IMPLEMENTATION OF NEAR REAL-TIME SOIL MOISTURE PRODUCTS IN THE SAF NETWORK BASED ON METOP ASCAT DATA

Hasenauer S., Wagner W., Scipal K., Naeimi V., Bartalis Z.

Institute of Photogrammetry and Remote Sensing, Vienna University of Technology, Austria

Abstract

Soil moisture data are of particular interest for the hydrology, meteorology and agronomy communities. With the establishment of dedicated Satellite Application Facilities (SAF), interested users will have the possibility of obtaining earth observation products on an operational basis. This will be the case for hydrology and water management (H-SAF), numerical weather prediction (NWP SAF) or land surface (LSA SAF) applications. The objective of this paper is to present plans for implementation of near real-time (NRT) soil moisture products for prospective user groups in the Satellite Application Facilities. The raw data will be retrieved from the Advanced Scatterometer (ASCAT) flown onboard the three Meteorological Operational (MetOp) satellites, the first of which is scheduled for launch in July 2006. We present the planned processing of Level 2 data (surface soil moisture product in orbit geometry) and give suggestions for future Level 3 data processing (various value-added soil moisture products).

1. INTRODUCTION

The retrieval of soil moisture information is important for a range of applications in hydrology, meteorology and agronomy, where the water content of the soil is a key parameter in models and assimilation schemes. Among different Earth Observation (EO) systems that are capable of retrieving the moisture content of the earth's surface, one approach is the retrieval with scatterometer instruments like the Active Microwave Instrument (AMI) onboard the satellites ERS-1 and ERS-2, operated by the European Space Agency (ESA). The soil moisture retrieval process at Vienna University of Technology (TU Wien) is based on a long-term time series approach (Wagner et al. 1999) where the radar backscatter is considered proportional to the dielectric constant of the soil surface. The approach interprets temporal changes of backscatter measurements and uses the multi-incidence observation capabilities of the instrument. As a result, long-term stable surface parameters (corresponding to land cover, surface roughness etc.) can be identified leading to quantitatively corrected soil moisture values. In the past, TU Wien has developed several versions of the scientific retrieval software leading to soil moisture products, which are published online (http://www.ipf.tuwien.ac.at/radar). The first product is the Level 2 *Surface Soil Degree of Saturation (SSDS)*, which is representing the soil moisture content within a thin soil surface layer. The second product is the Level 3 *Soil Water Index (SWI)*, which represents the water content in the soil profile.

With the upcoming Advanced Scatterometer (ASCAT) instrument onboard the first MetOp satellite (planned for launch in July 2006), the current goal of TU Wien is to prepare for processing ASCAT soil moisture data. A first prototype software was developed in 2005 and has already demonstrated the feasibility of generating NRT soil moisture products from Level 1 backscatter data. Current responses from data users along with their experiences have been and will be incorporated in the product design and will be further considered in user-specific applications. The advantage for interested users will consist in obtaining soil moisture data on an operational basis.

2. USER REQUIREMENTS

In order to survey the opinions and intentions of prospective user groups of soil moisture data, Level 2 and Level 3 data have been delivered to approximately 100 users worldwide so far since the year 2003. Stemming from a diverse range of organisations, most data users are from research entities but as well as laboratories and environmental agencies. Interaction with these pilot user groups have progressively been intensified and led to several independent published studies. One example is Pellarin et al. (2006) who compared the surface soil moisture product with a 10-year simulation dataset (ISBA-A-gs model) over a crop dominated test site in southwestern France. The comparison shows a good agreement between scatterometer derived versus modelled surface soil moisture with an RMS error of 0.061 m^3m^{-3}. In another study Laguardia et al. (2006) made a comparison between a grid-based catchment model (LISFLOOD) and the SWI data over Europe concluding that there is a good agreement on large regions, but a rather poor model behaviour in the Alps and Scandinavia where large differences occur due to snow and ice. Zhao et al. (2006) investigated heavy rainfall events in eastern China and compared SWI data with observational soil moisture from agricultural meteorological stations. Their analysis shows that SWI data as input to a meteorological model could improve the intensity and location of simulated precipitation events.

In parallel, user requirements for the soil moisture products have been investigated, where strong differences occurred in meeting the requirements regarding timelines, spatial and temporal resolution and data format.

