The EUMETSAT Network of Satellite Application Facilities

H SAF

Support to Operational Hydrology and Water Management

Products Validation Programme

Italian Meteorological Service

Italian Department of Civil Defence

# H-SAF Product Validation Report (PVR)

# SM-OBS-2 - Small-scale surface soil moisture by radar scatterometer

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Vienna University of Technology Institut für Photogrammetrie und Fernerkundung

Royal Meteorological Institute of Belgium

European Centre for Medium-Range Weather Forecasts

Finnish Meteorological Institute

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CNRS Laboratoire Atmosphères, Milieux, Observations Spatiales

CNRS Centre d'Etudes Spatiales de la BIOsphere

Bundesanstalt für Gewässerkunde

Hungarian Meteorological Service

CNR - Istituto Scienze dell'Atmosfera e del Clima

Università di Ferrara

Institute of Meteorology and Water Management

Romania National Meteorological Administration

Slovak Hydro-Meteorological Institute

Turkish State Meteorological Service

Middle East Technical University

Istanbul Technical University

Anadolu University

**31 August 2010**

# H-SAF Product Validation Report PVR-08
# Product SM-OBS-2
# Small-scale surface soil moisture by radar scatterometer

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## Acronyms [not including those in the Appendix]

| | |
|---|---|
| ACC | Fraction correct Accuracy |
| AMSR-E | Advanced Microwave Scanning Radiometer for EOS (on EOS-Aqua) |
| ASAR GM | ASAR Global Mode |
| ASAR | Advanced Synthetic Aperture Radar (on Envisat) |
| ASCAT | Advanced Scatterometer (om MetOp) |
| ATDD | Algorithms Theoretical Definition Document |
| AU | Anadolu University (in Turkey) |
| BfG | Bundesanstalt für Gewässerkunde (in Germany) |
| CAF | Central Application Facility (of EUMETSAT) |
| CC | Correlation Coefficient |
| CDF | Cumulative Distribution Function |
| CDOP | Continuous Development-Operations Phase |
| CESBIO | Centre d'Etudes Spatiales de la BIOsphere (of CNRS, in France) |
| CETP | Centre d'études des Environnements Terrestres et Planétaires (CNRS). Now LATMOS |
| 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) |
| CORINE | COoRdination of INformation on the Environment |
| CSI | Critical Success Index |
| DPC | Dipartimento Protezione Civile (of Italy) |
| DWD | Deutscher Wetterdienst |
| DWR | Dry to Wet Ratio |
| ECMWF | European Centre for Medium-range Weather Forecasts |
| ERA-40 | ECMWF's 40-year Re-Analysis |
| ERS | European Remote-sensing Satellite (1 and 2) |
| ETS | Equitable Threat Score |
| EUM | Short for EUMETSAT |
| EUMETCast | EUMETSAT's Broadcast System for Environmental Data |
| EUMETSAT | European Organisation for the Exploitation of Meteorological Satellites |
| FAR | False Alarm Rate |
| FBI | Frequency BIas |
| FMI | Finnish Meteorological Institute |
| GEO | Geostationary Earth Orbit |
| GLWD | Global Lakes and Wetlands Database |
| GPCC | Global Precipitation Climatology Centre |
| GRAS-SAF | SAF on GRAS Meteorology |
| H-SAF | SAF on Support to Operational Hydrology and Water Management |
| HSS | Heidke skill score |
| 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) |
| IR | Infra Red |
| IRM | Institut Royal Météorologique (of Belgium) (alternative of RMI) |
| IRPI | Istituto di Ricerca per la Protezione Idrogeologica (of CNR, Italy) |
| ISAC | Istituto di Scienze dell'Atmosfera e del Clima (of CNR, Italy) |
| ISBA | Interactions between Soil, Biosphere, and Atmosphere |
| ITU | İstanbul Technical University (in Turkey) |
| LATMOS | Laboratoire Atmosphères, Milieux, Observations Spatiales (of CNRS, in France) |
| LEO | Low Earth Orbit |
| LPJ | Lund-Potsdam-Jena dynamic global vegetation model |

| | |
|---|---|
| LSA-SAF | SAF on Land Surface Analysis |
| MARS | Meteorological Archival and Retrieval System (of ECMWF) |
| ME | Mean Error |
| Météo France | National Meteorological Service of France |
| MetOp | Meteorological Operational satellite |
| METU | Middle East Technical University (in Turkey) |
| MODIS | Moderate-resolution Imaging Spectro-radiometer (on EOS Terra and Aqua) |
| MTF | Modulation Transfer Function |
| MW | Micro Wave |
| NMA | National Meteorological Administration (of Romania) |
| NOAA | National Oceanic and Atmospheric Administration (Agency and satellite) |
| NSIDC | National Snow and Ice Data Center (of USA) |
| NWC | Nowcasting |
| 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 |
| Pixel | Picture element |
| POD | Probability of Detection |
| POFD | Probability Of False Detection |
| PRCGL | Public Research Center Gabriel Lippmann (in Luxembourg) |
| PUM | Product User Manual |
| PVR | Product Validation Report |
| REP-3 | H-SAF Products Valiadation Report |
| RMI | Royal Meteorological Institute (of Belgium) (alternative of IRM) |
| RMS | Root Mean Square |
| RMSE | Root Mean Square Error |
| SAF | Satellite Application Facility |
| SCAT | Scatterometer (on ERS 1 and 2) |
| SCHEME | for SCHEldt and MEuse (hydrological model) |
| SD | Standard Deviation |
| SHMÚ | Slovak Hydro-Meteorological Institute |
| SMOS | Soil Moisture and Ocean Salinity |
| SRTM | Shuttle Radar Topography Mission |
| SSM/I | Special Sensor Microwave Imager |
| SWI | Soil Water Index |
| SYKE | Suomen ympäristökeskus (Finnish Environment Institute) |
| TDR | Time Domain Reflectometry |
| TKK | Teknillinen korkeakoulu (Helsinki University of Technology) |
| TSMS | Turkish State Meteorological Service |
| TU-Wien | Technische Universität Wien (in Austria) |
| UniFe | University of Ferrara (in Italy) |
| VIS | Visible |
| WARP-H | WAter Retrieval Package for hydrologic applications |
| ZAMG | Zentralanstalt für Meteorologie und Geodynamik (of Austria) |

# 1. The EUMETSAT Satellite Application Facilities and H-SAF

The "*EUMETSAT Satellite Application Facility on Support to Operational Hydrology and Water Management (H-SAF)*" is part of the distributed application ground segment of the "*European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)*". The application ground segment consists of a "*Central Application Facility (CAF)*" and a network of eight "*Satellite Application Facilities (SAFs*)" dedicated to development and operational activities to provide satellite-derived data to support specific user communities. See ***Fig. 01***.

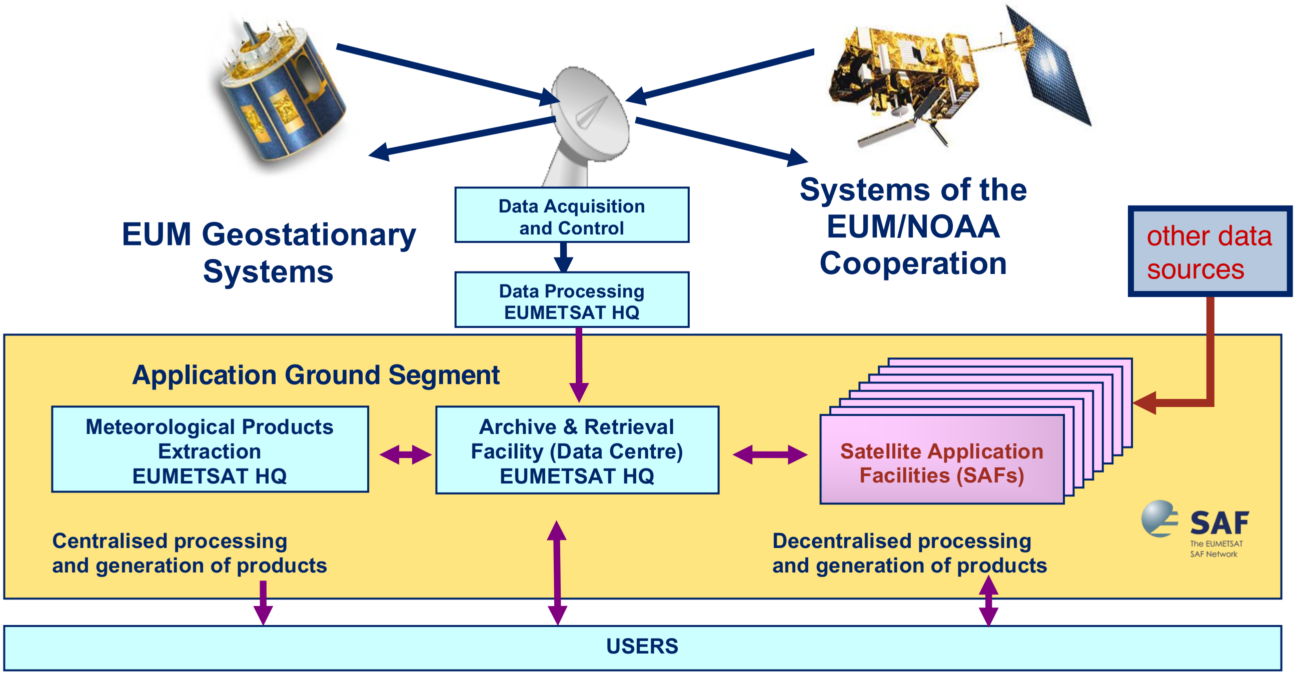


***Fig. 01 - Conceptual scheme of the EUMETSAT application ground segment.***

***Fig. 02*** reminds the current composition of the EUMETSAT SAF network (in order of establishment).

| NWC SAF | OSI SAF | O3M SAF | CM SAF | NWP SAF | GRAS SAF | LSA SAF | H SAF |
|---|---|---|---|---|---|---|---|
| Nowcasting & Very Short Range Forecasting | Ocean and Sea Ice | Ozone & Atmospheric Chemistry Monitoring | Climate Monitoring | Numerical Weather Prediction | GRAS Meteorology | Land Surface Analysis | Operational Hydrology & Water Management |

***Fig. 02 - Current composition of the EUMETSAT SAF network (in order of establishment).***

The H-SAF was established by the EUMETSAT Council on 3 July 2005; its Development Phase started on 1st September 2005 and ends on 31 August 2010. The list of H-SAF products is shown in ***Table 01.***

***Table 01 - List of H-SAF products***

| Code | Acronym | Product name |
|---|---|---|
| H01 | PR-OBS-1 | Precipitation rate at ground by MW conical scanners (with indication of phase) |
| H02 | PR-OBS-2 | Precipitation rate at ground by MW cross-track scanners (with indication of phase) |
| H03 | PR-OBS-3 | Precipitation rate at ground by GEO/IR supported by LEO/MW |
| H04 | PR-OBS-4 | Precipitation rate at ground by LEO/MW supported by GEO/IR (with flag for phase) |
| H05 | PR-OBS-5 | Accumulated precipitation at ground by blended MW and IR |
| H06 | PR-ASS-1 | Instantaneous and accumulated precipitation at ground computed by a NWP model |
| H07 | SM-OBS-1 | Large-scale surface soil moisture by radar scatterometer |
| H08 | SM-OBS-2 | Small-scale surface soil moisture by radar scatterometer |
| H09 | SM-ASS-1 | Volumetric soil moisture (roots region) by scatterometer assimilation in NWP model |
| H10 | SN-OBS-1 | Snow detection (snow mask) by VIS/IR radiometry |
| H11 | SN-OBS-2 | Snow status (dry/wet) by MW radiometry |
| H12 | SN-OBS-3 | Effective snow cover by VIS/IR radiometry |
| H13 | SN-OBS-4 | Snow water equivalent by MW radiometry |

# 2. Introduction to product 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 (*Large-scale surface soil moisture by radar scatterometer*) product extracted by ZAMG from the Global surface soil moisture product distributed by EUMETSAT. The 25-km resolution SM-OBS-1 product is disaggregated and re-sampled at 1-km intervals to better fit hydrological requirements.

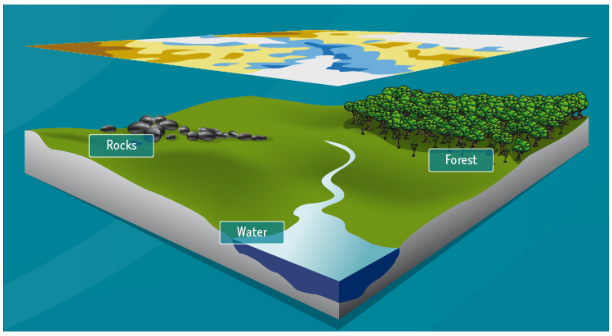


***Fig. 03 - Principle of disaggregation with auxiliary data.***

The disaggregation process (see ***Fig. 03***) 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 mode.

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

## 2.2 Algorithm principle

The baseline algorithm for SM-OBS-2 processing is described in ATDD-08. Only essential elements are highlighted here.

***Fig. 04*** illustrates the flow chart of the SM-OBS-2 processing chain. There is an off-line activity to prepare the disaggregation parameters and a real-time activity to exploit the satellite data for the product retrieval.

