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

EUMETSAT H SAF
SUPPORT TO OPERATIONAL HYDROLOGY AND WATER MANAGEMENT

Algorithm Theoretical Baseline Document (ATBD) for product H05B/P-AC-G-SEVIRI

Accumulated precipitation at ground by blended MW and IR

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DOCUMENT CHANGE RECORD

Issue / Revision	Date	Description
1.0	02/03/2015	Baseline version prepared for PCR
1.1	02/12/2015	Version prepared for PCR close-out which acknowledges the outcomes of the review. Following changes applied: • Area coverage specified (answer to RID 001) • Section 4 (Validation) improved (answer to RID 015, 025, 027, 029)
1.2	08/09/2017	RIDs acknowledgement from ORR

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1 Introduction to product P-AC-G-SEVIRI

1.1 Sensing principle

Product H05B (P-AC-G-SEVIRI over the full disk area) is based on frequent precipitation measurements as retrieved by blending LEO MW-derived precipitation rate measurements and GEO IR imagery. The input data are therefore P-IN-GRU-SEVIRI. The covered area is shown in **Figure 1**, same as for P-IN-GRU-SEVIRI.

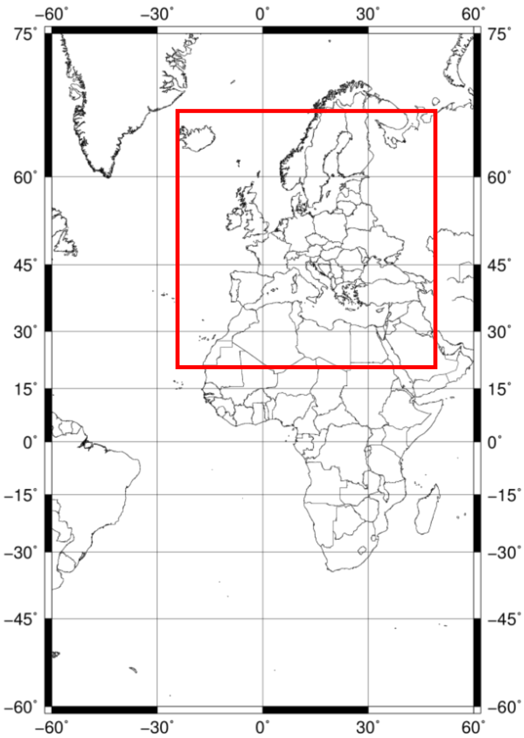

Figure 1 The P-AC-G-SEVIRI coverage 60°S-75°N , 60°W - 60°E. The HSAF area is indicated by the red square

1.2 Main operational characteristics

The operational characteristics of P-AC-G-SEVIRI are discussed in PUM-05B. Here are the main highlights.

__The horizontal resolution (Δx)__. The product is generated for each SEVIRI pixel. The SEVIRI IFOV is 4.8 km at nadir, and degrades moving away from nadir, becoming about 8 km in the H-SAF area. It is prudent to assume that the process leading to P-IN-GRU-SEVIRI hiddenly convolutes arrays of 3-4 SEVIRI pixels a side, finally ending with Δx ~ 30 km. However, sampling is made at ~ 5 km intervals, consistent with the SEVIRI pixel over Europe. Conclusion:

- resolution Δx ~ 30 km - sampling distance: ~ 5 km.

The *__observing cycle (Δt)__*. The product is generated each 3 h by integrating over the previous 3, 6, 12 and 24 h. We could refer to the product generation rate and, although inappropriately, quote:

- observing cycle: Δt = 3 h - sampling time: 3 h.

The *timeliness (δ)*[1]. After each full 3 hours, the product is processed within 15 min, to be added to the 15-min timeliness of the P-IN-GRU-SEVIRI frame last entering the time integration process. Thus:

- timeliness δ ~ 0.5 h.

The *accuracy* is evaluated *a-posteriori* by means of the validation activity. See Product Validation Report PVR-05B.

1.3 Architecture of the products generation chain

The architecture of the P-AC-G-SEVIRI product generation chain is shown in **Figure 2**.