For the time being, TU Wien is focusing on the requirements of the following user groups:

- Numerical Weather Prediction: The pilot users are the consortium members of the NWP SAF. A survey of their requirements showed a strong interest in soil moisture data that are, in a physical meaning, as “close” as possible to the raw satellite observation. This means, our data Level 2 *Surface Soil Degree of Saturation* will meet the requirements closest. Furthermore, it showed that there is a strong demand on availability of data in NRT, along with respective quality indicators.
- Hydrology: Prospective operational pilot users are the Joint Research Centre (JRC) of the European Commission and partners of the H-SAF. In our current understanding, the operational hydrological users require surface soil moisture products in short time intervals particularly in the case of flooding, but only for specific regions/catchments. Hydrologists are also interested in profile soil moisture data. One serious limitation of the data for hydrologic applications is the 25 km spatial resolution.
- Agrometeorology: Operational agrometeorological users such as the UN Food and Agricultural Organisation (FAO) or the US Department of Agriculture (USDA) are interested in weekly/decadal profile soil moisture products of all crop-growing areas worldwide. In addition, for determination of drought conditions or excessive wetness cases, soil moisture anomalies compared to long-term means are of strong interest.
- Scientific community: Other than the operational user communities mentioned above, the scientific community has no need for operational soil moisture products. Furthermore, timeliness is normally not an issue. Their main interests are long-term, consistent datasets for both surface and profile soil moisture. Equally important is the fact that the method and data are well documented in peer-reviewed literature.

The assessment of user requirements revealed that the specific requirements differ strongly with respect to spatial resolution, spatial extent, temporal sampling rate, timeliness, product cycle, data availability, layer depth, accuracy, and thematic content of the remotely sensed soil moisture data. An important lesson learned from these considerations is that, for the time being, only the NWP community requests global near real-time Level 2 surface soil moisture data in orbit geometry. All other user groups prefer obtaining regularly sampled, value-added Level 3 soil moisture products of specific geographic regions in image format.

As a result, there is not one single method for converting/upgrading the Level 2 surface soil moisture data into Level 3 soil moisture data, but many. Accordingly, several specific Level 3 product lines and data distribution chains have to be built up in order to meet the requirements of different user communities (Figure 1). This becomes even more apparent when the requirements of other potential user groups, such as fire brigades or water resource managers etc., are considered.

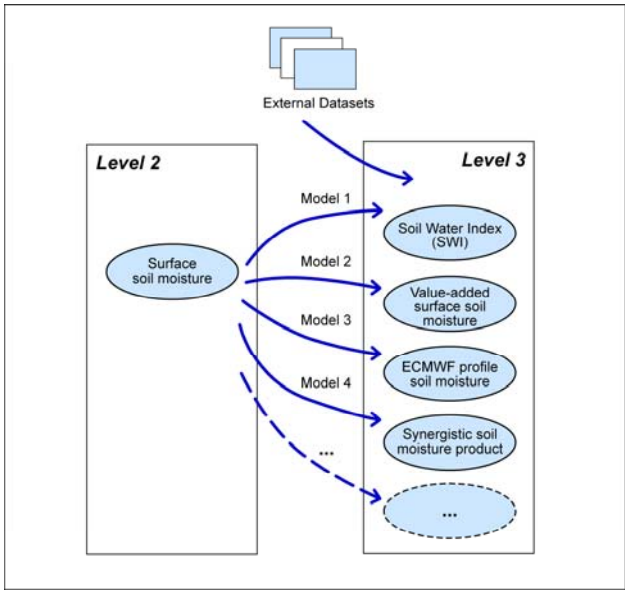

Figure 1: **Different processing strategies will lead to several value-added Level 3 products.**

The conclusion is that the Level 2 processing architecture should be designed to meet the requirements of NWP, utilizing the best technical performance offered by the MetOp ASCAT and the EPS system architecture. To meet the requirements of the other user communities like H-SAF, dedicated Level 3 processing lines are adapted, building upon the Level 2 processing architecture. The architecture for processing lines will be discussed in the following chapter.

3. IMPLEMENTATION PLAN FOR FUTURE SOIL MOISTURE PRODUCTS

The developed algorithms for current ERS-1/2 soil moisture retrieval are to a main extent applicable for MetOp ASCAT. The most significant improvement with new software versions will be an increased spatial resolution of 25 km and an increased temporal resolution with a global coverage within 2-3 days. Consequently, with the heritage of ERS-1/2 data since the year 1991 and the upcoming MetOp satellite series being operational over the next 14 years, we expect long-term datasets of soil hydrology being available. These soil moisture datasets will be of particular interest for several global environmental applications.

3.1. Processing of Level 1 soil moisture data

After receiving ASCAT raw data via the Global Data dump, all data acquired over the last orbit are dumped to the Command and Data Acquisition (CDA) station (Figure 2). The maximum age of the data is 117 minutes. Then the data are transferred to EUMETSAT's Central Product Processing Facility (PPF) and are converted to calibrated Level 1 backscatter data. The time from sensing at this stage is about 135 minutes. If European data are of interest, the processing can be accelerated by using EUMETSAT's Advanced Retransmission Service (EARS), which consists of a network of ground stations for retransmitting data immediately after reception. With this service, Level 1 processing can be completed within 30 minutes after data reception. As soon as the processing at PPF is finished, data are distributed to the users in NRT via EUMETSAT's Data Distribution System (EUMETCast).

