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Application of remote sensing for the determination of water management parameters, Hydrology SAF

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Abstract—The European Organisation for the Exploitation of Meteorological Satellite (EUMETSAT) established the Satellite Application Facility on Support to Operational Hydrology and Water management (H-SAF) on July 2005. The aim of the H-SAF is to derive parameters which are important for hydrology, for hydrological models. H-SAF derives precipitation, soil moisture, and snow products based on satellite information, and makes hydrological validation. The Hungarian Meteorological Service takes part in the product validation work.

In this paper we describe the different products, then the validation activities are shown including some examples.

Key-words: hydrology, satellite, H-SAF, precipitation, snow, soil moisture, product validation, hydrological validation, flood, drought

1. Introduction

In recent years, severe and catastrophic flood events occurred frequently in many parts of the world. These events demonstrate the importance of improving the flood forecasting and flood warning system. In Hungary, in the last 20 years, flood records were broken along 21 rivers, 3 times at Danube, 5 times at Tisza River.

Another type of meteorological events, the droughts have also caused large problems in the recent years. For example, in 2015, the long warm period during summer and the low precipitation caused drought in some areas of Hungary.

Large number of techniques were developed to derive hydrological parameters from ground and satellite measurements in the last 50 years. EUMETSAT supplies weather and climate-related satellite data, images, and products – 24 hours a day, 365 days a year – to the National Meteorological Services of the EUMETSAT Member and Cooperating States in Europe, and other users worldwide. EUMETSAT established eight Satellite Application Facilities (SAFs) to derive several meteorological parameters, and they also distribute software packages. The various SAFs were established at different times between 1997 and 2005, starting with the Development Phase (DP), which held for 5-years. The activities are now in the Continuous Development and Operations Phases (CDOP). The CDOP-2 period finished in February 2017, and the new 5 year period, the CDOP-3 has started in March 2017.

One of these SAFs is the Support to Operational Hydrology and Water management SAF (H-SAF or Hydrology SAF). The H-SAF was established by the EUMETSAT Council on July 3, 2005. The aim of the H-SAF is to generate and archive high-quality datasets and products for operational hydrological applications. The leading entity of the H-SAF is the Italian Meteorological Service, and the consortium members are eleven European countries (Austria, Belgium, Bulgaria, Finland, France, Germany, Hungary, Italy, Poland, Slovakia, and Turkey) and the ECMWF.

The H-SAF objectives are:

1. to provide new satellite-derived products from existing and future satellites for operational hydrology, as follows:
    a. precipitation (instantaneous, accumulated),
    b. soil moisture,
    c. snow parameter;
2. to perform independent validation of the products by
    a. statistical calculation using radar and rain-gauge dataset,
    b. case studies;
3. investigation of the products at hydrological model application.

The Hungarian Meteorological Service takes part as consortium member in the precipitation product validation.

In this paper, first we give information about the precipitation products, after that we describe the snow products. In the third part, we show the soil moisture products.

In Section 5, we detail the validation activity by OMSZ, and some results. Finally, we show some example for the hydrological validation, including Hungarian validation as well.

2. Precipitation products

Six different precipitation products (PR-OBS-x, where PR refers to the precipitation, x is the serial number of the product, also referred as Hx) have been developed during the first 5-year period (*Mugnai et al.,* 2013). Since then, one of them was withdrawn. Two of these products are based on passive microwave (MW) measurements received from polar orbiting satellites, while the other 3 products are derived as a combination of infrared and microwave measurements. The MW radiation is sensitive to changes in rain and cloud droplet size distributions due to scattering and emission/absorption processes in clouds. The infrared (IR) data are received from the EUMETSAT geostationary satellites. The infrared measurement gives information about the temperature of the cloud top and the surface of the Earth.

Fig. 1 shows the spatial coverage of the precipitation products based on the different measurements.

The H01 precipitation product is derived from SSMI or SSMI/S passive MW instruments onboard of polar orbiting DMSP satellites (DMSP F17, DMSP F18). Cloud microphysical properties are retrieved by a cloud resolving and a radiative transfer model. *Fig. 2* shows the different precipitation products compared to radar measurements.

