SUPPORT TO OPERATIONAL HYDROLOGY AND WATER MANAGEMENT

Algorithm Theoretical Baseline Document (ATBD) for product H50 – P-IN-LI

P-IN-LI Rainfall intensity from MTG-LI

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0.1	12/01/2017	Preliminary version prepared for PDR
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1. Introduction

One of the objectives of the "EUMETSAT Satellite Application Facility on Support to Operational Hydrology and Water Management (H-SAF)" is to provide new SAF satellite-derived products from existing and future satellites with sufficient time and space resolution to satisfy the needs of operational hydrology. Active and passive microwave sensors aboard polar-orbiting satellites provide observations physically connected to precipitation but at a temporal resolution (once or twice a day) that considerably limits their utility in many applications.

It's even possible that a severe storm can start and finish between two passages of satellites. In the ***Fig 1*** there is a comparison between precipitation retrieval by microwave sensor on polar satellite (turquoise elliptical footprint) and radar (with color scale). Precipitation volume estimation between satellite and radar is very similar but the field shape is different, in detail MW space measurement could not distinguish inside active pixel.

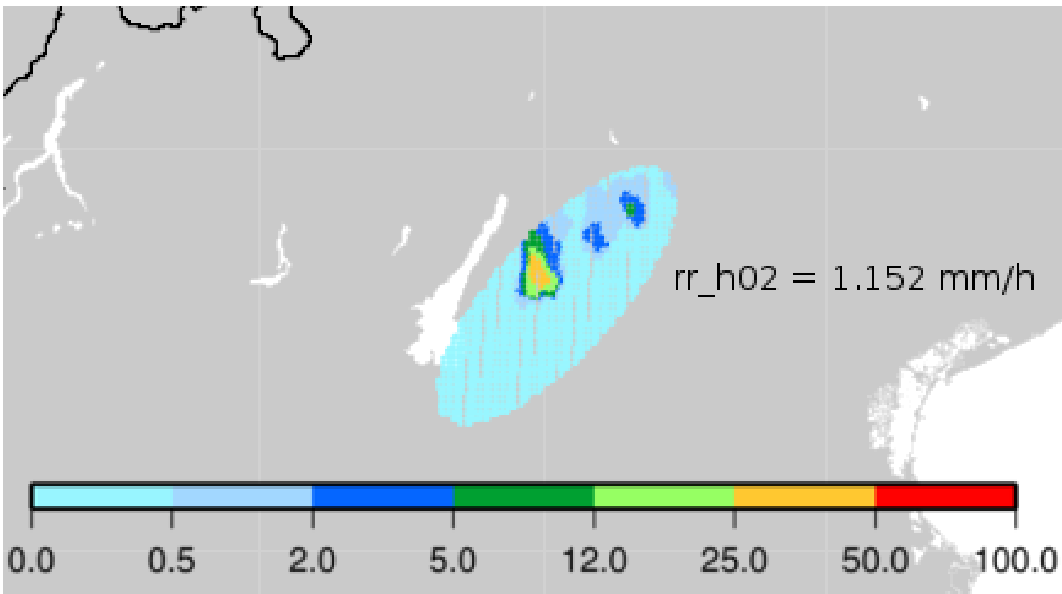

Fig 1: P-IN-MHS precipitation retrieval by microwave sensor on polar satellite (turquoise elliptical footprint) and radar (with colour scale).

In these conditions, the cloud-top infrared (IR) observations from geostationary satellites remain the main data source for near-continuous monitoring from space. The main difficulty in IR-based rainfall estimation is the fact that precipitation can only be inferred from cloud-top observations. Because a cloud's brightness temperature, or other cloud-top characteristics, may correspond to different surface rainfall rates depending on the rain regime or other factors, IR-based rainfall estimation may be improved significantly only by considering additional information. Past studies (Adler and Negri 1988; Anagnostou et al. 1999) have shown that minima in the IR temperature array may be associated with enhanced convective regions in the cloud, and substantially better estimates may be obtained by using distinct algorithms for convective and stratiform precipitation. The ability to detect convective cores and rain/no-rain boundaries, however, is limited from only being able to ''see'' the features at cloud top. Thus, the quantification of the convective rainfall is subject to significant uncertainty, despite the fine time resolution of the data. To reduce this uncertainty, additional information should be considered. Lightning data may represent such information; lightning data contain useful information for rainfall estimation, in particular in describing the field shape and the location of higher intensity rain cluster (De Leonibus et al. 2008). In the **Fig *2*** there is the electrical activity in the same area. The position of convective precipitation is almost entirely seen by means of lightning rate and locations.