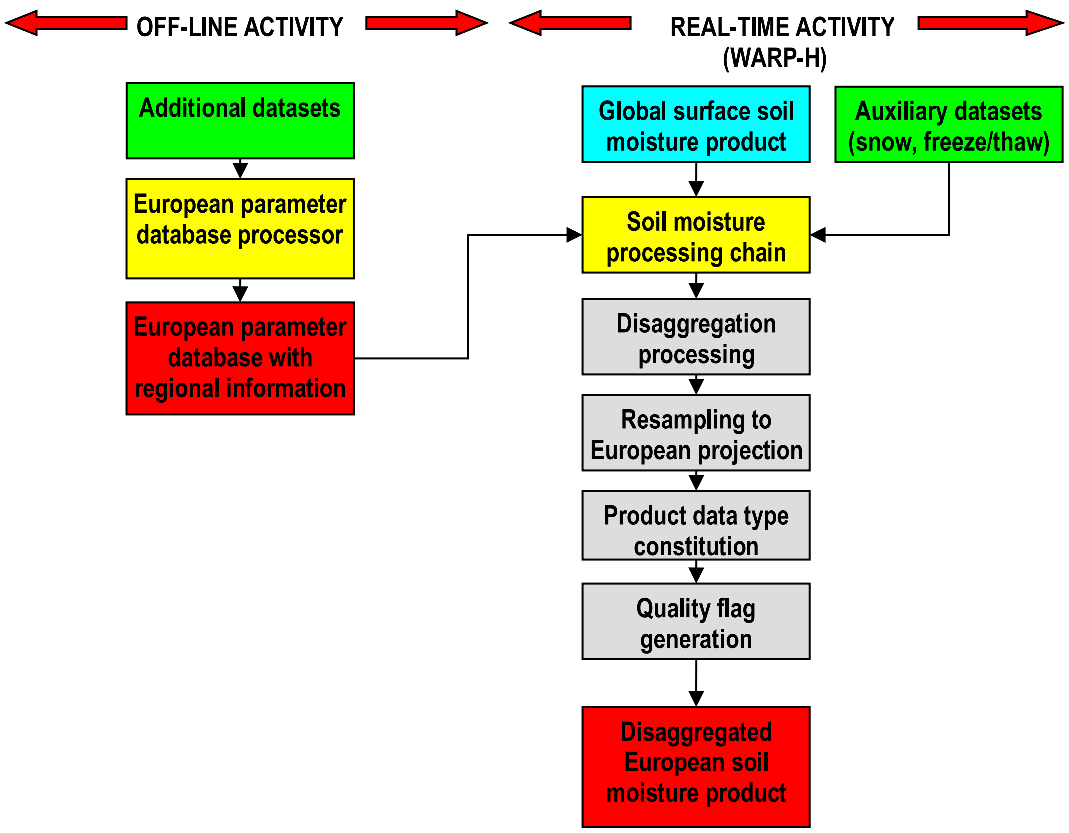


***Fig. 04 - Flow chart of the processing chain for the disaggregated soil moisture product.***

In the off-line pre-processing step, Envisat ASAR Global Mode (ASAR GM) datasets are re-sampled 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 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. Introduced by Vauchaud et al. 1985[1], 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[2] to describe the relation between local in-situ soil moisture data and regional soil moisture trends. If the spatial coverage of ASAR GM data is not sufficient for Europe, the scaling layer information is derived from a land cover-specific simulation. Therefore, TU-Wien uses the knowledge about temporal behaviour of the scaling layer of several land cover classes over the world and simulates the scaling layer information for the affected regions in Europe. For the Development Phase, this information has largely been derived from CORINE land cover classification, but will continue to be re-tuned as the coverage of acquisition of ASAR GM grows.

## 2.3 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)* is defined as the time between observation taking and product available at the user site assuming a defined dissemination mean. 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 (RMS)* is the convolution of several measurement features (random error, bias, sensitivity, precision, …). To simplify matters, it is generally agreed to quote the root-mean-square difference [observed - true values]. The accuracy of a satellite-derived product descends from the strength of the physical principle linking the satellite observation to the natural process determining the parameter. It is difficult to be estimated *a-priori*: it is generally evaluated *a-posteriori* by means of the validation activity.

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[1] Vauchaud G., A. Passerat de Silans, P. Balabanis and M. Vauclin, 1985: “Temporal stability of spatially measured soil water probability density function”. *Soil Science Society of America* **49**: 822-828.

[2] Martínez-Fernández J. and A. Ceballos, 2005: "Mean soil moisture estimation using temporal stability analysis”. *Journal of Hydrology* **312**: 28-38.

# 3. Validation strategy, methods and tools

## 3.1 Validation team and work plan

Whereas the previous operational characteristics have been evaluated on the base of system considerations (number of satellites, their orbits, access to the satellite) and instrument features (IFOV, swath, MTF and others), the evaluation of accuracy requires validation, i.e. comparison with the ground truth or with something assumed as "true". PR-OBS-2, as any other H-SAF product, has been submitted to validation entrusted to a number of institutes (see ***Fig. 05***).

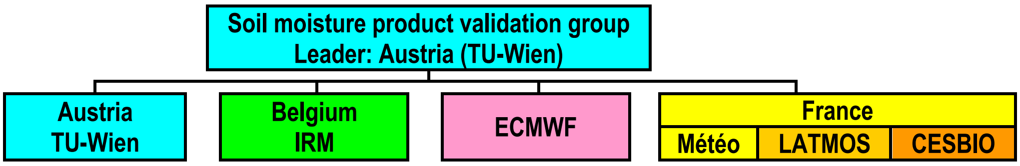


***Fig. 05 - Structure of the Soil moisture products validation team.***

***Table 02*** lists the persons involved in the validation of H-SAF precipitation products

***Table 02 - Validation Team for soil moisture products***

| | | | |
|---|---|---|---|
| Wolfgang Wagner (Leader) | Technische Universität Wien (TU-Wien) | Austria | ww@ipf.tuwien.ac.at |
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| Laurent Franchisteguy | Météo France | France | laurent.franchisteguy@meteo.fr |
| Fabienne Regimbeau | Météo France | France | fabienne.regimbeau@meteo.fr |
| Mehrez Zribi | Labor. ATmosph., Milieux, Observ. Spatiales (LATMOS) | France | mehrez.zribi@cetp.ipsl.fr |
| Olivier Merlin | CNRS Centre d'Etudes Spat. de la BIOsphere (CESBIO) | France | olivier.merlin@cesbio.cnes.fr |

The Soil moisture validation programme started soon after the H-SAF Requirements Review (26-27 April 2006). The first activity was to lay down the ***Validation plan***, that was finalised as early as ***30 September 2006***, i.e. about one year after the start of the H-SAF Development Phase.

At the 1$^{st}$ H-SAF Workshop (Rome,16-18 October 2007), a first set of significant validation exercises was presented. An internal document, called REP-3 (H-SAF Products Validation Report) started being compiled since then. Now, moving to the end of the H-SAF Development Phase, REP-3 has been restructured into this Product Validation Report (PVR) split into 13 volumes, one for each H-SAF product. The validation experiments recorded in REP-3 constitute "Appendixes" to the various volumes. Because of the initial aim of REP-3 (internal document at working level) the editorial level of the Appendixes is of rather low standard.

## 3.2 Validation philosophy

### 3.2.1 Objective and problems

Calibration and validation of soil moisture observation from space is a hard work, especially because ground systems are essentially based on very sparse in-field measurements. Comparison with results of numerical models obviously suffer of the limited skill of NWP in predicting soil moisture (a very downstream product that passes through quantitative precipitation forecast, that certainly is not the most accurate product of NWP). A mixture of several techniques is generally used, and the results change with the climatic situation and the status of soil.

Unlike precipitation and snow, for which the WMO-coordinated Global Observing System includes well-structured station networks, in the case of soil moisture the instrumentation is often experimental, and the observations are generally performed by campaigns, often in specially-equipped sites.

Therefore the H-SAF validation activity has made use of what was available, with limited or null possibility of overall structuring and coordinating.

This Chapter describes the H-SAF validation philosophy with regard to the following aspects:

- tools to be used for validation (in-situ measurements, numerical models, etc.) and relative merits,
- techniques to bring observations comparable (upscaling, downscaling, filtering, etc.),
- structuring of the results of the validation activity.

### 3.2.2 Tools to be used for validation

For the validation task, a wide range of datasets for comparison and validation of the soil moisture products can be used, e.g.:

- In-situ data:
  - soil moisture station networks,
  - Global Soil Moisture Data Bank,
  - time domain reflectometry (TDR)
- Related space-based soil moisture missions:
  - Soil Moisture and Ocean Salinity Mission surface soil moisture products (SMOS)
- Precipitation datasets:
  - Global Precipitation Climatology Centre (GPCC),
  - National Centers for Environmental Prediction (NCEP),
  - precipitation maps being produced in H-SAF consortium
- Model data from climatological, vegetation or crop simulation models:
  - Lund-Potsdam-Jena dynamic global vegetation model (LPJ),
  - Interactions between Soil, Biosphere, and Atmosphere scheme (ISBA)
- Data from international activities:
  - International Geosphere-Biosphere Programme (IGBP),
  - Integrated GMES Project on Land Cover and Vegetation (geoland)
- Comparison with climate classification charts:
  - Koeppen,
  - Holdridge
- Global water datasets:
  - Global Lakes and Wetlands Database (GLWD),
  - Global Self-consistent, Hierarchical, High-resolution Shoreline Database (GSHHS)
- Global snow datasets:
  - Daily Northern Hemi-sphere Snow and Ice Analysis from United States National Snow and Ice Data Center (NSIDC),
  - MODIS Snow Cover Daily,
  - SSM/I EASE-Grid Daily Global Ice Concentration and Snow Extent,
  - AMSR-E Global Snow Water Equivalent,
  - Snow maps being produced by H-SAF consortium
- Global topography datasets:
  - United States Geological Survey Global Topographic Data (USGS GTOPO30),
  - Global Land One-km Base Elevation project (GLOBE),
  - Shuttle Radar Topography Mission (SRTM)
- Global freeze/thaw datasets:
  - NCEP/NCAR Global Tropospheric Analyses,
  - ECMWF's 40-year Re-Analysis (ERA-40)
- Data from hydrological models:
- Validation form interaction with hydrologic pilot users:
  - H-SAF pilot users

The acquisition of the datasets, as well as the selection of which datasets to use will depend very much on the data availability and the cooperation with the interested user community.

### 3.2.3 Techniques to bring observations comparable

In order to bring soil moisture observations comparable with other datasets and modelled data, several strategies have to be investigated. The transferability of datasets has to be investigated, as has been done in Dirmeyer et al. 2004[3], where eight multiyear global soil wetness products have been compared. In this study, different ranges of soil moisture values and changing climatological conditions of the datasets had to be considered. When assimilating soil moisture data into hydrological models, the initialization of the model has to be performed and the model performance re-calibrated, as has been shown e.g. for Austrian simulations in both gauged and ungauged basins (Parajka et al. 2006[4]). This also applies when assimilating soil moisture data into conceptual land surface models, where rescaling issues have to be taken into account (Reichle et al. 2004[5]).

### 3.2.4 Structuring the results of the validation activity

The results of validation activities have direct impact on improvements in algorithms and software updates. Therefore, validation activities should be summarised in reports on a scheduled basis throughout the project phase. Basic outcomes of activities are foreseen to be published in scientific literature. Furthermore, the definition of advanced targets has to be considered for algorithmic improvements of the soil moisture product generation chains. These improvements should be communicated via the dedicated H-SAF electronic algorithm forum.

## 3.3 Definition of statistical scores

It is appropriate to deploy the definitions of the statistical scores utilised in H-SAF product validation activities. Some apply to “continuous statistics”, some to “dichotomous statistics”. Although no ground observing system constitutes a very accurate ground truth, we assume as “true” these observations, thus the departures of satellite observations will be designated as “errors”

***Scores for continuous statistics:***

- Mean Error (ME) or Bias
- Standard Deviation (SD)
- Correlation Coefficient (CC)
- Root Mean Square Error (RMSE)
- Root Mean Square Error percent (RMSE %), used for precipitation since error grows with rate.

$$ME \text{ or } bias = \frac{1}{N}\sum_{k=1}^{N}(sat_k - true_k)$$

$$SD = \sqrt{\frac{1}{N}\sum_{k=1}^{N}\left(sat_k - true_k - ME\right)^2}$$

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[3] Dirmeyer P.A,, Z. Guo and X. Gao, 2004: "Comparison, validation, and transferability of eight multiyear global soil wetness products". *Journal of Hydrometeorology* **5(6)**: 1011-1033.

[4] Parajka J., V. Naeimi, G. Blöschl and W. Wagner, 2006: "Assimilating scatterometer soil moisture data into conceptual hydrologic models at the regional scale, Hydrology and Earth System Sciences". *Hydrology and Earth System Sciences* **10(3)**: 353-368.

[5] Reichle R.H., R. D. Koster, J. Dong and A. A. Berg, 2004: "Global soil moisture from satellite observations, land surface models, and ground data: Implications for data assimilation". *Journal of Hydrometeorology* **5(3)**: 430-442.

$$CC = \frac{\sum_{k=1}^{N}\left(sat_k - \overline{sat}\right)\left(true_k - \overline{true}\right)}{\sqrt{\sum_{k=1}^{N}\left(sat_k - \overline{sat}\right)^2 \sum_{1}^{N}\left(true_k - \overline{true}\right)^2}}$$ with $\overline{\mathrm{sat}} = \frac{1}{\mathrm{N}}\sum_{k=1}^{\mathrm{N}} \mathrm{sat}_k$ and $\overline{true} = \frac{1}{N}\sum_{k=1}^{N} true_k$;

$$RMSE = \sqrt{\frac{1}{N}\sum_{k=1}^{N}\left(sat_k - true_k\right)^2}$$

$$RMSE\,\% = \sqrt{\frac{1}{N}\sum_{k=1}^{N}\frac{\left(sat_k - true_k\right)^2}{true^2{}_k}}$$

***Scores for dichotomous statistics***

Stemming from the contingency Table:

**Contingency Table**

| | | Observed (ground) | | |
|---|---|---|---|---|
| | | **yes** | **no** | **total** |
| **Forecast (satellite)** | **yes** | **hits** | **false alarms** | **forecast yes** |
| | **no** | **misses** | **correct negatives** | **forecast no** |
| | **total** | **observed yes** | **observed no** | **total** |

where:

- hit: event observed from the satellite, and also observed from the ground
- miss: event not observed from the satellite, but observed from the ground
- false alarm: event observed from the satellite, but not observed from the ground
- correct negative: event not observed from the satellite, and also not observed from the ground.

