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

Algorithm Theoretical Baseline Document (ATBD) for product P-AC-FCI(H42)

Accumulated precipitation at ground by blended MW+MTG FCI-IR

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0.1	12/01/2017	Preliminary version prepared for PDR
1.0	01/06/2018	Version prepared for MTG CDR
1.1	14/11/2019	Version prepared for MTG SIIR

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1 Introduction to product P-AC-FCI

1.1 Sensing principle

Product P-AC-FCI is based on frequent precipitation measurements as retrieved by blending LEO MW-derived precipitation rate measurements and MTG IR imagery. The input data are therefore P-IN-FCI (H40). The covered area is shown in Figure 1, same as for H40.

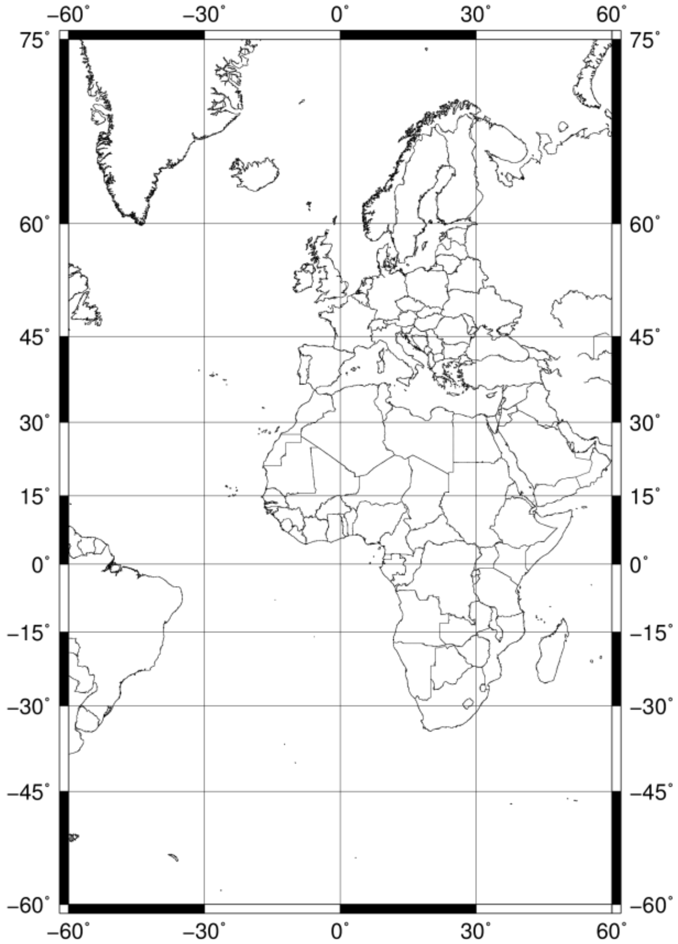


Figure 1 The P-AC-FCI coverage 60°S-75°N , 80°W - 80°E.

1.2 Main operational characteristics

The operational characteristics of P-AC-FCI are described in PUM-H42. Here are the main highlights.

Requirements for the FCI have been formulated by regional and global Numerical Weather Prediction (NWP) and Nowcasting communities. These requirements are reflected in the design which allows for Full Disk Scan (FDS), with a basic repeat cycle of 10 minutes. The FCI takes measurements in 16 channels, of which eight are in the thermal spectral domain between 3.8 µm to 13.3 µm, delivering data with a 2 km spatial resolution at nadir.

The horizontal resolution (Δx). The product is generated for each FCI pixel. The FCI IFOV degrades moving away from nadir, becoming about 3.5 km over Europe. Summing up, we can assume:

- resolution $\Delta x \sim 3.5$ km.
- The timeliness is 1h.
- Generation frequency : 1h accumulated precipitation every hour and 24h accumulated precipitation once a day.

The *output format*. The data format is **NetCDF**.

The *accuracy* is evaluated *a-posteriori* by means of the validation activity.

1.3 H42 Requirements

For detailed requirements characteristics see Product Requirement Document.

1.4 Architecture of the products generation chain

The architecture of the P-AC-FCI product generation chain is shown in

Figure 2.

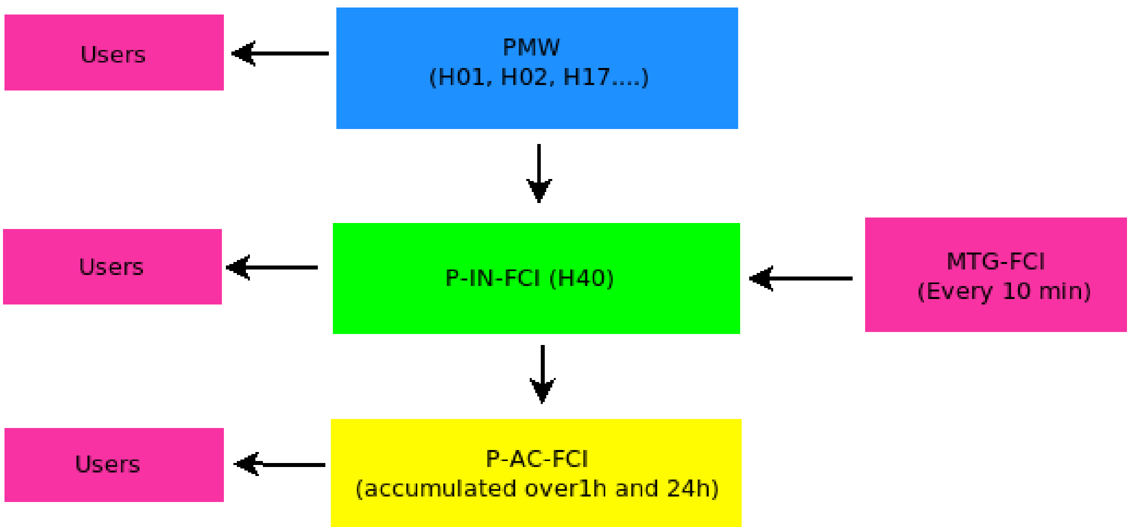


Figure 2: P-AC-FCI architecture.