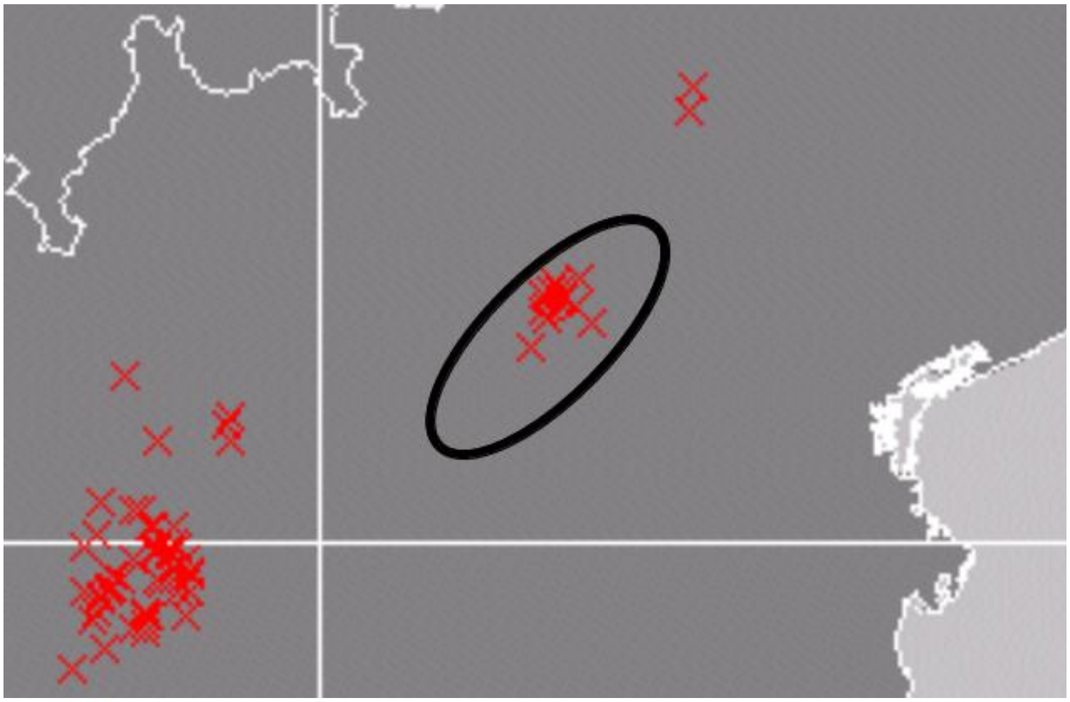

Fig 2: P-IN-MHS ellipsis as above and occurred lightnings in 15 minutes centred in microwave observation timestamp.

1.1. The MTG program

The MTG program provides meteorological imagery over Europe and Africa and maintains continuity of the Meteosat program, continuing and expanding the service provide by MSG.
The MTG system will be operated by EUMETSAT and will provide Europe's national meteorological services as well as international users and science community with improved imaging and new infrared sounding capabilities for both meteorological and climate applications. The MTG program is established as a common undertaking between EUMETSAT and the European Space Agency (ESA). ESA is responsible for the development of the MTG space segment. EUMETSAT is responsible for the development of the MTG ground segment and service provision. Thanks to advances in technology, MTG will also provide an enhanced service compared to the current MSG system, contributing significant improvements to the existing service with an improved imagery mission (Flexible Combined Imager - FCI) and introducing new sounding and lightning missions (Lightning Imager - LI) from a geostationary orbit.

1.2. The Flexible Combined Imager (FCI)

The FCI will provide follow-on services to the Full Disc Scanning Service (FDSS) and Rapid Scanning Service (RSS) currently provided by the Meteosat Second Generation (MSG) Spinning Enhanced

Visible and Infrared Imager (SEVIRI). The FCI has channels over 16 spectral ranges covering visible to infrared wavelengths.