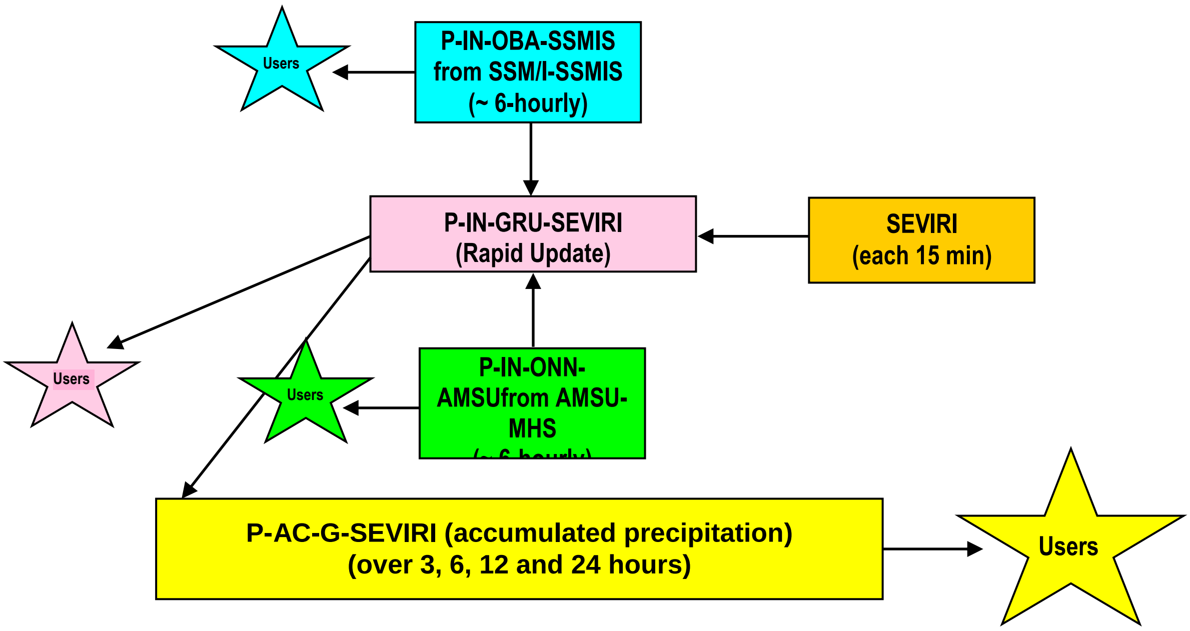

Figure 2 P-AC-G-SEVIRI architecture

The figure highlights that P-AC-G-SEVIRI is the final stage of all previous precipitation product chains:

- the Rapid Update process based on (frequent) SEVIRI IR images "calibrated" by the (infrequent) MW-derived precipitation data as retrieved from SSMIS (P-IN-OBA-SSMIS) or from AMSU-A, AMSU-B or MHS (P-IN-ONN-AMSU);

2 Processing concept

2.1 The sampling problem

It is useful to remind in this Section the relationship between accuracy of accumulated precipitation computation and sampling interval, function of the target integration interval (3, 6, 12 and 24 h).

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[1] Timeliness is usually defined as the time difference between end of image acquisition (of the last contributing image) at satellite level and end of data reception at the end-user.Within H-SAF this definition has been adopted once the specification of EUMETCast as the main dissemination mean was baselined; the tailored timeliness definition is expressed in the H- SAF Service Specifications [AD 7] as follows: timeliness corresponds to the time elapsed from beginning of sensing time to reception by the user via EUMETCast. Thus the requirement expressed in the PRD document is based on the end-to-end point of view; it include the SAF timeliness (time needed by the SAF to process the data, generate a L2 product and disseminate to the EUMETSAT HQ) and the time for dissemination to the end users.

We have to consider that scale-free power-law behaviour is found to govern the statistics of rain over a wide range of time and event size scales. An anomalous Hurst exponent and 1/f noise reflects the dynamics of a self-organized critical state of minimally stable clusters of all length scales, which in turn generates fluctuations on all time scales. The precipitation can be considered a stochastic event self organized similar to red noise (Bove et al. 2005). These considerations show that rainfall time series cannot be reproduced by conventional methods of probability theory and numerical modelling of precipitation sampling error is not possible.

Since H-SAF will deliver *instantaneous* rain rate retrievals and cumulated precipitation computed from those products, it is important to asses the impact of instantaneous sampling on reconstructing the phenomena which is the water mass at the ground.

We assume that perfect rain observations are taken at the ground by rain gauges. These instruments observe directly the physical parameter (mass of water) with continuous (perfect) time integration.

From the above assumption we may have perfect observation series after filtering rain gauges records from no rain observations.