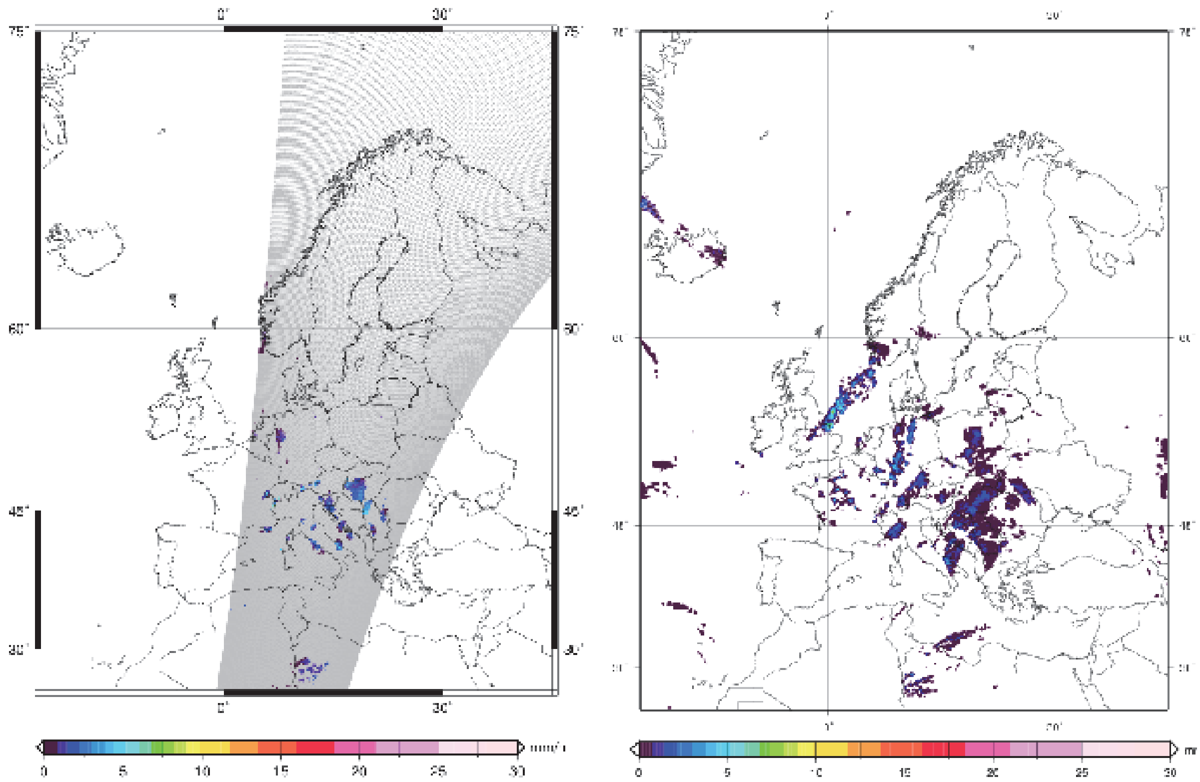

Fig. 1. Instantaneous precipitation rain rate from microwave (MW) observation (H01) on the left side, and from MSG IR measurement (H03) on the right side.

