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

Algorithm Theoretical Baseline Document (ATBD) for product H08 – SM-OBS-2

Small-scale surface soil moisture by radar scatterometer

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Algorithm Theoretical Baseline Document ATBD-15A
Product PR-OBS-6A
Blended SEVIRI Convection area/ LEO MW Convective Precipitation

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Acronyms

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)
ATDD	Algorithms Theoretical Definition Document
AU	Anadolu University (in Turkey)
BfG	Bundesanstalt für Gewässerkunde (in Germany)
CAF	Central Application Facility (of EUMETSAT)
CDOP	Continuous Development-Operations Phase
CESBIO	Centre d'Etudes Spatiales de la BIOsphere (of CNRS, in France)
CM-SAF	SAF on Climate Monitoring
CNMCA	Centro Nazionale di Meteorologia e Climatologia Aeronautica (in Italy)
CNR	Consiglio Nazionale delle Ricerche (of Italy)
CNRS	Centre Nationale de la Recherche Scientifique (of France)
DMSP	Defense Meteorological Satellite Program
DPC	Dipartimento Protezione Civile (of Italy)
EARS	EUMETSAT Advanced Retransmission Service
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
GRAS-SAF	SAF on GRAS Meteorology
HDF	Hierarchical Data Format
HRV	High Resolution Visible (one SEVIRI channel)
H-SAF	SAF on Support to Operational Hydrology and Water Management
IDL©	Interactive Data Language
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)
ISAC	Istituto di Scienze dell'Atmosfera e del Clima (of CNR, Italy)
ITU	İstanbul Technical University (in Turkey)
LATMOS	Laboratoire Atmosphères, Milieux, Observations Spatiales (of CNRS, in France)
LEO	Low Earth Orbit
LSA-SAF	SAF on Land Surface Analysis
Météo France	National Meteorological Service of France
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
NESDIS	National Environmental Satellite, Data and Information Services
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
O3M-SAF	SAF on Ozone and Atmospheric Chemistry Monitoring
OMSZ	Hungarian Meteorological Service
ORR	Operations Readiness Review
OSI-SAF	SAF on Ocean and Sea Ice
PDF	Probability Density Function
PEHRPP	Pilot Evaluation of High Resolution Precipitation Products
Pixel	Picture element
PMW	Passive Micro-Wave
PP	Project Plan
PR	Precipitation Radar (on TRMM)
PUM	Product User Manual
PVR	Product Validation Report
RMI	Royal Meteorological Institute (of Belgium) (alternative of IRM)
RR	Rain Rate
RU	Rapid Update
SAF	Satellite Application Facility
SEVIRI	Spinning Enhanced Visible and Infra-Red Imager (on Meteosat from 8 onwards)
SHMÚ	Slovak Hydro-Meteorological Institute
SSM/I	Special Sensor Microwave / Imager (on DMSP up to F-15)
SSMIS	Special Sensor Microwave Imager/Sounder (on DMSP starting with S-16)
SYKE	Suomen ympäristökeskus (Finnish Environment Institute)
T_{BB}	Equivalent Blackbody Temperature (used for IR)
TKK	Teknillinen korkeakoulu (Helsinki University of Technology)
TMI	TRMM Microwave Imager (on TRMM)
TRMM	Tropical Rainfall Measuring Mission UKMO
TSMS	Turkish State Meteorological Service
TU-Wien	Technische Universität Wien (in Austria)
U-MARF	Unified Meteorological Archive and Retrieval Facility
UniFe	University of Ferrara (in Italy)
URD	User Requirements Document
UTC	Universal Coordinated Time
VIS	Visible
ZAMG	Zentralanstalt für Meteorologie und Geodynamik (of Austria)

2 Introduction to product H08 - SM-OBS-2

2.1 Sensing principle

Product SM-OBS-2 (Small-scale surface soil moisture by radar scatterometer) results from post-processing of the SM-OBS-1 product extracted by ZAMG from the Global surface soil moisture product distributed by EUMETSAT. Product SM-OBS-1 is based on the radar scatterometer ASCAT embarked on MetOp satellites. The instrument scans the scene in a push-broom mode by six side-looking antennas, three left-hand, three right-hand (see Fig. 03). On each side, the three antennas, looking aside, + 45° and - 45° respectively, provide three views of each earth location under different viewing angles measuring three backscattering coefficients (σ0, sigma-nought) at slightly different time. Each antenna triplet provides a side swath of 550 km. The two swaths leave a gap (close to the sub-satellite track) of ~ 670 km. Global coverage over Europe is achieved in ~ 1.5 days.