A large variety of scores have been defined. The following are used in H-SAF

- Frequency BIas (FBI)
- Probability Of Detection (POD)
- False Alarm Rate (FAR)
- Probability Of False Detection (POFD)
- Fraction correct Accuracy (ACC)
- Critical Success Index (CSI)
- Equitable Threat Score (ETS)
- Heidke skill score (HSS)
- Dry-to-Wet Ratio (DWR).

$$FBI = \frac{hits + false\,alarms}{hits + misses} = \frac{forecast\ yes}{observed\,yes}$$ Range: 0 to ∞. Perfect score: 1

$$POD = \frac{hits}{hits + misses} = \frac{hits}{observed\ yes}$$ Range: 0 to 1. Perfect score: 1

$$FAR = \frac{false\,alarms}{hits + false\,alarms} = \frac{false\,alarms}{forecast\ yes}$$ Range: 0 to 1. Perfect score: 0

$$POFD = \frac{false\,alarms}{correct\ negatives + false\,alarms} = \frac{false\,alarms}{observed\ no}$$ Range: 0 to 1. Perfect score: 0

$$ACC = \frac{hits + correct\ negatives}{total}$$ Range: 0 to 1. Perfect score: 1

$$CSI = \frac{hits}{hits + misses + false\,alarm}$$ Range: 0 to 1. Perfect score: 1

$$ETS = \frac{hits - hits_{random}}{hits + misses + false\,alarm - hits_{random}} \quad \text{with} \quad hits_{random} = \frac{observed\ yes * forecast\ yes}{total}$$

ETS ranges from -1/3 to 1. 0 indicates no skill. Perfect score: 1.

$$HSS = \frac{(hits + correct\ negatives) - (expected\ correct)_{random}}{N - (expected\ correct)_{random}} \quad \text{with}$$

$$(expected\ correct)_{random} = \frac{1}{N}\left[(observed\ yes)(forecast\ yes) + (forecast\ no)(observed\ no)\right]$$

HSS ranges from -1 to 1. 0 indicates no skill. Perfect score: 1.

$$DWR = \frac{false\ alarm + correct\ negative}{hits + misses} = \frac{observed\ no}{observed\ yes}$$

Range: 0 to ∞. Perfect score: n/a.

### 3.4 Inventory of validation facilities

In the following sections the facilities utilised in the various Institutes to perform validation of precipitation products are described. It is apologised that editing is not well homogenised since the various sections are recorded as they were contributed by the individual institutes, with minimum harmonisation effort in respect of length and level of detail.

#### 3.4.1 Facilities in Austria (Tu-Wien)

The quality of the ERS surface soil moisture products has been investigated following several strategies, ranging from comparison with precipitation data to comparison with modelled data or in-situ soil moisture data. The validation of the ASCAT products shall follow the experiences made with SCAT validation events but with a focus on the European area. The following issues shall give an insight about further validation work.

Gridded precipitation data are available from the Global Precipitation Climatology Centre (GPCC). These data sets will be used for comparison with SCAT and ASCAT results. GPCC collects data worldwide from in-situ observations covering the Earth's land surface. Special interest will be put on the comparison of soil moisture data with precipitation anomalies.

Both optical and microwave systems are used to retrieve information on snow cover and there exist several hemispheric-scale satellite-derived snow-cover maps (Hall et al. 2002[6]). Among these, snow cover maps based on SSM/I, AMSR-E and MODIS are operationally available with daily updates from the United States National Snow and Ice Data Center (NSIDC).

To understand the backscatter behaviour of mountainous regions we plan to use elevation data stemming from either the Shuttle Radar Topography Mission (SRTM) or the seamless elevation dataset GTOPO30 that facilitates scientific use of elevation data over large areas.

To identify frozen surface and open water conditions it will be necessary to investigate freeze/thaw datasets as well as global water datasets like the Global Lakes and Wetlands Database (GLWD). This will give measures about the applicability of soil moisture products over inundated land, where water can lead to considerable errors backscatter behaviour and therefore in the retrieval of soil moisture.

An in-situ network of soil moisture measurement stations is available for the Mediterranean climate in Spain, called REMEDHUS. This is one of the few field networks providing multi-year data from almost two dozen stations within an area of about 1300 km$^2$. The stations are included within the same climatic context but are hydrologically independent (Martinez-Fernández and Ceballos 2005[7]).

Simulation models proved to be of interest for comparison studies. (Pellarin et al. 2006[8]) compared surface soil moisture data with a 10-year model simulation dataset (ISBA-A-gs model) over a crop dominated test site in southwestern France. Simulated monthly soil moisture fields can also be taken from vegetation models like the Lund-Potsdam-Jena (LPJ) dynamic global vegetation model, a nonequilibrium biogeography-biogeochemistry model that combines process-based representations of terrestrial vegetation dynamics and land-atmosphere carbon and water exchanges in a single framework (Sitch et al., 2003[9]).

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[6] Hall D.K., R.E.J. Kelly, G.A. Riggs, A.T.C. Chang and J.L. Foster, 2002: "Assessment of the relative accuracy of hemispheric-scale snow-cover maps". *Annals of Glaciology* **34**: 24-30.

[7] Martínez-Fernández J. and A. Ceballos, 2005: "Mean soil moisture estimation using temporal stability analysis." *Journal of Hydrology* **312**: 28-38.

[8] Pellarin T., J.-C. Calvet and W. Wagner, 2006: "Evaluation of ERS scatterometer soil moisture products over a half-degree region in southwestern France". *Geophysical Research Letters* v.33, L17401, doi:10.1029/2006GL027231.

[9] Sitch S. et al., 2003: "Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ dynamic global vegetation model". *Global Change Biol.* **9**: 161– 185.

### 3.4.2 Facilities in Belgium (IRM)

Observation of soil moisture is not an operational observation on the networks operated by IRM. Nevertheless, some research groups in Belgium have installed their own equipment in different test sites and their cooperation will be proposed.

The soil moisture products will be validated using the semi-distributed hydrological model SCHEME. This model comprises a soil moisture module consisting of two conceptual reservoirs for each of seven vegetation covers that are represented by their fraction coverage over the 7 km × 7 km grid cells. Simulated surface soil moisture has been shown comparable with gravimetric measurements in a field campaign (Roulin 2003[10]). Methods to assimilate large-scale soil moisture are being investigated. The usefulness of these satellite products for operational hydrology will be tested in a way similar to the other products.

[10] Roulin E., 2003: "Statistical correction applied to a water-balance model for the Meuse". In "Final report of the DAUFIN Project", van Loon, E.E., and P.A. Troch eds., Wageningen University, The Netherlands, 113-126.

### 3.4.3 Facilities in ECMWF

At ECMWF, modelled surface soil moisture fields (representing the top 7 cm layer of the soil) will be compared against the satellite derived surface soil moisture index. For the prototype development historic data, i.e. the ERS 1/2 scatterometer derived data set comprising 1992 to 2000, will be analysed. The corresponding model fields will be obtained from ECMWF's 40-year Re-Analysis (ERA-40). Once near real time observations from ASCAT are available, a continuous comparison against the operational analysis product will be performed. The following paragraph will give a short description of the ERA-40 data set (compiled from Uppala et al. 2005[11]).

ERA-40 is a re-analysis of meteorological observations from September 1957 to August 2002. The data assimilation comprises a sequence of analysis steps, in which background information for a short period (typically 6 h) is combined with observations for the period to produce an estimate of the state of the atmosphere at a particular time. The observations and the background forecast are combined using statistically based estimates of their errors. The surface analyses are based on a set of analyses of temperature and humidity at 2 m height. These analyses were produced as part of the ERA-40 data assimilation, but not directly by the primary 3D-Var analysis of atmospheric fields. A separate analysis of measurements of dry-bulb temperature and dew-point was made using an Optimum Interpolation scheme. The background field for this analysis was derived from the background forecast of the main data assimilation, by interpolating between the surface and the lowest model level. The 2 m temperature and humidity analyses were not used directly to modify the atmospheric fields used to initialize the background forecast for the next analysis in the data assimilation sequence. They nevertheless influenced this background forecast, since they were used as input to an Optimum Interpolation analysis of soil temperature and moisture for the use in the background model. Soil moisture was analysed for the upper three soil layers representing 100 cm depth. The analysed soil moisture fields for the uppermost 7 cm soil layer will be used for the evaluation.

The re-analysis data were produced on a reduced Gaussian grid with an almost uniform spacing of about 125 km. Since the resolution of the scatterometer derived surface soil moisture index is ~ 50 km the data will be aggregated to the coarser model grid and archived in GRIB format. Both data sets will be compared on a grid box by grid box basis for the entire 9-year period. This reflects i) the philosophy of the change detection algorithm for the soil moisture index and ii) the setup for the surface data assimilation system. The objective of this comparison is twofold. Firstly, systematic differences between both data sets (e.g. mean value, maximum and minimum) will be quantified. In a second step, parameterizations for the conversion of the index into volumetric soil moisture will be developed.

All model data used in this comparison are obtained from ECMWF's Meteorological Archival and Retrieval System (MARS), which is the main repository of meteorological data. It contains more than a petabyte of operational and research data as well as data from special projects. MARS data is freely available to registered users in the Member States and Cooperating States. There is no public access to MARS; for research and commercial use, data can be obtained through ECMWF's Data Services section.

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[11] Uppala S.M., P.W. Kållberg, A.J. Simmons, U. Andrae, V. da Costa Bechtold, M. Fiorino, J.K. Gibson, J. Haseler, A. Hernandez, G.A. Kelly, X. Li, K. Onogi, S. Saarinen, N. Sokka, R.P. Allan, E. Andersson, K. Arpe, M.A. Balmaseda, A.C.M. Beljaars, L. van de Berg, J. Bidlot, N. Bormann, S. Caires, F. Chevallier, A. Dethof, M. Dragosavac, M. Fisher, M. Fuentes, S. Hagemann, E. Hólm, B.J. Hoskins, L. Isaksen, L., P.A.E.M. Janssen, R. Jenne, A.P. McNally, J.-F. Mahfouf, J.-J. Morcrette, N.A. Rayner, R.W. Saunders, P. Simon, A. Sterl, K.E. Trenberth, A. Untch, D. Vasiljevic, P. Viterbo and J. Woollen, 2005: "The ERA-40 re-analysis". *Quart. J. R. Meteorol. Soc.* **131**: 2961-3012.

### 3.4.4 Facilities in France (Météo-France, LATMOS, CESBIO)

***Météo-France***

The study performed by Météo-France compare satellite and observation data with re-analysed surface soil moisture data from the hydrometeorological model SIM (Safran-ISBA-Modcou) of Météo-France. This coupled meteorological-hydrological model uses a grid cell of 8 x 8 km² to simulate the water and energy budget at the surface, the soil moisture and the discharge of the main French rivers (Habets et al. 2008[12]). It is used operational at Météo-France and furthermore serves for several applications like drought and flood monitoring. The study area may be the whole continental France. Special effort, associated to the H-SAF Hydrological validation programme, is focused on the Adour-Garonne basin.

***LATMOS*** (former CETP, Centre d'études des Environnements Terrestres et Planétaires, of CNRS)

The following two test-sites are utilised by LATMOS:

- Grand and Petit Morin;
- Beauce site

At the test-site Grand and Petit Morin, several experimental measurements will be used for soil moisture products. Three Time Domain Reflectometry (TDR) continuous measurements exist in the studied site as shown in the ***Fig. 06***. These data are calibrated by gravimetric measurements. Measurements are made for different soil depths (5, 15, 25, 35, 45, 55, 75, 95, 115, 135, and 155 cm). These measurements will be made two times per day. The geographical position of these measurements allows a good representation of moisture values on the studied site. Furthermore, experimental field campaigns are envisaged. Approximately 10 experimental campaigns to measure surface soil moisture (the first 5 cm) will be made in the studied site using hand gravimetric measurements. These measurements will concern a large number of agricultural fields in order to have a good statistical representation of the studied site.

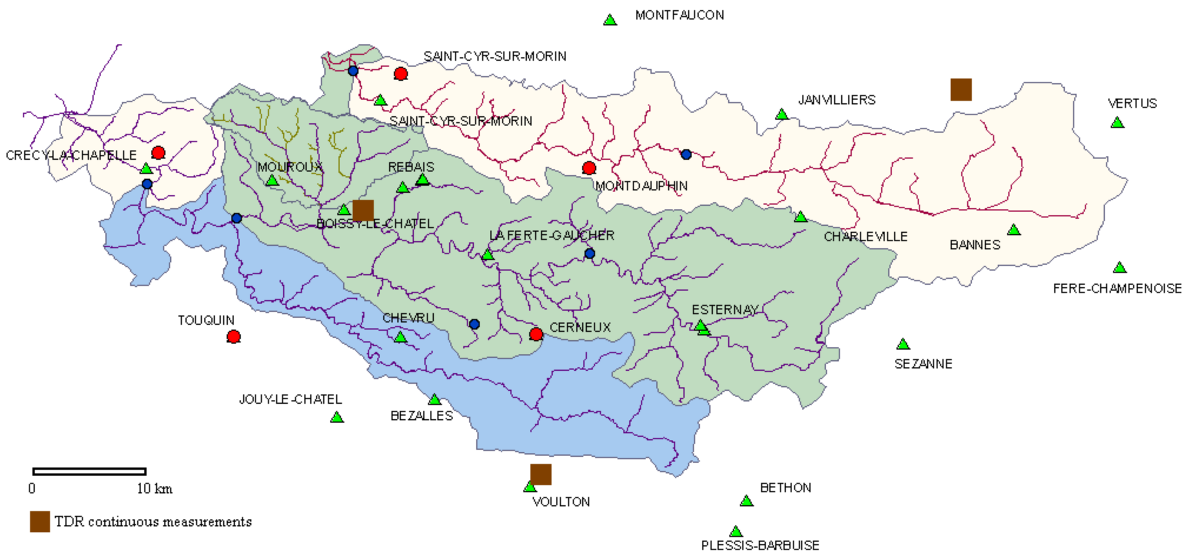



***Fig. 06 - Location of TDR continuous measurement instruments at Grand and Petit Morin site.***

At the test-site Beauce, one continuous TDR measurement allowing moisture values one time per week for different depths up to 1m is planned. Furthermore, one Theta-probe continuous measurements allowing surface soil moisture (the first 5 cm) will be valuable in the studied site. In addition, approximately 10 experimental campaigns in 2006-2007 during vegetation season will be made on the

[12] Habets F, A. Boone, J.L. Champeaux, P. Etchevers, L. Franchistéguy, E. Leblois, E. Ledoux, P. Le Moigne, E. Martin, S. Morel, J. Noilhan, P. Quintana Segui, F. Rousset-Regimbeau and P. Viennot, 2008: "The SAFRAN-ISBA-MODCOU hydrometeorological model applied over France". *Journal of Geophysical Research,* 113, D06113, doi:10.1029/2007JD008548.

studied site with soil moisture measurements over a large number of agricultural fields in order to estimate soil moisture values.

