*, 70, 9, 1069-1079.

[3] Riano D., E. Chuvieco, J. Salas and I. Aguado, 2003: “Assessment of different topographic corrections in landsat-tm data for mapping vegetation types (2003)”. *IEEE Trans. Geosci. Remote Sensing*, 41, 1056-1061.

[4] Smith J.A., T.L. Lin, and K.J. Ranson, 1980: “The Lambertian assumption and Landsat data”, *Photogrammetric Engineering and Remote Sensing*, 46(9), 1183-1189.

where sz(⚠i) is the solar zenith angle, sa (⋒o)is the solar azimuth angle, tz(⚠p) is the surface normal zenith angle or the terrain slope and ta (⋒a) is the terrain azimuth angle.

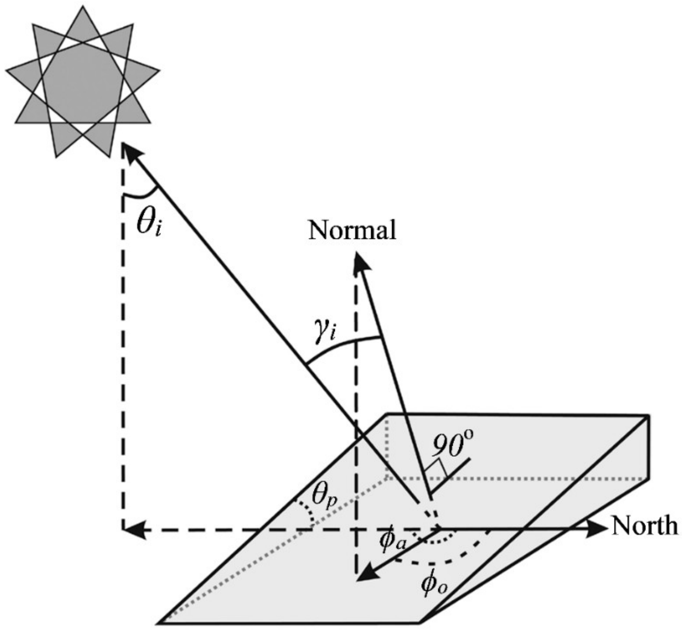


Figure 4. Angles involved in the computation of illumination angle (i)

Table 4. Summary of the Product versions

Product version	**Description**
0.90	Baseline product from the development phase
0.91	Temporary cloud cover improvement implemented by substituting the cloud cover of flat regions over Africa from mountainous product
1.0	Cloud masking algorithm has been replaced by NWC SAF PPS v2021 software to obtain binary cloud masking of the GDS AVHRR input data. This change has resolved the overestimation of clouds that has been present until this point. During this change, it was also noted that quality flags product also was updated to accommodate the change from the temporary cloud cover improvement to the current version.

1.2.4 Architecture of the products generation chain

The architecture of the ESC-H Product generation chain is shown in next figure:

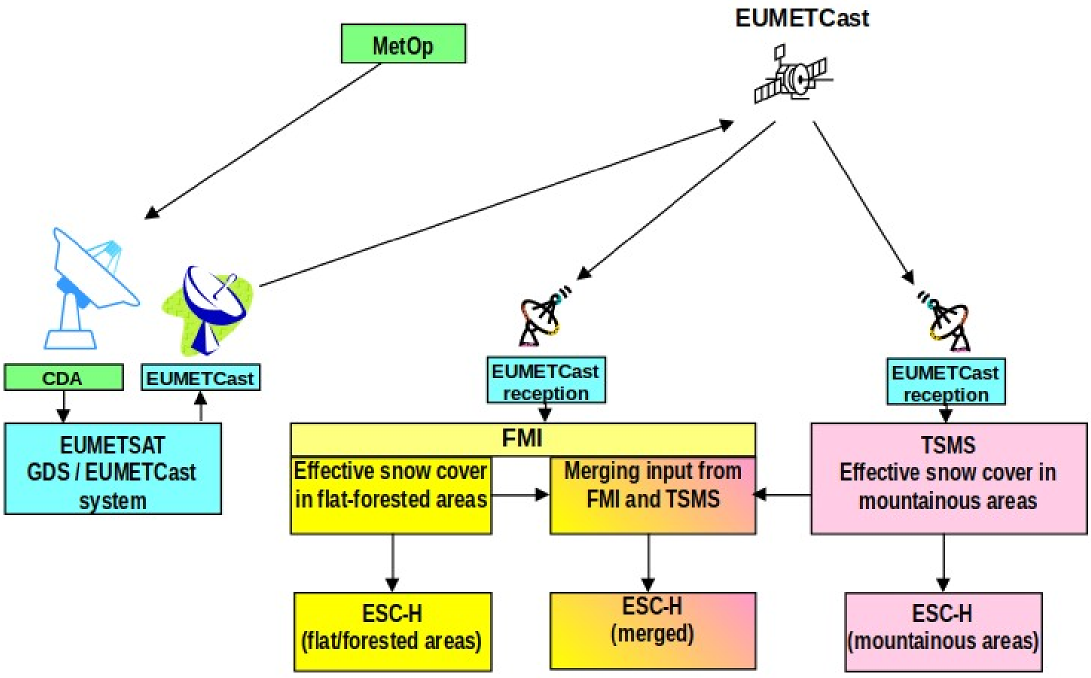


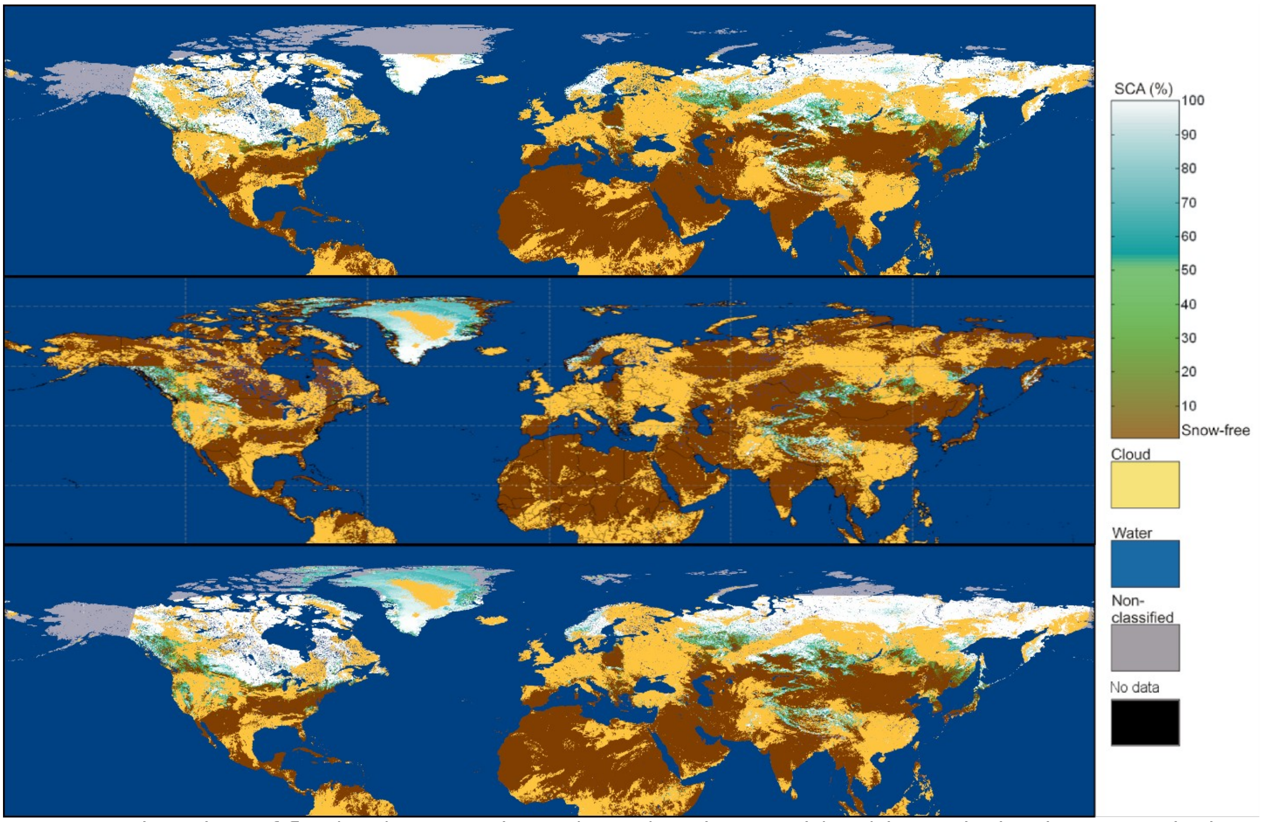
Figure 5. Conceptual architecture of the ESC-H chain