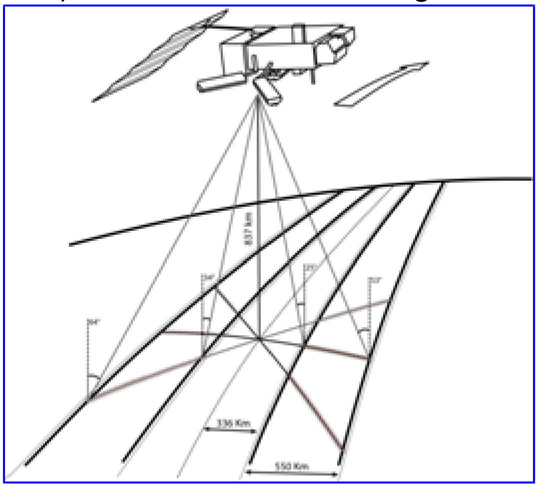

Fig. 03 - Scanning geometry of ASCAT.

The basic instrument sampling distance is 12.5 km. The primary ASCAT observation, sea-surface wind, is processed at 50 km resolution. For soil moisture, processing is performed at 50 km (operational) and 25 km (research) resolution.

For the purpose of SM-OBS-2, the 25-km resolution SM-OBS-1 product is disaggregated and re-sampled at 1-km intervals to better fit hydrological requirements.

Fig. 04 - Principle of disaggregation by auxiliary data.

The disaggregation process (see Fig. 04) makes use of a fine-mesh layer pre-computed and stored in a parameter database. The fine-mesh information includes backscatter and scaling characteristics derived from SAR imagery from Envisat ASAR operating in the ScanSAR Global monitoring model.

For more information, please refer to the Products User Manual (specifically, volume PUM-08).

2.2 Main operational characteristics

The operational characteristics of SM-OBS-2 are discussed in PUM-08. Here are the main highlights.
The horizontal resolution (Δx). The effective resolution is controlled by the originating product, SM-OBS-1, therefore the worst-case figure representative of the SM-OBS-2 resolution is: Δx = 25 km. However, the disaggregation process performs re-sampling at 1 km intervals, that therefore would constitute the resolution in best conditions. The effectiveness of disaggregation depends on the availability and the effectiveness of the disaggregation parameters. Conclusion:

- resolution: Δx = 1 ÷ 25 km - sampling distance: 1 km.

The observing cycle (Δt). The ASCAT swath is 550 + 550 km on the two sides, with a 670 km gap in between. The gap left by ascending orbits is mostly filled by descending orbits. In average the observing cycle over Europe is Δt ~ 36 h, improving with latitude. However, areas where disaggregation parameters are not available, are not processed, therefore the SM-OBS-2 maps leave several gaps of coverage. Conclusion:

- observing cycle Δt ~ 36 h [areas lacking disaggregation parameters are not covered].

The timeliness (δ). The product is generated shortly after reception of the Global product from EUMETSAT via EUMETCast, that has a timeliness of ~ 1.5 h. The processing time is less than 20 minutes. Adding 10 min for distribution we have:

- timeliness δ ~ 2 h.

The accuracy, is measured in m3·m-3 . It is evaluated a-posteriori by means of the validation activity. See Product Validation Report PVR-08.

2.3 Architecture of the products generation chain

The architecture of the SM-OBS-2 product generation chain is shown in Fig. 05. The figure includes mention of the primary source of satellite data, the Global surface soil moisture product generated by EUMETSAT and disseminated via EUMETCast; and of the source for disaggregation parameters, the ASAR instrument on Envisat, with data available from the ESA archive.