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

- the P-IN-FCI process based on (frequent) FCI IR images "calibrated" by the (infrequent) MW-derived precipitation data as retrieved from SSMIS (P-IN- -SSMIS), from AMSU and MHS (P-IN-MHS), from ATMS (P-IN- ATMS), from AMSR2 and other MW available instruments;

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 (1 and 24 h).

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 assess 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.

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 up-scaling 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 is computed by temporal integration of the blended LEO/MW and GEO/IR precipitation rate products generated by the Rapid Update method (P-IN-FCI). The accumulation periods will be 1 and 24 hours.

Figure 3 Flow chart of the accumulated precipitation processing chain.

The P-AC-FCI products is generated and distributed every hour . The product incorporates precipitation rate retrievals from data collected up to 10 min before the delivery time. The periods of integration of blended MW+IR retrievals at 10-min intervals (P-IN-FCI) are the previous 1 and 24 hours.

The product quality depends on the type of precipitation and, to a minor extent, on 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 (10 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 10 minutes the second step of the algorithm consists in a quality control of 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 1 and 24 hours is a sum up of contributions every 10 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-FCI 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.
Speaking about the validation outside Europe, in Africa in particular, there are few precipitation data derived by ground networks: the operational rain gauges 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).. 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.

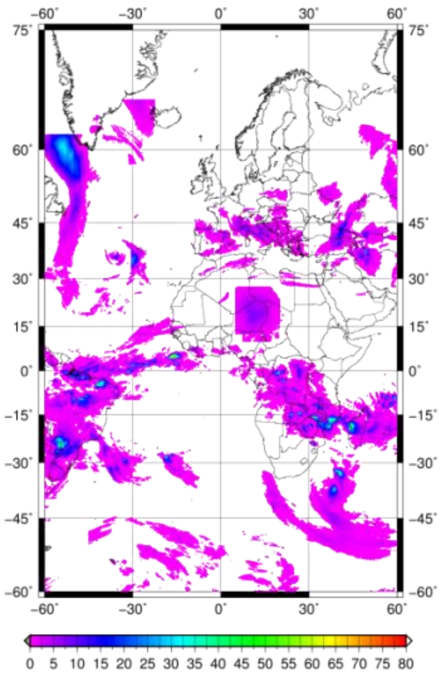
Rain gauge measurements provide relatively accurate point estimates of precipitation but suffer from sampling errors in representing area means and they are not available over most oceans and remote areas. Moreover the inhomogeneity in time and space of the precipitation field and the strong relationship 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.

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.

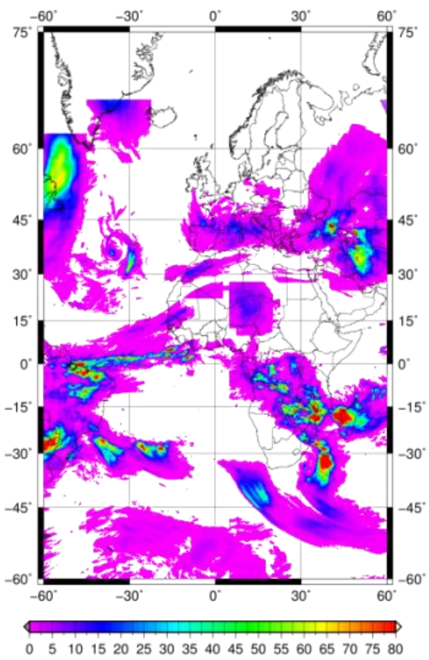
In the July 2001 the International Precipitation Working Group (IPWG) was established as a permanent Working Group of the Coordination Group for Meteorological Satellites (CGMS). The IPWG is co-sponsored by CGMS and the World Meteorological Organization (WMO) and it focuses on operational and research 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).

5 Examples of P-AC-FCI products

Fig 4 shows accumulated precipitation at 1and 24 hours. The projection is *mercator* with the MTG area correspondent to 60°S-75°N, 80°W - 80°E [1], the same as for the basic P-IN-FCI product.



03 Feb 2015, time 00 UTC – 1 hour cumulative precipitation.



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

Figure 4 Accumulated precipitation over 1 and24 hours.

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1 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

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Annex 1: Acronyms

AMSR2	Advanced Microwave Scanning Radiometer 2
AMSU	Advanced Microwave Sounding Unit (on NOAA and MetOp)
ATDD	Algorithms Theoretical Definition Document
ATMS	Advanced Technology Microwave Sounder
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
GPM	Global Precipitation Measurement
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
REMET	Reparto di Meteorologia (in Italy)
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)