The two studied sites are flat in a temperate region with homogenous land uses, then spatial soil moisture variability is not important. A mean filtering seems sufficient to estimate a mean soil moisture value. Therefore, soil moisture satellite products will be compared with the mean value of soil moisture measurements. For days with only continuous measurements, we will propose a mean value of these data. For days with field gravimetric measurements, we will propose a mean value of all measurements (gravimetric and continuous).

***CESBIO***

CESBIO is involved in comparing SMOS and H-SAF soil moisture products. Inter-comparison between global soil moisture products generated by H-SAF and related space based soil moisture missions is of crucial importance in support of development of soil moisture products. The SMOS (Soil Moisture and Ocean Salinity) mission has been launched in end-2009. Since it operates in L-band (1.4 GHz), SMOS is being sensing soil moisture in the presence of vegetation, significant of the roots region. SMOS is expected to provide estimates of surface soil moisture with a precision better than 4 % in volumetric soil moisture. It will therefore support the efforts to characterise the H-SAF products generated on the base of data from operational satellites (specifically MetOp ASCAT) and modelling (at ECMWF). CESBIO leads the European space mission SMOS. This laboratory aims at developing knowledge on continental biosphere dynamics and functioning at various temporal and spatial scales. This includes its interactions with atmosphere and anthropic impact on water resources and land use. CESBIO proposes to compare SMOS-derived soil moisture with H-SAF products and ECMWF soil moisture analysis.

The SMOS Level-2 soil moisture products are being acquired for 2010. Soil moisture products obtained from SMOS and MetOp-ASCAT as well as the soil moisture simulated by ECMWF will be re-gridded in order to obtain the three products on the same grid at the European scale.

- Spatial features of surface soil moisture products from SMOS and ASCAT and ECMWF model, will be compared for different seasons.
- Dynamics of soil moisture will compared between the three products at the monthly, seasonal, and annual scales.
- The effect of vegetation water content on the retrieved surface soil moisture products of both SMOS and ASCAT will be analysed by comparison with the ECMWF surface soil moisture. This analysis will be performed for spring and autumn where the vegetation phenology is significant.

# 4. Validation of the product release as at the end of the Development Phase

## 4.1 Introduction

This Chapter collects the results of the validation experiments as at the end of the H-SAF Development Phase. The validation is performed on the product release currently in force. All previous validation exercises were recorded in the so-called "REP-3 (H-SAF Products Validation Report)", last issue dated 28 February 2010. There is no need to refer to that internal document, since the recorded experiments are described in the Appendix to this document. The Appendix is a simple transcription of the experiments, thus it is characterised by a low level of editing, as it was appropriate to a project-internal working document.

SM-OBS-2 is intended to be submitted to the ORR. The final validation period provides continuation of what was just initiated in REP-3/09 (*Results of validation activities for product SM-OBS-2*), thus it covers about one year, from spring 2009 to spring 2010

This Chapter 4 is structured by Country/Team, and is complementary to Chapter 5 (*Overview of findings*). Each Country/Team contributes to Section 5.1 (*Synopsis of validation results*) by providing the main statistical features enabling to assess the degree of compliance of the product with user requirements. For product SM-OBS-2 the User requirements are recorded in ***Table 03***.

***Table 03 - Accuracy requirements for product SM-OBS-2 [RMSE]***

| Unit | threshold | target | optimal |
|---|---|---|---|
| $m^3 m^{-3}$ | 0.1 | 0.05 | 0.03 |

This implies that the main score to be evaluated is the Root Mean Square Error. Supportive scores are: the Mean Error (or *bias*, ME), the Standard Deviation (SD) and the Correlation Coefficient (CC).

The results displayed in Section 5.1, side by side for the different Countries, enable the users of H-SAF products to appreciate the error structure in the closest geographical and climatic conditions, and at the time (month, season) of their interest.

This Chapter 4 is available to each Country/Team to provide more in-depth analysis of the product performance on the area of concern of the specific Country/Team. This implies more complex tests than those required for the general statistics. These tests may consist of the application of further statistical scores of the dichotomous set (POD, FAR, CSI, FBI, POFD, ACC, ETS, HSS, DWR; see Section 3.3), scatter plots, diagrams, histograms, and anything considered useful to better characterise the performance of the product, function of the observing conditions.

Each Country/Team should conclude its Section by listing the main features of the product, function of whatever the Team considers as a significant change of conditions associated to change of performance. The purpose is to characterise the applicability of the product for a correct use, especially in hydrology. The partial conclusions of the individual Country/Team are the basis for the overall summary recorded in Section 5.2 (*Summary conclusions on the status of product validation*). ***Table 04*** gives a short overview about the product format versions used in the validation studies.

***Table 04 - SM-OBS-2 scatterometer data versions used for validation***

| Version | Validity / Release date | Description | Country, test site |
|---|---|---|---|
| v1 | Mar 2009 | Prototype version, Eastern Europe only, image format (GeoTiff) | - |
| v2 | Dec 2009 | Improved version, whole Europe (with limits over Italy, Benelux countries, Alps), image format (BUFR) | France, several |
| v2a | Dec 2009 | Offline-generation at TU-Wien, image format (GeoTiff) | Luxembourg, Bibeschbach<br>Belgium, Demer/Ourthe |
| v3 | Mar 2010 | Increased geographic coverage (some gaps closed), image format (BUFR) | - |
| v3a | Mar 2010 | Offline-generation at TU-Wien, image format (GeoTiff) | Italy, Tiber |
| v3b | Mar 2010 | Offline-generation at TU-Wien, modified GeoTiff format, masked in regions with low correlation | Luxembourg, Bibeschbach<br>Italy, Tiber |

## 4.2 Validation in Austria (Tu-Wien)

### 4.2.1 Validation results with in-situ data over Luxembourg (PRCGL)

The validation study focuses on the usefulness of downscaling coarse resolution soil moisture estimates retrieved from ASCAT using long ENVISAT ASAR image time series by comparison with field measurements. The archived ENVISAT ASAR images allowed the retrieval of regression coefficients that were used for downscaling bi-daily ASCAT soil wetness indices at 25 km spatial resolution to simulate the H-SAF SM-OBS-2 product.

An analysis of *in situ* soil moisture measurements, acquired over the Bibeschbach experimental catchment (10.8 km$^2$) in Luxembourg (***Public Research Center Gabriel Lippmann***) (***Fig. 07***), has been conducted in order to improve the understanding of the potential for hydrological applications of the new high resolution SM-OBS-2 product. Since 2005, the experimental Bibeschbach basin is equipped with a set of 40 ECH$_2$O Decagon soil moisture sensors, which measure the permittivity of the topsoil layer at a depth of 4-7 cm. The sensors are connected to data loggers that store the dielectric constant of the medium with a time step of one hour. In particular, the study investigated the relationship between local and regional backscatter as well as between ground measurements and remote-sensing derived soil wetness indices over representative land cover classes and soil types.

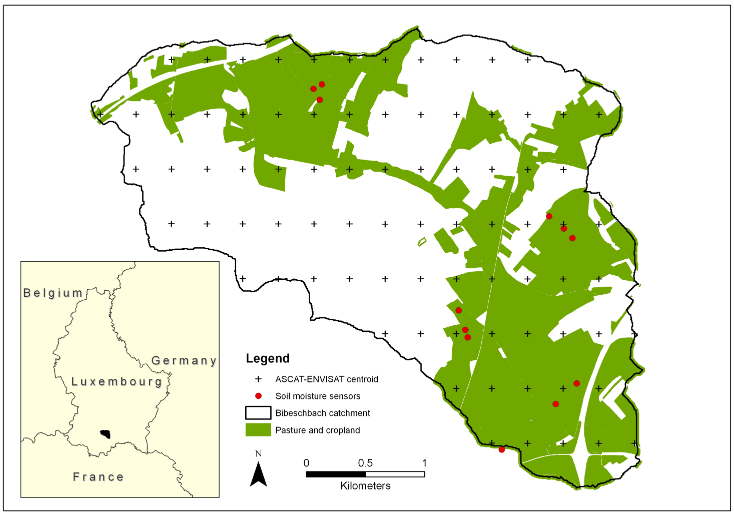



***Fig. 07 - Location of the investigation area (Bibeschbach basin, Luxembourg)***

The ASCAT data have been processed to Soil Water Index (SWI) data following the approach of Wagner et al. 1999[13] by using an exponential filter. To remove the systematic differences between the two data sets, respectively the SWI values derived from *in situ* measurements and and remote sensing imagery, a cumulative distribution function (CDF) matching technique has been applied to correct the bias (Drusch et al. 2005[14]). The same processing steps have been applied to both the 25 km and 1 km ASCAT products.

The 25 km resolution ASCAT-derived SWI time series show a good correlation with basin-averaged soil wetness indices derived from field measurements, with an $R^2$ of 0.88 and an RMSE of 0.10 (***Fig. 08***). By selecting the pixels over regions with low vegetation that are located within the Bibeschbach catchment, the downscaled 1 km spatial resolution simulated SM-OBS-2 product presents similar correlation with field measurements, with an $R^2$ of 0.89 and an RMSE of 0.11. It is concluded that the

[13] Wagner W., G. Lemoine and H. Rott, 1999: "A Method for Estimating Soil Moisture from ERS Scatterometer and Soil Data". *Remote Sensing of Environment*, 70 (2), 191-207.

[14] Drusch M., E.F. Wood and H. Gao, 2005: "Observation Operators for the Direct Assimilation of TRMM Microwave Imager Retrieved Soil Moisture". *Geophys. Res. Lett.*, 32, L15403, doi:10.1029/2005GL023623.

high resolution simulated SM-OBS-2 soil wetness index needs more investigations in order to highlight its merits and understand the advantages in model updating procedures.

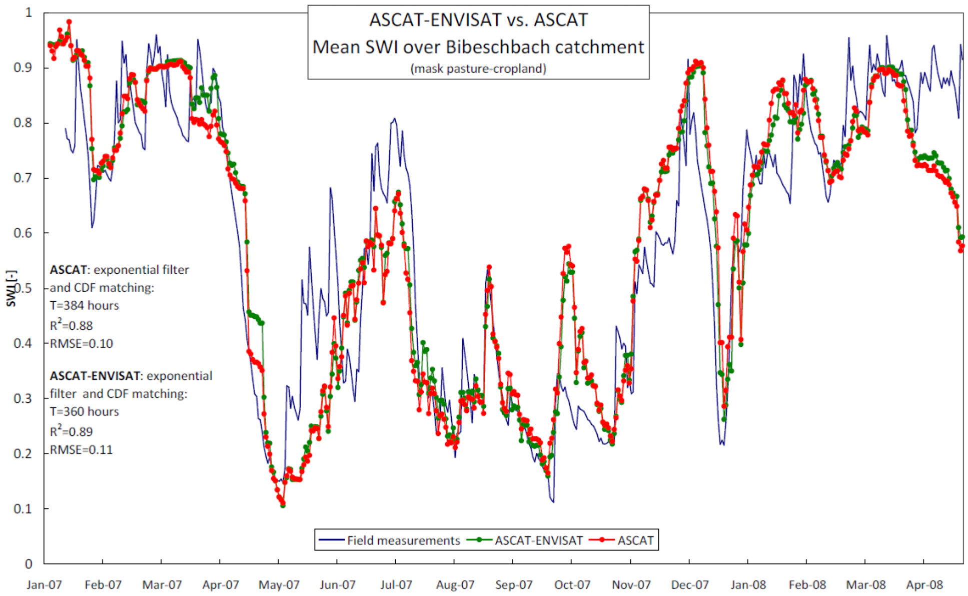



***Fig. 08 - Investigation results for the Bibeschbach basin***

It appears that the local and regional backscatter values are highly correlated over areas covered with low vegetation, whereas the correlation becomes weaker or indeed close to zero over densely vegetated areas and urban settlements. The results confirm the high level of temporal persistence of soil moisture patterns within the experimental catchment and show the necessity of focusing the analysis on regions with high signal to noise ratios.

### 4.2.2 Comparison of SM-OBS-2 vs. model data in Italy (CNR-IRPI)

This validation experiment has been performed in collaboration between TU-Wien and the CNR Istituto di Ricerca per la Protezione Idrogeologica (IRPI).

Due to the fact that the SM-OBS-2 data set is derived from SM-OBS-1 through a linear downscaling approach, based on background information on soil moisture spatial variability retrieved from Envisat ASAR images, it is expected that the results of SM-OBS-2 versus ground data are essentially the same of those obtained for SM-OBS-1, at least in terms of correlation coefficient. However, the actual version of SM-OBS-2 is derived from the downscaling of the "old" SM-OBS-1 v1 product that is characterized by much more noise than the actual SM-OBS-1 v2 product due to the different calibration based on ERS Scatterometer data.

For this study, modeled saturation degree data for layer depths of both 5 cm and 15 cm are used. The model (***Fig. 09***) requires as input data the meteorological variables routinely measured (rainfall and air temperature) and incorporates only five parameters ($W_{max}$, $K_s$, $\psi/L$, $\lambda$, b). Moreover, because the parameters are physically based and their value range is limited, the model was found consistent even when it was calibrated only with a limited number of observations (Brocca et al. 2008[15]). These two characteristics allow to confidently use the model over large areas and for periods different from those employed for parameters calibration.

[15] Brocca L., F. Melone and T. Moramarco, 2008: "On the estimation of antecedent wetness condition in rainfall-runoff modelling". *Hydrol. Process.*, vol. 22, no. 5, pp. 629-642.