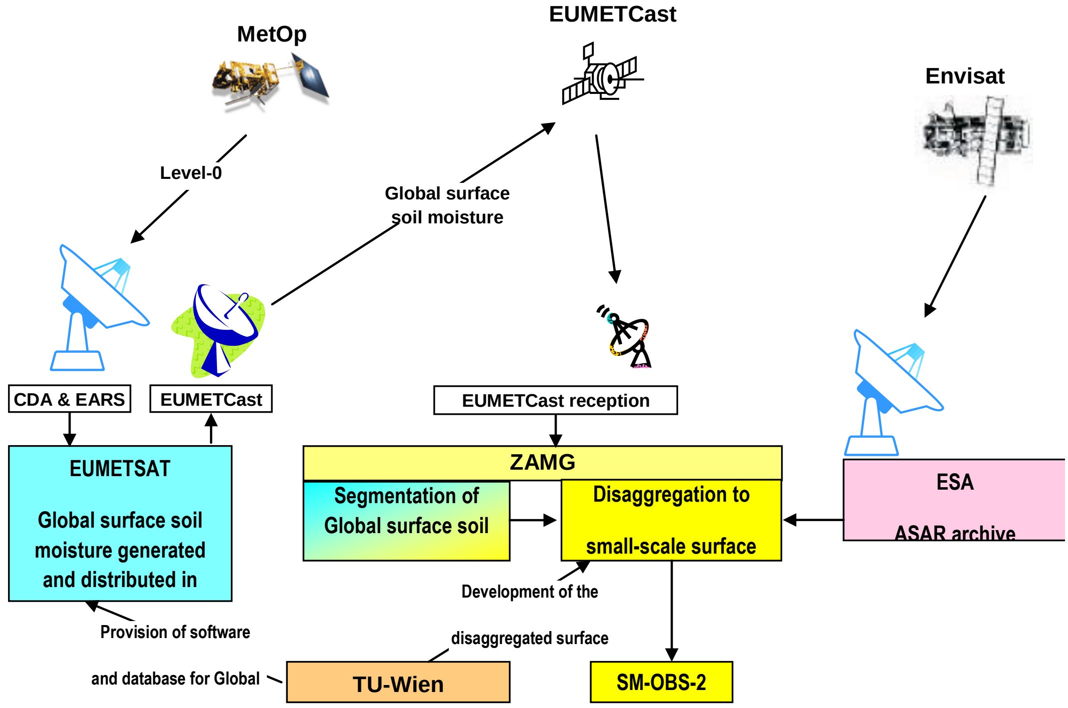

Fig. 05 - Conceptual architecture of the SM-OBS-2 production chain.

3 Processing concept

The basis for the disaggregated soil moisture product is the aforementioned global coarse-resolution 25 km surface soil moisture product generated at the EUMETSAT premises. It is merged with high-resolution local information to generate a new product sampled at kilometre-scale. The algorithms for this product will be developed by Technische Universität Wien (TU-Wien), while processing is foreseen to be run at Zentralanstalt für Meteorologie und Geodynamik (ZAMG).

The benefits for users of this product will be the following:

- Downscaled product information disaggregated to kilometre-scale, this increases the applicability of the data,
- Additional quality information from various NRT datasets (snow, freeze/thaw etc.) available for Europe,
- Advanced quality information will give a measure of soil moisture suitability,
- European geographic projection tailored to European users,
- Data type format directly suitable for further hydrologic modelling and data assimilation schemes (WMO BUFR).

Soil moisture is a spatially and temporally highly variable parameter. In-situ measurements give exact values but are spatially limited to a small scale, while remote sensing methods give area estimates on a much larger scale. Active and passive remote sensing methods are considered to have the largest potential due to their unique sensitivity to dielectric constant of the soil, which is directly related to water content.

The disaggregated product will benefit from the information of a scaling layer. This layer allows the interpretation of coarse resolution soil moisture information at 1 km resolution by identifying targets which have similar backscatter characteristics at both local (observed with the Envisat ASAR Global Mode sensor) and regional (observed with the MetOp ASCAT) scale. For these targets, soil moisture trends observed in the coarse resolution product can be used instantaneously at 1 km scale.

The flow chart of the processing chain for the disaggregated soil moisture product is shown in Fig. 06.