Data used is GDS Metop data fetched from EUMETCast and the product is generated both at FMI and at TSMS. The FMI product is tuned to flat/forested areas, that one from TSMS is tuned to mountainous areas. The TSMS data are delivered to FMI, that implements the merging of the two products.

Currently, the products are held on the TSMS server (mountainous areas) and on the FMI and CNMCA servers (both flat/forested areas and merged). Eventually, only the merged product will be disseminated through EUMETCast.

1.2.5 Product coverage and appearance

Next figure shows examples of ESC-H products generated at FMI (flat and forested areas), at TSMS (mountainous area), and merged, for the same day. Maps are in *equal latitude/longitude grid*.



Processed product of flat (FMI), mountainous (TSMS) and merged (FMI) in vertical order respectively.

Figure 6. Effective snow cover from MetOp AVHRR - Time-composite maps over 24 hours, March 29 2023

2 Product operational characteristics

2.1 Horizontal resolution and sampling

The *horizontal resolution (°x)* is the convolution of several features (sampling distance, degree of independence of the information relative to nearby samples, ...). To simplify matters, it is generally agreed to refer to the sampling distance between two successive product values, assuming that they carry forward reasonably independent information. The horizontal resolution descends from the instrument Instantaneous Field of View (*IFOV*), sampling distance (*pixel*), Modulation Transfer Function (*MTF*) and number of pixels to co-process for filtering out disturbing factors (e.g. clouds) or improving accuracy. It may be appropriate to specify both the resolution *°x* associated to independent information, and the *sampling distance*, useful to minimise aliasing problems when data have to undertake resampling (e.g., for co-registration with other data).

In AVHRR the IFOV at the s.s.p. is 1.1 km, that degrades moving to the swath's edge for an average ~ 2 km. The product is sampled at 0.01-degree intervals. To simplify matters, we quote as resolution ***°x ~ 2 km***, and sampling distance ***~ 1 km***.

2.2 Observing cycle and time sampling

The *observing cycle (°t)* is defined as the average time interval between two measurements over the same area. In the case of H35 which is produced from METOP GDS AVHRR data that is LEO, observing cycle is *°t = 24 h* since multi-temporal analysis over 24 hours of data is used to obtain maximum amount of cloud-free pixels.

2.3 Timeliness

The *timeliness (➦)* is defined as the time between observation taking and product available at the user site assuming a defined dissemination mean. The timeliness depends on the satellite transmission facilities, the availability of acquisition stations, the processing time required to generate the product and the reference dissemination means. In the case of H SAF the future dissemination tool is EUMETCast, but currently we refer to the availability on the FTP site.

For ESC-H, that results from multi-temporal analysis disseminated at ~03:30 UTC every day, the time of observation may change pixel by pixel (some pixel may have been cloud-free early in the time window, e.g. in the early morning, thus up to 12-h old at the time of dissemination; some very recently, just before product dissemination in the late afternoon).

Table 5. Summary of Product Specifications

Product Name	H35 ESC-H Effective snow Cover by VIS/IR radiometry	
Timeliness	Daily operational product with average timeliness of 6 hours	
Coverage	Northern Hemisphere	
Projection	EPSG 4326 (Lat/Lon Grid)	
Resolution	0.01-degree	
Data Format	GRIB2	
Data Content	SC; Fractional Snow Cover SC_Q_Flags; Quality flags	
Digital Coding	Digital coding for SC	
	Ground - Fractional Snow	[0, 100]
	CLOUD	101
	SEA	102
	UNCLASSIFIED	104
	NODATA	105
	Digital coding for SC_Q_Flags	
	Number of observations of the surface, i.e. if the pixel was cloudy during the whole day value would be 0 but if it was observed once it would be 1 etc.	0 to number of observations of the surface
	Mountain	255
	LAT/LON bands are not provided with the product however it can be generated easily by creating a 0.01-degree grid over the coverage of the product	

3 Product validation

3.1 Validation strategy

Whereas the previous operational characteristics have been evaluated on the base of system considerations (number of satellites, their orbits, access to the satellite) and instrument features (IFOV, swath, MTF and others), the evaluation of accuracy requires validation, i.e. comparison with the ground truth or with something assumed as "true". In the case of H35, product is validated with the approved validation methodology of comparing FSC maps of H35 with FSC maps derived from Sentinel-2.

