TIME SERIES ANALYSIS OF SMOS AND ASCAT: SOIL MOISTURE PRODUCT VALIDATION IN THE RUR AND ERFT CATCHMENTS

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ABSTRACT

ASCAT and SMOS soil moisture products were validated for the year 2010 in the Rur and Erft catchments in the west of Germany. In situ data of three test sites of the TERENO initiative were used to calibrate the hydrological model WaSiM-ETH, which was applied to generate a soil moisture reference for the whole study area. Comparison of SMOS soil moisture with the reference displayed a high dry bias and low to moderate correlations. ASCAT soil moisture showed higher correlations and no bias. A temporal stability analysis exhibits low stability of the SMOS data and higher stability of ASCAT data. Generally, the performance of ASCAT is well, while there are still some problems with soil moisture retrieval and RFI in the SMOS soil moisture product.

Index Terms— soil moisture, validation, temporal stability

1. INTRODUCTION

Soil moisture is an important driver for different climatic and hydrological processes. Hence, area-wide time series of soil moisture data are very important for numerical weather predictions, for example at the European Centre for Medium-Range Weather Forecasts (ECMWF), as well as for climate and hydrological modeling.

A way to provide global soil moisture data in the required temporal resolution is remote sensing with sensors using different measurement techniques and frequencies. Amongst them, the Soil Moisture and Ocean Salinity (SMOS) mission is the first satellite mission specifically designed for the remote sensing of soil moisture. SMOS records brightness temperatures in the L-Band at 1.4 GHz. Soil penetration depth is about 5 cm, the spatial resolution is 30 to 50 km [1]. The satellite was launched in November 2009. Since then, validation of the SMOS soil moisture product is going on in different regions of the world (e.g. [2], [3], [4]) Another sensor, the Advanced Scatterometer (ASCAT) is a real-aperture radar that measures surface backscattering coefficients in C-band at 5.255 GHz with a resolution of 30 to 50 km. Soil penetration depth is between 0.5 and 2 cm [5].

For a long-term validation in the Rur and Erft catchments for the year 2010, this study uses 2012 reprocessed SMOS Level 2 soil moisture and time-series of soil moisture derived from ASCAT data. The individual accuracy and suitability of both datasets for the further use in numerical weather prediction and hydrological modeling are analyzed with the help of a soil moisture reference calculated by the hydrological model WaSiM-ETH.

2. MATERIAL AND METHODS

2.1. Study area

The long-term validation study was carried out in the catchments of the rivers Rur and Erft in the south of North Rhine-Westphalia in western Germany close to the city of Aachen. The area has a size of 4125 km².

The study area consists of two regions with different character: The southern part is in the Eifel Mountains, where the annual long-term precipitation is relatively high with 850 – 1300 mm. Land use type is primarily forest and grassland. The northern part shows a relatively low annual long-term precipitation of 650-850 mm. The predominant land use type is fertile agricultural land [6].

The advantage of the study region is the multiple sensor systems, installed by the TERENO (Terrestrial Environmental Observatories) initiative, so in situ data is available from three test sites: Selhausen in the northern part of the study area, the forested site Wüstebach, and the grassland site Rollesbroich,, both in the southern part of the study area and equipped with a wireless soil moisture sensor network [7].

2.2. SMOS soil moisture product

The SMOS Level 2 product soil moisture is retrieved from the Level 1 product brightness temperature through an operational routine provided by ESA, which uses the inversion of the model L-MEB (L-band Microwave Emission of the Biosphere) [8].

In this study we were using a version of the SMOS soil moisture product that was reprocessed in 2012.

Only data from the ascending node is considered which additionally was filtered by the Soil Moisture DQX (SM_DQX > 0.02) and the Global Quality Index (GQX > 3). The data was tested on the influence of RFI through the confidence flags FL_RFI_Prone_H and FL_RFI_Prone_V, but no soil moisture values with these flags raised were found.

2.3. ASCAT soil moisture product

ASCAT relative soil moisture is retrieved from the backscattering coefficient using the time series-based change detection approach of [9], where the backscattering coefficients are scaled between the lowest and highest backscattering coefficients of a time-series of the respective grid point, resulting in relative soil moisture values between 0 and 100 %. The influence of the vegetation is determined through the long-term seasonal behavior of the relationship between backscattering coefficient and incidence angle.

For this study, reprocessed data generated with the WARP 5.4 software was used. Values of relative soil moisture were converted to absolute soil moisture by scaling them between wilting point and soil saturation point of the soil type of the corresponding grid point. Filtering was done by removing the data points for which the advisory flags indicated the possibility of snow or frozen soil.

2.4. Soil moisture reference

The soil moisture reference was calculated with the hydrological model WaSiM-ETH, a distributed hydrological model developed at ETH Zürich for investigating spatial and temporal variability of hydrological processes in complex river basins [10].