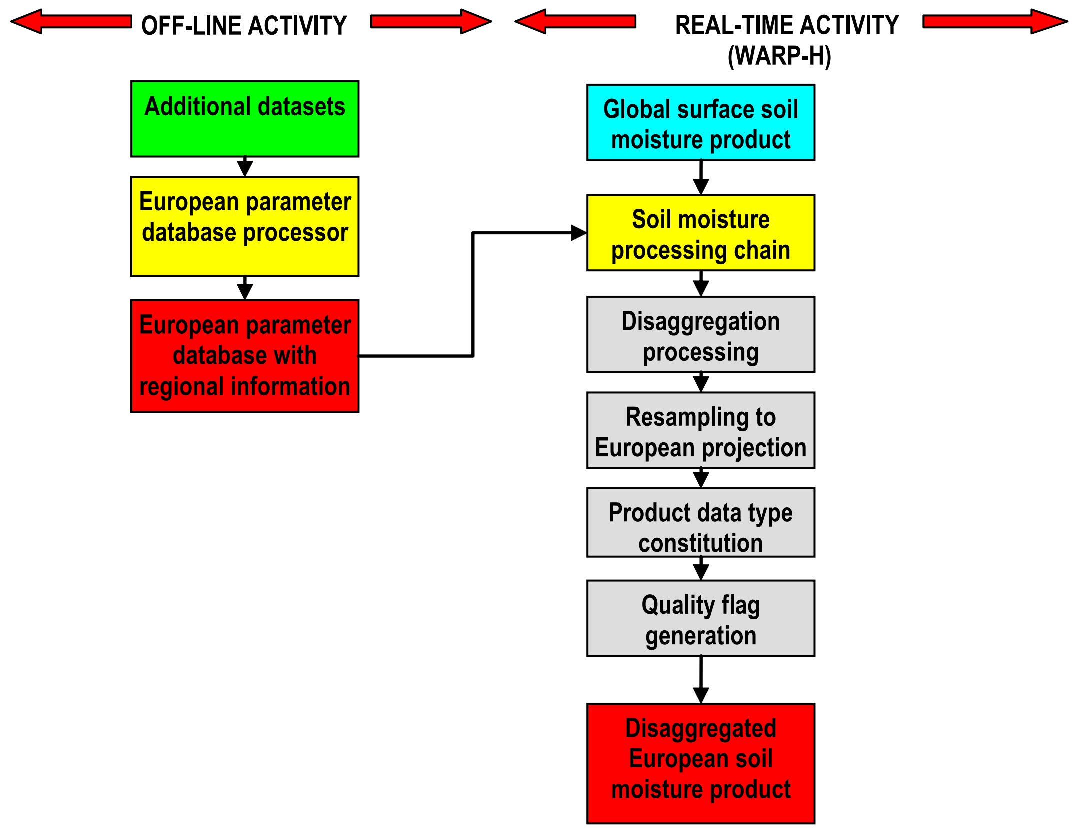

Fig. 06 - Flow chart of the processing chain for the disaggregated soil moisture product.

Since the disaggregation processing is a time-consuming task, this task will be performed off-line to generate a European parameter database with all sufficient information. For generation of the disaggregated product itself, the European parameter database will be restored in near real-time and all further processing steps will be performed with the software package WARP-H.

The following processing steps will be implemented:

- Reading the global soil moisture product
- Restoring the European parameter database for disaggregation processing
- Disaggregation of the soil moisture information
- Resampling of disaggregated information to European projection type
- Setting of complementary quality flags (internal quality checks and processing information)
- Storing of the product in pre-defined product data type.

3.1 Algorithms description

Basics

Following the principle of the global coarse-resolution 25 km surface soil moisture product, the processing of the European disaggregated product is again established in a stepwise processing. In the off-line pre-processing step, Envisat ASAR Global Mode (ASAR GM) datasets are resampled to the geometry of the output product over a predefined European grid. All the parameters are stored in a European parameter database. When it comes to product generation itself with the software WARP-H, the disaggregated product is being calculated with the restored European parameter database in near-real time.

The idea of the disaggregation approach is to use a temporal stability concept. This concept has been established originally in hydrology, but has been used in different applications as well. Being introduced by Vauchaud et al. 1985, it is used to estimate representative soil moisture stations within a catchment area. With this method, the relation between a single local in-situ soil moisture station and the regional mean of all in-situ soil moisture stations can be described. Since then the method has for example been used by (Martínez-Fernández and Ceballos 2005) to describe the relation between local in-situ soil moisture data and regional soil moisture trends.

For the disaggregated soil moisture product, we envisage to retrieve the scaling layer information from ASAR GM images. The data are geocoded and resampled to a predefined regular 1 km grid. In the next processing step, the correlation between a time series of local (a) and regional (b) backscatter spanning for a time-series (currently December 2004 - March 2010) is derived for each grid point. In this calculation, the local scale data (a) are the instantaneous ASAR GM backscatter measurements. The regional scale data (b) are generated by aggregating ASAR GM backscatter measurements up to 25 km using simple linear averaging with equal weight given to each measurement.