Here, the summary of the results will be presented but the detailed report of the product validation activity for product ESC-H is provided as a document:

- PVR-35: Product Validation Report for ESC-H.

Table 6. Product Requirements of H35 RMSE

Score	Threshold	Target	Optimal
Flat/ forested areas RMSE	40%	20%	10%
Mountainous areas RMSE	50%	30%	10%

3.2 Summary of the results

Below are the results of validation for 2019-2020 early snow season and areas of interest were the Caucasus mountain range, Belarus (predominantly flat areas), Mount Atlas in Morocco, and Mount Lebanon. With such selection, the validation region includes a mixture of predominantly flat areas and predominantly mountainous areas. It is important to note that Belarus and the Caucasus region are the most significant testing regions here and should be considered as the two reference areas of interest for flat and mountain performance. Since Lebanon and the Atlas region have much dryer climate, which is an inherent challenge for large-scale products such as H35, these two regions were chosen as experimental study cases. Results show good agreement between H35 and Sentinel-2, where all RMSEs are below thresholds and target varying by regions. It was also noted that RMSE tends to increase when the used Sentinel-2 tile had more vegetation cover.

Table 7. Validation results for 2019-2020 Early snow season over Caucasus, Belarus, Mount Atlas and Mount Lebanon

Area of Interest	RMSE	Bias
Caucasus	38%	-20%
Belarus	3%	0.25%
Atlas	19%	-6%
Lebanon	22%	-6%

Results of another validation study to extend the validation area over the full snow season of 2019-2020 are presented below. In this study, same aforementioned methodology was used and the area was extended by adding regions in California and Japan that has seasonally significant snow cover and with complex topography, as well as regions in central Siberia with flat topography and far from seas/lakes or cities. Results as seen in table 5 show good agreement between H35 and Sentinel-2, where the global RMSE values are below thresholds and between target and optimal in the Siberia region.

Table 8. Validation results for 2019-2020 snow season over California, Siberia and Japan

Area of Interest	RMSE
California (mountainous)	40%
Siberia (flat)	17.5%
Japan (mountainous)	39%

3.3 Product limitations

Some limitations are derived from the validation results while some others are inherent from the methodologies. Current known limitations can be listed as follows:

- No detection during polar night
- No detection over areas that are completely cloud covered during the day
- Extreme climates such as extremely dry regions may result in degraded accuracy
- Complex topography with large elevation gradients may cause degraded accuracy

4 Product availability

4.1 Site

ESC-H is available via EUMETCast and H SAF download centre which can be accessed from https://hsaf.meteoam.it after registration (https://hsaf.meteoam.it/User/Register). Upon registration the user will have access to the H SAF FTP server 'ftphsaf.meteoam.it' where they can download the data and PNG quicklooks of the last 60 days.

4.2 Formats and Codes

Two types of files are provided for ESC-H:

- the digital data, coded in GRIB2
- the image-like maps, coded in PNG

The information to retrieve, read and handle the GRIB2 data is provided in the H SAF Snow Training Repository (https://github.com/H-SAF/snow-training). Further detail about the repository is provided in Appendix.

4.3 Description of the Files

In the Table 6 summary of instructions on how to access and naming convention of the files are presented.