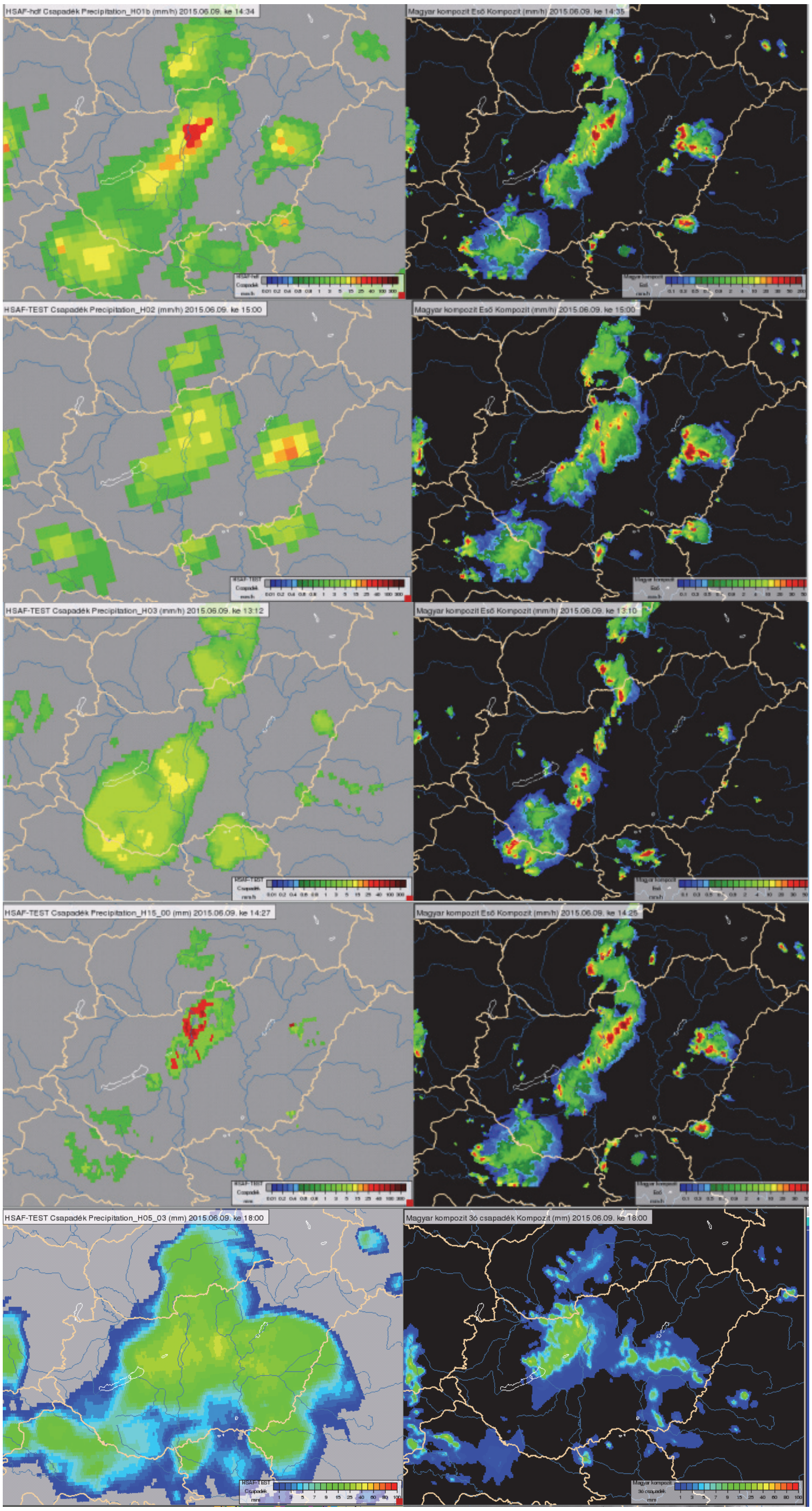

Fig. 2. On the left side, the different precipitation products (H01, H02, H03, H15, H05) can be seen, on the right side, the actual radar composite images are presented at different times (H01-14:34 UTC, H02-15:00 UTC, H03-13:12 UTC, H15-14:27 UTC, H05-18:00 UTC) but on the same day, June 9, 2015.

The H02 precipitation product is determined from the MW measurements of the AMSU-A and AMSU-B instruments onboard NOAA satellites (NOAA-18, NOAA-19), and AMSU-A instruments onboard MetOp satellites (MetOp-A, MetOp-B). The precipitation rate is calculated by applying artificial neural network technique. This product consists of the surface precipitation rate and indication of the phase of the precipitation.

The H03 gives instantaneous precipitation intensity in every 15 minutes using IR and MW data. The blended algorithm is based on a real-time collection of IR brightness temperature from MSG satellites and rain intensity estimation from MW measurement (H02) matching in time and space.

The H05 product is an accumulated precipitation product generated from H03 products. The product is derived in every 3 hours, and provides the accumulated precipitation over 3, 6, 12, and 24 hours. It is generated from the H03 data using time integration, but other information such as rain-gauge measurements and very short forecasts from numerical weather prediction model are also used.

H15 product provides instantaneous precipitation intensity in every 15 minutes, which is based on H03 product and DYNAmic NEFOanalysis (NEFODINA) techniques (*Puca et al.,* 2005; *Melfi et al.*, 2012). The NEFODINA is applied for the determination of a convection mask and for redistributing the precipitation value from H01 and H02, based on the characteristics of the convective cells.

3. Snow products

Monitoring the snow parameters – e.g., snow covered area, snow water equivalent (*Fig. 3*) – is not easy because of its natural physical properties. The determination of snow products over mountainous regions is much more complicated. Therefore, different methods were developed for flat land and for mountainous area (*Surer et al.*, 2012).

The snow cover map (H10) is derived based on visible and infrared images from both polar and geostationary satellites. Spectral threshold methods are applied. The different spectral characteristics of cloud, snow, and land determine the structure of the algorithm, and these characteristics are obtained from subjective classification of known snow cover features in the images.

The snow status (H11) product gives information whether it is wet or dry and in time series thawing or freezing. At the calculation MW measurements are used, considering that the snow emissivity is different for dry and wet snow. The emissivity increases when snow is wet.