In the pixels, where the resulting correlation coefficients is positive, the local scale backscatter follows a regional scale backscatter indicating that there are similar backscatter conditions in the images and a downscaling of coarse resolution 25 km ASCAT data to 1 km resolution is performed. If the spatial coverage of ASAR GM data is not sufficient for Europe, the scaling layer information cannot be derived and the final product quality flag is set, but this may be re-tuned in operational phase.

Off-line generation of the European parameter database

The following pre-processing steps are applied for generation of the European parameter database and use as input all available auxiliary datasets. These steps are implemented off-line and are provided by TU-Wien with in-house software:

Step 1: Geocoding of ASAR GM scenes.

The exact parameters for geocoding are taken from Envisat DORIS Precise Orbit files, while geocoding itself is performed using a SRTM digital elevation model.

Step 2: Resampling to discrete grid.

Stacks of 0.5° regions of ASAR GM time-series are extracted and resampled to a fixed grid with 0.5 km resolution. Mean backscatter values of the 1km Envisat pixels are stored as local mean values.

Step 3: Normalisation .

A time-series region of ASAR GM is taken and a radiometric normalisation is applied to a reference incidence angle at 30°.

Step 4: Regional mean calculation.

In a moving window of 25*25 km surrounding each pixel of the time-series, the mean backscatter values are calculated as regional mean values.

Step 5: Correlation coefficient calculation.

Calculation of Pearson's coefficient of correlation (R) between the local and regional mean time series and storing. This gives a measure of the temporal consistency between the regional and local backscatter signals.

Step 6: Quality flag processing.

Several quality flags, which stem from the abovementioned calculation steps, are stored in the parameter database. Examples of flags: number of measurements, fraction of regional coverage of ASAR within one MetOp cell, or statistical parameters like residuals.

The processing steps for generating the disaggregated European product

Near real-time processing as implemented in WARP-H is dedicated only to the generation of products and does not require the intermediate parameter retrieval steps. Following near real-time processing steps are therefore implemented in WARP-H:

Step 1: Restoring the European parameter database.

This database stores the auxiliary data parameters of the previously described methodological steps in a 0.5 km grid.

Step 2: Reading of the global soil moisture product (as described in Chapter 4.2).

Step 3: Disaggregation step.

The correlation information with 1km resolution from the European parameter database is appended to the ASCAT soil moisture product and stored as a scaling layer with a resolution of 1km.

Step 4: Resampling to European projection.

Depending on the fine-tuning during development phase, the geographic projection, which is tailored to European users, will be applied.

Step 5: Product data type constitution.

For the prototype phase the BUFR data format is envisaged, which may be re-tuned during development phase to better serve needs of H-SAF product users.

Algorithm validation/heritage

In the past, several studies showed that variations of soil moisture in space and time can be addressed to two different scaling components – namely a small scale and a large scale component. On the one hand, small scale component can lead to local variations of soil moisture due to soil properties, land cover attributes and local topography. The processes behind act in the range of tens of meters within a few days (Entin et al. 1999; Robock et al. 2000). On the other hand, the large-scale components of the climate explain spatio-temporal soil moisture patterns. This explains why in-situ soil moisture measurements, although representing point measurements, can be compared to remotely sensed soil moisture information. A number of studies showed that a comparison of coarse resolution soil moisture time series (representing an area larger than 1000 km2), with in-situ measurements of soil moisture (typically representing an area of 0.01 km2 or less) can exhibit a large correlation, although being of significantly different spatial scales. Wen and Su 2003 found a high correlation coefficient (R=0.63) between ERS scatterometer derived relative surface soil moisture time series and top horizon soil moisture in Tibet. In another study, Bindlish et al. 2003 derived soil moisture estimates from a coarse resolution space-borne microwave radiometer over the Southern United States. Comparisons of relative soil moisture values extracted from SSM/I radiometer data to in-situ soil moisture measurements showed that the coarse resolution products are capable of explaining the temporal behaviour of the soil moisture. Following these well established agreements between soil moisture point data and remotely sensed areal soil moisture estimates at different scales, we consider the scaling approaches in the development of the regional product generation.

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4 Examples of small-scale surface soil moisture maps.

Fig. 07 shows an example of downscaled surface soil moisture at 1 km resolution for Europe representing a 3-minute strip of a full ASCAT orbit. The two sub-swaths can be clearly identified, no-data values (e.g. over the sea) are masked out.