Table 9. Summary of instructions for accessing ESC-H data

<table>
<tr><td colspan="2">URL: https://hsaf.meteoam.it/

ftp://ftphsaf.meteoam.it</td><td>username: register at H SAF webpage (https://hsaf.meteoam.it/User/Register)</td><td>password: register at H SAF webpage (https://hsaf.meteoam.it/User/Register)</td><td>directory: products</td><td>folder: h35</td></tr>
<tr><td colspan="2" rowspan="2">Product identifier: h35.
Folders under h35:</td><td colspan="4">h35_cur_mon_data</td></tr>
<tr><td colspan="4">h35_cur_mon_png</td></tr>
<tr><td rowspan="2">Files description:</td><td>h35_cur_mon_data</td><td colspan="3">h35_yyyymmdd_day_merged.grib2.gz
h35_yyyymmdd_QC_day_merged.grib2.gz</td><td>digital data + quality flag</td></tr>
<tr><td>h35_cur_mon_png</td><td colspan="3">h35_yyyymmdd_day_merged.png</td><td>image data</td></tr>
<tr><td colspan="6">yyyymmdd: year, month, day
day: indicates that the product results from multi-temporal analysis over 24 hours (in daylight)
QC: Quality Control: number of observations of the surface, i.e. non-cloudy and during daytime</td></tr>
</table>

5 References documents

[RD1] Product Requirement Document, SAF/HSAF/PRD/1.3

Annex 1. H SAF Snow Training Github Repository

In this public repository, which is created by experts from H SAF snow cluster, python Jupyter Notebooks can be found which are constructed in a modular fashion. These modules are to 'Connect to FTP and retrieve the data', 'Read the downloaded data and visualize' and 'Data projection and Spatial Analysis'. These codes/notebooks can be used to retrieve, read and handle (reprojection, analysis etc.) the products.

H-SAF Snow Cluster Lab Content

Within the content of this lab session information about snow products those are being produced by the snow cluster of H-SAF is presented. It is aimed to make the users familiar with the products and how to make use of the products in their studies easily. This lab session will provide users a quick reference guide and easy to follow instructions on the snow products. This reference will guide you though 3 steps including:

- Module 1

Connect to FTP and retrive data

- Module 2

Read the downloaded data and visualize

- Module 3

Data Projection and Spatial Analysis

Snow Products

The snow products those are being produced by HSAF Snow cluster are as follows, each product is categorized by the following titles

- H10 – SE-E-SEVIRI
- H11 – WS-E
- H12 – ESC-E
- H13 – SWE-E
- H34 – SE-D-SEVIRI
- H35 – ESC-H

Monitoring and modelling of snow characteristics are important since snow cover is an essential climate variable directly affecting the Earth's energy balance. Snow cover has a number of important physical properties that exert an influence on global and regional energy, water and carbon cycles.

Operational snow products namely

- H10 (Snow detection (snow mask) by VIS/IR radiometry),
- H11 (Snow status (dry/wet) by MW radiometry),
- H12 (Effective snow cover by VIS/IR radiometry),
- H13 (Snow Water Equivalent by MW radiometry),
- H31 (Snow detection for flat land (snow mask) by VIS/NIR of SEVIRI),
- H32 (Effective snow cover by VIS/IR radiometry AVHRR),
- H34 (Snow detection (snow mask) by VIS/IR radiometry covering full MSG Disk, superseding H10 and H31),
- H35 (Effective snow cover by VIS/IR radiometry covering Northern Hemisphere, superseding H12 and H32),

H11 and H13 are the products obtained from microwave sensors namely SSMI/S and they have 0.25° spatial resolution. H11 retrieval is based on the wet snow detection algorithm based on 19H and 37H channels. H10 product is used in H11 as a basis to get the snow covered pixels to apply the wet snow detection algorithm. H13 retrieval is based on snow depth algorithm based on 19H and 37H microwave channels. H13 algorithm uses the Helsinki University of Technology (HUT) snow emission model having slightly changes in the assimilation for flat/forest and mountainous areas.

Figure 7. Snippet from a portion of the Jupyter notebook provided in the repository

To give an example on how these mentioned modules look, below is a snippet from the jupyter notebook for the Module 2 of the H35 product. It shows one of the ways to read the data file, read the data values and visualize these values using python.

Module 2

Downloaded product can be read via pygrib library (or other grib2 readers of your choice). Then, data can be visualized as in the following code snippet. For the sake of the trial we will use the data from 20210408 which is already available.

