DATA-BASED DISAGGREGATION OF SMOS SOIL MOISTURE

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ABSTRACT

The Soil Moisture and Ocean Salinity (SMOS) microwave radiometer is used to retrieve surface soil moisture with a grid resolution of 15 km. Due to various contributing factors SMOS soil moisture is known to have bias with respect to *in situ* soil moisture measurements and land surface models. For this reason it is common practice to match the cumulative distribution function (CDF) of retrieved soil moisture prior to analysis. Using the concept of temporal stability this study demonstrates that CDF matching is effective for correcting the bias at both grid and sub-grid scales with minimal impact on the time in-variant component of SMOS error.

Index Terms— *Soil Moisture and Ocean Salinity (SMOS), Soil moisture, Radiometry, Land Surface*

1. INTRODUCTION

Soil moisture is an important hydrological state variable as it affects the partition between the surface energy fluxes and mass transfer. Operational monitoring of surface soil moisture at the global scale has been achieved by passive microwave remote sensing such as the Soil Moisture and Ocean Salinity (SMOS) mission [1]. In the case of SMOS, the Level 2 (L2) soil moisture product is based on the retrieval of soil moisture from an integrated land surface area of approximately 40 km which is over-sampled onto a 15 km grid. With respect to the observed temperature brightness (Tb) from SMOS, [2] demonstrated that the uncertainty of using the 15 km SMOS product was less than that of the native SMOS radiometer and therefore does not represent a loss of information. This scale is acceptable for large scale hydro-climatic modelling, but is coarser than that used for many hydrological applications and is beyond the extent of most hydrological processes, including those responsible for soil moisture spatial distribution. Many methods have been proposed to deal with this discrepancy, some of which are based on the relationship between soil moisture and satellite observed surface skin temperatures and evaporation [3], while other are based on topographical and vegetation indices [4].

This paper proposes to evaluate the matching of the cumulative distribution function (CDF) of SMOS L2 soil moisture to that of local scale soil moisture observations. CDF matching is a common step prior to the assimilation of satellite soil moisture to match the climatology of the model and observations at a common scale [5, 6] and has been used to homogenize multi-product soil moisture time-series [7]. Given that many watersheds have been found to demonstrate the property of temporal stability [8] in which a consistent relationship is found between local soil moisture measurements and the basin average value [9, 10], it can be expected that CDF matching can be effectively used to downscale SMOS soil moisture to a local scale with similar performance as CDF matching to the grid scale mean soil moisture.

2. STUDY AREA AND DATA

2.1. Study Area and Observations

The selected study area was in the Spencer Creek Watershed which drains through the City of Hamilton to the western end of Lake Ontario, Canada. The western head waters are agricultural land and the basin drains towards the urban land in the east. At the scale of a SMOS grid cell, the study area is a mix of agricultural and forest land with some urban land and low lying areas being intermittently inundated.

This study was conducted using *in situ* soil moisture collected at the Orchard (O) and Governor Road (G) sites of the McMaster Mesonet located on conservation land near Hamilton, Ontario, Canada [10]. Each site has 9 (i.e. G1-9) Campbell Scientific time domain reflectometry (TDR) soil probes at a depth of 10 cm distributed in a grid covering an area of ~ 150 m × 150 m which collect soil moisture information hourly. Despite their small size and close proximity, variations in topography and vegetation result in sometimes significant spatial differences in soil moisture [10]. The Orchard site is reclaimed agricultural land which is mostly covered by meadow grasses with sparse apple trees on a gentle north facing slope and the Governor Road site is a mix of meadow grasses and mixed forest located on sloping terrain.

