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Validation and scaling of soil moisture in a semi-arid environment: SMAP validation experiment 2015 (SMAPVEX15)

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ABSTRACT

The NASA SMAP (Soil Moisture Active Passive) mission conducted the SMAP Validation Experiment 2015 (SMAPVEX15) in order to support the calibration and validation activities of SMAP soil moisture data products. The main goals of the experiment were to address issues regarding the spatial disaggregation methodologies for improvement of soil moisture products and validation of the *in situ* measurement upscaling techniques. To support these objectives high-resolution soil moisture maps were acquired with the airborne PALS (Passive Active L-band Sensor) instrument over an area in southeast Arizona that includes the Walnut Gulch Experimental Watershed (WGEW), and intensive ground sampling was carried out to augment the permanent *in situ* instrumentation. The objective of the paper was to establish the correspondence and relationship between the highly heterogeneous spatial distribution of soil moisture on the ground and the coarse resolution radiometer-based soil moisture retrievals of SMAP. The high-resolution mapping conducted with PALS provided the required connection between the *in situ* measurements and SMAP retrievals. The *in situ* measurements were used to validate the PALS soil moisture acquired at 1-km resolution. Based on the information from a dense network of rain gauges in the study area, the *in situ* soil moisture measurements did not capture all the precipitation events accurately. That is, the PALS and SMAP soil moisture estimates responded to precipitation events detected by rain gauges, which were in some cases not detected by the *in situ* soil moisture sensors. It was also concluded that the spatial distribution of the soil moisture resulted from the relatively small spatial extents of the typical convective storms in this region was not completely captured with the *in situ* stations. After removing those cases (approximately 10% of the observations) the following metrics were obtained: RMSD (root mean square difference) of 0.016 m^3/m^3 and correlation of 0.83. The PALS soil moisture was also compared to SMAP and *in situ* soil moisture at the 36-km scale, which is the SMAP grid size for the standard product. PALS and SMAP soil moistures were found to be very similar owing to the close match of the brightness temperature measurements and the use of a common soil moisture retrieval algorithm. Spatial heterogeneity, which was identified using the high-resolution PALS soil moisture and the intensive ground sampling, also contributed to differences between the soil moisture estimates. In general, discrepancies found between the L-band soil moisture estimates and the 5-cm depth *in situ* measurements require methodologies to mitigate the impact on their interpretations in soil moisture validation and algorithm development. Specifically, the metrics computed for the SMAP radiometer-based soil moisture product over WGEW will include errors resulting from rainfall, particularly during the monsoon season when the spatial distribution of soil moisture is especially heterogeneous.

1. Introduction

The SMAP post-launch Calibration/Validation (Cal/Val) plan is intended to assess the quality of the mission products and to support analyses that lead to their improvement. A suite of complementary methodologies employed together will result in a robust global assessment (Jackson et al., 2013). These methodologies include the utilization of core validation sites (Colliander et al., 2017), sparse networks (Chen et al., 2017), other satellite data products (Burgin et al., 2017), model-based data products (Pan et al., 2016), and field campaigns. Field campaigns, in particular those using aircraft-based higher-resolution satellite sensor simulators, play an important role in satellite product Cal/Val by providing detailed ground truth; however, they are limited in

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their spatial extent and duration by logistics and costs. Specific SMAP science activities that can be addressed using an aircraft-based campaign include: validating spatial disaggregation of satellite soil moisture or brightness temperatures, investigating and resolving anomalous observations and products (such as large deviations from *in situ* estimated soil moistures), defining site specific upscaling, understanding the effects and contribution of heterogeneity on coarser resolution retrievals, and providing correlative analysis of L1 data product calibration.

SMAPVEX15 was the first SMAP post-launch field campaign and was designed to address the issues noted above. Post-launch field experiments were also carried out in Australia (Ye et al., 2016) in 2015. The SMAP post-launch field campaigns follow a series of pre-launch field campaigns carried out in USA, Canada and Australia (Colliander et al., 2012; Panciera et al., 2014; Magagi et al., 2013; McNairn et al., 2015). The timing and location of the SMAPVEX15 campaign was based on the needs to capture a range of soil moisture conditions in a short period of time and to observe well-defined and highly heterogeneous soil moisture spatial patterns that would provide a clear validation of disaggregation approaches. This led to the selection of a core validation site in southeast Arizona during the summer monsoon season. The campaign was conducted between August 1 and 18, 2015. This was shortly after the loss of the SMAP radar; therefore, the campaign objectives shifted from the validation of the SMAP disaggregation techniques and the other goals were reprioritized. However, the data set will be of value for the validation of future disaggregation approaches.