In [3]:

```
import pygrib
import numpy as np
import matplotlib.pyplot as plt
import matplotlib.cm as cm

grbfile = pygrib.open("./h35_data_op/h35_20210408_day_merged.grib2")
grbdata = grbfile.select(name="Remotely sensed snow cover")[0]
data = np.flip(grbdata.values, 0)
fig, ax = plt.subplots(figsize=(15,5))
ax.set_title("H35 ESC-H Product")
ratio = 0.5

pcm = ax.pcolormesh(data, cmap = "RdYlBu")
ax.set_aspect(1.0/ax.get_data_ratio()*ratio)
fig.colorbar(pcm, ax=ax, extend = "max")

plt.show()
```

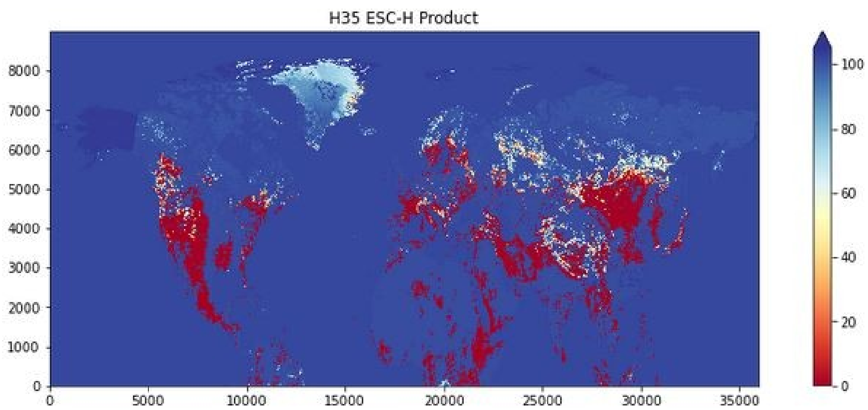


Figure 8. Snippet from the module 2 of H35 from the Jupyter notebook provided in the repository

Annex 2. Introduction to H SAF

5.1 The EUMETSAT Satellite Application Facilities

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 9):