For the purposes herein, grid scale soil moisture $\overline{OBS_i}$ is considered as the mean, and its standard deviation, of all

TABLE I

COMPARISON OF SMOS SOIL MOISTURE RETRIEVAL PERFORMANCE BEFORE AND AFTER CDF MATCHING

Product	Ascending 0600 h				Descending 1800 h			
	R	RMSE	Bias	N	R	RMSE	Bias	N
SM-SMOS	0.50	0.19	-0.18	148	0.23	0.19	-0.17	34
$CDF - \overline{OBS}_i$	0.54	0.07	0.00	148	0.40	0.06	0.00	34
RMSE and Bias are in cm^3/cm^3, R = Linear correlation coefficient (-), N = Number of Samples								

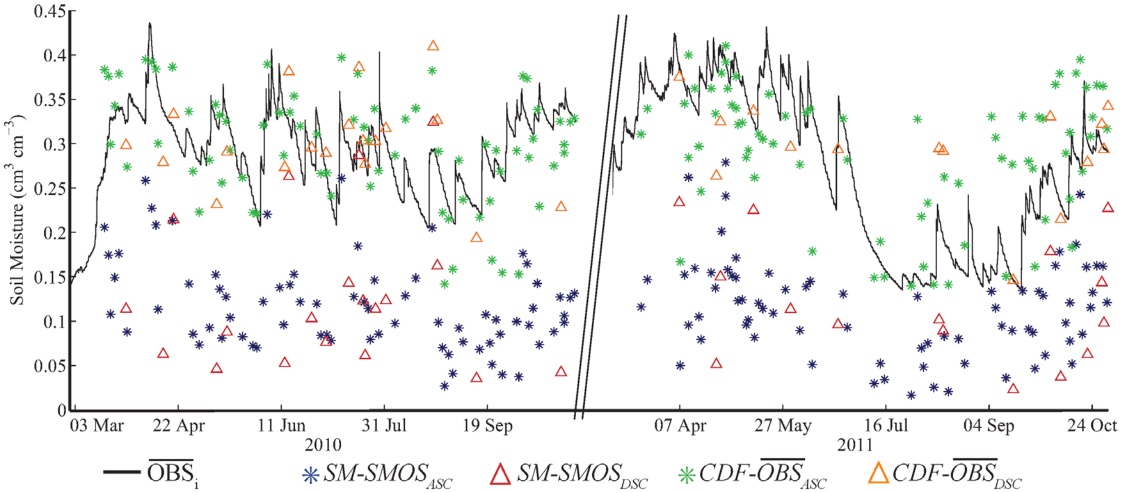

Figure 1. Comparison of SMOS retrievals CDF matched SMOS retrievels versus weighted mean observed soil moisture from the McMaster Mesonet for 1 Mar - 31 Oct 2010 & 2011.

of the McMaster Mesonet observations weighted based on land-cover fractions derived from the incidence angle independent land cover fractions of the SMOS Data Analysis Product (DAP) from June 30, 2010. Each site is categorized as 'nominal' or 'forest' and the weights from the DAP divided by the number of stations which fall into that category.

2.2. SMOS Data

SMOS soil moisture retrievals were collected from the L2 reprocessing campaign (ver.551) for the snow free season (March to October) of 2010 and 2011. SMOS L2 soil moisture data are projected onto an ISEA 4H9 discrete global grid (DGG) that has a surface resolution of 15 km [1]. Data were extracted for DGG208839 which covers all of the *in situ* sites of the study area and are analyzed separately for the ascending (0600 h) and descending (1800 h) overpasses. A time-series comparison of the mean and standard deviation of the McMaster Mesonet observations and SMOS soil moisture retrievals can be seen in Fig 1.

It must be recognized that there is a discrepancy between the ~5 cm penetration depth of microwave energy at L-band (1.4-GHz) and the observation depth of the McMaster Mesonet (10 cm). Because of the discrepancy of depths, it should be expected that SMOS retrievals would have a dry bias with respect to observations, but should have a similar temporal pattern.