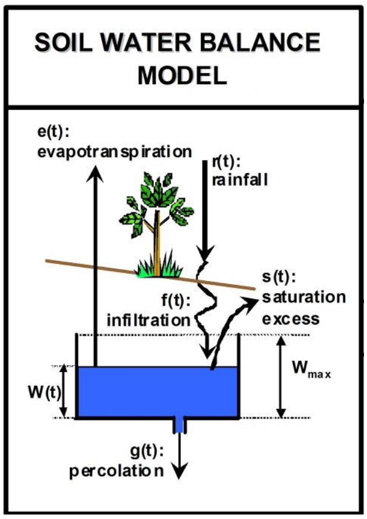



***Fig. 09 - Scheme of the soil water balance model used for this study.***

It has to be noticed that the modeled data for the 5 cm layer depth are particularly useful because they represent, approximately, the same layer depth investigated by the ASCAT sensor. The structure of the soil water balance model used in this study was derived by using soil moisture observations carried out in an experimental catchment located in the study area. In particular, different expressions were considered for the different components of the model: i.e. infiltration, percolation and evapotranspiration (Brocca et al. 2008). The best performance was obtained when the Green-Ampt relation for infiltration, a gravity driven non-linear relationship for percolation and a linear relation between the actual and the potential evapotranspiration (computed through the Blaney and Criddle formula) were used.

The Vallaccia site (hereinafter named VAL) covers an area of ~56 km$^2$ with elevation ranging between 288 and 818 m above sea level (see ***Fig. 10***).

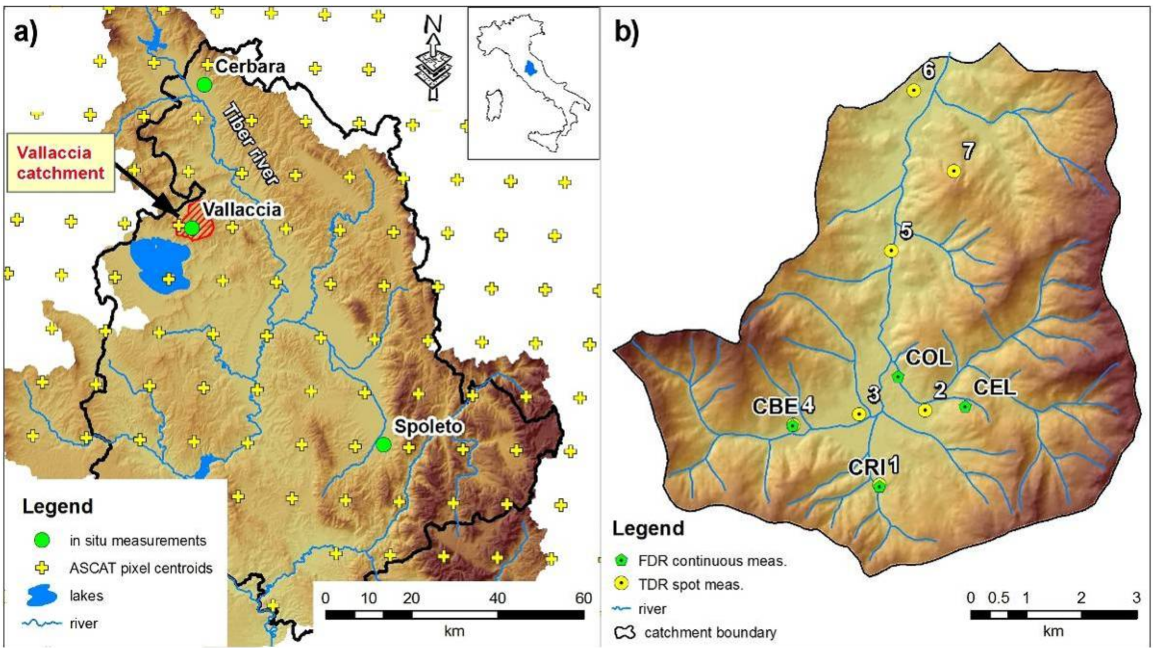



***Fig. 10 - a) Framework of the study area with the location of the three soil moisture sites (Vallaccia, Cerbara and Spoleto) and of the ASCAT pixel centroids. b) Enlargement for the Vallaccia catchment with the location of the four FDR continuous soil moisture probes and of the spot TDR measurement plots.***

Previous results were performed with the comparison between SM-OBS-1 v2 and the Soil Water Index (SWI) and a linear rescaling of SWI (denoted SWI*) indices derived from it with modeled data at 5 cm depth for the VAL site in Italy. In terms of correlation, for SM-OBS-1 v1 product it is equal to 0.73 against the value of 0.84 that we obtained with SM-OBS-1 v2 product. Thanks to the capability of the exponential filter to reduce noise, the results for the two products are more similar when SWI (or SWI*) indices are considered.

Based on these previous results, it can be expected that the actual version of SM-OBS-2 product suffers of the same drawbacks of SM-OBS-1 v1 product. ***Fig. 11*** shows the results with SM-OBS-2. Results are basically the same as of SM-OBS-1 v1 product and, hence, for a reliable evaluation of the SM-OBS-2 product, further data processing is required starting from the actual (less noisy) version of SM-OBS-1 (v2). However, these results already show that the reliability of SM-OBS-2 product should be nearly the same of SM-OBS-1. The improved spatial resolution of SM-OBS-2 will be surely an added value for soil moisture retrieval from remote sensing.

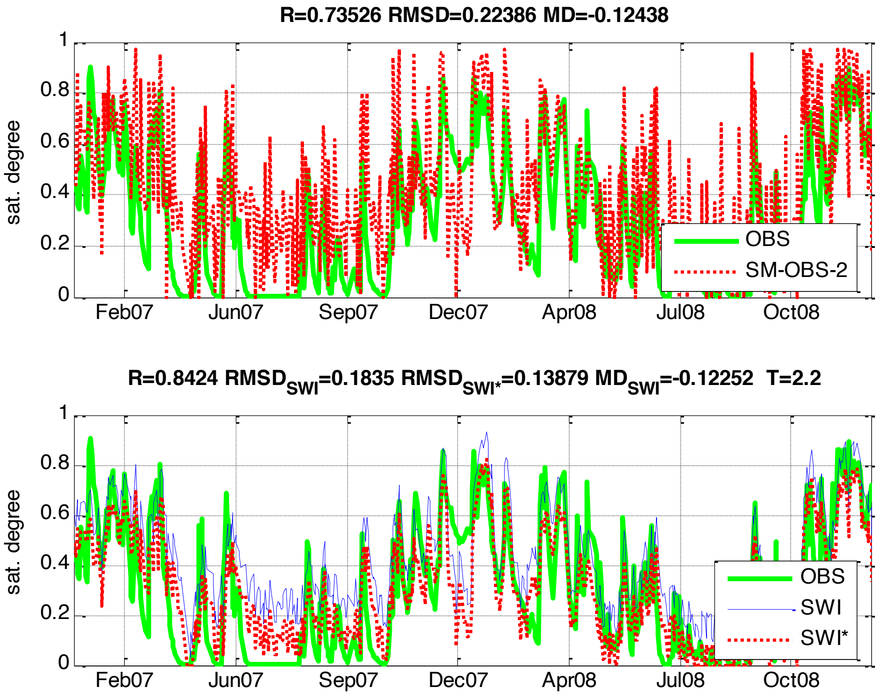



***Fig. 11 - SM-OBS-2, SWI and SWI* products versus in situ modeled soil moisture data at 5 cm depth for Vallaccia site (Italy).***

### 4.2.3 Comparison of SM-OBS-2 vs. in-situ data in Luxembourg and Italy (CNR-IRPI)

In another part of the study, the latest version of SM-OBS-2 (v3b) has been compared with in-situ data of the Bibeschbach catchment in Luxembourg (see chapter 4.2.1 for a site description). The difference to the previous versions of SM-OBS-2 is the fact that regions with a low performance of the downscaling approach (correlation between local and regional backscatter below 0.3) are now masked. Again, the Soil Water Index (SWI) and a linear rescaling of SWI (denoted SWI*) indices has been derived from SM-OBS-2 and compared with modeled data at 5 cm depth for the Bibeschbach site in Luxembourg. ***Fig. 12*** shows the time series and statistical results for the comparison for one in-situ location (6.1285°E, 49.7375°N) after taking an average region of 11 × 11 pixels into account. The dataset shows a bias of -0.18 and correlation values are 0.58 for the surface and 0.84 for the SWI* product, respectively.

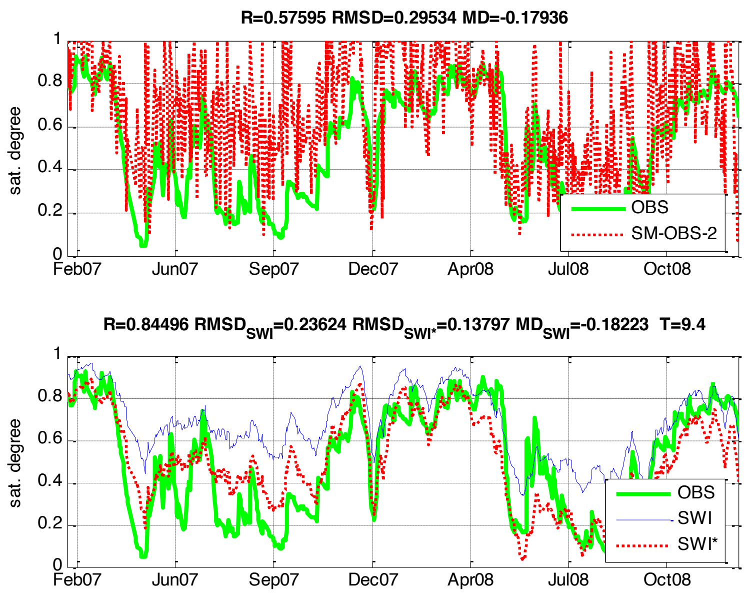



***Fig. 12 - SM-OBS-2, SWI and SWI* products versus in-situ soil moisture data at 5 cm depth for the Bibeschbach site.***

The same task has been performed with in-situ data from the Vallaccia site in Italy (see previous section 4.2.2 for a site description) with several depths ranging from 10-40 cm investigated. ***Fig. 13*** shows the results for 10 cm depth. The datasets show a correlation of 0.46 for the surface and 0.86 for the SWI* product.

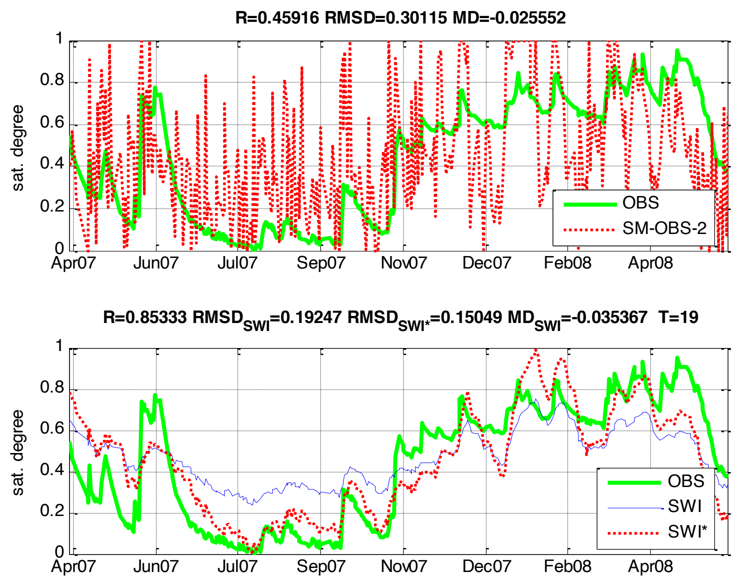



***Fig.13 - SM-OBS-2, SWI and SWI* products versus in-situ soil moisture data at 10 cm depth for the Vallaccia site.***

### 4.3 Validation in Belgium (IRM)

#### 4.3.1 Comparison with the SCHEME hydrological model

The test dataset prepared by TU-Wien for Belgium and Luxemburg was investigated. It covers the period from January 2007 to June 2009. Unfortunately, the downscaling is relying on long-term ENVISAT ASAR data that were not available for most part of the Demer test-catchment. Therefore the sub-catchment of Grote Gete at the gauge station Hoegaarden has been considered (208 km$^2$, ***Fig. 14***). The Ourthe test-catchment is entirely included. It has to be reminded that with SM-OBS-1 as well as with ERS derived soil moisture, the best correlation was obtained over the Demer catchment and this was explained with the difference in topography and land cover between the two catchments.

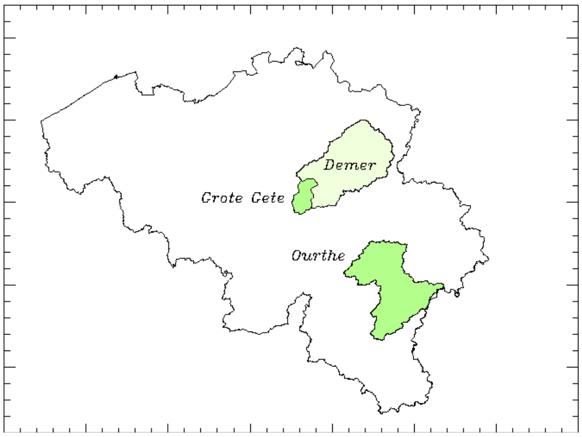



***Fig. 14 - Map of Belgium with the test-catchments.***

As a preliminary activity, the GEOTIFF files were decoded. The files with coverage of 90-93 % of the catchment area (respectively for the Grote Gete and the Ourthe) were taken into account. The threshold were taken different because the coverage of the Ourthe was found better than for the Grote Gete. The average soil moisture over the chosen catchments was computed as it was done for the SM-OBS-1 product, and it was compared with the average surface soil moisture simulated with the SCHEME hydrological model for all the seven vegetated covers defined in the model. The frozen soils were screened on the base of the temperature measured at the synoptic stations and interpolated on the hydrological model grid. In ***Fig. 15*** and ***Fig. 16***, the series corresponding to the entire dataset are plotted.

