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Soil moisture variability over Odra watershed: Comparison between SMOS and GLDAS data

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ABSTRACT

Monitoring of temporal and spatial soil moisture variability is an important issue, both from practical and scientific point of view. It is well known that passive, L-band, radiometric measurements provide best soil moisture estimates. Unfortunately as it was observed during Soil Moisture and Ocean Salinity (SMOS) mission, which was specially dedicated to measure soil moisture, these measurements suffer significant data loss. It is caused mainly by radio frequency interference (RFI) which strongly contaminates Central Europe and even in particularly unfavorable conditions, might prevent these data from being used for regional or watershed scale analysis. Nevertheless, it is highly awaited by researchers to receive statistically significant information on soil moisture over the area of a big watershed. One of such watersheds, the Odra (Oder) river watershed, lies in three European countries – Poland, Germany and the Czech Republic. The area of the Odra river watershed is equal to 118,861 km^2 making it the second most important river in Poland as well as one of the most significant one in Central Europe.

This paper examines the SMOS soil moisture data in the Odra river watershed in the period from 2010 to 2012. This attempt was made to check the possibility of assessing, from the low spatial resolution observations of SMOS, useful information that could be exploited for practical aims in watershed scale, for example, in water storage models even while moderate RFI takes place. Such studies, performed over the area of a large watershed, were recommended by researchers in order to obtain statistically significant results. To meet these expectations, Centre Aval de Traitement des Donnes SMOS (CATDS), 3-days averaged data, together with Global Land Data Assimilation System (GLDAS) National Centers for Environmental Prediction/Oregon State University/Air Force/Hydrologic Research Lab (NOAH) model 0.25 soil moisture values were used for statistical analyses and mutual comparisons.

The results obtained using various statistical tools unveil high scientific potential of CATDS SMOS data to study soil moisture over the Odra river watershed. This was also confirmed by reasonable agreement between results derived from CATDS SMOS Ascending and GLDAS data sets. This agreement was achieved mainly by using these data spatially averaged over the whole watershed area, and for observations performed in the period longer than three-day averaging time. Comparisons of separate three-day data in a given pixel position, or at smaller areas would be difficult because of data gaps. Hence, the results of the work suggest that despite of RFI interferences, SMOS observations can provide effective input for analysis of soil moisture at regional scales. Moreover, it was shown that CATDS SMOS soil moisture data are better correlated with rainfall rate than GLDAS ones.

1. Introduction

1.1. Overview

Soil moisture (SM) is one of the most important hydrological variables used in a wide range of scientific studies and practical applications such as flood and drought monitoring and prediction, numerical weather and climate forecast as well as agricultural modeling (Lakshmi et al., 1993). Therefore measurements of SM, carried out in a suitable amount and with sufficient precision can greatly improve scientific reasonings on many pivotal hydrological phenomena such as water runoff, evaporation or infiltration. Watershed scale SM estimates are of great interest in a variety of fields of the Earth sciences (Fang and Lakshmi, 2014; Moran et al., 2014; Rodell et al., 2011; Cosh et al., 2004). It was shown that investigation on the watershed areas is needed to reveal sources of SM remote sensing observations biases and describe SM

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variability properly. However, such systematic measurement of SM is not trivial task because this physical property changes with time and space in a complex way (Ochsner et al., 2013).

So far, many techniques have been developed to measure this parameter in situ, e.g. thermo-gravimetric (oven-drying) method, neutron probe. Other, more contemporary measurement methods are based on soil resistivity, or dielectric measurements such as TDR/FDR (Time/Frequency Domain Reflectometry) as well as capacitance measurements (Lekshmi et al., 2014). However, ground measurements although relatively accurate, have also many disadvantages. For example, in most cases they are rather expensive and laborious. Moreover, in situ SM measurements are rather point ones, and therefore their sets are often not spatially coherent enough, particularly if they are performed over large and heterogeneous areas (Martnez-Fernandez and Ceballos, 2005). In practice, the mutual comparisons of measurements that were carried out in situ by different methods are also rather complicated. This is why applications of in situ SM measurements are limited mainly to relatively small areas. On the other hand, the ground measuring campaigns of SM carried out at greater areas are usually limited to short periods.