We worked with an ensemble populated by the time series recorded by a network of 76 automatic stations along one year period ranging from September 2001 to August 2002. From these perfect series we may simulate instantaneous rain rate with a time differential equal to the shortest integration time (15 minutes). This time differential allows to simulate sampling from 30-min period onwards.

Three sampling periods were simulated (30 min, 1 hour and 3 hours) and compared to two perfect cumulated series of 3 hours and 24 hours which corresponds to two time scales of the phenomena.

Only two statistical parameters were computed: the bias which gives information on the systematic error, and the standard deviation (STD) which gives indication on the accuracy obtained by the simulated samplings.

The results are reported in **Table 1**.

Sampling periods	**24-h cumulated**		**3-h cumulated**	
	Bias	STD	Bias	STD
3 h	- 1.52 %	142 %	- 0.84 %	167 %
1 h	- 3.70 %	66 %	- 5.1 %	74 %
30 min	0.54 %	37 %	- 2.98 %	43 %

Table 1 Expected errors of accumulated precipitation measurement function of sampling

From this study we may see that instantaneous time sampling does not produce a significant bias, but it affects accuracy. From this short study is possible also to say a more general statement that accuracy (STD) depends on the sampling period and to a less extent on the accumulation period.

In conclusion regarding the H-SAF products of cumulated precipitation estimation we have to consider that for the planned operations in order to produce usable estimations the time scale of the measures must be kept of the same order of the sampling period and/or vice versa.

In addition to that we will keep open the research issue of demonstrating the precipitation ergodic property which should be used in order to obtain measures properly scaled with the sampling practice.

The basic operational algorithms for computing the cumulated precipitation relies on the assumption that:

- instantaneous derivative (the retrieved rain rate) is constant along the integration period;
- spatial resolution will be kept constant, no upscaling is performed along time integration of highest space time resolution rain rate products (IR+MW);
- one value is considered for tentative accuracy (i.e. 30 %) regardless the integration period.

2.2 *Introduction to the accumulated precipitation processing chain*

Accumulated precipitation will be computed by temporal integration of the blended LEO/MW and GEO/IR precipitation rate products generated by the Rapid Update method (P-IN-GRU-SEVIRI). The accumulation periods will be 3, 6, 12 and 24 hours.