It can already be seen that the major drying phases are well captured. There seems a tendency of the downscaled product not to exceed ~90 % for the Grote Gete and ~85 % for the Ourthe. This is explained by the step in the production chain consisting in setting values between 100 and 120 % to 100 % and discarding values exceeding 120 %. The screening of frozen soils may have failed for some points during winter and should be improved in future. Statistical scores are given on ***Table 05***. These should be taken as indicative because of the problems referred above; for instance, the correlation coefficient is slightly better for the Ourthe, which was not the case with SURFWET (ERS) and with SM-OBS-1.

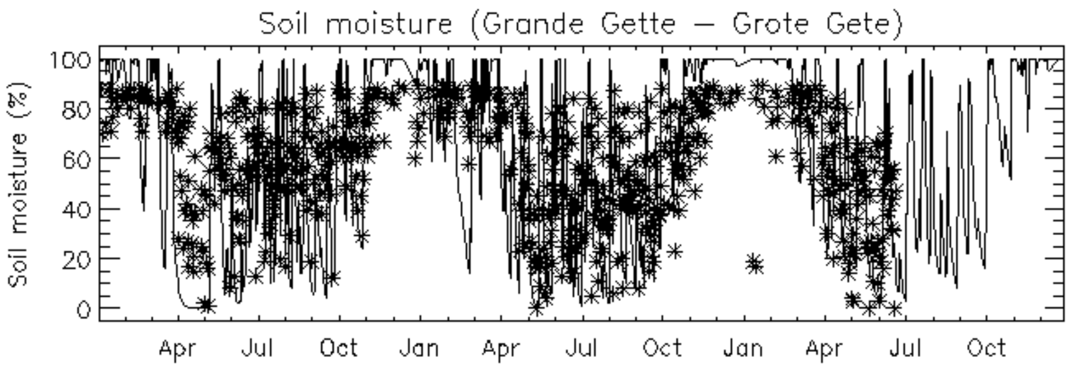



*Fig. 15 - Time-series of average surface soil moisture over the Grande Gette – Grote Gete test-catchment from January 2007 to June 2009: simulated with SCHEME model (continuous line) and SM-OBS-2 (stars).*

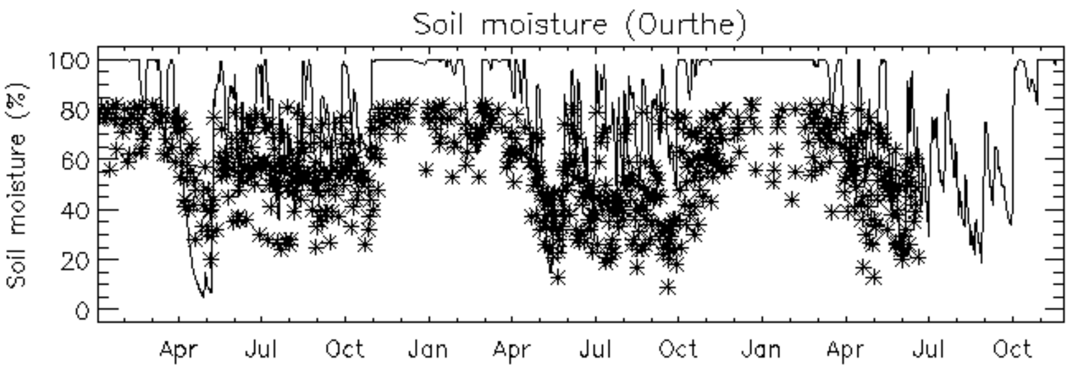



*Fig. 16 - Time-series of average surface soil moisture over the Ourthe test-catchment from January 2007 to June 2009: simulated with SCHEME model (continuous line) and SM-OBS-2 (stars).*

The comparison has been made on values averaged over the catchments. The downscaled product is aimed at reproducing more local patterns. Future work will include up-scaling SM-OBS-2 at the SCHEME model resolution and measure the agreement spatially.

*Table 05 - Statistics of the comparison between the soil moisture in the upper layer of the SCHEME model and SM-OBS-2; the mean error (ME) and the root mean squared error are in % saturation; January 2007 to June 2009.*

| | Grote Gete | Ourthe |
|---|---|---|
| Sample size | 709 | 685 |
| ME (%) | 8 | -21 |
| RMSE (%) | 30 | 29 |
| $R^2$ | 0.558 | 0.579 |

## 4.4 Validation in France (LATMOS, Météo France)

### 4.4.1 Comparison of ASCAT products and ground measurements in Tunisia (LATMOS)

The ground measurements used in this study are taken form the semi-arid Merguellil site in northern Tunisia. They are realized at a depth between 5 and 10 cm. For a preliminary study, data for the year 2009 were taken and compared to the ASCAT surface soil moisture dataset, displayed in ***Fig. 17***.

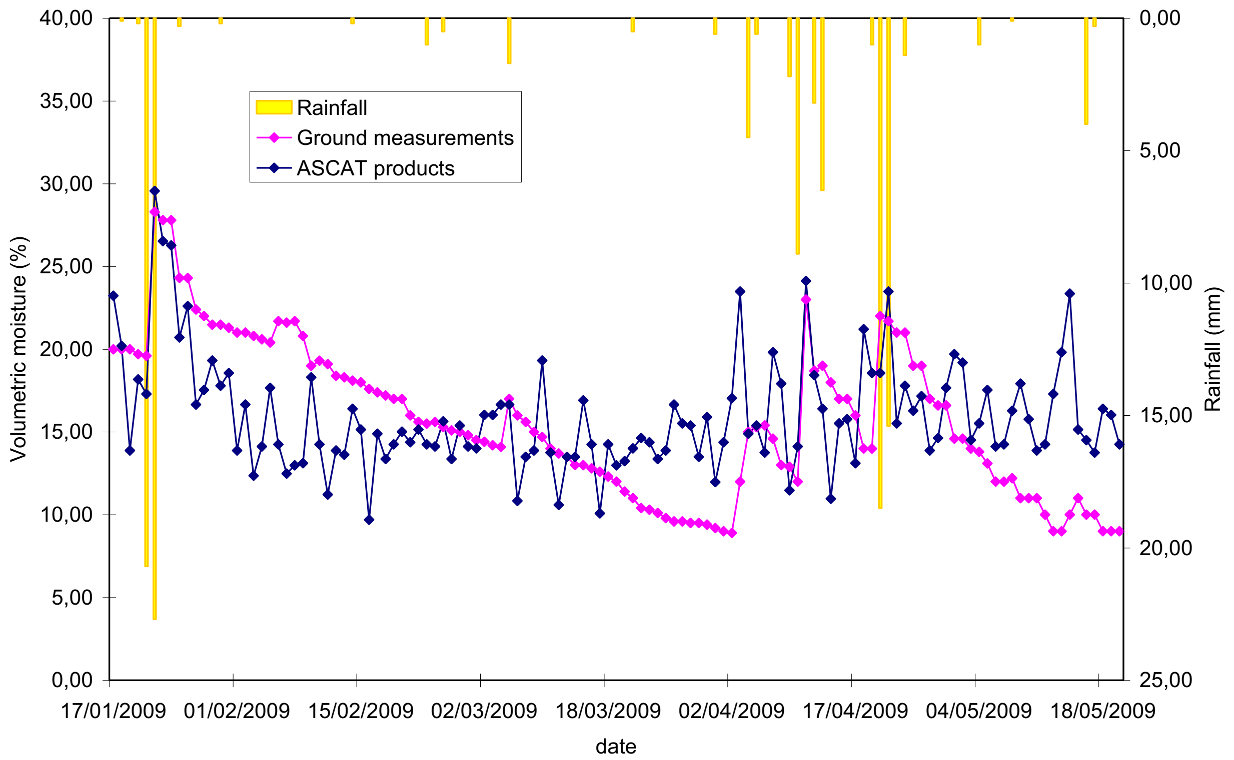



***Fig. 17 - ASCAT vs. ground measurements over Merguellil site in Tunisia.***

We can observe a coherence between the two products, following the different rainfall events. Decreasing of moisture level after rain events is more rapid for ASCAT products, because of the fact that ASCAT measurements are correlated to the first centimetres of depth. Surface moisture variations are certainly more important than moisture in other depths, because of very high evapotranspiration level in the studied site.

Furthermore, we can observe variations on ASCAT products even without rainfall. This could be explained by irrigation presence. However, at the end of spring, some variations are not clearly identified and need further investigation.

### 4.4.2 Comparison of ASCAT products and ground measurements in France (LATMOS)

In another part of the study, comparisons were made for ASCAT versus ground measurements at the Grand-Morin site in France. ***Fig. 18*** shows the time-series for one ASCAT pixel for a period of 2 years (2007-2009). Again, we observe a generally good coherence between the two soil moisture series and both curves follow the precipitation patterns (not shown in the plot). However, high variations of ASCAT are observable, particularly in wet seasons. This may be explained with the fact of calibration issues of the instrument.

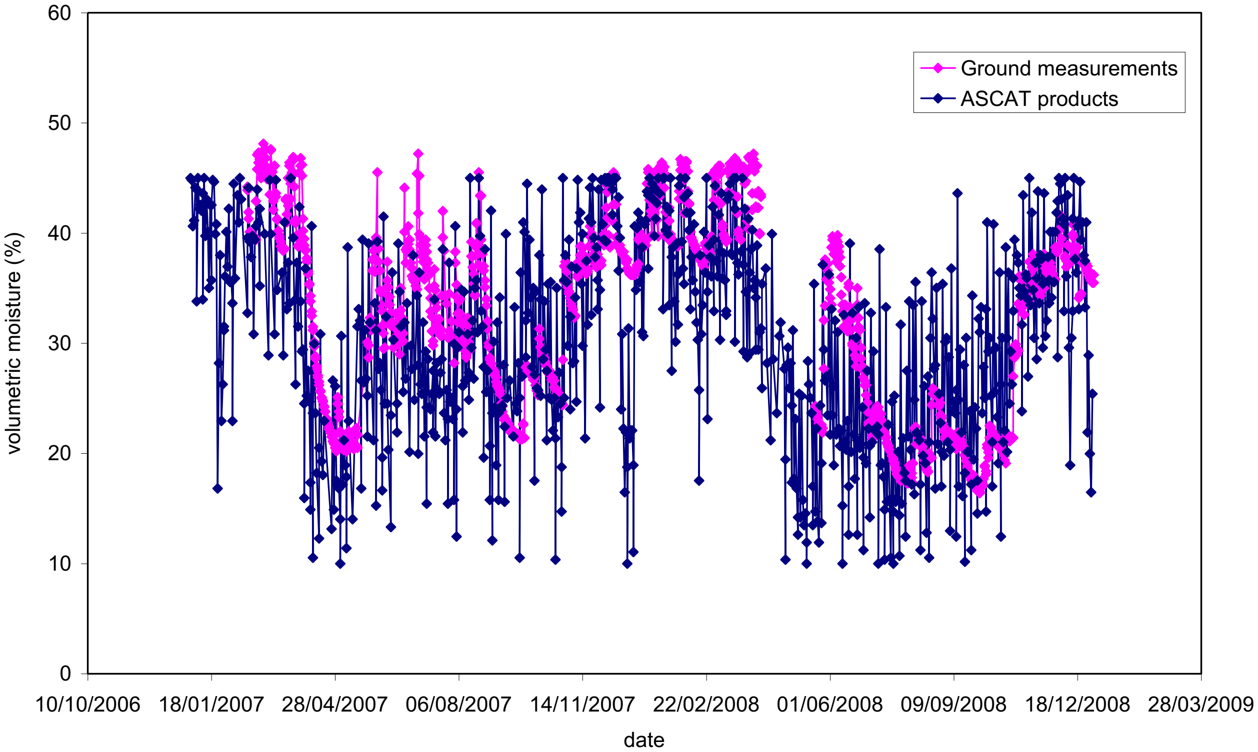



***Fig. 18 - ASCAT vs. ground measurements over Grand-Morin site in France.***

### 4.4.3 Validation results of SM-OBS-2 vs. SMOSMANIA in-situ (Météo-France)

Since the approach to downscale ASCAT products at a one kilometre scale is linear, it is not of interest to investigate temporal correlations between the downscaled ASCAT SSM and the in-situ data. Instead of considering temporal correlations, spatial correlations can be investigated. Over the 2007-2008 period, the comparison could be made only for nine of the twelve SMOSMANIA stations and the SMOSREX site. One station could not be used because of a lack in satellite data coverage. Moreover, the covered area is limited by the availability of the downscaling parameter database derived from ASAR. The area close to the Mediterranean sea is not covered, and the stations of LZC and NBN could therefore not be considered. A total of 150 ASCAT swaths covering all the considered stations at 150 dates in 2007 or 2008 are considered for this analysis. For each date at nine stations, ASCAT data at one kilometre scale are spatially averaged and compared with the in-situ observations. The same spatial correlation is performed for each considered date and the nearest low resolution (WARP-5) ASCAT grid point. The spatial correlations derived from the low resolution product are compared with those derived from the downscaled product in ***Fig. 19***. In 115 out of the 150 swaths (about 77 %), correlations are greater when downscaled ASCAT estimates are used. This result underlines the added value of the downscaled SM-OBS-2 product.

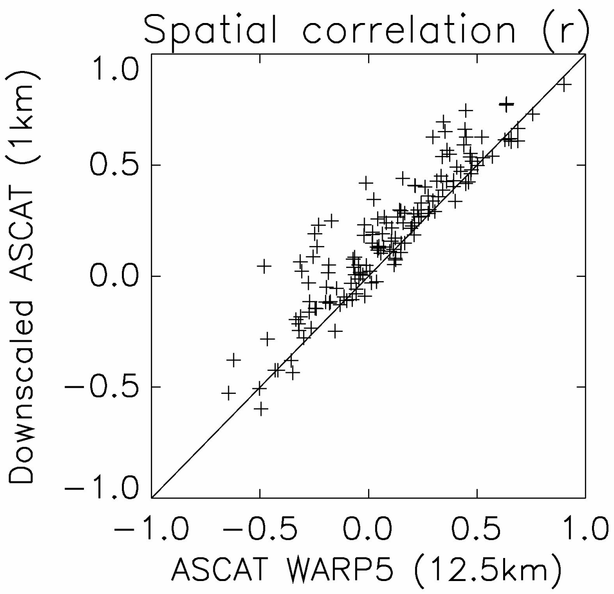



***Fig. 19 - Spatial correlation between a) ASCAT SM-OBS-1 estimates and in-situ SSM vs. b) downscaled ASCAT SM-OBS-2 estimates and in-situ SSM. 150 ASCAT swaths (i.e. days) are considered.***

# 5. Overview of findings

## 5.1 Synopsis of validation results

In the various sections of Chapter 4 the validation results have been quoted separately by each Team operating on a different geographic area associated to a proper climatic condition. This is correct, since the soil moisture field is affected by orography and local climatology. In this section a synoptic overview is provided, of the results achieved in the different countries, and in different seasons.

