SEASONAL DEPENDENCE OF SMAP RADIOMETER-BASED SOIL MOISTURE PERFORMANCE AS OBSERVED OVER CORE VALIDATION SITES

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ABSTRACT

The NASA SMAP (Soil Moisture Active Passive) mission provides a global coverage of soil moisture measurements based on its L-band microwave radiometer every 2-3 days at about 40 km resolution. The soil moisture retrieval algorithms model the brightness temperature as a function of soil moisture, surface conditions and vegetation. External data sources inform the algorithms about the surface conditions and vegetation, which enable the retrieval of soil moisture. The inversion process contains uncertainties related to radiometer measurements, forward model assumptions and ancillary data sources. This study focuses on the uncertainties that depend on the seasonal evolution of the surface conditions and vegetation. The study compares the SMAP and core validation site (CVS) soil moisture values over a period of four years to extract the evolution of performance metrics over time. The analysis showed that most CVS that include managed agriculture exhibit significant time-dependent seasonal bias. This bias was linked to seasonal temperature cycle, which is a proxy to several features that can cause seasonally dependent errors in the SMAP product.

Index Terms**—** Soil Moisture, SMAP, core validation site

1. INTRODUCTION

NASA's (National Aeronautics and Space Administration) Soil Moisture Active Passive (SMAP) mission was launched in January 2015. The objective of the mission is global mapping of soil moisture and freeze/thaw state [1]. The performance of the SMAP radiometer-based soil moisture product meets the mission requirements [2],[3]. However, the time-varying performance of the products has not been investigated thoroughly yet. The algorithm is subject to seasonally varying uncertainties due to soil moisture, temperature and vegetation seasonality. These seasonal dependencies can manifest themselves as seasonal errors in the SMAP soil moisture products. The SMAP soil moisture products extends now over 4 years. While longer time-series are desirable for investigating seasonal anomalies, the coverage of four seasons allow initial analysis of these effects. The goal of this investigation is to analyze the variability of the performance metrics and their correlation to the most important algorithm parameters. The effort complements the statistical analysis on the time-dependence of the SMAP soil moisture biases presented by [4].

2. MATERIAL

2.1 SMAP Data

The analysis used the SMAP enhanced radiometer-based soil moisture product (L2SMPE) version R16. The product has the same resolution as the original SMAP radiometer-based soil moisture product but presents the data on a 9-km EASE v. 2 grid instead of the 36-km EASE v.2 grid of the original product [3]. Otherwise, the products are very similar and the conclusions of the study are applicable to both products.

2.2 Core Validation Sites

The SMAP mission partners with dense soil moisture observation networks across the world, called the core validation sites (CVS). The CVS provide the reference soil moisture for the assessment of the time-variance of the performance metrics. These are the sites that have been used to validate and characterize the SMAP soil moisture products and to test whether the products meet the mission criteria [5],[6]. The CVS are well-characterized sites with multiple calibrated in situ soil moisture measurements within the SMAP resolution cell. Table 1 lists the CVS used in this study and Figure 1 shows their locations. The measurements from the multiple stations facilitate an estimation of the soil moisture at the SMAP footprint scale as opposed to the point-scale provided by individual stations.

3. METHOD

The SMAP soil moisture was matched up with the CVS provided soil moisture estimates. The differences were arranged by the seasonal timing of the observations (using day of year); the arranged data was averaged with a sliding window of 30 days. This resulted in a one-year long time-series of mean difference for each site (this abstract focuses on mean difference; the future analysis will include other metrics as well). The quantified seasonal bias variation was correlated with parameters affecting the soil moisture retrieval. These parameters included soil moisture as measured at the CVS; vegetation water content (VWC) based on MODIS NDVI; soil temperature as measured by the soil moisture stations at the CVS, and the difference between the measured soil temperature and modeled effective soil temperature used by the SMAP soil moisture retrieval algorithm. The MODIS NDVI based VWC is included in the SMAP product as it is used by the soil moisture retrieval algorithm to estimate the impact of vegetation on the brightness temperature [2]. The modeled effective soil temperature is computed from the modeled 0-10 cm and 10-20 cm soil temperatures. Therefore, the difference between the modeled and measured soil temperatures are not expected to match exactly, but relative deviations can inform on the underlying causes for any potential bias anomalies.