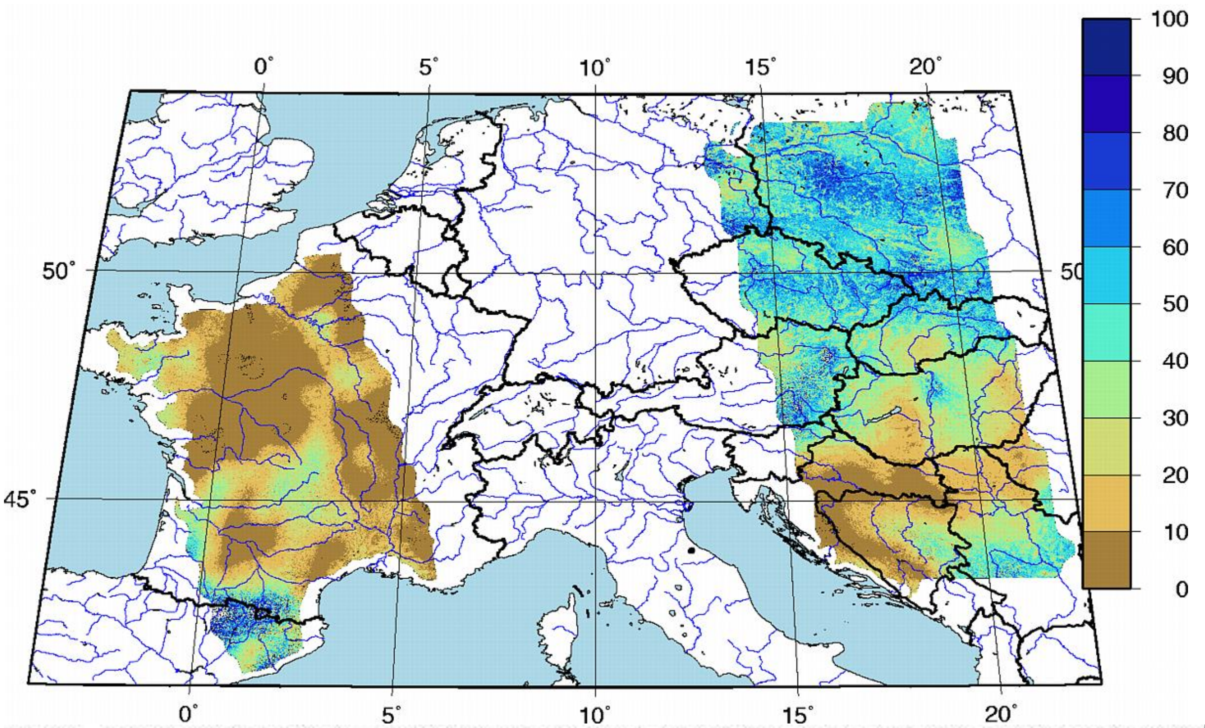

Fig. 07 - Example of small-scale surface soil moisture (SM-OBS-2) from ASCAT. Note the two side swaths (550 km each) and the 670 km gap in between. MetOp-A, 30 September 2009, 20:12 UTC.

Fig. 08 compares the 1-km sampled SM-OBS-2 with the 25-km original resolution of SM-OBS-1.