1.3. Lightning Imager

The Lightning Imager (LI) will offer improvements for nowcasting by delivering information on total lightning (Intra Cloud (IC) and Cloud to Ground (CG)). The instrument will bring full near real-time total lightning detection capabilities.
The benefit of the LI mission is that it will observe total lightning continuously and simultaneously over the full disk, providing the information to the users with an extremely high timeliness.
The LI mission will be able to detect, monitor, track and extrapolate, in time, the development of active convective areas and storm life cycles — critical for nowcasting and very short range forecasting of severe weather events.
Additionally, one method of assessing the impact of climate change on thunderstorm activity is to globally monitor and long-term analyze the lightning characteristics, which would require a long-term stable and spatially homogeneous lightning observing system.
Lightning is also a major source of harmful nitrogen oxides (NOx) in the atmosphere. NOx plays a key role in the ozone conversion process and acid rain generation. A detailed knowledge of the global distribution of the total lightning (CG + IC) is a prerequisite for studying and monitoring the physical and chemical processes in the atmosphere, regarding NOx.
The LI on MTG will complement the two NOAA GLMs (Geostationary Lightning Mapper) on the GOES-R and the GOES-S satellites, thus contributing, in the long term, to near global coverage.

1.4. P-IN-LI Requirements

For detailed description of requirements characteristics see Product Requirement Document

2. Algorithm description

According to Grecu et al. (2000), to determine a quantitative relationship for rainfall estimation using lightning and Infrared data a bivariate linear regression for clusters rain volume has to be used:

$$RR = \left(b_0 + \frac{b_1 * S}{N} + b_2 * T\right) * N$$

where RR is the radar measured cluster rain volume in on hour ($mm*h^{-1}*km^2$), S is the number of strokes in the cluster, T (°K) is the minimum in the 10.8µm brightness temperature in the cluster and N is the number of pixels in the cluster. The coefficients b_0, b_1, and b_2 has to be calculated by means of least squares regression.
To disaggregate cluster rain volume to its individual pixel, it has to build the histogram counting all pixels associated with lightning that exist in the dataset for a given temperature. The probability

P(T) = P(that raining pixel temperature > T) is retrieved from the histogram features. The disaggregating procedure uses these probabilities to compute weights for each individual pixel of a convective cluster. A pixel weight is defined as the ratio of the pixel's probability to the sum of probabilities of all pixels located within the same convective cluster.

An example of such a histogram is in **Fig 3**. It has been built using a dataset composed by 27 days of 10.8 µm SEVIRI images and lightning data provided by LAMPINET, lightning network of Italian Air force meteorological service.

