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Validation of SMAP surface soil moisture products with core validation sites

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ABSTRACT

The NASA Soil Moisture Active Passive (SMAP) mission has utilized a set of core validation sites as the primary methodology in assessing the soil moisture retrieval algorithm performance. Those sites provide well-calibrated in situ soil moisture measurements within SMAP product grid pixels for diverse conditions and locations. The estimation of the average soil moisture within the SMAP product grid pixels based on in situ measurements is more reliable when location specific calibration of the sensors has been performed and there is adequate replication over the spatial domain, with an up-scaling function based on analysis using independent estimates of the soil moisture distribution. SMAP fulfilled these requirements through a collaborative Cal/Val Partner program. This paper presents the results from 34 candidate core validation sites for the first eleven months of the SMAP mission. As a result of the screening of the sites prior to the availability of SMAP data, out of the 34

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candidate sites 18 sites fulfilled all the requirements at one of the resolution scales (at least). The rest of the sites are used as secondary information in algorithm evaluation. The results indicate that the SMAP radiometer-based soil moisture data product meets its expected performance of 0.04 m^3/m^3 volumetric soil moisture (unbiased root mean square error); the combined radar-radiometer product is close to its expected performance of 0.04 m^3/m^3, and the radar-based product meets its target accuracy of 0.06 m^3/m^3 (the lengths of the combined and radar-based products are truncated to about 10 weeks because of the SMAP radar failure). Upon completing the intensive Cal/Val phase of the mission the SMAP project will continue to enhance the products in the primary and extended geographic domains, in co-operation with the Cal/Val Partners, by continuing the comparisons over the existing core validation sites and inclusion of candidate sites that can address shortcomings.

1. Introduction

NASA's Soil Moisture Active Passive (SMAP) satellite mission was launched on January 31, 2015. The objective of the mission is global mapping of soil moisture and landscape freeze/thaw state. The SMAP measurements will, therefore, contribute to improved estimates of water, energy and carbon transfers between the land and atmosphere (Entekhabi et al., 2010a). The satellite employed both an L-band radar and an L-band radiometer, however, the radar instrument suffered a failure after about 11 weeks of operation. The radiometer continues to operate. The radar measurements offered higher spatial resolution (1–3 km) observations to increase the fidelity of the coarser resolution (40 km) radiometer observations. The instruments shared a rotating 6-m mesh reflector antenna on a platform in a 685-km sun-synchronous near-polar orbit, viewing the Earth's surface at a constant 40-degree incidence angle with a 1000-km swath width. The SMAP science data product suite of geophysical parameters includes estimates of surface (top 5 cm) and root-zone (down to 1-m depth) soil moisture, net ecosystem exchange of carbon (NEE), and classification of the predominant frozen/non-frozen state of the landscape. The production of soil moisture data products continues using the radiometer data alone.

There is a long history of retrieving soil moisture or soil wetness index using microwave radiometers, e.g., (Schmugge et al., 1974; Njoku and Entekhabi, 1996; Owe et al., 2008) and scatterometers, e.g., (Wagner et al., 1999). The L-band frequency regime was identified as the best choice for soil moisture retrieval using microwave radiometers about three decades ago (Schmugge et al., 1986). However, technology to support the deployment of a large enough aperture to achieve high enough spatial resolution held back spaceborne observations until the launch of ESA's SMOS (Soil Moisture and Ocean Salinity) (Kerr et al., 2010) and NASA's SMAP satellites in 2009 and 2015, respectively. Furthermore, observations at L-band have been challenged by unexpected and illegal radio frequency interference (RFI). The RFI is generated, for example, by systems that transmit outright on the protected frequency band or by systems that inadvertently leak to the protected band. In particular, it is prohibited by international agreements at the observation band of the SMAP and SMOS radiometers (1.4–1.427 GHz). The SMOS mission has suffered significantly from RFI effects in certain regions (Oliva et al., 2012). Consequently, SMAP has incorporated aggressive RFI avoidance and filtering for both the radiometer (Piepmeier et al., 2014) and radar (Spencer et al., 2013) instruments (moreover, the synthetic aperture processing is somewhat more prone to RFI effects than the real aperture pencil beam of SMAP). These approaches enabled the SMAP calibration and validation program to focus on optimizing the performance of the sensor and geophysical products immediately after the start of the data production.