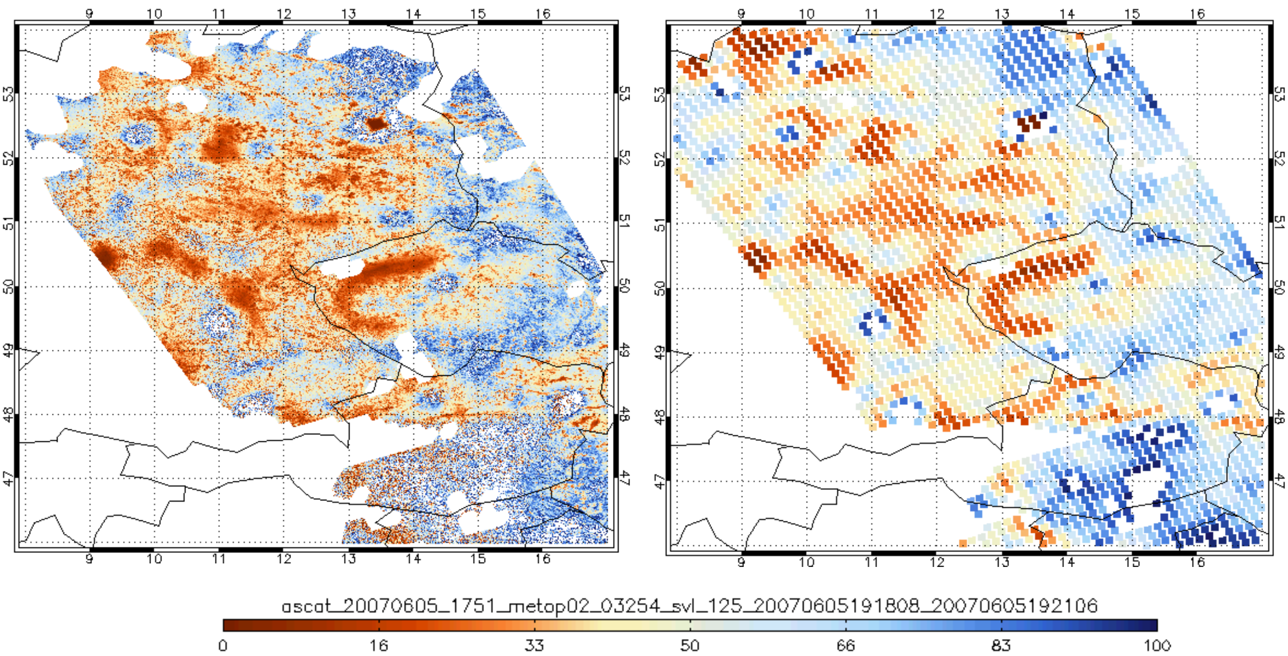

Fig. 08 - Detailed view of SM-OBS-2 over central Europe (left panel). MetOp-A, 5 June 2007, 19:18 - 19:19 UTC. Area of ~880 x 650 km². For comparison, the SM-OBS-1 product is shown (right panel). No-data values are masked.

5 References

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6 Annex 1: Introduction to H-SAF

6.1 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 17):