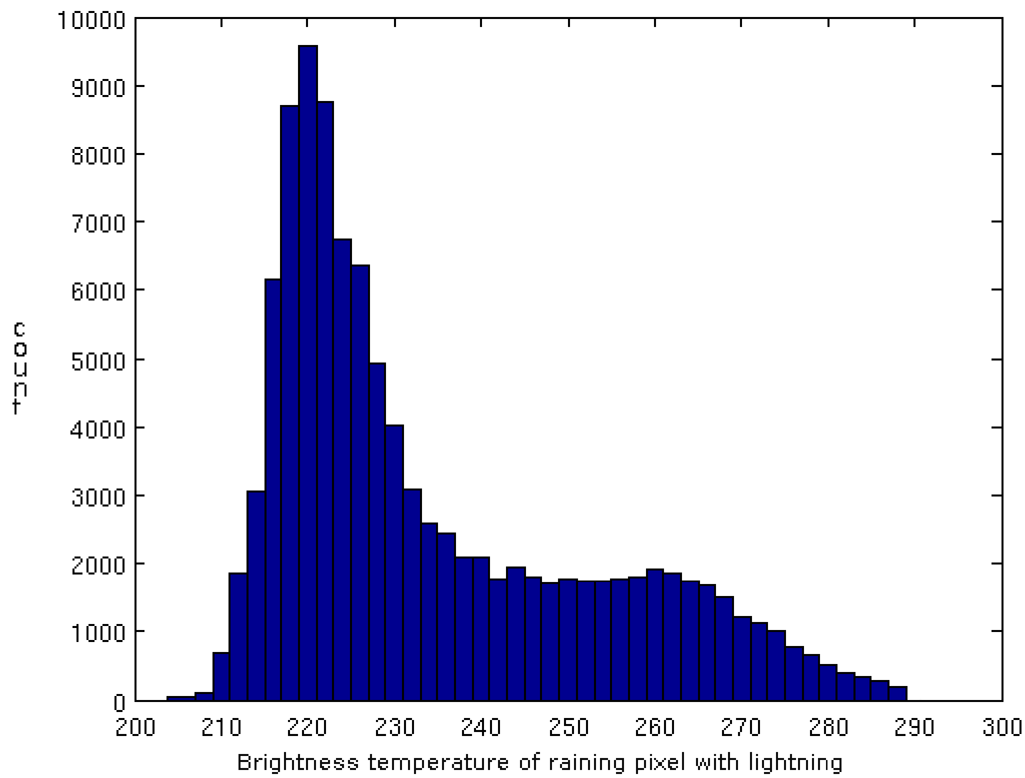

Fig 3: Histogram of IR brightness temperatures at lightning locations

3. Operational chain

The proposed algorithm combining brightness temperature and lightning for the estimation of convective rainfall can be summarized as follows:

1. load Flexible Combined Imager (FCI) IR data and compute 10.5µm brightness temperature;
2. compute lightning number from Lightning Imager (LI) within a 10 minutes' window, centered around IR sampling time;
3. individuate lightning clusters;
4. estimate rain volume of each cluster with the equation above;
5. allocate the rain volume of each cluster to pixels based on probability of the brightness temperature histogram.

The histogram of IR brightness temperature should be different accordingly the season and climatological area (mid-latitudes, tropics, etc.).

4. P-IN-LI – SEVIRI based prototype

To verify the effectiveness of the algorithm, a prototype using SEVIRI images and lightning data from LAMPINET has been realized.
A dataset composed by 27 days of gathered data (radar rainfall rate, 10.8µm SEVIRI images, lightning data, P-IN-MHS precipitation rate at ground) from 3rd March 2011 to 30th June 2011 is being used. Lightning data are provided by LAMPINET, lightning network of Italian Air force meteorological service. The network is based on Vaisala technology with 15 IMPACT ESP sensors distributed on the Italian peninsula and islands. Performances of the network can reach a detection efficiency of 90% and location accuracy of 0.5 km all over Italian area. Brightness temperature of SEVIRI channel 9 (10.8µm) is processed straight from HRIT raw files. P-IN-MHS is based on the instruments AMSU-A and MHS flown on NOAA and MetOp satellites. These cross-track scanners provide images with constant angular sampling across Track.
Radar rainfall rate is provided by DPC (Dipartimento di Protezione Civile, Italian Civil Protection Department). Currently, the National Radar Network is composed of 21 radars that work in the C band. The volume made available from each site, with a generation frequency of at least 10 minutes, is pre-processed according to a set of techniques to de-clutter and resampled at a resolution of 1km. The product of SRI calculates the precipitation to the ground by applying an algorithm on volumetric data of the PPI reflectivity at lower elevation between those acquired which meet the quality criteria in the planning stage. The reflectivity values are converted to measure precipitation (rain rate mm/h) according to the Marshall Palmer equation.

In each day of the dataset there are multiple storms. Dataset contains 4703 lightning's clusters. This dataset has been used for the calibration of the prototype (i.e. least squares regression to determinate the coefficients b_0, b_1, and b_2). The values of the parameters identified by this calibration are b_0 = 0.5131, b_1 = 0.2373 and b_2 = -0.0014.
To characterize statistically the agreement between radar rainfall rate (considered as “true” value) and lightning observations three performance scores has been used: the probability of detection (POD), the false alarm rate (FAR), and the critical success index (CSI), defined as

$$POD = \frac{n_{success}}{n_{success} + n_{failure}}$$

$$FAR = \frac{n_{falsealarm}}{n_{success} + n_{falsealarm}}$$

$$CSI = \frac{n_{success}}{n_{success} + n_{falsealarm} + n_{failure}}$$

where $n_{success}$, $n_{failure}$ and $n_{falsealarm}$ are the number of successes, failures, and false alarms, respectively, in the comparison. A comparison yields a success when there is lightning and a radar rainfall rate greater than 10 mm/h, a false alarm when there is lightning but not rainfall, and a failure when there is rainfall greater than 10 mm/h with no lightning indications.