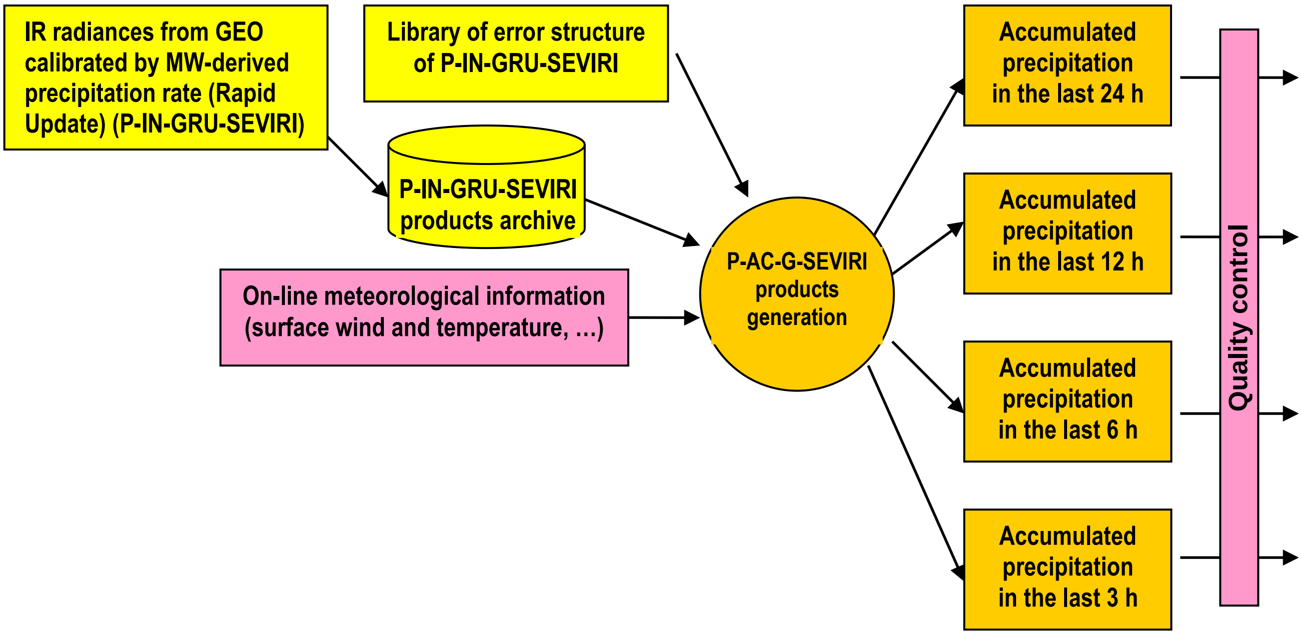


Figure 3 Flow chart of the accumulated precipitation processing chain

The P-AC-G-SEVIRI products is generated every 3 hours and distributed at synoptic hours (00, 03, 06, 09, 12, 15, 18, 21 UTC). The product will incorporate precipitation rate retrievals from data collected up to 15 min before the delivery time. The periods of integration of blended MW+IR retrievals at 15-min intervals (P-IN-GRU-SEVIRI) are the previous 3, 6, 12 and 24 hours.

The product quality depends on the type of precipitation and, to a minor extent, the period of integration (see section 2.1).

3 Algorithms description

The following Sections describe the algorithms used in the various modules of the precipitation products generation chain. The level of detail is consistent with the requirement of a manageable document.

3.1 Sampling enhancement

The first step of the algorithm is to obtains an accumulated precipitation value at the time resolution of geostationary observations (15 minutes) starting from the rain rate satellite estimates.

It was necessary to find the best way to extend the instantaneous precipitation over the whole time step, minimizing the random error due to the sampling. Many interpolation functions (linear, cubic, spline, nearest, etc...) were tried in order to compare the integration results. These were very similar, hence the choice went to the simplest method which means to assume that the precipitation rate is constant during the whole time step, so the accumulated precipitation for each time step is obtained multiplying the rain rate estimation by the time step. Once calculated the accumulated precipitation in 15 minutes the second step of the algorithm consists in a very simple quality control on the data. It has based on the comparison between potential outliers and the kind of cloud that produces them and the research of rainy points associated to sky clear, both using the cloud mask coming from the Nowcasting SAF products. When a very high value of rain rate is associated to a cumulonimbus, it comes compared with a climatological threshold. If the accumulated precipitation is greater than the threshold then its value is replaced by the threshold value. Total accumulated precipitation in 3, 6, 12 and 24 hours is a sum up of contributions every 15 minutes.
At this point the output of the algorithm contains not negligible random and bias error due to the indirect nature of the relationship between the variables measured by the satellite and the precipitation estimates, the poor sampling and algorithms imperfections. In particular the random error is basically introduced by the poor sampling in time for the accurate estimates of rain rate based on MW observations, while the IR observations from geostationary satellite increase the number of estimates in time but introduce a significant bias (Adler et al. 1993 and 1994).

4 Validation activities of the P-AC-G-SEVIRI product

The validation methodology of the precipitation products in H-SAF area (European region) is composed by two components: one based on large statistics (multi-categorical and continuous), and one on selected case studies. Both components are considered complementary in assessing the accuracy of the implemented algorithms. Large statistics helps in identifying existence of pathological behaviour, selected case studies are useful in identifying the roots of such behaviour, when present.
During the CDOP-3 the availability of the satellite precipitation products over the full disk poses the problem of their validation outside Europe. In Africa there are few precipitation data derived by ground networks: the operational raingauges stations are sparse and the radar networks are often not fully operational or not available at all. For all these reasons the large statistic quality assessment in African region will be mainly focused on the comparison of H-SAF precipitation products with other satellite products as the Global Precipitation Mission (GPM) products derived by Dual-frequency (Ka-band and Ku-band) Precipitation Radar (DPR). While the cases study analysis will be performed using the DPR based products coupled with ground based precipitation measurements as the ones (rain gauge and radar) provided by the "Institut de Recherche pour le Développement" (IRD) in West Africa. Which GPM product would be used, if one-band or dual-band together with the introduction of

different analysis techniques, as triple collocation method, is still under discussion within the validation group.

Rain gauge measurements provide relatively accurate point estimates of precipitation but suffer from sampling errors in representing area means and they are not available over most oceans and remote areas. Moreover the inhomogeneity in time and space of the precipitation field and the strong relationship between the rainfall and the orography strongly suggest making use of continuous precipitation retrieved fields like as those retrieved from satellite data to achieve a global precipitation analysis. Satellite measurements can cover most of the globe, however, they suffer from errors due to lack of a direct relationship between observation parameters and precipitation. To reduce those overall errors scientists use to merge gauge measurements and satellite estimates.