In the following, we can distinguish two different product types (Level 2 and Level 3), which are upgraded products from the standard Level 1 calibrated backscatter data.

3.2. Processing of Level 2 soil moisture data

Directly after Level 1 processing, the Level 2 soil moisture data could be processed. Therefore, TU Wien has developed the near real-time software called WARP^{NRT}, which is capable of processing

complete ASCAT orbits in a matter of seconds. It is foreseen to implement the software at EUMETSAT's PPF, which will allow for near real-time data access for the users. In this way, practically no time is lost for retrieving the soil moisture data. The Level 2 soil moisture data could be collocated to the Level 1 backscatter data and distributed immediately over EUMETCast. As a result, users can receive global soil moisture information about 135 minutes after sensing, European data within about 30 minutes (Figure 2). This is deemed very important for NWP applications because timeliness is critical for accepting the ASCAT data as input into the NWP assimilation schemes.

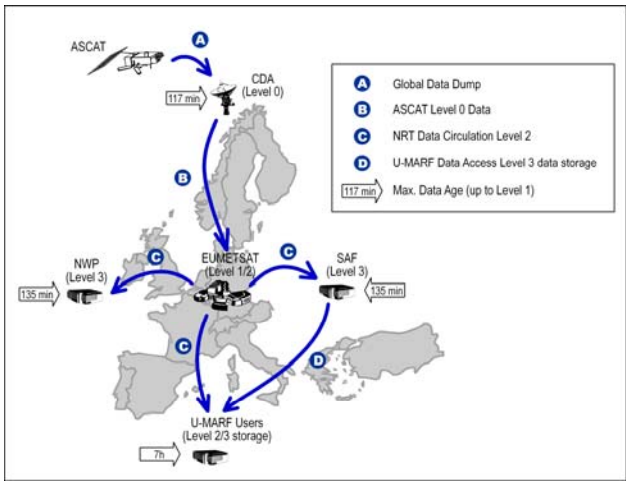

Figure 2: **Processing architecture of Level 2 data.**

3.3. Processing of Level 3 soil moisture data

Level 3 products are obtained by several methods of modelling approaches using Level 2 data and other auxiliary data sources as input. Linked to on-going research activities, most importantly the H-SAF, typical products are the soil moisture content for different soil layers for different temporal and spatial sampling characteristics. Prospective value-added Level 3 products are:

Soil Water Index (SWI)
This index is obtained by filtering the surface soil moisture time series with an exponential function to produce profile soil moisture time series. This product is sampled regularly in space and time and is the current standard ERS-1/2 soil moisture product distributed to users.

Disaggregated Surface Soil Moisture
The 25 km spatial resolution of Level 2 surface soil moisture products is not sufficient for many hydrologic applications. Therefore, a method for disaggregating the Level 2 data to a finer grid is an important development goal. This subject will be undertaken in the framework of the H-SAF, which aims to address the needs of operational hydrologic users in Europe.

ECMWF Profile Soil Moisture
Also within the framework of the H-SAF, it is planned that the European Centre for Medium-Range Weather Forecasts (ECMWF) develops a method for assimilating ASCAT Level 2 surface soil moisture products into forecast models. This is done by obtaining more physically based profile soil moisture estimates through minimising the estimates of modelled first guess and the individual observations.

As one prospective Level 3 example, a potential system architecture for the H-SAF surface soil moisture product is shown in Figure 3. The H-SAF receives EARS Level 2 surface soil moisture products over EUMETCast within about 30 minutes, performs several processing steps for producing a Level 3 product most suited for hydrologic users, and distributes the data immediately afterwards over different channels to reach the various hydrologic user groups. Level 3 processing could e.g. include a projection of the orbit data into national coordinate systems (taking the topography into account), disaggregation of the 25 km pixels to a finer grid (planned resolution 1 km), and by adding

various quality information layers. The disaggregation method may be based upon land cover information or C-band backscatter data acquired with the Global Monitoring Mode of the ENVISAT Advanced Synthetic Aperture Radar (ASAR), where recent research findings indicate that a useful downscaling layer can be computed (Pathe and Wagner 2006).