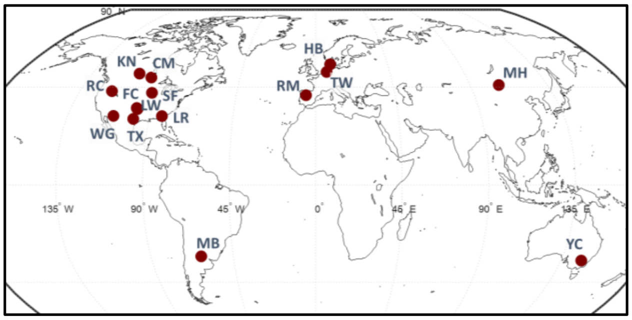

Figure 1. Map of the core validation site (CVS) locations.

The analysis categorized the results based on the land cover type at each CVS. The categories are Grasslands, Mixed Agriculture, Agriculture, and Mixed Landscape (Table 1). These categories deviate in some cases somewhat

Table 1. List of core validation sites (CVS). Figure 1 maps the locations of the sites. IGBP land cover is based on the dominant land cover within the grid-processing pixel. Categorization is the land type used in this study to categorize the results. It is based on the local information on the land cover at each site.

Site	**Map**	**PI**	**Location**	**Climate**	**IGBP Land cover**	**Categorization**
Walnut Gulch	WG	C. Holifield Collins	USA (Arizona)	Arid	Shrub open	Grasslands
TxSON	TX	T. Caldwell	USA (Texas)	Temperate	Grasslands	Grasslands
Little Washita	LW	P. J. Starks	USA (Oklahoma)	Temperate	Grasslands	Grasslands
Mongolian	MH	J. Asanuma	Mongolia	Cold	Grasslands	Grasslands
Fort Cobb	FC	P. J. Starks	USA (Oklahoma)	Temperate	Grasslands	Mixed Agriculture
Little River	LR	D. Bosch	USA (Georgia)	Temperate	Cropland/natural mosaic	Mixed Agriculture
Twente	TW	Z. Su	The Netherlands	Temperate	Cropland/natural mosaic	Mixed Agriculture
HOBE	HB	K. Jensen	Denmark	Temperate	Cropland/natural mosaic	Mixed Agriculture
Yanco	YC	J. Walker	Australia	Semi-Arid	Grasslands	Mixed Agriculture
South Fork	SF	M. H. Cosh/J. Prueger	USA (Iowa)	Cold	Croplands	Agriculture
Kenaston	KN	A. Berg	Canada	Cold	Croplands	Agriculture
Carman	CM	H. McNairn	Canada	Cold	Croplands	Agriculture
Monte Buey	MB	M. Thibeault	Argentina	Arid	Croplands	Agriculture
REMEDHUS	RD	J. Martínez-Fernández	Spain	Temperate	Croplands	Agriculture
Reynolds Creek	RC	M. Seyfried	USA (Idaho)	Arid	Grasslands	Mixed Landscape

from the dominant IGBP classification for the sites based on the local information regarding the actual land type and practical similarities and differences between the sites.

4. RESULTS

Figure 2 shows the time series and yearly scatter plots of SMAP and in situ soil moisture at the TxSON site to illustrate how a typical data set looked before processing. Figure 3 shows the one-year long seasonal record for multiple parameters at two sites, REMEDHUS and Kenaston. The top row plots show the averaged bias (red line) with the original data points (dots). For both of these sites the seasonal bias is relatively significant as indicated by the standard deviation displayed in the plot title. The second row plots show the seasonal soil moisture as determined by the CVS measurements. The third row plots show the seasonal soil temperature as measured by the CVS measurements. The fourth row plots show the difference between the measured soil temperature (row three) and modeled effective soil temperature. The fifth row shows the seasonal VWC. The figures feature the Pearson correlation (R) below the plots computed between the seasonal bias and the parameters shown on the plots (given in the parenthesis).