In the last decades, the efforts on the study about the best possible analysis of global precipitation on gridded field, using satellite estimates have increased, following the pace of the satellite technological development and the increased number of the available satellites. Many papers published in the first years of the 90's, (Adler et al. 1993 and 1994, Huffmann et al. 1995 and 1997) assumed that estimates based on MW observations from SSM/I on board the DMSP satellites gave relatively accurate instantaneous rain rate but with poor sampling in time. From geostationary satellites the IR observations were used to estimate the GOES Precipitation Index (GPI; Arkin and Meisner 1987) in order to have a frequent coverage but significant bias (Adler et al. 1993). The GPI technique estimates tropical rainfall using cloud-top temperature as the sole predictor. The estimation procedure is the following:

Precipitation (mm) = F x R x T

where:

- F is the fractional coverage of IR pixels < 235 K over a reasonably large domain (50 km x 50 km and larger)
- R is 3 mm/h
- T is the number of hours over which "F" was compiled

Many studies have shown that the GPI yields useful results in the tropics and warm-season extratropics. The advantage of this technique is the introduction of IR data which is available frequently over most areas of the globe from geostationary satellites. The major weakness of the method is that estimation of precipitation from cloud-top temperature is relatively far removed from the physics of precipitation generation process.

Use of rain gauge data has been going to be very effective in reducing the bias error. For example Huffman produced in the 1997 the Global Precipitation Climatology Project (GPCP) constituted by an analysis of global monthly precipitation based on the combination between satellite estimates and rain gauge data using optimal coefficients that are inversely proportional to the error variance of each source.

Another approach was introduced by Xie and Arkin (1996) where the satellite estimates and the model predictions are combined linearly through the maximum likelihood estimation method, in which the weighting coefficients are inversely proportional to the error variance for the individual data source. In this way the random error has been reduced. To remove the bias error, the output of the first step is blended with the gauge observations using the method of Reynolds 1988. This second method produced a large-scale precipitation dataset called Climate Prediction Center Merged Analysis of Precipitation (CMAP).

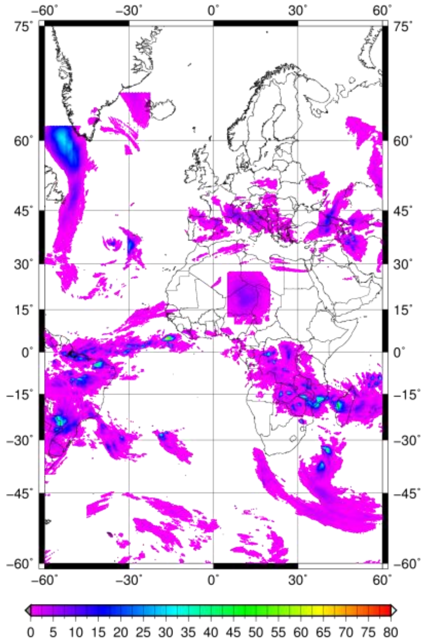
In the July 2001 the International Precipitation Working Group (IPWG) was established as a permanent Working Group of the Coordination Group for Meteorological Satellites (CGMS). The IPWG is co-sponsored by CGMS and the World Meteorological Organization (WMO) and it focuses on operational and research satellite based quantitative precipitation measurement issues. The IPWG has a program on *in situ* continental-scale validation of daily rainfall estimates from all of the operational satellite algorithms providing near real time global rainfall products against rainfall measurements from rain gauges and radars. Satellite algorithms show good performances during warm season and at low latitudes (Adler et al. 2001).