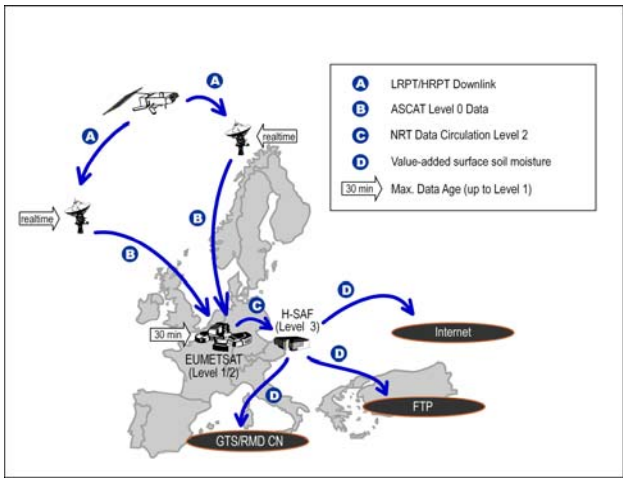

Figure 3: **Processing architecture of Level 3 data.**

Table 1 gives an overview of the Level 2 surface soil moisture product and two Level 3 products (only main parameters given). To support data users in judging the quality of the soil moisture products, additional flags (indicating processing status, correction of data as well as overall quality indicators) will be stored as complementary information.

Processing Level	Level 2	Level 3	Level 3
Dataset Name	Surface Soil Degree of Saturation (SSDS)	Soil Water Index (SWI)	Disaggregated Surface Soil Moisture
Parameter Definition	Soil moisture content in the first 5cm of the soil in relative units between 0 and total water capacity	Soil moisture content in the first 1m of soil in relative units ranging between wilting level and field capacity	Soil moisture content in the first 5cm of the soil in relative units between 0 and total water capacity
Unit	%	%	%
Range	[0,100]	[0,100]	[0,100]
Spatial Resolution	25 km	25 km	25 km (with quality layers sampled to 1 km grid)
Temporal Resolution	1-2 days	10-day composite	1-2 days
Geographic Coverage	Global	Global	Europe
Limitations	No values over dense tropical forest, snow, sand desert areas and frozen soil	No values over dense tropical forest, snow, sand desert areas and frozen soil	No values over dense tropical forest, snow, sand desert areas and frozen soil
Additional Product Information	Processing flags, advisory flags, quality flags	Processing flags, advisory flags, quality flags	Processing flags, advisory flags, quality flags, (tailored to hydrologic needs)
Projection	MetOp orbit frame	Geographic, Discrete Global Grid	Tbd
Timeliness	Global: 135 min (EUMETCast) Europe: 30 min (EARS)	Tbd	Global: 135 min (EUMETCast) Europe: 30 min (EARS)
Data Format	BUFR	Binary	Tbd (BUFR/GRIB)

Table 1: **Planned soil moisture product specifications for future products.**

4. SUMMARY AND OUTLOOK

With the launch of MetOp in the near future, the ASCAT instrument will continue the long scientific heritage of ERS-1/2. For the first time global operational soil moisture data will be made available to interested users, making it possible to obtain continuous long-term soil moisture information ranging back to 1991. We presented plans how to implement different soil moisture products, targeted at specific user groups, especially in the framework of the NWP SAF and the H-SAF. Current investigations include the interaction with hydrologic pilot users to assess further user needs. Therefore, the existing soil moisture data have been distributed to the H-SAF consortium. Furthermore, a survey has been started, to help us trim product specifications. Additional research activities comprise further software development and improved quality flag information delivered along with soil moisture data.

5. ACKNOWLEDGEMENTS

A main part of this work is the outcome of a study carried out in the framework of an Associate Scientist Mission funded by the “Satellite Application Facility for Numerical Weather Prediction” (NWP SAF). The study is also based on findings from the “Satellite Application Facility on Support to Operational Hydrology and Water Management” (H-SAF), and results of the EUMETSAT funded project “Processor for ERS-SCAT based soil moisture” (Contract EUM/CO/05/1421/HGB).

6. REFERENCES

Laguardia, G., Niemeyer, S., Wagner, W., Scipal, K. (2006). On the comparison between the LISFLOOD modelled and the ERS/SCAT derived soil moisture estimates. Geophysical Research Abstracts, **8**, 08385.

Pathe, C., and Wagner, W. (2006). A Scaling Layer for Downscaling Remotely Sensed Coarse Resolution Soil Moisture Products. Geophysical Research Abstracts, **8**, 04410.

Pellarin, T., Calvet, J.-C., Wagner, W. (2006). Evaluation of ERS scatterometer soil moisture products over a half-degree region in southwestern France. Geophysical Research Letters (submitted).

Wagner, W., Lemoine, G., Rott, H. (1999). A method for estimating soil moisture from ERS scatterometer and soil data. Remote Sensing of Environment, **70**, pp. 191-207.

Zhao, D., Su, B., Zhao, M. (2006). Soil Moisture Retrieval from Satellite Images and Its Application to Heavy Rainfall Simulation in Eastern China. Advances in Atmospheric Sciences, **23**, 2, pp. 299-316.