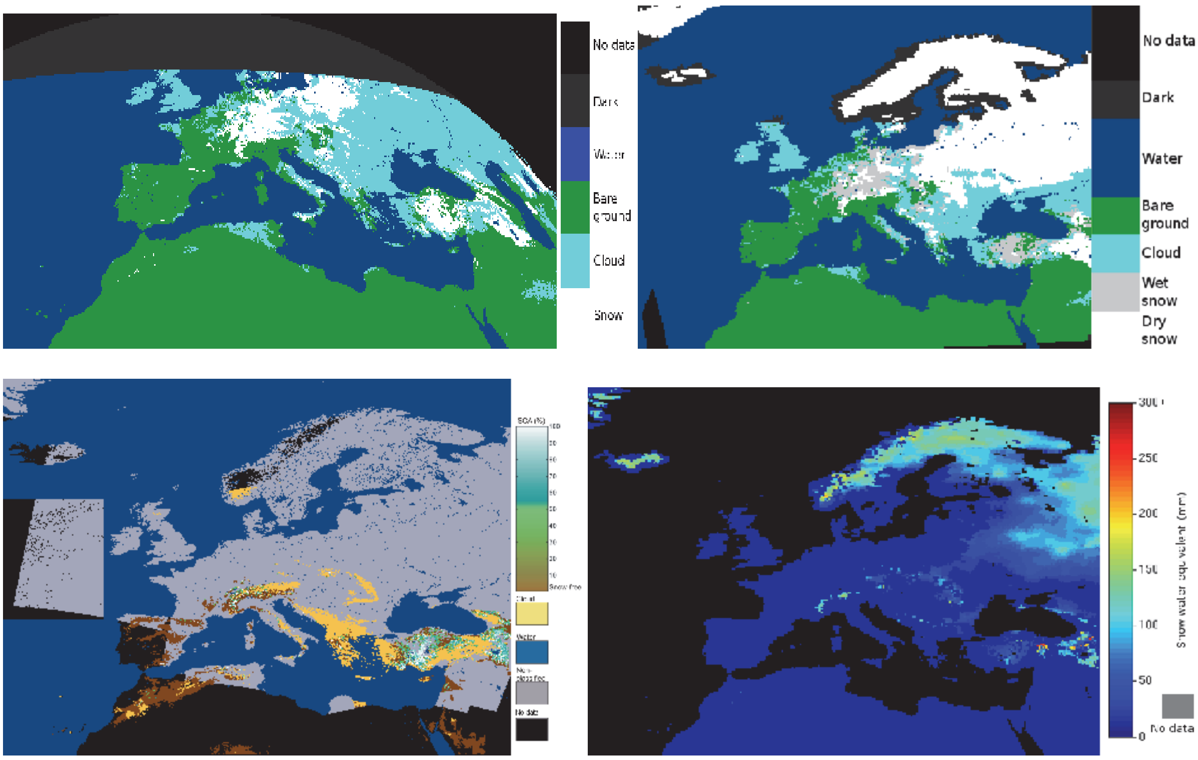

Fig. 3. Top left is the snow cover, top right is the snow status, bottom left is the effective snow cover, bottom right is the snow water equivalent image on January 6, 2017.

The effective snow cover (H12) algorithm is based on a sub-pixel reflectance model applied on METOP-AVHRR data. The product describes the percentage of Snow Covered Area (SCA) within product pixels (0–100%). Knowing the effects of topography on satellite-measured radiances in rough terrain, the sun zenith and azimuth angles, as well as direction of observation relative to these are taken into account in estimating the target reflectances from the satellite images.

The snow water equivalent product (H13) is derived using MW measurements considering that the MWs are sensitive to snow thickness and density. Depending on the snow being dry or wet, the penetration changes (dry snow is more transparent). For mountainous areas, H13 is derived using radiometer data only, while for flat areas, H13 is an assimilation of ground based snow depth observations and satellite data.

4. Soil moisture products

Compared to other components of the hydrologic cycle, the volume of soil moisture is small, nonetheless, it has fundamental importance in many hydrological, biological, and biogeochemical processes, it is a key parameter for flood forecast and numerical weather prediction systems.

The large scale surface soil moisture for the 0.5–2 cm surface layer (H07) is derived using ASCAT scatterometer (*Cenci et al*., 2016). Based on ERS-1/2 and MetOp scatterometers, there is possibility to measure soil moisture because of the high sensitivity of microwaves to the water content in the soil surface layer due to the pronounced increase in the soil dielectric constant with increasing water content. We have to mention that the scattering depends on vegetation and surface roughness.

The small scale surface soil moisture (H08) is derived from the global product (H07) limited to the H-SAF area. It is generated by disaggregating the global-scale product (25 km resolution) to 1 km sampling. The disaggregation process is performed with a fine-mesh layer.

The profile index in the roots region (H14) is derived by ASCAT scatterometer data assimilation in the ECMWF Land Data Assimilation System. It is derived for 4 layers (thicknesses 0.07, 0.21, 0.72, and 1.89 m). The ECMWF model generates soil moisture profile information according to the Hydrology Tiled ECMWF Scheme for Surface Exchanges over Land (HTESSEL).

Fig. 4 shows examples for these soil moisture parameters.

