

# STRATEGIES FOR VALIDATING SATELLITE SOIL MOISTURE PRODUCTS USING IN SITU NETWORKS: LESSONS FROM THE USDA-ARS WATERSHEDS

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## ABSTRACT

There are a variety of soil moisture station designs and networks deployed throughout the world, each with varying applications and uses. For the purpose of satellite validation of soil moisture products, a dense network of soil moisture networks are required with soil moisture sensors at the near surface (~5 cm or less) to correspond to the satellite footprints and signals. The USDA- Agricultural Research Service operates a collection of soil moisture networks as a part of the Long Term Agro-ecosystem Research (LTAR) network to this end. These networks have been used to validate products from AMSR-E, SMOS, Aquarius, and SMAP. A review of these results and a synopsis of successful scaling strategies are discussed.

**Index Terms**— Soil Moisture, Validation, Networks, Satellite Products,

## 1. INTRODUCTION

Satellite remote sensing of soil moisture became mature with the launch of the Aqua satellite, which carried the Advanced Microwave Scanning Radiometer (AMSR-E), in 2002. To provide a set of validation data points, the USDA Agricultural Research Service instrumented four of their long-term experimental watersheds with soil moisture and soil temperature sensors in tandem with established precipitation networks [1]. These watersheds, shown in Figure 1, were distributed across a diverse set of land cover conditions, with Walnut Gulch (Arizona) representing semi-arid landscape, Little River (Georgia), representing a humid cropland, Little Washita (Oklahoma) representing sub-

humid cropland, and rangeland, and Reynolds Creek (Idaho), representing semi-arid mountainous rangeland. These watershed networks were established originally as precipitation networks; therefore, the distribution in space of the stations was not optimized to represent soil moisture, but rather capture the variability of the precipitation. For example, Walnut Gulch has a uniform distribution of stations across the network to capture the small convective events that frequently occur in southeastern Arizona. In Reynolds Creek, the precipitation network has a greater number of stations deployed in the mountainous areas to capture the orthographic variation in snowfall amount. This type of deployment makes it challenging to scale the network to a remote sensing footprint, which is approximately 25-50 km in scale. Beginning in 2007, additional networks began to be deployed to address additional missions which were in the planning stages, including the Soil Moisture Ocean Salinity (SMOS) mission [2]. These networks included the Fort Cobb (Oklahoma) watershed, which included irrigated cropland, Saint Joseph's Watershed (Indiana), mixed cropland, and South Fork (Iowa), which is dominated by corn and soybean cropland. Each of these watershed networks uses the Stevens Water Hydra Probe at a 5 cm depth with some sites providing additional depths for further modeling. These networks alone would not be sufficient to provide validation data, unless there was some calibration and verification that the networks provide an accurate estimate of the large scale soil moisture average for satellite validation. Therefore, various strategies needed to be developed and implemented at each watershed to fully qualify these locations for inclusion in the satellite cal/val programs.

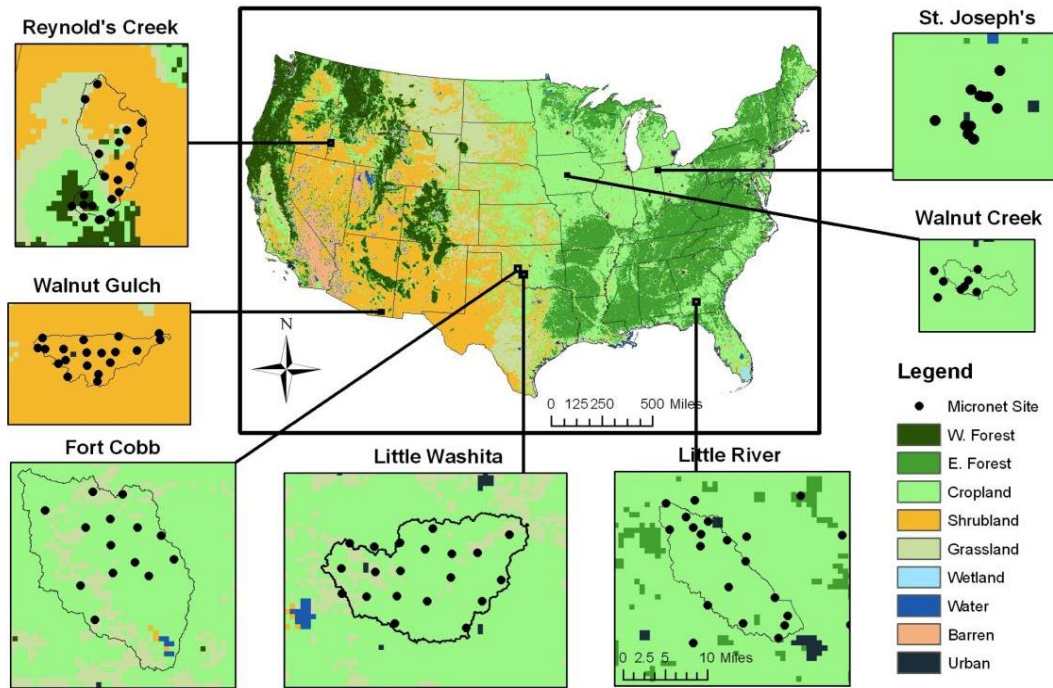


Figure 1: ARS watersheds with a land cover classification color scheme

## 2. METHODOLOGY OF VALIDATION

A critical element of a watershed program is a validation of the measurements being made to assure that they are accurate. For soil moisture, this involves calibration of the sensors, which are installed in the soil. This will account for sensor variation, but it is also necessary to scale the local measurement to the surrounding area, if the data is to be used in a remote sensing validation program. There are several methods of scaling in situ data. The most common is conducting an intensive field experiment with field samplers and synchronous aircraft flights of an instrument similar to the satellite instrument in question. There is a long history of soil moisture experiments with this design, including Soil