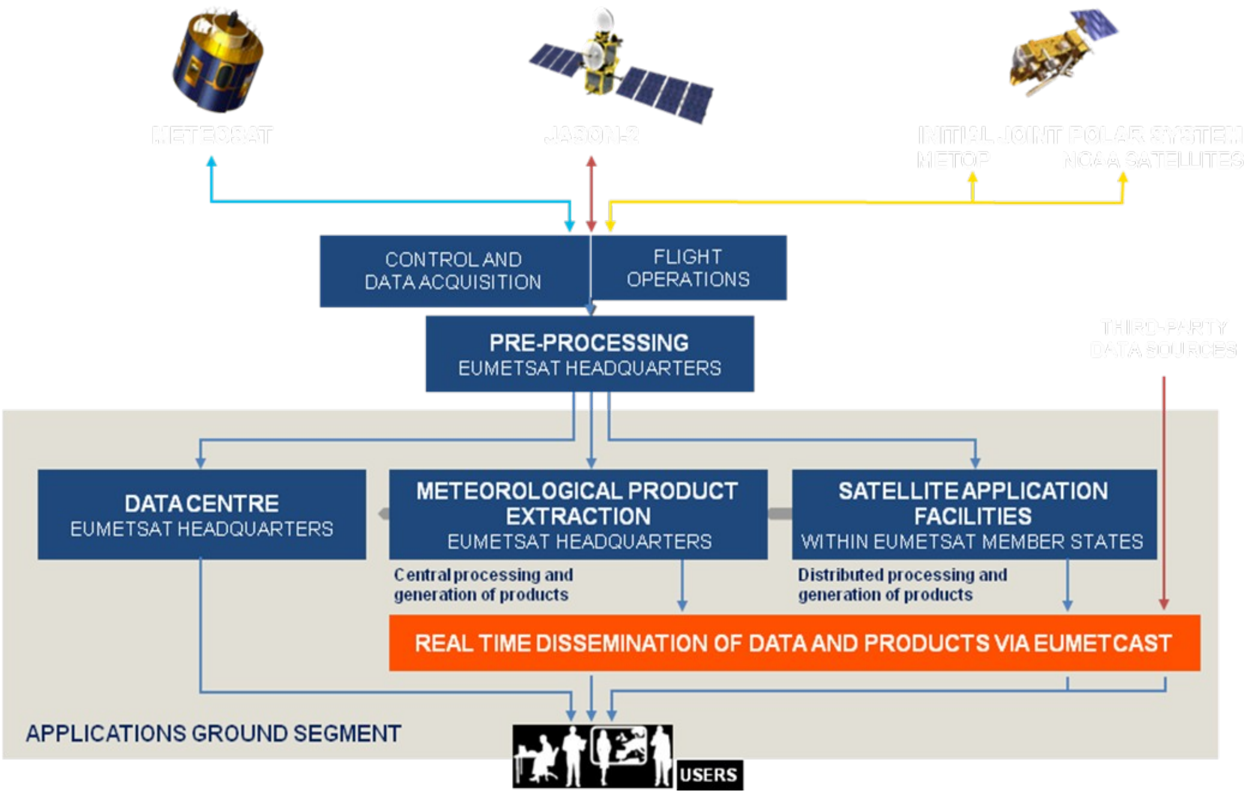


Figure 9. Conceptual scheme of the EUMETSAT Application Ground Segment

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

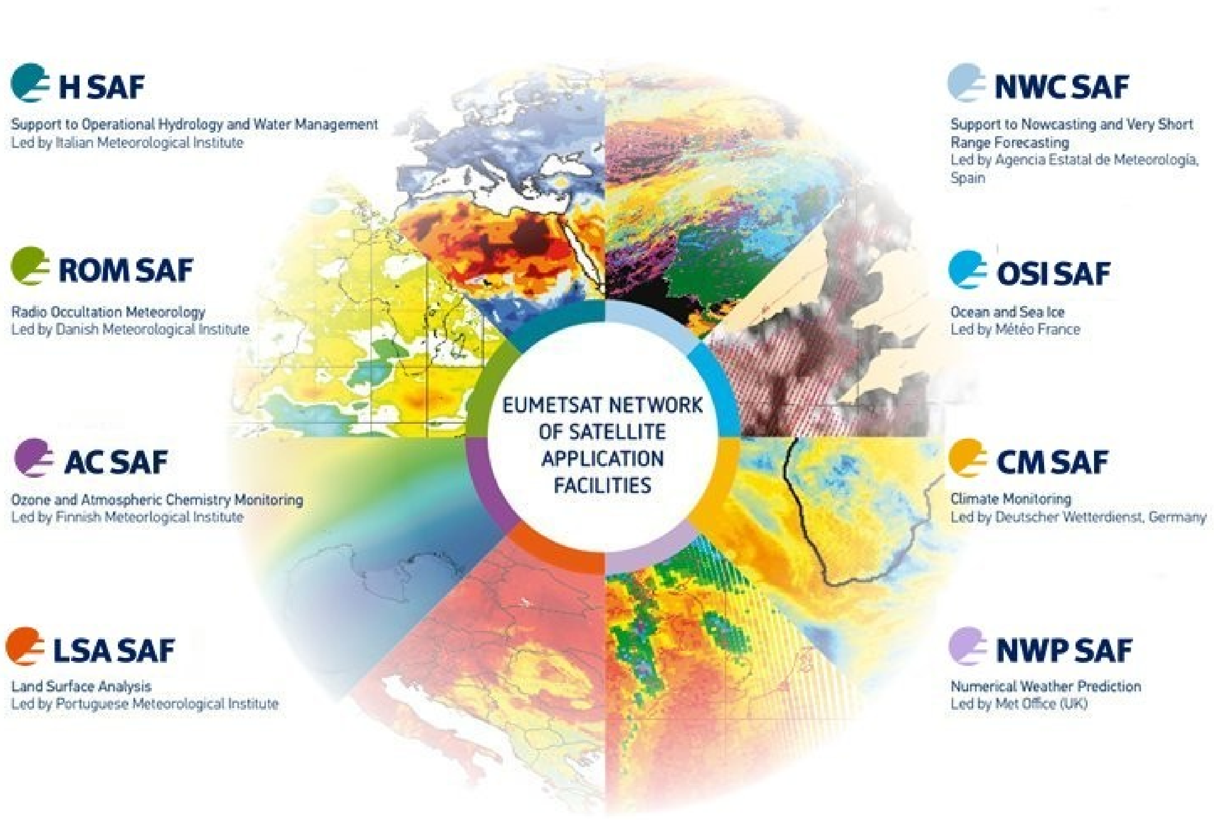


Figure 10. Current composition of the EUMETSAT SAF Network

5.2 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);
   - 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.