In contrast to field measurements, remote sensing from low earth orbit make it possible to perform relatively frequent SM observations over large areas. Since 1970's, it has been known that satellite passive radiometers working in the domain of low frequency microwaves are efficient tools for SM observations (Kerr, 2007). Intensive development of microwave satellite observations of soil moisture is still going on, among others together with validation and improving their spatial resolution (Fang et al., 2013; Mladenovaa et al., 2011; Mladenova et al., 2010; Lakshmi et al., 1993). Such radiation penetrates atmosphere better than others electromagnetic waves and is more resistant to other interfering factors. The SMOS is the European Space Agency satellite mission - response to present-day requirements of SM observations at a global scale (Kerr et al., 2010b; Mecklenburg et al., 2012). SMOS uses microwave, L-band, imaging radiometer with aperture synthesis called MIRAS which is Y-shaped instrument with 69 elementary antennas arranged regularly along the arms. MIRAS provides at each integration step, the Earth's surface image at one of imaging modes: dual-polarization or full-polarimetric. SMOS mission ensures proper accuracy of SM assessment equal to 0.04 m^3/m^3, with spatial resolution less than 50 km and frequent revisit time of 3–5 days (Kerr et al., 2010b). Within the mission framework, SM community achieved a huge amount of valuable scientific results ((Delwart et al., 2008; Jackson et al., 2012; Ochsner et al., 2013; Kerr et al., 2010a)). In numerous works the SMOS soil moisture assessments were validated or compared against those obtained by other satellites or ground measurements (Delwart et al., 2008). Unfortunately, RFI turned out to be a serious problem for SM observations. It causes data gaps in some locations or periods. For this reason intense efforts were undertaken to develop algorithms limiting negative influence of RFI on SM retrievals or allocating incorrect pixels, where the RFI is too large to determine the SM with sufficient accuracy (Skou et al., 2014). There are also other difficulties, although easier to overcome. For example, algorithms for SM retrieval do not eliminate entirely wet/dry bias, which impedes among other things, the possibility of pixel disaggregation (Bircher et al., 2013; Jackson et al., 2012). SM retrievals significantly depend also on vegetation and heterogeneous land cover. Errors generated by those factors are greater for L-band SM retrievals than those for in-situ measurements (Nagarajan and Judge, 2013). It was reported many times in the literature, that SM spatial patterns often show a strong temporal stability (Lukowski, 2014), and that even for large areas from 100 to 1000 km^2, the SM temporal pattern observed at one site or point closely follows the temporal pattern of the spatial average ((Brocca et al., 2010; Cosh et al., 2008; Fernandez and Ceballos, 2003; Wagner et al., 2008). The spatio-temporal characterization of SM variability on vaster areas, e.g. larger than 100 km^2, may help to develop down-scaling techniques. For example, the ASCAT retrievals with the spatial resolution of 25 km have been downscaled successfully to ASAR resolution of 1 km (Brocca et al., 2012). Similarly, SM products with 4 km spatial resolution were generated and validated by means of SMOS and fractional vegetation cover obtained using MODerate resolution Imaging Spectroradiometer (MODIS) (Merlin et al., 2010). Algorithm, developed in 2014, based on relationship between daily temperature change and average soil moisture modulated by vegetation conditions, allowed to derive soil moisture with the spatial resolution of 1 km and successfully compare it against AMSR-E/SMOS data (Fang and Lakshmi, 2014). According to a recent study (Rtzer et al., 2014), research of soil moisture over large watershed using low-resolution satellite imagery would be particularly important since it would allow to obtain statistically significant results.

1.2. Purpose of the studies

Watershed scale soil moisture (SM) estimates are of great importance, and in spite of low resolution, passive satellite SM observations can be representative even for relatively small areas just like a river watershed. For instance, SM, in spite of its variability, can reveal similar temporal patterns both at local and large scale which can be a basis for validation efforts. Therefore it was interesting to check whether and to what extent the results of SMOS mission can be potentially useful in the study of SM in the scale of a large river watershed. This could be of a great importance from the point of view of river basins modeling (Brocca et al., 2010), because in exchange for the low spatial resolution of SMOS imaging one receives relatively high, a few days time resolution, at a very low cost. For this purpose, we have chosen the Odra (Oder) river, which is one of the biggest and most important rivers in Central Europe. In its watershed area, there are often dangerous floods that threatens hundreds of thousands of inhabitants living both in the mountain areas and on floodplains. Up to now, there have been no papers dedicated to SMOS mission data over the Odra river region. This kind of research in Central Europe is aimed mainly at southern Germany, Denmark (Bircher et al., 2013). In Poland, Institute of Agrohysics of Polish Academy of Sciences conducted research mainly in the eastern part of the Vistula river watershed in Eastern Poland (Usowicz et al., 2014). Before releasing SMOS L2 product, some small parts of Odra watershed have been used for SMOS Cal/Val validation purposes, but without analysis carried out for the whole region (Marczewski et al., 2010). The goal stated in this paper was more difficult to achieve, since the SMOS observations in the watershed area of the Odra river are hampered by the RFI occurrence typical for a densely populated region. In particular the purposes of this work were as follows:

- retrieving main statistical parameters of SM over the Odra river watershed using low-resolution SMOS data,
- statistical comparisons of SMOS and GLDAS retrievals of SM, in terms of temporal and spatial distributions, over the Odra river watershed,
- evaluation of the impact of RFI occurrence on the obtained results.

2. Data and methods

2.1. Study area

We analyzed the Odra (Oder) river watershed area (Fig. 1) which lies in three central European Countries, namely, the Czech