3. METHODS

Matching of the cumulative distribution functions (CDF) of data sets was recommended for soil moisture assimilation by [5] as a means to remove the systematic differences between a set of soil moisture observations (SMOS) and a reference data set (McMaster Mesonet). The CDF matching technique of [6] was used in this study. The standard metrics of correlation, root mean squared error (RMSE) and bias are used to assess the impact of the matching the CDF of SMOS retrieved soil moisture to the grid scale mean and local soil moisture values.

4. RESULTS

4.1. Grid scale soil moisture

For CDF matching to be a viable tool for downscaling soil moisture, it must be established that the temporal pattern of $\overline{OBS}_i$ was consistent with that of the individual sites OBS_i within the SMOS grid. Considering all times that are consistent with SMOS overpasses (i.e. 0600 h & 1800 h) temporal correlation was used to calculate the linear

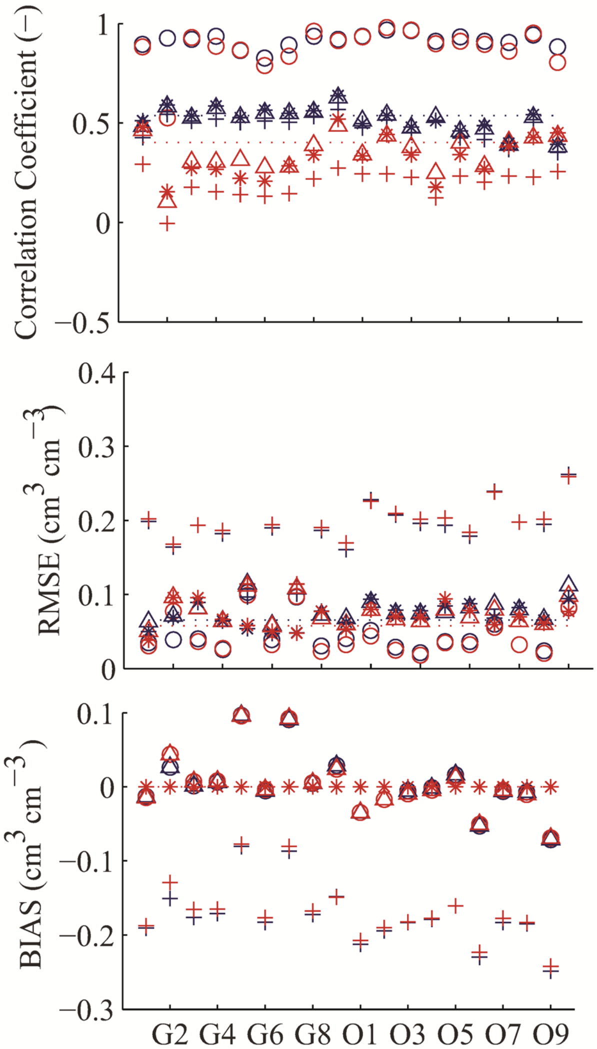

Figure 2. Preformance of $\overline{OBS}_i$ (circle), *SM-SMOS* (cross), *CDF-*$\overline{OBS}_i$ (triangle), and *CDF-*OBS_i (star) for ascending (blue) and descending (red) overpasses of SMOS compared to local scale *in situ* measurements for each station of the McMaster Mesonet. Dotted lines represent benchmark grid scale CDF matching performance.

dependence between individual sites and the weighted mean grid scale soil moisture. A correlation of 1 indicates the two datasets have the exact same temporal pattern ignoring any bias relative to the grid mean value, i.e. temporal stability is perfectly demonstrated. The mean (±1σ) correlation for all sites was 0.87±0.06 with a mean root mean squared error (RMSE) of 0.05±0.02. The correlation, RMSE and bias for each local soil moisture station compared to the grid scale soil moisture can be seen in Fig. 2.