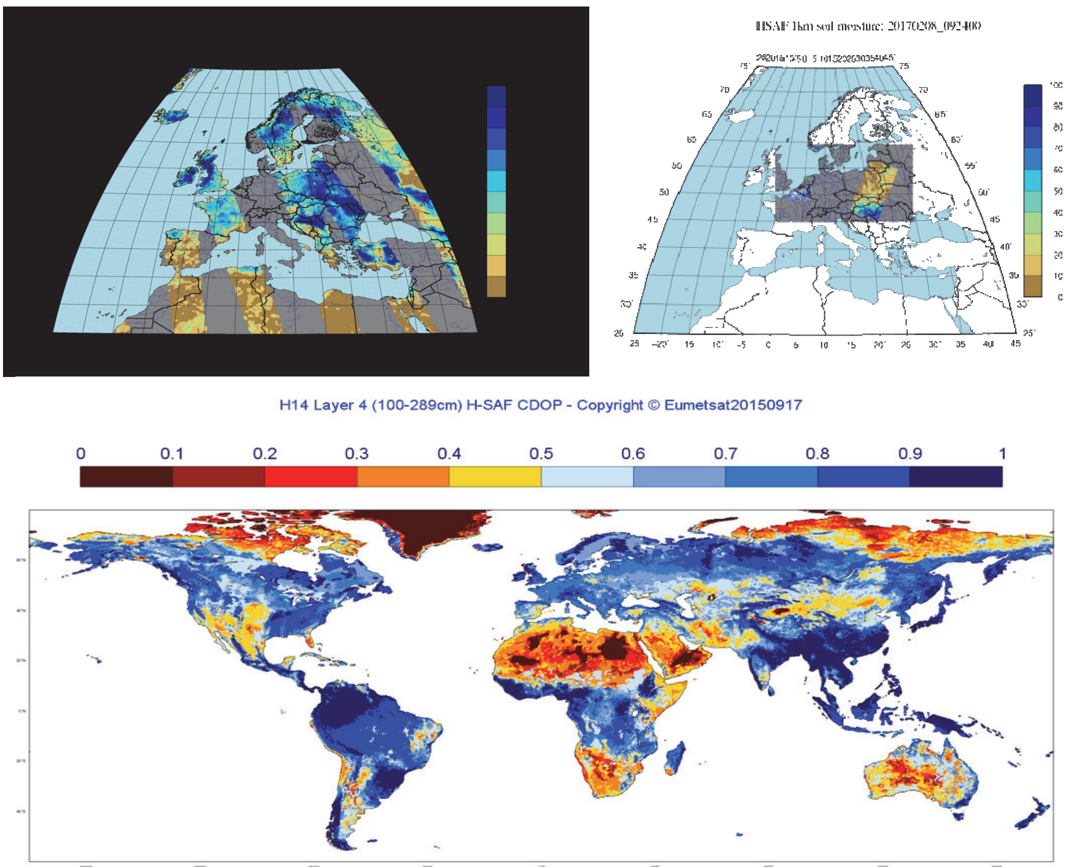

Fig. 4. The top left image shows an example for the large scale surface soil moisture. The top right image presents the small scale surface soil moisture. The bottom image is an example of the profile index in the roots region.

5. Precipitation validation at the Hungarian Meteorological Service

In the H-SAF project, an independent working group was established to validate the products (*Puca et al.*, 2014). The Hungarian Meteorological Service takes part in the precipitation validation (PV) work. The main activity of the PV is:

- to calculate statistical scores using ground measurements (radar and rain-gauge measurements),
- to perform case study analyses.

For the validation the Hungarian Meteorological Service uses both radar and rain-gauge datasets. The radar network consists of four C-band Doppler radars, the data are available in every 5 minutes. 269 automatic rain-gauge measurements are also used in the validation. From the instantaneous rain-gauge precipitation intensity, at first one hour precipitation intensity is derived, after that the Random Generator of Space Interpolations from Uncertain Observation (GRISO) method (*Pignone et al.*, 2010) is applied to create a precipitation field. *Fig. 5* shows an example for the GRISO precipitation field compared to radar measurements. The interpolated field and the radar measurements show good accordance both in precipitation area and precipitation intensity, mainly at high intensity precipitation.