An alternative source of global rainfall information is the short range quantitative precipitation forecasts (QPFs) from numerical weather prediction (NWP) models. From an intercomparison of QPFs from several operational NWP models, as a function of region and season (Ebert et al. 2003), the models show a greatest skill during the cool season in mid-latitudes (no convective systems) and poorer skill for rainfall due to convective clouds. Therefore the NWP models behaviour is opposite to the satellite algorithms. Nowadays the combination of precipitation estimates from models and satellite algorithms seems to be the most promising way to follow, together with the improvement of these data. In particular some studies were carried on the improvements of QPF achieved by local model using a particular data assimilation technique called “Latent Heat Nudging (LHN)” (Klink 2004). This method allows to assimilate the radar-derived precipitation rates during the assimilation runs. Experiments have shown that the explicit simulation of convection leads to more realistic results than model runs with parameterized convection. An additional humidity adjustment during the LHN results in a more exact analysis of the atmospheric state and in more realistic free forecasts, also if the positive impact of the radar data decreases rapidly during the free forecast. On the other side the improvement of the satellite precipitation estimates is continuously in progress. After the GPI index, used in the 90’s, others methods were used, recently the rapid-update blending technique (Turk et al. 2000 a and b) and, still in progress, the Morphing technique (Joyce et al. 2004). The combination of precipitation estimates from models and satellite algorithms can be done in different ways like: weighted combination (Xie and Arkin 1997), linear regression, neural networks, and so on. In this algorithm has been used a new method based on the weighted combination using as weighting coefficients the correlation coefficients achieved by kriging method during the intercalibration between rain gauge measurements-satellite estimates and rain gauge measurements - QPF.

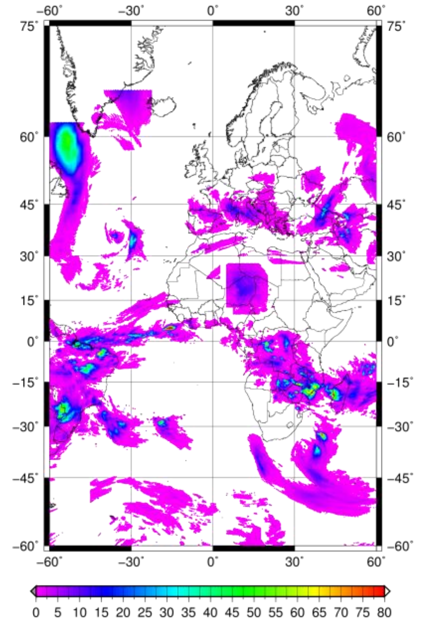
5 Examples of P-AC-G-SEVIRI products

Figure 4 shows accumulated precipitation at 3, 6, 12 and 24 hours. The projection is *mercator* with the MSG area correspondent to 60°S-75°N, 60°W - 60°E [2], the same as for the basic P-IN-GRU-SEVIRI product.

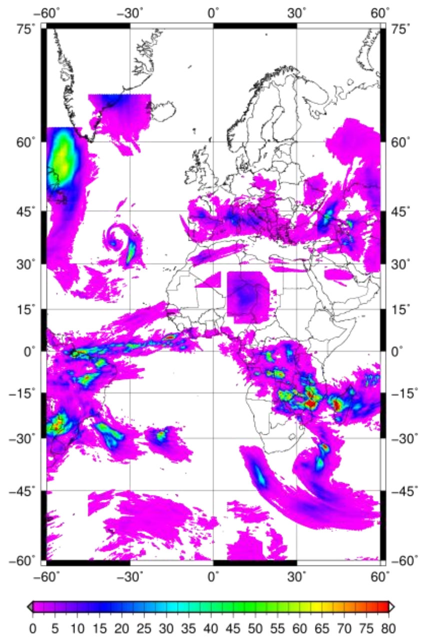
[2] It is noted that throughout this document the statement "full disc" could be used in some cases as a simplified indication of the overall applicability of the product



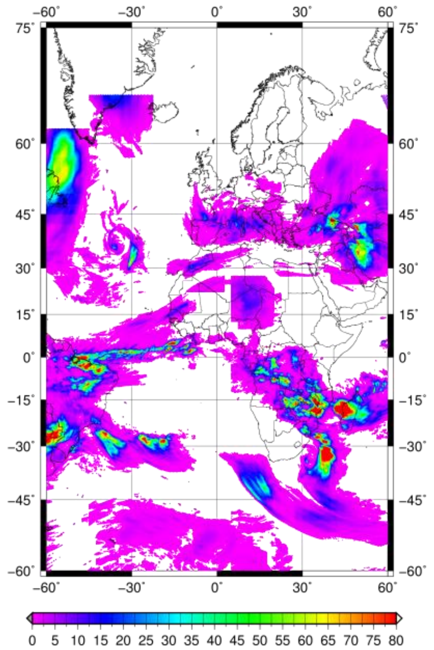
03 Feb 2015, time 00 UTC – 3 hours cumulative precipitation.