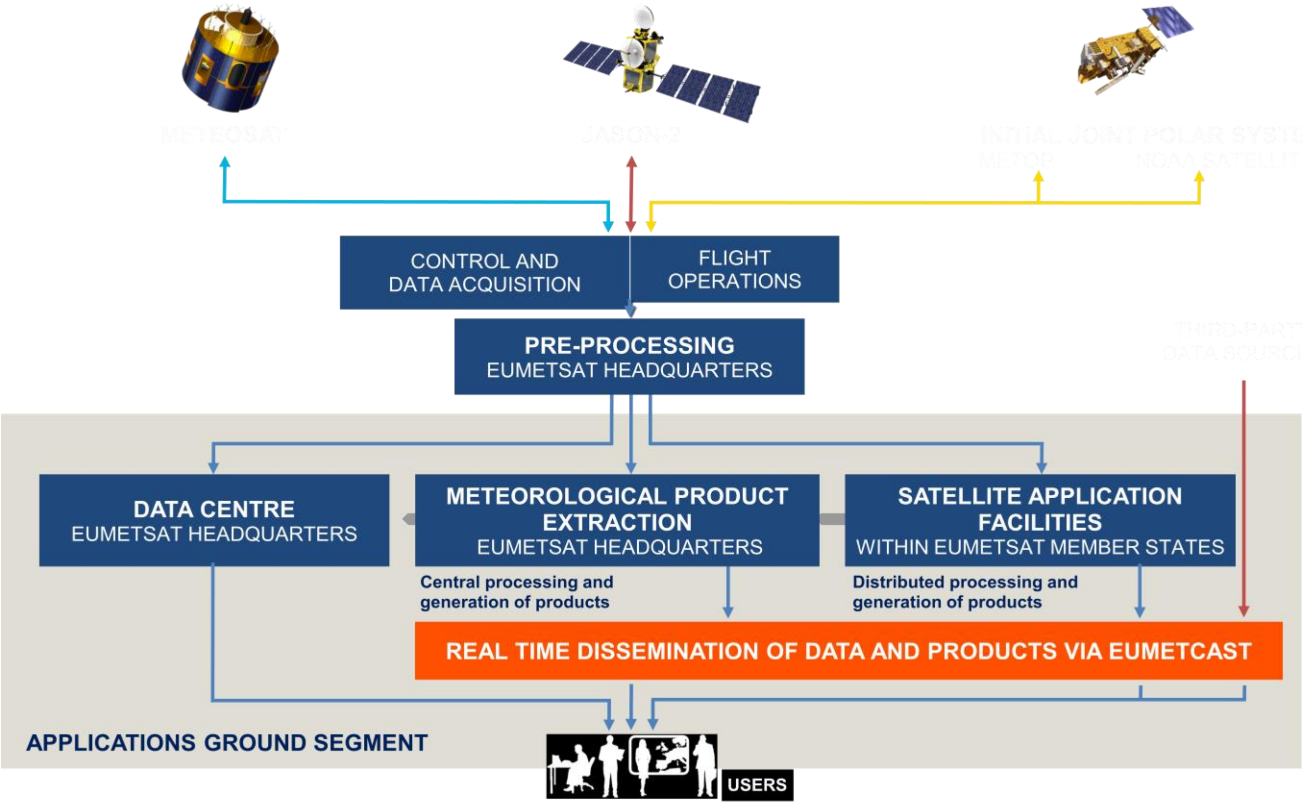

Figure 17: Conceptual scheme of the EUMETSAT Application Ground Segment

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

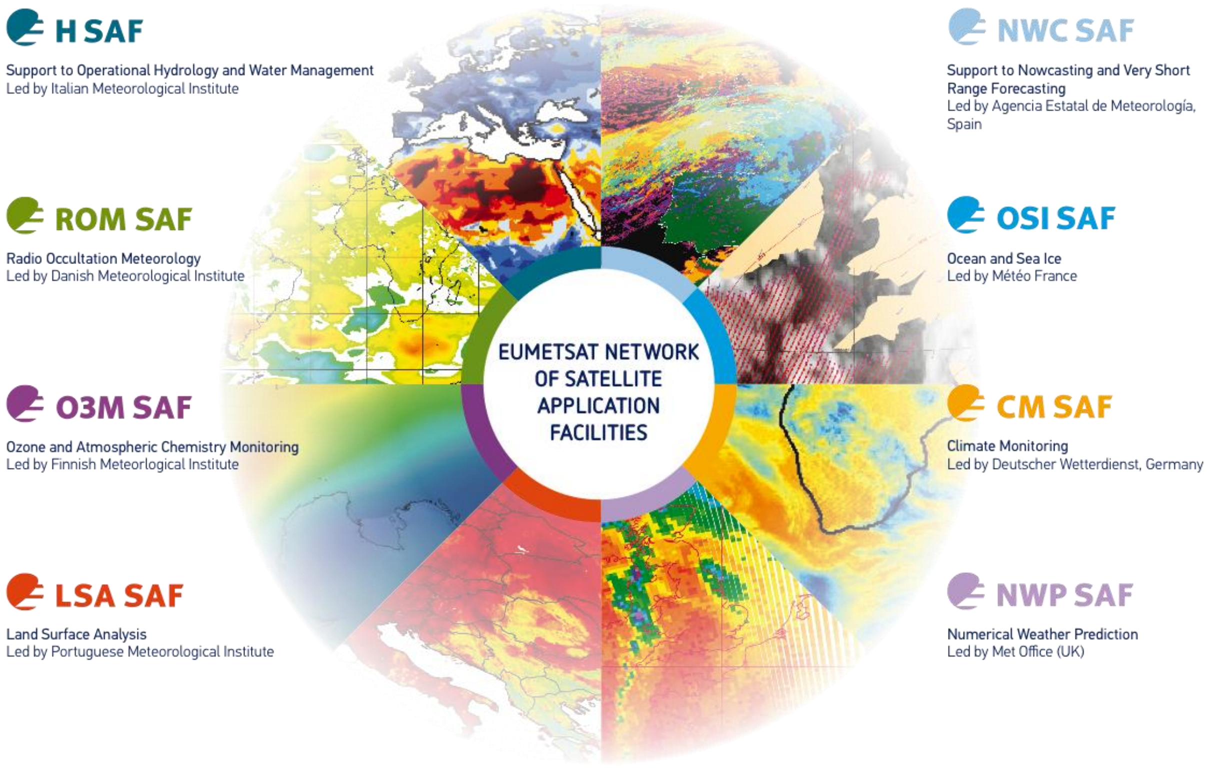

Figure 18: Current composition of the EUMETSAT SAF Network

6.2 Purpose of the H-SAF

The main objectives of H-SAF are:

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);

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.

6.3 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.
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6.4 System Overview

H-SAF is lead by the Italian Air Force Meteorological Service (ITAF USAM) 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 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.