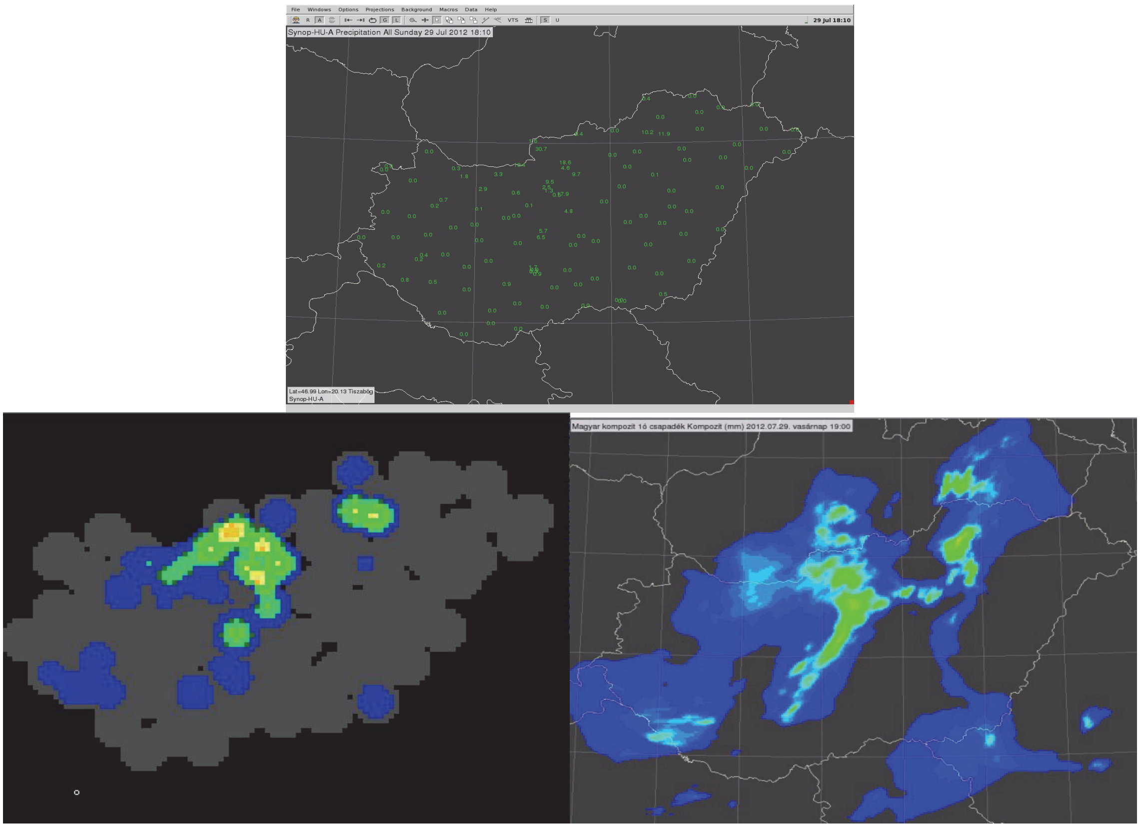

Fig. 5. The top image shows the precipitation measurements based on rain-gauge network. The bottom left image presents the interpolated precipitation field based on GRISO method. The bottom right image is the radar measurements.

Statistical scores (mean error, standard deviation, root mean square error, correlation coefficient) for a monthly dataset are calculated. Multicategory scores (probability of detection (POD), false alarm rate (FAR), critical success index (CSI)) are also derived.

Hereinafter we would like to show an example from the multicategory results. *Fig. 6* shows the scores for H03 product for the June 2012 – May 2013 period. The statistical calculation is performed for different precipitation categories. This figure shows the multicategory scores when the precipitation intensity is larger than 0.25 mm/h (index is 0), and at >1 mm/h (index is 1). As we can see they have an annual trend. During the summer period, POD values are much higher than during winter time. During summer time, when convective precipitation is much more frequent and the intensity is higher, the determination of the precipitation intensity values is much easier.

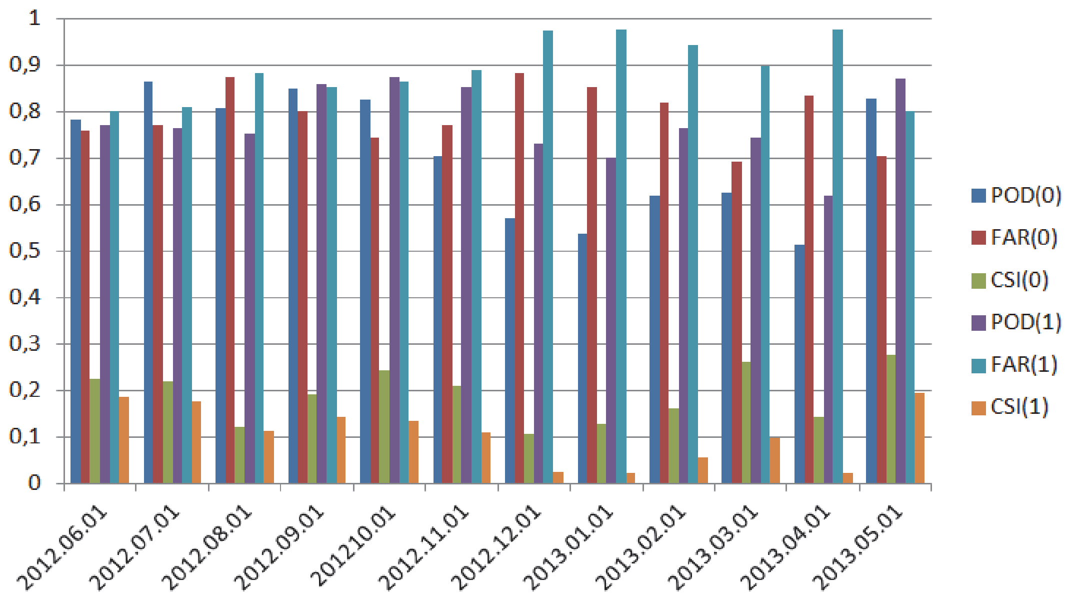

Fig. 6. Multicategory scores for the H03 product for the June 2012 – May 2013 period for two different datasets: precipitation intensity is larger than 0.25 mm/h (index is 0), and at >1 mm/h (index is 1).

6. Hydrological validation

The main purpose of the hydrological validation program is products' quality assessment and their continuous monitoring by product validation, evaluation, and interfacing with hydrological models, performed both through near real-time and off-line impact studies. The test sites for hydrological validation are located in different parts of the HSAF area. 8 countries (Belgium, Bulgaria, Finland Germany, Italy, Poland, Slovakia, and Turkey) participate in the validation (*Fig. 7*).