4.2. Grid scale SMOS validation

To provide a benchmark by which to compare the performance of the CDF matched soil moisture at local scale, a comparison is first made to soil moisture at the grid scale. Table I summarizes the performance of the SMOS L2 soil moisture *SM-SMOS* and that of the SMOS L2 soil moisture which has been CDF matched to the climatology of the grid scale mean observations $CDF-\overline{OBS}_i$ for both ascending and descending overpasses. Matching the cumulative distribution functions results in an increase in the correlation, decrease in RMSE and elimination of the bias between the SMOS soil moisture and that of $\overline{OBS}_i$. The correlation is least improved by matching the CDF's because it is most strongly influenced by the random component of the errors in the SMOS data which are not removed by the CDF matching technique.

4.3. Local scale soil moisture

The plots in Fig. 2 compare the soil moisture at each individual site to that of $\overline{OBS}_i$, *SM-SMOS*, $CDF-\overline{OBS}_i$ and SMOS soil moisture which had been matched to the local soil moisture climatology $CDF-OBS_i$.

With the exception of O9 the SMOS ascending soil moisture performs better in comparison to local soil moisture than descending overpasses for all three performance metrics. This may have been due to the presence of RFI and other errors which has resulted far fewer successful retrievals during descending overpasses.

For ascending overpasses the correlation between *SM-SMOS*, $CDF-\overline{OBS}_i$ and $CDF-OBS_i$ with OBS_i is relatively minor showing that the CDF matching technique provides only minor improvements in what was presumed the random component of the SMOS errors. CDF matching provides greater improvement in the correlation for the descending overpasses which may be an artefact of the small sample size. In all cases, CDF matching did improve the correlation compared to a comparison with raw SMOS L2 soil moisture.

Comparing the bias between (OBS_i, $\overline{OBS}_i$) and (OBS_i, $CDF-\overline{OBS}_i$) with a Kruskal-Wallis test (α = 0.01) reveals that the biases share the same distribution. This indicates that CDF matching *SM-SMOS* to $\overline{OBS}_i$ preserved the relative spatial distribution (i.e. temporal stability) of the soil moisture stations as compared to the relative difference to the actual $\overline{OBS}_i$ value. When the CDF of *SM-SMOS* was matched to each station in OBS_i the bias predictably reduced to near zero and there was a corresponding decrease in RMSE for most ascending overpasses. The greater error in the SMOS descending overpass (see Fig. 1) resulted in CDF matching producing a near zero bias, but increased the RMSE and decreased the correlation between OBS_i and $CDF-\overline{OBS}_i$ for descending overpasses.

5. CONCLUSIONS

Matching the cumulative distribution function of satellite retrieved soil moisture is a recommended practice prior to data assimilation [5] and comparison with *in situ* measurements of soil moisture [6] as it eliminates bias in the retrieval. In most cases, there is a presumed consistency between the scale of the retrieved soil moisture and that of the *in situ* measurements. This study presents a preliminary evaluation of the use of CDF matching to downscale soil moisture from the scale of the satellite retrieval to that of local scale measurements.

Prior to downscaling SMOS soil moisture, it was demonstrated that the weighted mean of all observations was highly correlated with that of individual sites showing consistency of the soil moisture temporal dynamics. At the grid scale, matching the SMOS CDF to that of $\overline{OBS}_i$ significantly decreased the bias and RMSE of SMOS soil moisture while having little impact on correlation. The same patterns of spatial bias were found between $CDF - \overline{OBS}_i$ and $\overline{OBS}_i$ with each individual site, confirming that the sub-grid temporally stable soil moisture pattern was retained. Matching the CDF of *SM-SMOS* to that of each individual site eliminated the bias between the two datasets but had little impact in further improving the RMSE or correlation beyond that of matching the CDF of SMOS to that of grid scale observed soil moisture. Therefore, matching the CDF of SMOS retrieved soil moisture to that of sub-grid soil moisture can be an effective downscaling technique to remove time in-variant errors with minimal impact on the time-variable errors in comparison to grid scale mean soil moisture CDF matching.

6. ACKNOWLEDGEMENTS

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