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Evaluating New SMAP Soil Moisture for Drought Monitoring in the Rangelands of the US High Plains

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On the Ground

- Level 3 soil moisture datasets from the recently launched Soil Moisture Active Passive (SMAP) satellite are evaluated for drought monitoring in rangelands.
- Validation of SMAP soil moisture (SSM) with *in situ* and modeled estimates showed high level of agreement.
- SSM showed the highest correlation with surface soil moisture (0-5 cm) and a strong correlation to depths up to 20 cm.
- SSM showed a reliable and expected response of capturing seasonal dynamics in relation to precipitation, land surface temperature, and evapotranspiration.
- Further evaluation using multi-year SMAP datasets is necessary to quantify the full benefits and limitations for drought monitoring in rangelands.

Keywords: drought monitoring, remote sensing, SMAP, soil moisture, rangelands.

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Droughts are one of the costliest natural disasters and globally affect a large number of people and their livelihoods every year. In the United States, droughts, on average, cause financial damage of $6 to $8 billion per year.[1] The 1996 drought resulted in estimated loss of about $6 billion for the state of Texas alone[1] and had the greatest negative impact on rangeland ecosystems. Gathering knowledge of the onset, duration, and severity of prior droughts is important for efficient planning of drought mitigation strategies. In order to minimize losses due to droughts and to manage the impact of water scarcities, it is essential to develop scientifically-based drought monitoring tools and early warning systems.[2]

Understanding the hydrologic cycle and its parameters is of paramount importance to identify the nature and characteristics of droughts. Precipitation is one of the most important parameters that provides information on the availability of water and potential occurrence of drought. Although precipitation is the best observed hydrologic variable, it alone cannot adequately characterize a drought. Nevertheless, several widely used drought monitoring indices have been developed based on the information obtained from precipitation data.[3] Other agro-hydrologic parameters such as land surface temperature, normalized difference vegetation index (NDVI), and evapotranspiration (ET) have also been used in several standard drought indices.[4] While each of these standard indices used for drought monitoring has its own advantages and disadvantages, all of them are expressions of the key hydrologic variable, i.e., soil moisture. It may be worth considering a multi-sensor approach that would look for a convergence of evidence, which would allow for as many of the agro-hydrologic variables as possible when trying to derive a reliable drought product that can be used consistently over space and time.[2]

Of all the hydrologic variables, soil moisture is one of the least measured variables for understanding droughts at large spatial scales. Because of the lack of large-scale and long-term observations of soil moisture in the United States and elsewhere, the use of simulated soil moisture fields from land surface models, forced with observed precipitation and near surface meteorology, has been a viable aproach.[2] Soil moisture combines the response from recent precipitation, antecedent moisture, and the soil and vegetation characteristics. The amount of water in the top layers of the soil is correlated with shorter-term precipitation and atmospheric demand. This governs the amount of water available to meet the demands of evapotranspiration and, in turn, plant growth. In water-limited ecosystems such as semi-arid rangelands, soil water content in the root zone is a strong predictor of future vegetation condition. Therefore, characterizing soil moisture plays a critical role for drought monitoring in general but becomes a critical parameter for water-limited rangeland ecosystems.

The goal of this study is to evaluate the capability of level 3 soil moisture estimates obtained from the Soil Moisture Active Passive (SMAP) mission particularly for drought monitoring over rangelands. However, due to the limited (nine months) and preliminary nature of the SMAP data, this paper focuses on *in situ* validation as well as a comparison of SMAP soil moisture (SSM) with other currently available drought monitoring data. The results should be considered a demonstration of the reliability and usefulness of SSM but not an exhaustive synthesis on its application for drought monitoring, which would require multi-year time series evaluation of the product over diverse ecosystems.