03 Feb 2015, time 00 UTC – 6 hours cumulative precipitation.



03 Feb 2015, time 00 UTC – 12 hours cumulative precipitation.



03 Feb 2015, time 00 UTC – 24 hours cumulative precipitation.

Figure 4 Accumulated precipitation over 24 hours

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Annex1: Introduction to H-SAF

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 7):

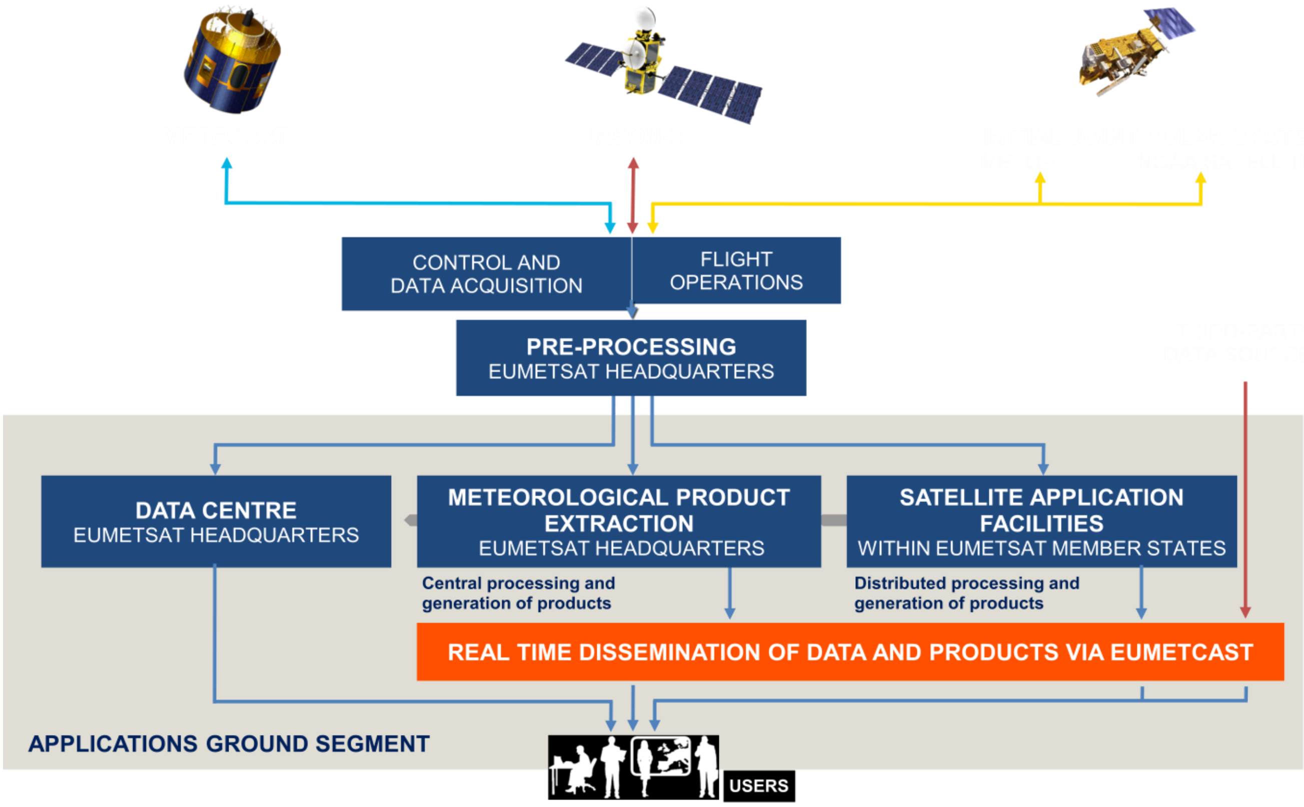

Figure 7: Conceptual scheme of the EUMETSAT Application Ground Segment

Figure 8 depicts the composition of the EUMETSAT SAF network, with the indication of each SAF's specific theme and Leading Entity.