The software has been tested on 873 lightning's clusters and the results are:
POD = 0.48
FAR = 0.34
CSI = 0.30

In **Fig *4*** there is a visual comparison in a case study (7th July 2011 02:15 UTC) between H50 prototype OUTPUT and rainfall rate from radar.

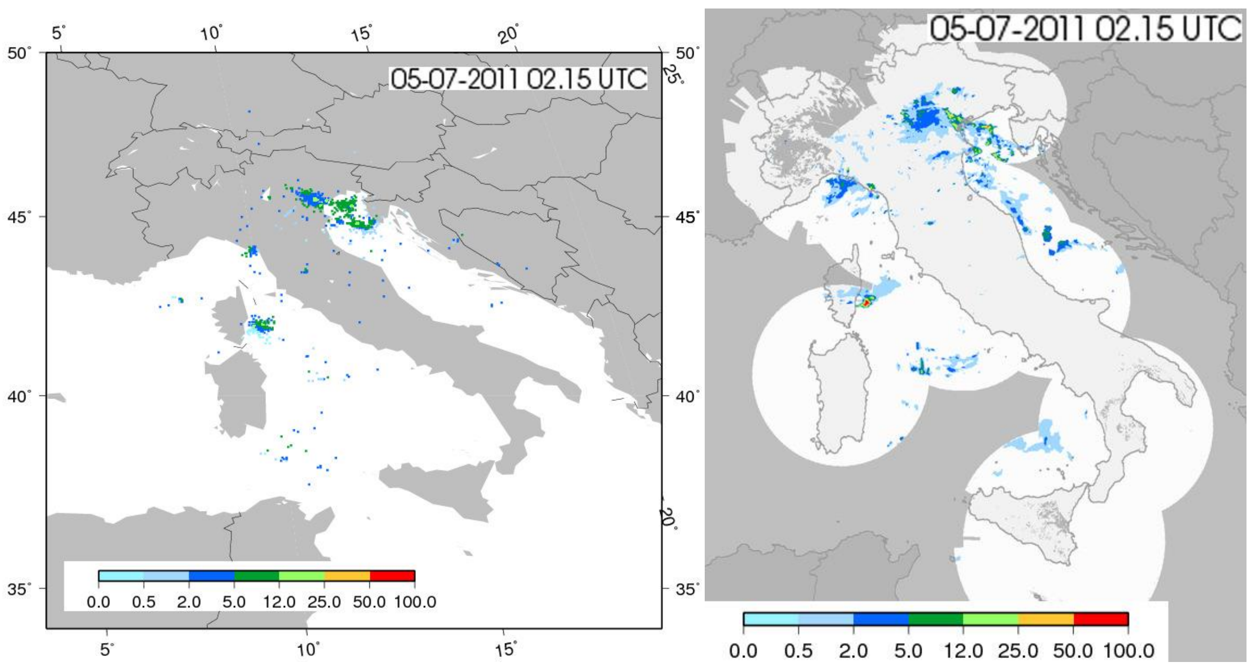

Fig 4: H50 prototype rainfall retrieval and radar rain rate

The general conclusion of this study is that lightning data contain useful information for satellite rainfall estimation, mainly in convective phenomena where MW retrieval can presents some problems. Good scores of P-IN-LI prototype suggests a possible use as product in HSAF project to improve rainfall estimation of MW and IR techniques. In future the prototype will be tested with LI and after a calibration period it will be able to work with the sensor data.

5. References

Grecu, Mircea, Emmanouil N. Anagnostou, and Robert F. Adler. "Assessment of the use of lightning information in satellite infrared rainfall estimation." Journal of Hydrometeorology 1.3 (2000): 211-221.

Adler, Robert F., and Andrew J. Negri. "A satellite infrared technique to estimate tropical convective and stratiform rainfall." Journal of Applied Meteorology 27.1 (1988): 30-51.

Anagnostou, Emmanouil. "A satellite infrared technique for diurnal rainfall variability studies." (1999).

De Leonibus, Luigi, et al. "Rainfall Field Reconstruction over Italy Through LAMPINET Lightning Data" (2008).

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)