The contents of the various columns for the various months have been provided by the individual Countries/Teams. An attempt to derive an average performance for all sites is also quoted, to be used with care since the average of measurements collected in heterogeneous geographic, orographical and climatological conditions, is not particularly meaningful. More meaningful, for any user, is to pay attention to the performances quoted for the Country closer to its area of interest. In other words, the table is not intended to respond to the question whether the product meets the requirements or not, but rather <u>where</u> and <u>when</u> meets or approaches or fails the requirements.

The user requirements for SM-OBS-2 have already been recorded in Table 03. The basic score to be reported is RMSE, and supportive scores are: Mean Error (or *bias*, ME), Standard Deviation (SD) and Correlation Coefficient (CC).

***Table 06*** provides a synoptic view of the results of the various assessment. It is structured by campaigns, and indicates whether the comparison was made against field measurements or hydrological model.

*Table 06 - Statistical scores for SM-OBS-2*

| SM-OBS-2 | | Region | V. | Period | N. of sites | ME ($m^3 \cdot m^{-3}$) | SD ($m^3 \cdot m^{-3}$) | RMSE ($m^3 \cdot m^{-3}$) | CC |
|---|---|---|---|---|---|---|---|---|---|
| In-situ measurements | **Météo-France** | France (South-West) | 2 | 01/2007-12/2008 | 13 | - | - | - | 0.86 (max) |
| | **TU-Wien & Lippmann** | Luxembourg (Bibeschbach) | 2a | 01/2007-05/2008 | 40 | - | - | 0.10 - 0.11 | 0.88 - 0.89 |
| | **LATMOS** | France (Grand Morin) | 2a | 01/2007-12/2008 | 2 | - | - | - | - |
| | **LATMOS** | Tunisia (Merguellil) | 2a | 01/2009-05/2009 | 1 | - | - | - | - |
| | **TU-Wien & CNR-IRPI** | Luxembourg (Bibeschbach) | 3b | 01/2007-12/2008 | 2 | Sfc: -0.18 Root: -0.18 | - | Sfc: 0.29 Root: 0.14 | Sfc: 0.58 Root: 0.84 |
| | **TU-Wien & CNR-IRPI** | Italy (Tiber) | 3b | 01/2007-12/2008 | 1 | Sfc: -0.03 Root: -0.04 | - | Sfc: 0.30 Root: 0.15 | Sfc: 0.46 Root: 0.85 |
| Hydro. Model | **RMI** | Belgium (Demer) | 2a | 01/2007-06/2009 | 709 (samples) | 0.08 | - | 0.30 | 0.75 |
| | **RMI** | Belgium (Ourthe) | 2a | 01/2007-06/2009 | 685 (samples) | 0.21 | - | 0.29 | 0.76 |
| | **TU-Wien & CNR-IRPI** | Italy (Tiber) | 3a | 01/2007-12/2008 | 1 | Sfc: -0.12 Root: -0.12 | - | Sfc: 0.22 Root: 0.14 | Sfc: 0.74 Root: 0.84 |

## 5.2 Summary conclusions on the status of product validation

In the various sections of Chapter 4 the Countries/Teams have concluded with highlighting the main positive aspects of the product and the main failures, according to the experience on their area of investigation. In this Section attempt is made to synthesise the common findings that might characterise the product at the end of the Development Phase.

In general, it is agreed that:

- the product performs well in temperate and semi-arid regions of Europe. Validation activities are ongoing to extend the investigation areas in order to get an even better picture in near future;

- the product is meeting the threshold user requirements with respect to RMSE. Additional parameters (like the correlation) show a good overall agreement with both measured (in-situ) and modelled datasets.

However, the product exhibits the following limitations.

- Limitations occur with the usage of SM-OBS-2 in winter, when soil freezing occurs. This is a known issue, since the backscatter behaviour of frozen ground is similar to that of wet soil. The product should not be used in that situtation, and this is tackled with performing a screening with auxiliary datasets by the users, given their background knowledge.
- A high level of variability of soil moisture values has been detected, for specific product versions. This is due to the fact that EUMETSAT has changed the calibration of the input product during the development phase, and the older versions of SM-OBS-2 therefore showed a higher degree of variability. With the latest versions of input datasets, this issue is regarded to be solved.

The product developing team believes that the following aspect can be improved:

- The quality information of the product could further be improved. The current existing flag table is able to be expanded. This may be done by investigating auxiliary datasets but care should be given not to rely too much on the availability of external data.

### 5.3 Comments on the compliance of performances with user requirements

When comparing the results from the validation activity with the stated user requirements from the URD, the following has to be considered:

a. User requirements - There are reasons to believe that the current set of User requirements, adopted from external authoritative sources such as WMO, are overstated. It may be envisaged that, in CDOP-1, the approach to define user requirements should change in the direction of adopting figures representing achievable targets rather than theoretical whish; i.e., the User Requirements Document (URD) will eventually be replaced by the Product Requirements Document (PRD). An important addition will have to specify under which observing conditions, for example, the soil texture, the requirements have to be verified. In the case of precipitation the requested accuracy changes with precipitation intensity; in the case of soil moisture, different accuracy requirements could be stated for different soil textures.

b. The figures resulting from the current validation procedure represent the convolution of at least three factors: the satellite product accuracy, the accuracy of the ground system adopted as "truth" and the limitations of the comparison methodology (e.g., errors of space and time co-location, representativeness changing with scale, etc.) Partitioning of the observed "error" among these components has not yet occurred. Therefore, the figures currently found are by far too pessimistic in respect of what we need for comparing with the user requirement, i.e. the portion of error due to the satellite retrieval. However, it is fair to note that, even if partitioning is clarified, it is unlikely that the validation error can be substantially reduced. There are methods to reduce the effect of one specific factor (e.g., triple comparisons by techniques providing uncorrelated errors; etc.) but experience shows that the benefit of each special solution may be offset by a new rising problem (in the examples above: reduction of number of comparisons). Therefore, the partitioning exercise will have the purpose of <u>understanding</u> the lower limit that can be expected by the validation exercise, not of <u>reducing</u> the comparison error.

c. Pending in-depth studies of the validation error structure, we quote error estimates from a number of studies utilising the basic gravimetric method (collection of a volume of moist soil, and weigh before and after drying) compared with TDR (Time Domain Reflectometer) and capacity probes.

| Parameter | Source | Performance | Main limiting factors |
|---|---|---|---|
| Surface soil moisture | Walker J.P., G.R. Willgoose et al., 2004: "In situ measurement of soil moisture: A comparison of techniques." <u>Journal of Hydrology</u> **293**(1-4): 85-99. | - TDR: accuracy: ± 2.5 % vol. | - Measurement impossible when soil saturates.<br>- Some sensor types give estimates with a systematic bias and diurnal variations of up to 10 % volume. |
| | Francesca V., F. Osvaldo, et al., 2010: "Soil Moisture Measurements: Comparison of Instrumentation Performances." <u>Journal of Irrigation and Drainage Engineering</u> **136**(2): 81-89. | - Capacity probe: accuracy 2.5 ÷ 3.6 % vol.<br>- TDR: accuracy 1.6 % vol. | - Capacity probe: accuracy independent on depth.<br>- TDR: accuracy dependent on depth. |
| | Famiglietti J.S., D. Ryu et al., 2008: "Field observations of soil moisture variability across scales." <u>Water Resources Research</u> **44**(1): W01423. | - TDR: accuracy 0.036 ÷ 0.071 $m^3/m^3$. | - Accuracy degrading with increasing scale, from point to 50 km. |
| Volumetric soil moisture | SMOSMANIA stations (12) | - Capacity probe: accuracy 0.01 $m^3/m^3$ | - Accuracy degrading with increasing scale.<br>- Representativeness errors may amount to 0.1 $m^3/m^3$.<br>- Accuracy depending on soil texture, degrading with increasing sand content. |

# Appendix to PVR-08 (Small-scale surface soil moisture by radar scatterometer)
## Collection of validation experiment reports

(extracted from REP-3/09 dated 28 February 2010)

## INDEX

# 2. Validation exercises in Austria

## 2.1 Validation results with in-situ data over Luxembourg

The validation study focuses on the usefulness of downscaling coarse resolution soil moisture estimates retrieved from ASCAT using long ENVISAT ASAR image time series by comparison with field measurements. The archived ENVISAT ASAR images allowed the retrieval of regression coefficients that were used for downscaling bi-daily ASCAT soil wetness indices at 25 km spatial resolution to simulate the H-SAF SM-OBS-2 product.

An analysis of *in situ* soil moisture measurements, acquired over the Bibeschbach experimental catchment (10.8 km$^2$) in Luxembourg (Public Research Center Gabriel Lippmann) (***Fig. 2.1***), has been conducted in order to improve the understanding of the potential for hydrological applications of the new high resolution SM-OBS-2 product. Since 2005, the experimental Bibeschbach basin is equipped with a set of 40 ECH$_2$O Decagon soil moisture sensors, which measure the permittivity of the topsoil layer at a depth of 4 – 7cm. The sensors are connected to data loggers that store the dielectric constant of the medium with a time step of one hour. In particular, the study investigated the relationship between local and regional backscatter as well as between ground measurements and remote-sensing derived soil wetness indices over representative land cover classes and soil types.

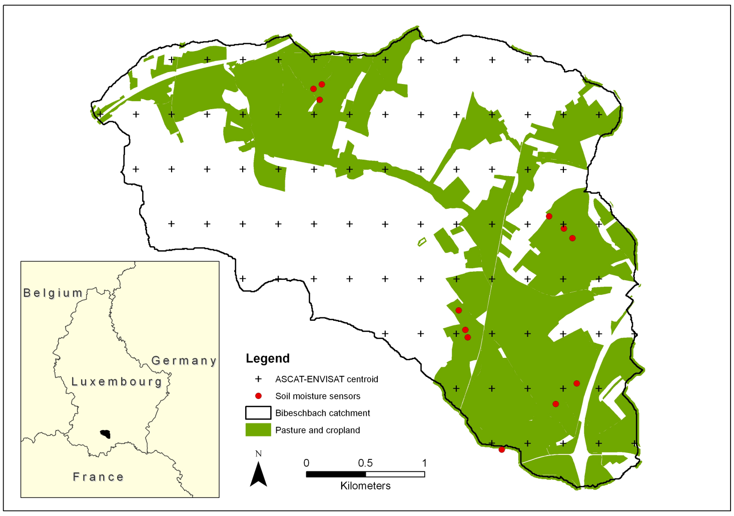



***Fig. 2.1 - Location of the investigation area (Bibeschbach basin, Luxembourg)***

The ASCAT data have been processed to Soil Water Index (SWI) data following the approach of Wagner et al., 1999 by using an exponential filter. To remove the systematic differences between the two data sets, field investigation and remotely sensed SWI, a cumulative distribution function (CDF) matching technique has been applied which is an improved method used to correct the bias (Drusch et al., 2005).

The 25km resolution ASCAT-derived SWI time series show a good correlation with basin-averaged soil wetness indices derived from field measurements, with an $R^2$ of 0.88 and an RMSE of 0.10 (***Fig. 2.2***). By selecting the pixels over regions with low vegetation that are located within the Bibeschbach catchment, the downscaled 1km spatial resolution simulated SM-OBS-2 product presents similar correlation with field measurements, with an $R^2$ of 0.89 and an RMSE of 0.11. It is concluded that the high resolution simulated SM-OBS-2 soil wetness index needs more investigations in order to highlight its merits and understand the advantages in model updating procedures.

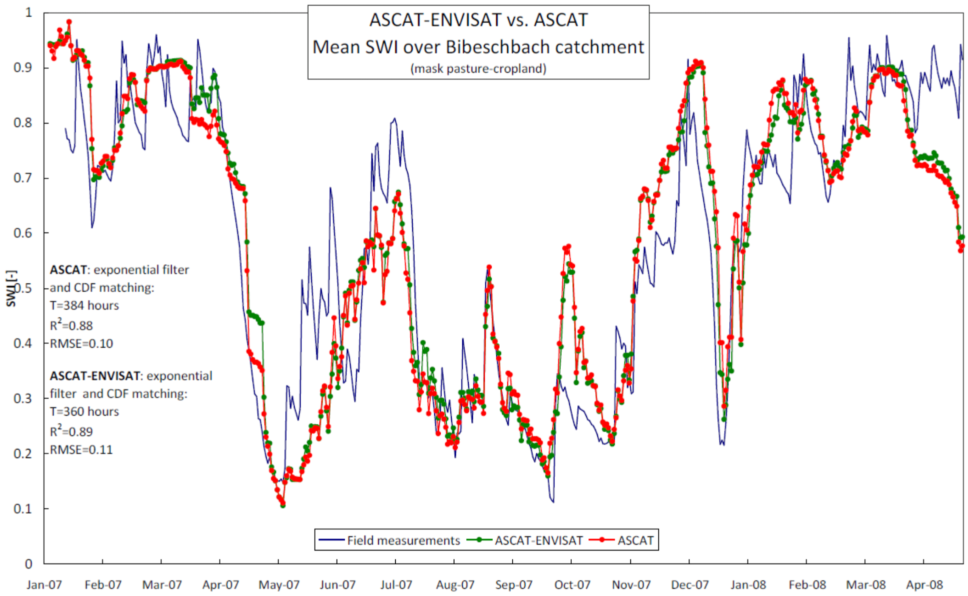



***Fig. 2.2 - Investigation results for the Bibeschbach basin***

It appears that the local and regional backscatter values are highly correlated over areas covered with low vegetation, whereas the correlation becomes weaker or indeed close to zero over densely vegetated areas and urban settlements. The results confirm the high level of temporal persistence of soil moisture patterns within the experimental catchment and show the necessity of focusing the analysis on regions with high signal to noise ratios.