This paper focuses on the investigation of the sub-pixel soil moisture heterogeneity as measured with the PALS (Passive Active L-band System) airborne radiometer as it scales to the SMAP data products. The objective of the paper is to establish the correspondence and relationship between the highly heterogeneous spatial distribution of soil moisture on the ground and the coarse resolution radiometer-based soil moisture retrievals of SMAP. The high-resolution mapping conducted with PALS provided the required connection between the *in situ* measurements and SMAP retrievals. SMAPVEX15 was the first major campaign to utilize the conical scanning mode of the PALS instrument installed on a DC-3 aircraft (Misra et al., 2017). Data collected with PALS radar are available as well, but because of the failure of the SMAP radar this study is solely focused on the radiometer data. The data collected by PALS on multiple days were used to produce high-resolution brightness temperature data sets. The PALS radiometer observations were then translated into high-resolution soil moisture retrievals that were validated using ground-based observations. The PALS brightness temperature and validated soil moisture were aggregated to the spatial resolution of the SMAP L2 radiometer-based soil moisture product (36 km). These soil moisture estimates were compared to each other and to up-scaled *in situ* soil moistures. The comparison of the *in situ* soil moistures at 5-cm depth and the radiometer-based soil moisture, which is sensitive to moisture starting from the top surface, also gives a perspective on the vertical distribution of soil moisture in addition to the horizontal distribution captured by the PALS measurements. The study focuses on the area of the WGEW validation pixel, which is used for SMAP data product validation (Keefer et al., 2008; Colliander et al., 2017).

2. Site description

The SMAPVEX15 campaign took place in southeastern Arizona, encompassing several experimental sites and ranges operated by the United States Department of Agriculture (USDA) Agricultural Research Service (ARS) Southwest Watershed Research Center in Tucson, AZ, and the University of Arizona. Fig. 1 shows the domain along with the specific watersheds and experimental ranges included in the study. The Walnut Gulch Experimental Watershed (Moran et al., 2008), located in the eastern portion of the domain has been the location of numerous soil moisture field experiments in the past, including MONSOON '90 (Kustas et al., 1994) and SMEX04 (Soil Moisture Experiment in 2004) (Bindlish et al., 2008). It is a semi-arid region with an annual average precipitation of 312 mm, approximately 60% of it coming during the summer monsoon season, July to September (Goodrich et al., 2008). The majority of this monsoon rainfall occurs within highly localized convective storms – leading to large amounts of spatial variability in rainfall accumulations. During August of 2015, the average air temperature was 25 °C and the average relative humidity was 53%. The Santa Rita Experimental Range (SRER) in the western portion of the study domain is a more traditional desert landscape dominated by cactus and large shrubs. In the center of the SMAPVEX15 domain is a grassland

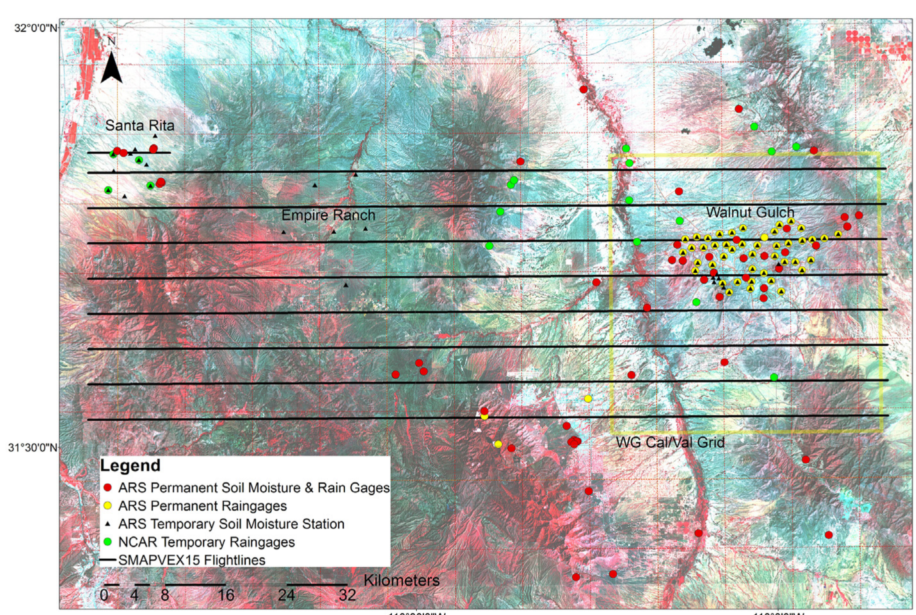

Fig. 1. SMAPVEX15 campaign domain and the PALS flight lines (black). The underlying image is a false color image of Landsat 8 from 8/3/15 (West) and 8/12/15 (East).