Moisture Experiments in 2002 (SMEX02), 2003 (SMEX03), and 2004 (SMEX04), which focused on the AMSR-E instrument [3]-[5]. The CANEX-SM10 experiment in 2010 [6]-[7] focused on validating the SMOS instrument, and the SMAP Validation Experiments in 2015 and 2016 (SMAPVEX15, 16) were coordinated with the SMAP instrument. These experiments provided significant validation of in situ network accuracy and representativeness. Another methodology involves the regular sampling of soil moisture samplers with broad sampling throughout the season of interest (usually summer). One such campaign was conducted in support of the South Fork network in 2014, which established an error less than  $0.04 \text{ m}^3/\text{m}^3$  for several SMAP product pixels. Another method of scaling is by deploying additional temporary

Table 1: Description of USDA ARS Experimental Watersheds with dominant features for each.

Watershed Name	Established	# of Stations	Topography	Landscape	Size (km <sup>2</sup> )
Walnut Gulch, Arizona	2002	19	Rolling	Rangeland	148
Reynolds Creek, Idaho	2002	19	Mountainous	Rangeland	238
Little Washita, Oklahoma	2002	20	Rolling	Rangeland/Wheat	610
Little River, Georgia	2002	29	Flat	Row Crop/Forest	334
Fort Cobb, Oklahoma	2007	15	Rolling	Row Crop	813
Saint Joseph's, Indiana	2009	15	Flat	Row Crop	300
South Fork, Iowa	2013	20	Flat	Row Crop	625

Table 2: Summary of satellite validation RMSE results for the ARS experimental watersheds.

Watershed Name	AMSR-E RMSE, in $\text{m}^3/\text{m}^3$	SMOS RMSE, in $\text{m}^3/\text{m}^3$	Aquarius RMSE, in $\text{m}^3/\text{m}^3$	SMAP ubRMSE, in $\text{m}^3/\text{m}^3$	Network Accuracy, $\text{m}^3/\text{m}^3$
Walnut Gulch, Arizona	0.025	0.024	-	0.031	$\sim 0.01 \text{ m}^3/\text{m}^3$
Reynolds Creek, Idaho	0.040	0.039	-	0.042	TBD
Little Washita, Oklahoma	0.045	0.036	0.031	0.025	$\sim 0.01 \text{ m}^3/\text{m}^3$
Little River, Georgia	0.048	0.048	0.030	0.027	$< 0.03 \text{ m}^3/\text{m}^3$
Fort Cobb, Oklahoma	-	-	-	0.031	$< 0.03 \text{ m}^3/\text{m}^3$
Saint Joseph's, Indiana	-	-	-	0.042	TBD
South Fork, Iowa	-	-	-	0.045	$\sim 0.03 \text{ m}^3/\text{m}^3$

network stations to increase the number of samples of calibrated sensors, providing a better estimate of large scale soil moisture distributions. This has been conducted in coordination with large scale field experiments, such as CANEX-SM10, SMAPVEX12, SMAPVEX15, and SMAPVEX16, as well as standalone experiments in New York and Tennessee [8]. These three methodologies all contribute valuable information to the veracity and accuracy of a soil moisture network estimate.

### 3. RESULTS OF VALIDATION

Data from these watersheds have been compared to that of various satellites for available timeframes, depending on the satellite mission. Table 2 contains a summary of the published results of these network comparisons to the large-scale products. The overall accuracy of the AMSR-E products were less than  $0.05 \text{ m}^3/\text{m}^3$  RMSE [1], while the RMSE for SMOS was less than  $0.04 \text{ m}^3/\text{m}^3$  [9]. Each of these has a nominal footprint of 40 km and have similar performance metrics. The Aquarius soil moisture product has a nominal footprint of 100 km therefore only two watersheds were of sufficient size and homogeneity to provide validation data [10]. SMAP is similar to SMOS in both footprint and frequency (L-band) and had similar performance metrics [11]-[12]. Each of these missions were able to achieve their performance goals with the inclusion of ARS watersheds as a part of their validation program.

Critical to the incorporation of these networks into a validation program however is some understanding of the accuracy and quality of the network data. The first validation experiment on one of these networks was conducted in 2003, during the SMEX03 experiment, which established the accuracy of the Little Washita network to within  $0.01 \text{ m}^3/\text{m}^3$  of the overall domain average [4]. This was followed up in 2004 where the Walnut Gulch network was validated to within  $0.01 \text{ m}^3/\text{m}^3$  as well [5]. Other network validations were conducted and are listed in Table 2. Network deployments have aided in other network

validations with deployments as short as 3 months and as long as 12 months [8].

### 4. CONCLUSION

Network validation is a critical element to satellite validation programs, but quality control is essential to ensure the estimate represents the entire domain. Field experiments are a key tool to provide scaling data for a network, but as instrumentation evolves, temporary networks have become more useful for scaling activities.

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