# 3. Validation exercises in Belgium

## 3.1 Comparison with hydrological model SCHEME

The test dataset prepared by TUWien for Belgium and Luxemburg was investigated. It covers the period from January 2007 to June 2009. Unfortunately, the downscaling is relying on long-term ENVISAT ASAR data that were not available for most part of the Demer test-catchment, whereas the Ourthe test-catchment is entirely included. It has to be reminded that with ERS derived soil moisture, the best correlation was obtained over the Demer catchment and this was explained with the difference in topography and land cover between the two catchments. As a preliminary activity, the GEOTIFF files were decoded. The average soil moisture over the Ourthe test-catchment was computed as for the SM-OBS-1 product, and it was compared with the average surface soil moisture simulated with the SCHEME hydrological model for crops and pastures. In ***Fig. 3.1***, the series corresponding to the entire dataset are plotted.

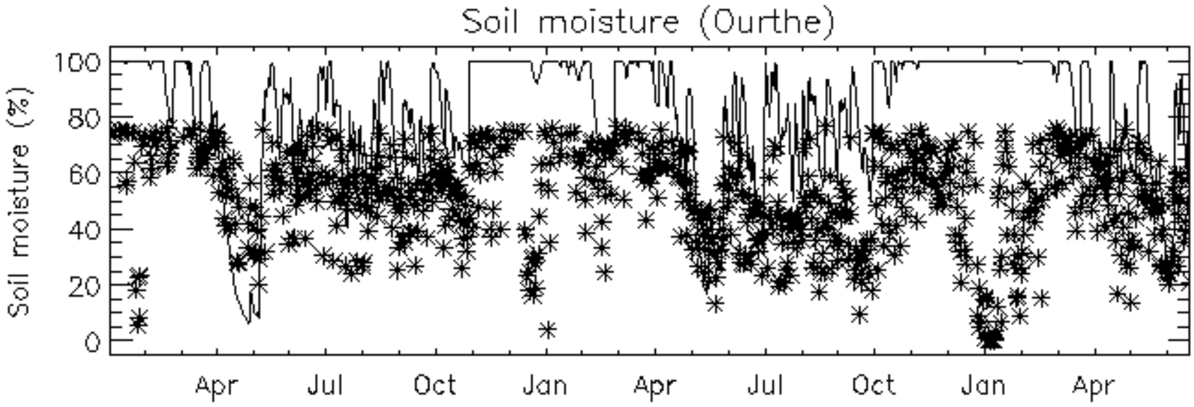
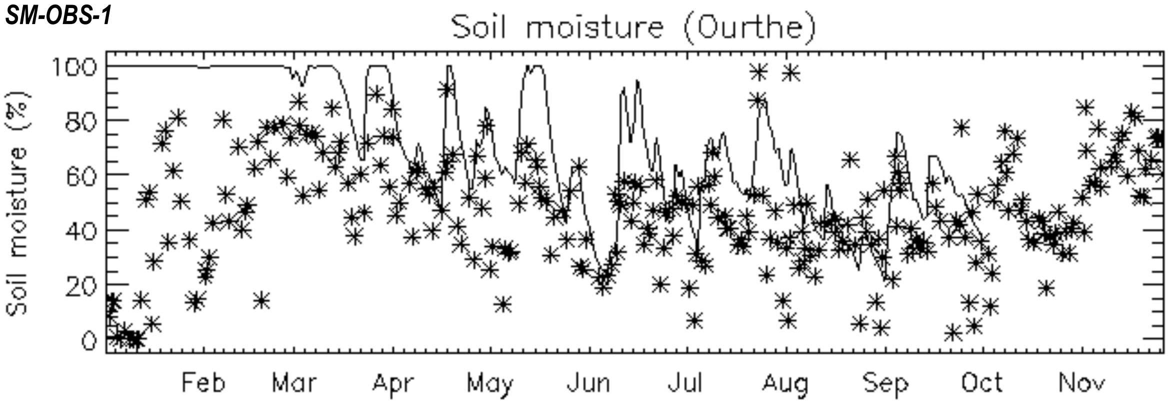



***Fig. 3.1 - Time-series of average surface soil moisture over the Ourthe test-catchment from Jan 2007 to June 2009: simulated with SCHEME model (continuous line) and SM-OBS-2 (stars).***

As was already mentioned in the report on SM-OBS-1, no screening for frozen soils was performed at this stage. Some low values during winter should be removed as was observed in the screening of ERS-derived product. However it can already be seen that the major drying phases are well captured. There seems a tendency of the downscaled product not to exceed 80 %. In ***Fig. 3.2*** the same series are compared with the SM-OBS-1 for a shorter period (the year 2009).

**SM-OBS-1**




**SM-OBS-2**

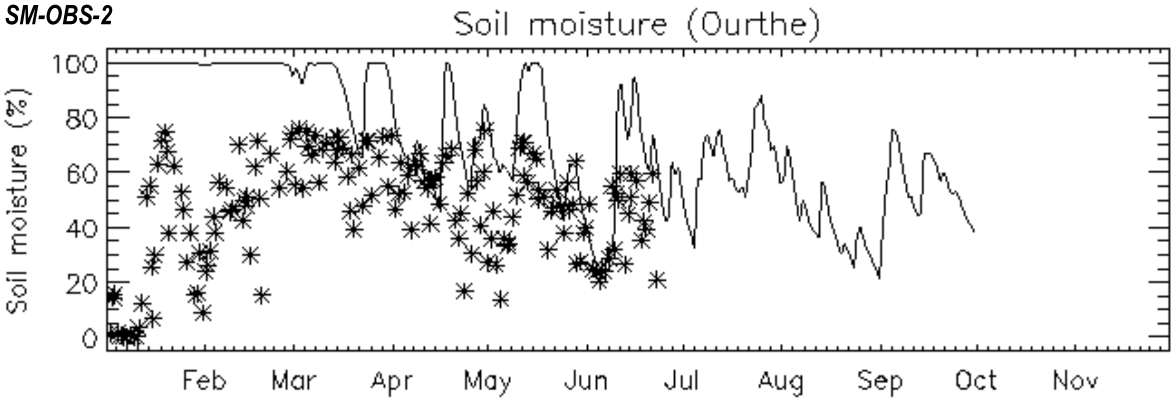



***Fig. 2 - Time-series of average soil moisture over the Ourthe test-catchment during 2009: simulated with SCHEME hydrological model (continuous line) and with SM-OBS-1 (stars on top graph) and SM-OBS-2 (stars on bottom graph).***

Future activities will start with the comparison between the SM-OBS-2 product and the model output performed at the resolution of the hydrological model (7 km × 7 km).

# 4. Validation exercises in ECMWF

*NO CONTRIBUTION EXPECTED FROM ECMWF ON THIS PRODUCT*

# 5. Validation exercises in France (LATMOS)

## 5.1 Preliminary comparison between ASCAT products and ground measurements in Tunisia

The ground measurements used in this study are taken form the semi-arid Merguellil site in northern Tunisia. They are realized at a depth between 5 and 10cm. For a preliminary study, data for the year 2009 were taken and compared to the ASCAT surface soil moisture dataset, displayed in ***Fig. 5.1***.

We can observe a coherence between the two products, following the different rainfall events. Decreasing of moisture level after rain events is more rapid for ASCAT products, because of the fact that ASCAT measurements are correlated to the first centimetres of depth. Surface moisture variations are certainly more important than moisture in other depths, because of very high evapotranspiration level in the studied site.
Furthermore, we can observe variations on ASCAT products even without rainfall. This could be explained by irrigation presence. However, at the end of spring, some variations are not clearly identified and need further investigation.

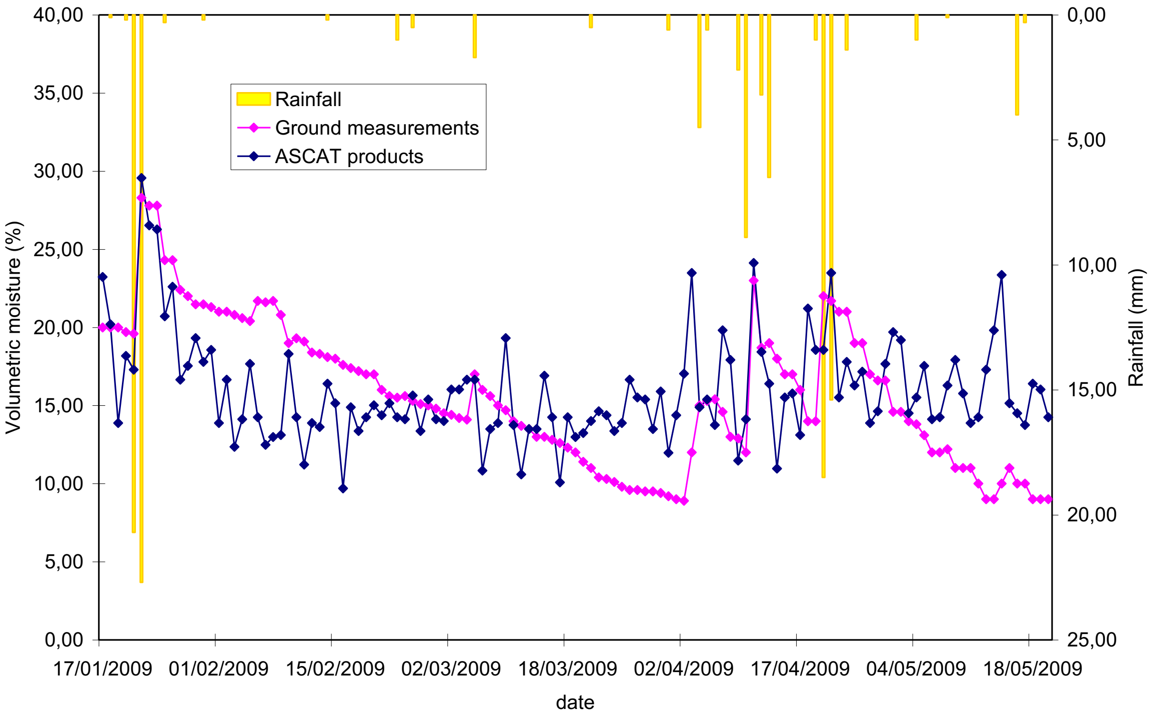



***Fig. 5.1 - ASCAT vs. ground measurements over Merguellil site in Tunisia***

## 5.2 Preliminary comparison between ASCAT products and ground measurements in France

In another part of the study, comparisons were made for ASCAT versus ground measurements at the Grand-Morin site in France. ***Fig. 5.2*** shows the time-series for one ASCAT pixel for a period of 3 years (2006-2009). Again, we observe a generally good coherence between the two soil moisture series and both curves follow the precipitation patterns (not shown in the plot). However, high variations of ASCAT are observable, particularly in wet seasons. This may be explained with the fact of calibration issues of the instrument.

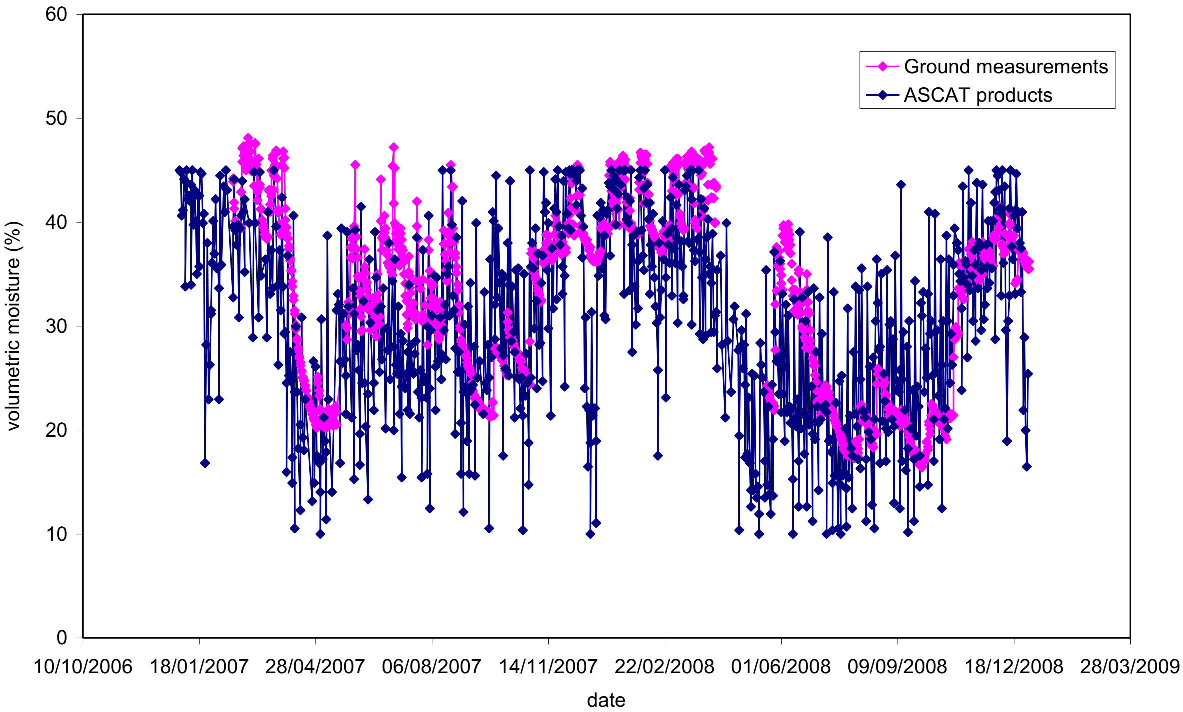



***Fig. 5.2 - ASCAT vs. ground measurements over Grand-Morin site in France.***