5.3 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.

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

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.

5.4 System Overview

H SAF is led 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 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 COMET (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 COMET (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 COMET.
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.

Annex 3. Acronyms

AC-SAF	SAF on Atmospheric Composition Monitoring
AMSU	Advanced Microwave Sounding Unit (on NOAA and MetOp)
AMSU-A	Advanced Microwave Sounding Unit - A (on NOAA and MetOp)
AMSU-B	Advanced Microwave Sounding Unit - B (on NOAA up to 17)
ATBD	Algorithms Theoretical Baseline Document
BfG	Bundesanstalt für Gewässerkunde (in Germany)
CAF	Central Application Facility (of EUMETSAT)
CDOP	Continuous Development-Operations Phase
CM-SAF	SAF on Climate Monitoring
CNMCA	Centro Nazionale di Meteorologia e Climatologia Aeronautica (in Italy)
DMSP	Defense Meteorological Satellite Program
DPC	Dipartimento Protezione Civile (of Italy)
ECMWF	European Centre for Medium-range Weather Forecasts
EDC	EUMETSAT Data Centre, previously known as U-MARF
EUM	Short for EUMETSAT
EUMETCast	EUMETSAT's Broadcast System for Environmental Data
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FMI	Finnish Meteorological Institute
FTP	File Transfer Protocol
GEO	Geostationary Earth Orbit
HDF	Hierarchical Data Format
H SAF	SAF on Support to Operational Hydrology and Water Management
IFOV	Instantaneous Field Of View
IMWM	Institute of Meteorology and Water Management (in Poland)
IPF	Institut für Photogrammetrie und Fernerkundung (of TU-Wien, in Austria)
IPWG	International Precipitation Working Group
IR	Infra Red
IRM	Institut Royal Météorologique (of Belgium) (alternative of RMI)
LEO	Low Earth Orbit
LSA-SAF	SAF on Land Surface Analysis
LST	Local Satellite Time (if referred to time) or Land Surface Temperature (if referred to temperature)
METU	Middle East Technical University (in Turkey)
MHS	Microwave Humidity Sounder (on NOAA 18 and 19, and on MetOp)
MSG	Meteosat Second Generation (Meteosat 8, 9, 10, 11)
MVIRI	Meteosat Visible and Infra Red Imager (on Meteosat up to 7)
MW	Micro Wave
NEΔT	Net Radiation
NMA	National Meteorological Administration (of Romania)
NOAA	National Oceanic and Atmospheric Administration (Agency and satellite)
NWC-SAF	SAF in support to Nowcasting & Very Short Range Forecasting
NWP	Numerical Weather Prediction
NWP-SAF	SAF on Numerical Weather Prediction
OMSZ	Hungarian Meteorological Service
ORR	Operations Readiness Review
OSI-SAF	SAF on Ocean and Sea Ice
Pixel	Picture element
PP	Project Plan
PR	Precipitation Radar (on TRMM)

PRD	Product Requirements Document
PUM	Product User Manual
PVR	Product Validation Report
RMI	Royal Meteorological Institute (of Belgium) (alternative of IRM)
RMSE	Root Mean Squared Error
ROM-SAF	SAF on Radio Occultation Meteorology
SAF	Satellite Application Facility
SEVIRI	Spinning Enhanced Visible and Infra-Red Imager (on Meteosat from 8 onwards)
SSM/I	Special Sensor Microwave / Imager (on DMSP up to F-15)
SSMIS	Special Sensor Microwave Imager/Sounder (on DMSP starting with S-16)
T_{BB}	Equivalent Blackbody Temperature (used for IR)
TKK	Teknillinen korkeakoulu (Helsinki University of Technology)
TMI	TRMM Microwave Imager (on TRMM)
TSMS	Turkish State Meteorological Service
TU-Wien	Technische Universität Wien (in Austria)
U-MARF	Unified Meteorological Archive and Retrieval Facility
UTC	Universal Coordinated Time
VIS	Visible
ZAMG	Zentralanstalt für Meteorologie und Geodynamik (of Austria)