Calibration of the model took place with help of observation data from the TERENO test sites. For Selhausen, in situ soil moisture was obtained from the average of three Hydra Probes at a soil depth of 4 cm, in Rollesbroich from 3 TDRs at a depth of 10 cm. In situ data of Wüstebach was attained from the wireless sensor network in a depth of 5 cm and averaged over the whole site.

The model run was carried out at a horizontal spatial resolution of 200 m and hourly time steps for the time period of January 1st 2010 to December 31st 2010 with a spin-up of one year. Due to the SMOS penetration depth, only the soil moisture data of the topmost layer with a thickness of 5 cm was used.

The arithmetic mean of the modeled soil moisture data was calculated for every pixel of both soil moisture products, resulting in one averaged value for every corresponding satellite soil moisture value.

3. RESULTS AND DISCUSSION

3.1. Soil moisture reference

The soil moisture reference, calculated with the hydrological model WaSiM-ETH shows a similar spatial distribution at all dates. In the southern part of the study area the top soil moisture values are consistently higher than in the northern part due to its mountainous location and therefore higher precipitation amounts.

The comparison of time series of modeled data to in situ measurements indicates good results for all three test sites.

The correlation of the measured soil moisture with WaSiM-ETH results (Fig. 1) shows an overall correlation coefficient of 0.95 and a bias of 0.01.

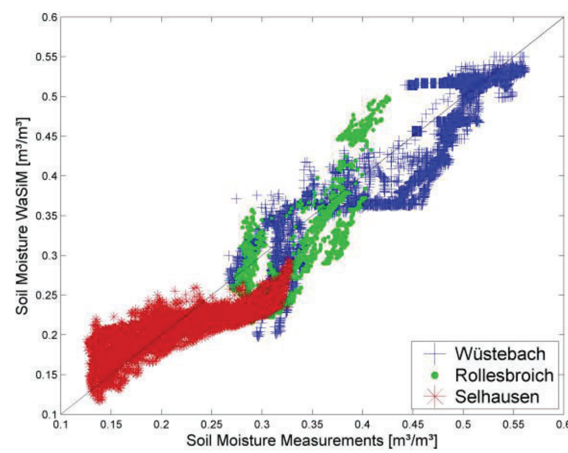

Fig. 1: Correlation of measured and modeled soil moisture for the test sites Wüstebach, Rollesbroich and Selhausen, n = 11701

3.2. Validation of soil moisture products

The time series of the SMOS soil moisture product shows high dry biases to the modeled soil moisture. For all pixels, that are completely located in the study area, the bias varies between 0.15m³/m³ and 0.30m³/m³. The biases show a clear spatial distribution: they are higher in the mountainous and often forested southern region and get smaller in the agriculturally used northern part. The overall bias for all pixels is 0.21 m³/m³ and it is similar for all seasons (Table 1). This is consistent with findings of [3], who found bias values between 0.11m³/m³ and 0.3m³/m³ for the Upper Danube Catchment, Germany.

Table 1: Correlation and biases of modeled soil moisture to SMOS and ASCAT soil moisture for the whole year and different seasons (spring: March-May, summer: June-August, autumn: September-November, winter: December-February)

	SMOS			ASCAT		
	n	R	bias	n	R	bias
overall	1964	0.29	0.21	11535	0.61	0.02
Spring	741	0.34	0.21	3465	0.71	0.06
Summer	557	0.30	0.19	4669	0.52	0.00
Autumn	569	-0.03	0.23	3360	0.67	0.01
Winter	97	-0.08	0.23	41	0.81	-0.05

The overall correlation coefficient for all pixels is rather low with 0.29. Best values are achieved in spring and summer with 0.34 and 0.30, respectively. In autumn and winter there is no correlation (Table1). The low correlation in winter should be noted, because, as long as there is no snow or soil frost, the retrieval of soil moisture should work better than in other seasons since the influence of the vegetation canopy is less high. This indicates that the flagging of snow and frost does not work properly.

For single pixels the correlation coefficients are consistently higher with values between 0.34 and 0.68. Unlike the biases, the correlation coefficients do not show patterns in the distribution across the study area.

Due to the scaling described in section 2.3., the time series of the ASCAT soil moisture product do not show high values of bias to the modeled soil moisture. The spatial distribution of the biases over the study area is even and does not show any patterns. The overall bias for all pixels in the study area, as well as the biases for the different seasons, are very small (Table 1).

The overall correlation coefficient of ASCAT soil moisture and soil moisture modeled by WaSiM-ETH is higher than for SMOS with 0.61. Spring and winter show the best correlations with 0.71 and 0.81, respectively (Table 1). For the single pixels, which are completely confined to the study area, correlation coefficients do not vary as much as for the SMOS pixels and with values between 0.46 and 0.62 they are in the same range as the correlation coefficients for all pixels. However, pixels localized in the southern part of the study area show the smallest correlations, which points out that the mountainous terrain and the many forests in this region complicate the retrieval.