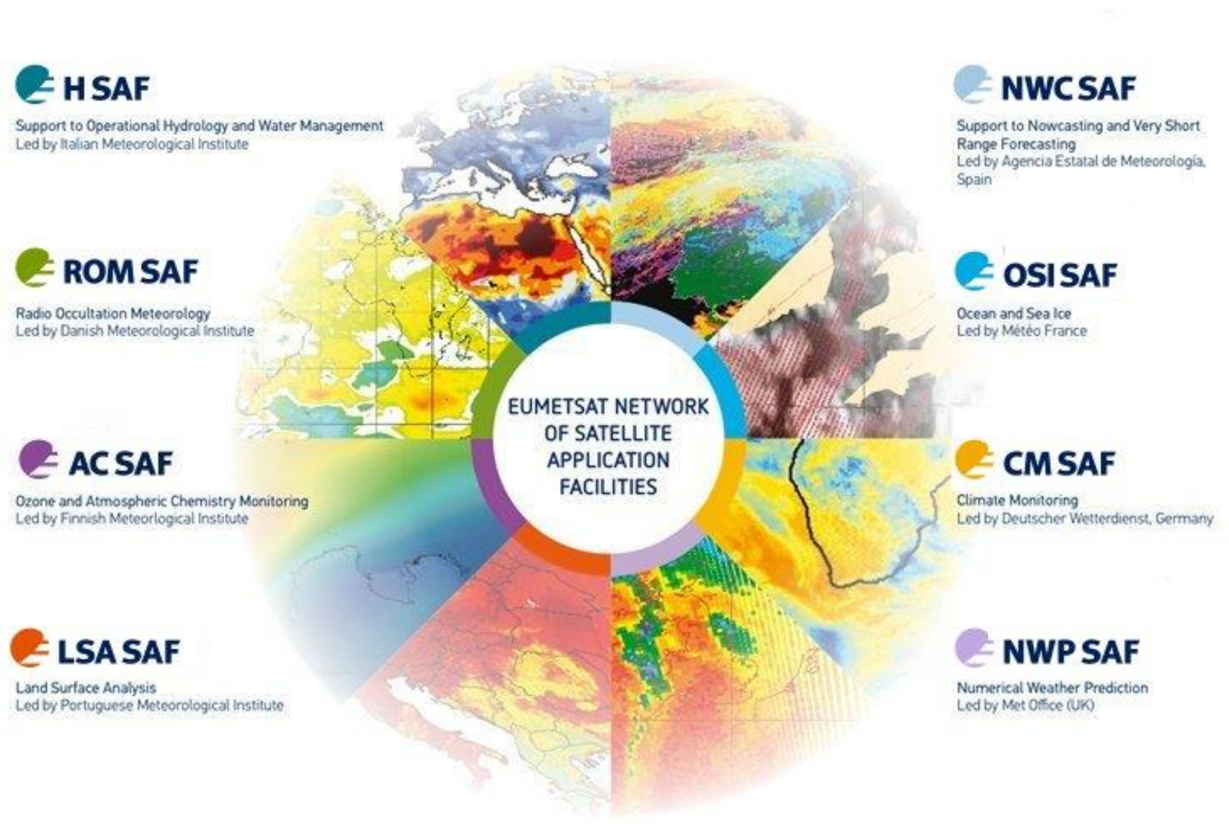

Figure 8: Current composition of the EUMETSAT SAF Network

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.

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.

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 2: Acronyms

AMSU	Advanced Microwave Sounding Unit (on NOAA and MetOp)
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-Operation Phase
CESBIO	Centre d'Etudes Spatiales de la BIOsphere (of CNRS, in France)
CGMS	Coordination Group for Meteorological Satellites
CMAP	Climate Prediction Center Merged Analysis of Precipitation
CM-SAF	SAF on Climate Monitoring
COMET	Centro Operativo per la Meteorologia (in Italy)
CNR	Consiglio Nazionale delle Ricerche (of Italy)
CNRS	Centre Nationale de la Recherche Scientifique (of France)
COSMO-ME	Consortium for Small-Scale Modelling - version for Mediterranean
DMSP	Defence 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
GPCP	Global Precipitation Climatology Project
GPI	GOES Precipitation Index
GRAS-SAF	SAF on GRAS Meteorology
H-SAF	SAF on Support to Operational Hydrology and Water Management
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
LHN	Latent Heat Nudging
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)
MW	Micro Wave
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
OSI-SAF	SAF on Ocean and Sea Ice
PMW	Passive Micro-Wave
PP	Project Plan
PUM	Product User Manual
PVR	Product Validation Report
QPF	Quantitative Precipitation Forecast
RMI	Royal Meteorological Institute (of Belgium) (alternative of IRM)
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)
STD	Standard Deviation
SYKE	Suomen ympäristökeskus (Finnish Environment Institute)
TKK	Teknillinen korkeakoulu (Helsinki University of Technology)
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
WMO	World Meteorological Organization
ZAMG	Zentralanstalt für Meteorologie und Geodynamik (of Austria)