Need for Satellite-Based Estimates of Soil Moisture

Soil moisture may be measured by a variety of methods, but unfortunately, there is no comprehensive, national network of soil moisture monitoring instruments[3] that can provide us with seamless information on soil moisture status across the nation. Although there are few national networks available, the density of observations does not provide a comprehensive understanding of change in soil moisture conditions nationally. Hence, soil moisture is generally modeled over large areas using precipitation and temperature, or through root-zone water balance modeling. The SMAP mission is one of the first Earth observation satellites built by the National Aeronautics and Space Administration (NASA) in response to the National Research Council's Decadal Survey to provide global measurements of soil moisture in the top 5 cm of the soil and freeze/thaw state.[5] The passive radiometer onboard SMAP measures naturally emitted microwave radiation at 1.4 GHz. The radiometer detects the minute differences in microwave signals caused by the presence of moisture on the land surface. In general, a dry surface (such as desert sand) emits larger amounts of microwave radiation whereas surface water features emit very low amounts of radiation. Using satellite-based soil moisture estimates for drought monitoring has several advantages: 1) global coverage enables monitoring of large areas; 2) daily coverage improves the ability to monitor the onset of drought-related events; 3) the application of consistent data and algorithms enables inter-comparison of SMAP data over time; 4) lower frequency of microwave (e.g., L-band) enables all-weather (that is, cloud-penetrating) monitoring; 5) soil moisture observations are made even when sparse and moderate vegetation is present on the soil surface; and 6) unlike other visible/near-infrared sensors, SMAP measurements are independent of solar illumination which allows for day and night observations. On the other hand, these soil moisture estimates for drought monitoring have some limitations: 1) soil moisture estimates that can have higher uncertainties or be unavailable over regions with dense vegetation, 2) the SSM estimates have coarse resolution (36 km), and 3) validation needs to be performed using *in situ* observations.

Evaluation of SSM Using *In Situ* and Modeled Datasets

During August 2015, NASA released the first calibrated level 1 data from SMAP.[i] By January 2016, all radiometer data products from the SMAP were available. At the time of the writing of this paper, SMAP level 3 data products[6] available for April to December of 2015 were obtained from the National Snow and Ice Data Center (NSIDC) website.[ii] These preliminary beta-quality data are generated using preliminary algorithms that are not yet validated and, hence, subject to some degree of uncertainties and improvements.

In this study, we validated the performance of the early access SSM product available at 36 km spatial resolution equal area scalable Earth-2 (EASE2) grids covering rangeland regions in the states of Texas and Oklahoma, USA. First, we validated SSM against *in situ* soil moisture observations obtained from eight United States Climate Reference Network (USCRN) sites[7] (see Fig. 1 for locations). *In situ* soil moisture measurements are publicly available online.[iii] We also performed basin-scale validation using modeled soil moisture obtained from the VegET agro-hydrologic model.[8] Because SMAP data products and validation data used in this study are available at different spatial resolutions, we summarized both input SMAP and validation data at a watershed scale. We identified hydrologic units (HUC8 watersheds, HUC) that are dominated by grasslands and shrublands. We used 0.5-km land cover climatology products[iv] obtained from Moderate Resolution Imaging Spectroradiometer (MODIS) data[9] to compute the percentage of grasslands and shrublands for each HUC (Fig. 1). Then, we selected HUCs with grassland and shrublands cover greater than 70%. Fig. 1 shows grasslands- and shrublands-dominated watersheds across the United States. However, in this study, we used HUCs covering the USCRN sites in Texas and Oklahoma. The SMAP level 3 soil moisture is summarized (spatial average) for eight HUCs and temporally aggregated over an 8-day time period for comparison with validation products. The list of all the datasets and their characteristics are presented in the appendix, Table A1.

Point and Basin-Scale Validation of SSM

Retrieval of soil moisture from brightness temperature observations is based on the radiative transfer equation, commonly known in the passive microwave soil moisture community as the tau-omega model.[10] Allowing for spatial heterogeneity and scaling issues, soil moisture measurements from SSM should be comparable to *in situ* measurements or modeled soil moisture estimates. Twofold validation of SSM was conducted in this study. First, SSM estimates (cm^3/cm^3) were validated using *in situ* soil moisture observations (m^3/m^3) obtained from eight USCRN sites. Second, basin-scale

[i] Read about this release at http://smap.jpl.nasa.gov/news/1246/.

[ii] Available at http://nsidc.org/data/docs/daac/smap/sp_l3_smp/.

[iii] Available at https://www.ncdc.noaa.gov/crn/.

[iv] Available at http://landcover.usgs.gov/global_climatology.php.