Generally, the ASCAT soil moisture product shows similar or slightly higher correlations than the SMOS product, which is in accordance with [2], who found slightly better correlations of ASCAT soil moisture with in situ data than of SMOS Level 2 product in Europe.

The overall performance of ASCAT is better, mainly because of the high and spatial different biases of the SMOS data. These biases may be due to local or low energy RFI, which was not detected by the approach or to inadequate parameterization of the retrieval algorithm.

3.3. Temporal stability analysis

To assess the temporal stability of the SMOS and ASCAT soil moisture products, mean relative differences and their standard deviations were calculated and ranked for the two datasets and their corresponding averaged modeled soil moisture after the method of [11]. This analysis is used to test the applicability of the SMOS and ASCAT soil moisture products for model applications (e.g. data assimilation [12]).

Results show mean relative differences between $-0.67 m^3/m^3$ and $0.54 m^3/m^3$ for SMOS and $-0.3 m^3/m^3$ and $0.68 m^3/m^3$ for the WaSiM-ETH soil moisture averaged over the SMOS pixel extents. ASCAT mean relative differences range between $-0.43 m^3/m^3$ and $0.55 m^3/m^3$, the mean relative differences of the modeled soil moisture, averaged over the ASCAT pixel extents are between $-0.36 m^3/m^3$ and $0.28 m^3/m^3$. While the standard deviations of the relative differences of the modeled soil moisture are low with $0.02 m^3/m^3$ to $0.11 m^3/m^3$ and $0.02 m^3/m^3$ to $0.13 m^3/m^3$ for SMOS pixel means and ASCAT pixel means, respectively, standard deviations of SMOS are quite large and range from $0.26 m^3/m^3$ to $0.6 m^3/m^3$. The standard deviations of ASCAT relative differences are smaller than for SMOS with values between $0.06 m^3/m^3$ and $0.29 m^3/m^3$, but are still larger than the results of the modeled soil moisture.

Generally, pixels of SMOS, ASCAT, and both pixel averages of WaSiM-ETH, in the southern part of the study area show high relative difference means, while pixels in the northern part have the lower relative difference means.

The relative difference means for every pixel were ranked and the ranks of the WaSiM-ETH pixel means were compared to the respective soil moisture products in Fig. 2.

While the ranking of the mean relative difference of the ASCAT soil moisture product correlates well with the WaSiM-ETH means, there is no correlation for the rankings of the SMOS pixels and their respective modeled averages.

As the study area shows a clear spatial distribution of soil moisture with smaller soil moisture values in the northern region and higher soil moisture in the southern part, this distribution should also be visible in the soil moisture products, which means they should show temporal stability. While this is given to some extent for ASCAT with not too large standard deviations and stable ranks for the means of the relative difference, the SMOS dataset does not show stability.

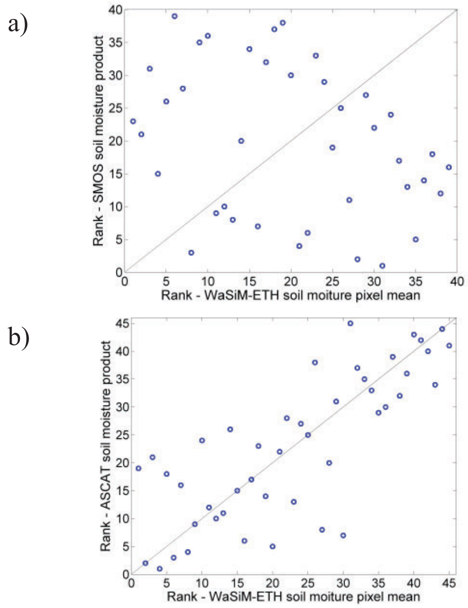

Fig. 2: Comparison of Ranks of the relative difference means of WaSiM-ETH pixel means to ranks of relative difference means of a) SMOS b) ASCAT

4. CONCLUSION

The SMOS Level 2 product soil moisture in the reprocessed version of 2012 and the newly reprocessed ASCAT soil moisture product for the Rur and Erft catchments were compared to a soil moisture reference calculated by the hydrological model WaSiM-ETH for the year 2010.

ASCAT soil moisture generally showed a good agreement with the modeled data and a relatively high temporal stability. A problem of the data set arises due to the conversion of relative soil moisture that is dependent on the soil type, which is difficult to choose for one pixel.

SMOS soil moisture displays high dry biases and lower correlations for the whole study area and somehow better correlations for the single pixels in the study area. The temporal stability of the dataset is low. Further investigation is needed to determine, whether these problems are due to RFI or to inaccuracies in the retrieval algorithm.

In order to increase the quality and reduce the bias in SMOS data, [12] developed a parameter estimation method for the soil moisture retrieval algorithm. Further tests will show the applicability of this method for different sites.

Currently the analysis of SMOS and ASCAT soil moisture products is extended to the year 2011.

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