In the case of REMEDHUS, the bias is most strongly correlated (inversely) with the seasonal soil temperature (R=-0.80). The strongly seasonal VWC is not significantly correlated (P=0.28) indicating that it is not factoring into the seasonal signature of the SM bias. In the case of Kenaston, both soil temperature and VWC are strongly correlated with the bias (R=0.78 and 0.79, respectively). In the case of both of these CVS, the soil temperature is a proxy for many seasonal effects where the impact of the actual soil temperature is only one factor. For REMEDHUS, the correlation with the difference between the measured and modeled effective soil temperatures is suspiciously high (0.56) suggesting that seasonal errors in the modeled soil temperature may be causing a significant portion of the seasonal bias. For Kenaston, the correlation with the soil temperature difference seems not significant; the VWC may be the main cause for the bias and the reason for the high soil temperature correlation may be its mutual correlation with the VWC.

The analysis described above was replicated for all the sites. Table 2 shows a summary of the observations. The table shows the bias variability (magnitude and classification into Low/Moderate/High) and the most significant explaining parameters in correlative sense. The magnitude of the seasonal bias increases towards managed agriculture, which is explained by their inherently strongly seasonal variation in land cover features. In most cases, the seasonality of soil temperature is correlated with the seasonal bias. Vegetation plays an important role in many cases as well. There are also additional seasonal effects that may be affecting both the retrieval and the in situ measurements. One of them is the vertical profile of the near surface soil moisture, which is dependent on the overall soil moisture in the column and atmospheric conditions (evaporation). Further analysis is

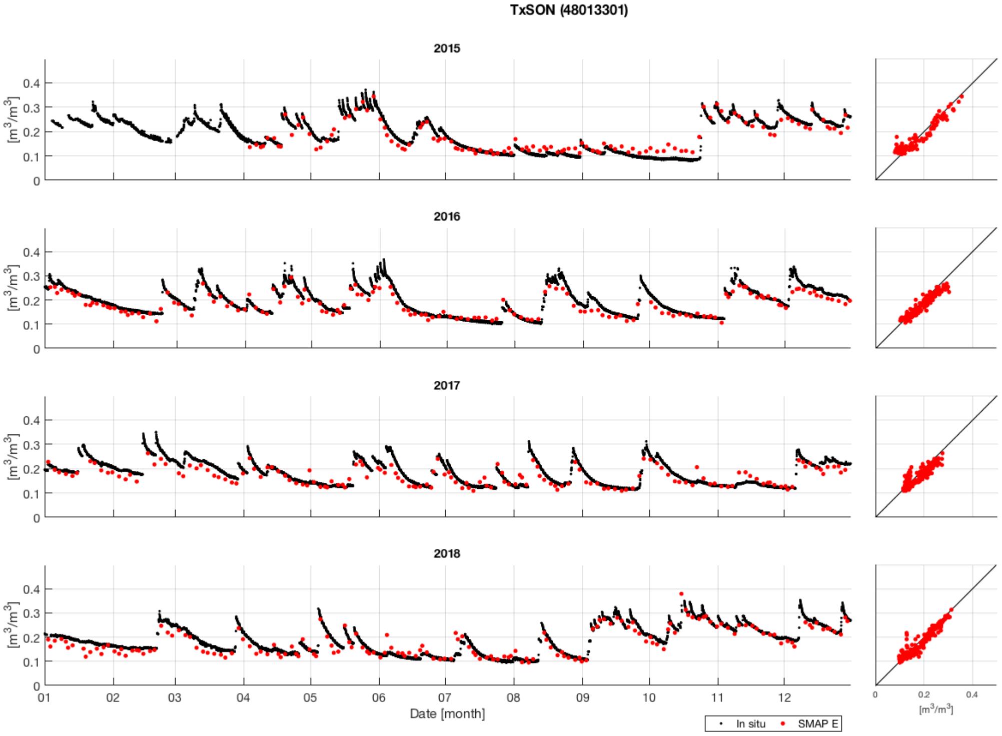

Figure 2. SMAP soil moisture (red) and in situ based soil moisture (black) at TxSON for April 2015-December 2018.