Information on the reliability of remote sensing data products is essential for their utilization in scientific studies and applications. Validation approaches that provide this information vary depending on the type of product and its application. Matching the spatial scale of a remote sensing measurement with the reference measurements is a major challenge (Colliander, 2014; Jackson et al., 2014). In the case of soil moisture, several studies have investigated the reliability of the in situ measurements, e.g., (Cosh et al., 2005; Burns et al., 2014; Adams et al., 2015), spatial variability, e.g., (Choi et al., 2007; Famiglietti et al., 2008; Das and Mohanty, 2008) and the representativeness of the in situ soil moisture measurements at larger scale, e.g., (Cosh et al., 2006; Starks et al., 2006; Gruber et al., 2013;Yee et al., 2016). The focus here is on the validation of the SMAP surface soil moisture products using core validation sites (CVS), which are defined as sites that have multiple calibrated and representative soil moisture measurement locations within a SMAP pixel (Jackson et al., 2013). Comparison of the CVS and SMAP estimates is the primary basis for assessing the performance of the soil moisture retrieval algorithms, and evaluating the mission success. Previous studies have used a similar approach, e.g., (Jackson et al., 2010, 2012); however, the SMAP CVS represent a significant expansion in terms of both number of sites and diversity of land cover and soil types. SMAP also utilizes data from sparse networks (defined as those that provide a single point observation in a specific product grid cell) in its calibration and validation plan (Jackson et al., 2013, Chen et al., 2016). Sparse network measurements have been used previously (Al Bitar et al., 2012) but present challenges that compromise the evaluation of the performance in the absolute sense (Crow et al., 2012).

The challenge faced by SMAP, as well as other satellite-based soil moisture observations, e.g., (Kerr et al., 2016), is finding validation sites that meet the measurement requirements. In an effort to increase the number of CVS as well as their geographic distribution and diversity of conditions, SMAP partnered with investigators across the globe in a collaborative Cal/Val Partners program. This paper describes the SMAP mission data products, and the calibration and validation approach, the core sites and their utilization, the processing of the data for metrics computations, and the results from using the core sites in the SMAP validation.

2. SMAP data products

The SMAP mission delivers data products from its instrument measurements (Level 1), geophysical retrievals (swath based, Level 2, and daily composite, Level 3), and land surface models assimilating SMAP measurements (Level 4); see Table 1. Prior to the radar malfunction, SMAP provided three different Level 2 surface soil moisture products: 1) L2SMP is based on the SMAP radiometer measurements and provides an estimate of the soil moisture within 36-km grid cells (O'Neill et al., 2014; Chan et al., 2016), 2) L2SMA is based on the SMAP synthetic aperture radar (SAR) measurements and provides an estimate of the soil moisture within 3-km grid cells (Kim et al., 2014a, 2014b), 3) L2SMAP utilizes SMAP radar measurements to disaggregate the radiometer measurements and provides an estimate of the soil moisture within 9-km grid cells before retrieving soil moisture (Entekhabi et al., 2014; Das et al., 2016). The products are gridded on 36-km, 9-km and 3-km (nested) Equal-Area Scalable Earth grid ver. 2 (EASE-2), respectively. The products are swath based and produced separately. A daily Level 3 composite product is generated from each of the products as well. It is recognized that the sensing depth of a microwave instrument varies depending on the soil moisture content and its distribution (Njoku and Kong, 1977; Escorihuela et al., 2010). Accounting for this effect in