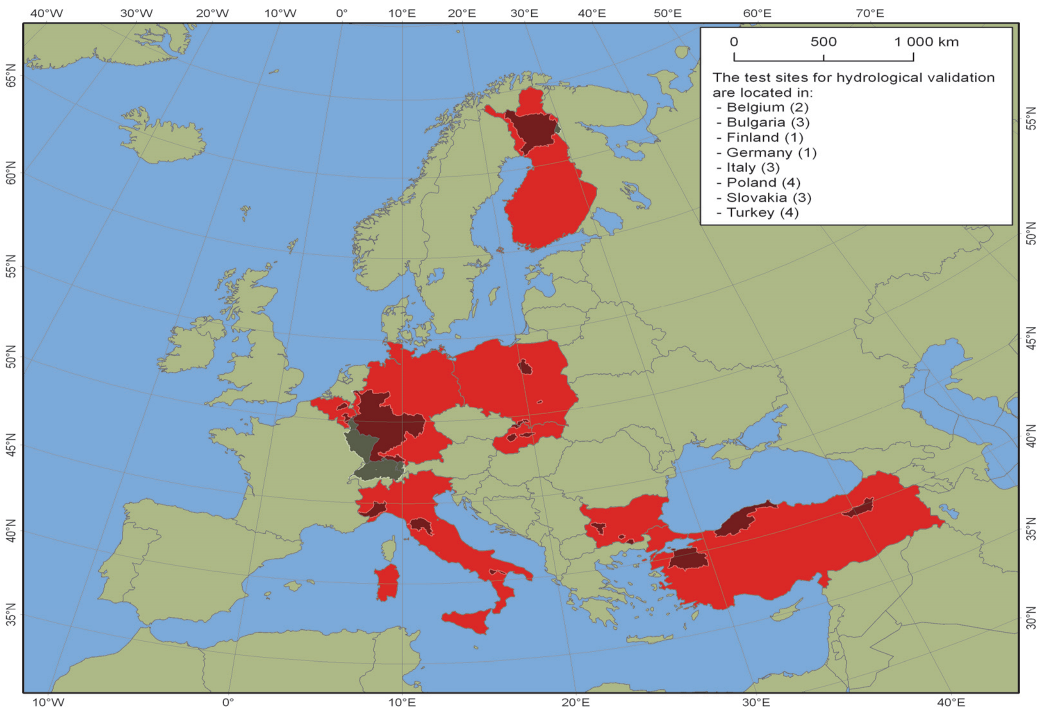

Fig. 7. The test sites of the hydrological validation program.

Different runoff models are applied by the countries to calculate the discharge. Using the runoff model, they calculate the discharge for the catchment area using H-SAF, or ground precipitation products. These calculations are compared with ground truth measurements. *Fig. 8* shows the scheme of this proceeding. At the simulation the H03 and H05 products are used, considering the time resolution.

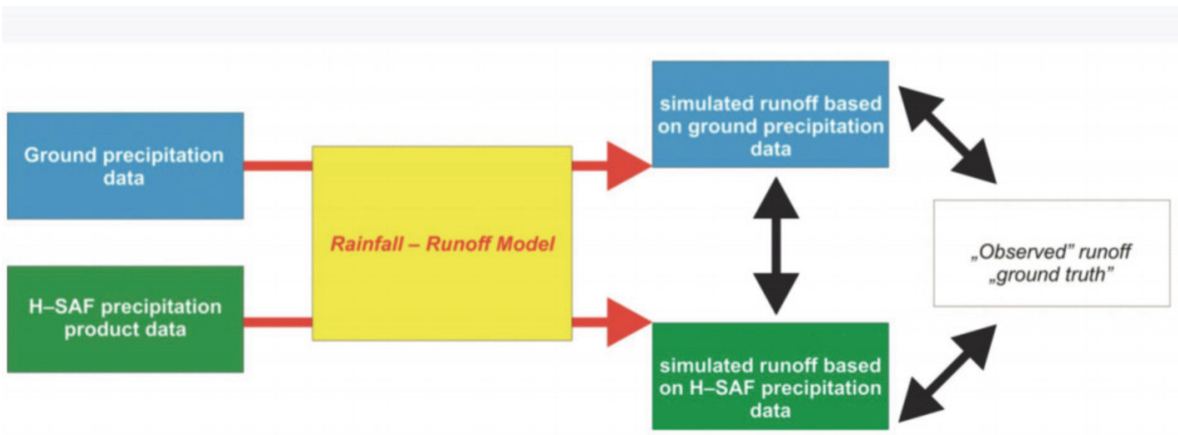

Fig. 8. The scheme of the hydrological validation using runoff model based on two different datasets (H-SAF product, ground precipitation product) and ground truth measurement.

In the next part, 2 different results will be shown, one is calculated for the Demer catchment area in Belgium, the other is for Wkra catchment area in Poland during the June 2012 – May 2013 period (*Fig. 9*).

Red lines show the results simulated by ground measurements, blue lines represent the calculation using the H-SAF product, finally, green lines indicate the ground observations. If we look at the result at Demer catchment, we can see better agreement during the summer period than in winter, due to the fact that the determination of the precipitation area / intensity is much more easier at convective cases. If we look at the other catchment area, during the first half of the period when the discharges were low, the two simulated data show very good agreement, while the measured data were higher. In the second half, for example in January, the two simulated data overestimated the discharge, while since February, the three dataset show similar trends.