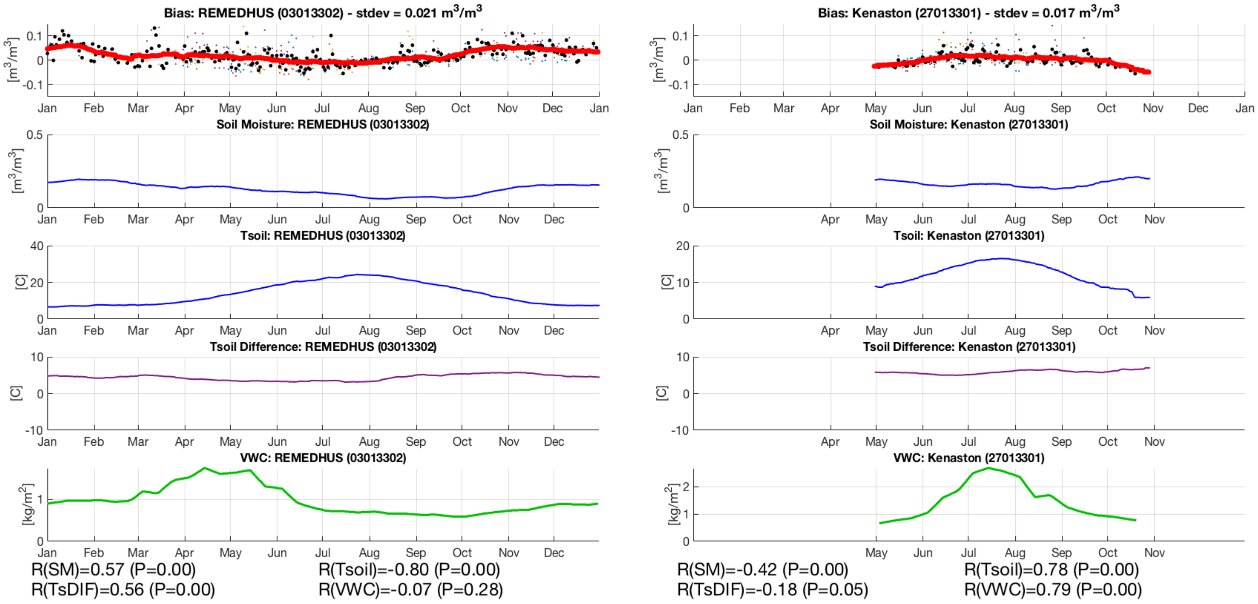

Figure 3. Seasonal bias (top row), seasonal soil moisture as measured by the CVS (2nd row), seasonal soil temperature as determined by the CVS (3rd row), seasonal difference between measured soil temperature and modeled effective soil temperature (4th row), and seasonal VWC (bottom row).

required to disentangle the different explaining parameters to determine the root cause for the bias, or their combination.

5. CONCLUSION

The analysis into seasonal biases of SMAP radiometer-based soil moisture product showed that most CVS that include managed agriculture exhibit significant time-dependent seasonal bias. This bias was linked to seasonal temperature cycle, which is a proxy to several features that can cause seasonally dependent errors in the SMAP product. The modeled soil temperature and seasonal VWC were identified in some cases. A further analysis will include a computation of other metrics in additional to bias and disentanglement of the different explaining factors.

Table 2. Summary observations of the seasonal bias variability and explaining factors, based on the correlative analysis. Parenthesis indicate secondary importance.

Site	stdev	Bias Variability	Correlation
Grasslands			
Walnut Gulch	0.013	Moderate	(SM)/(Temp)/Model Temp
Little Washita	0.009	Low	-
TxSON	0.009	Low	(SM)/Temp/(Veg)
Mongolia	0.005	Low	(Temp)/Veg
Mixed Agriculture			
Fort Cobb	0.006	Low	-
Little River	0.018	High	(SM)/Temp/Veg
Yanco	0.021	High	Temp/(Veg)
Agriculture			
REMEDHUS	0.021	High	SM/Temp/Model Temp
Kenaston	0.017	High	(SM)/Temp/Veg
South Fork	0.022	High	(Temp)
Carman	0.025	High	(SM)/Temp/Veg
Mixed Landscape			
Reynolds Creek	0.022	High	SM/Veg

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