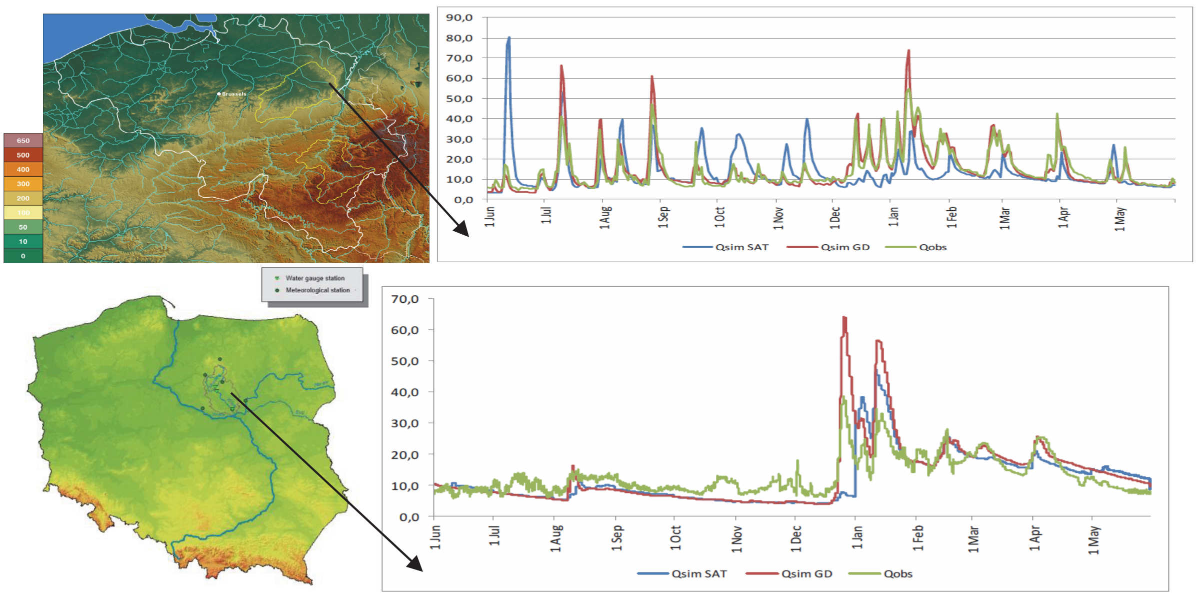

Fig. 9. The top images show the catchment area in Belgium, and the results of the hydrological validation, the bottom images show the same in Poland

In Hungary, no company takes part in the Hydrology Validation group. Nevertheless, recently the General Directorate of Water Management in Hungary has chance within a framework of a Visiting Scientic Program (2017) to make similar calculation for the Rába catchment area to investigate the H-SAF precipitation products. The first preliminary results are shown in *Fig. 10*.

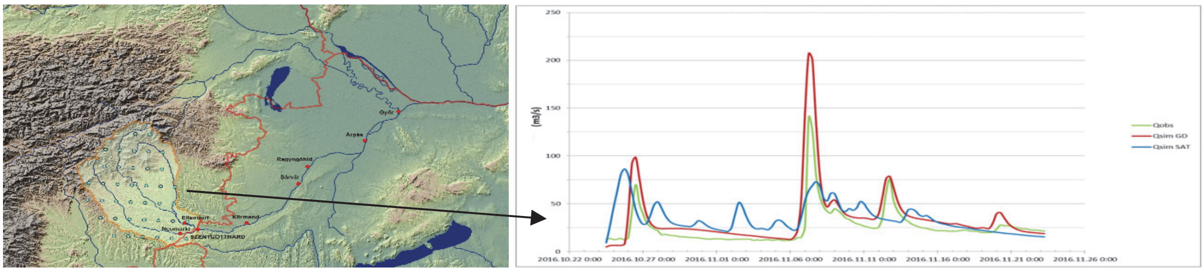

Fig. 10. The images show the catchment area in Hungary, and the results of the hydrological validation for the period October 22–November 26, 2016.

In October 2016, large flood caused problem at the Rába River. Based on the 3-hour H05 precipitation product, the discharge was calculated for this period. At the beginning of the period, a time shift can be seen at the simulated discharge derived from H-SAF data. To derive the reason of this, further investigation is needed. In some days, when the discharge was low, the H-SAF product overestimated it, while other cases were underestimated. Only at the last 10 days we can see good agreement between the three datasets.

7. Summary

In this paper we gave a short description about the Hydrology SAF work. The webpage of the H-SAF project, where all information can be reached is http://hsaf.meteoam.it/.

All H-SAF products are available for all users free of charge. At the moment, there are two ways to get the H-SAF product: download the data from H-SAF server, the near real-time data are available via EUMETCast (EUMETSAT's primary dissemination mechanism). The number of the users reached 1000 by the end of 2015. The main users are: state institutions (51%), universities (20%), private companies (18%), and private users (11 %).

In this paper we presented the products developed until the end of the CDOP-2 period. The following period started in March 2017. The EUMETSAT in this 5-year period plans to launch the Meteosat Third Generation (MTG) satellite, which will give much more information: better time and spatial resolution, more channels. For example, the benefits of the Lightning Imager are detecting, monitoring, tracking, and extrapolating, in space as development of active convective areas and storm lifecycles in time. The application of this information will improve the accuracy of the precipitation area derived by H-SAF.

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