Soil Moisture from Point to Footprint Scale: Spatio-Temporal Variability, Time Stability, and Physical Controls

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Soil moisture is a key state variable of the hydrologic cycle. It plays a significant role in many hydrological, meteorological and other natural processes in the land-atmosphere continuum. In the past two decades we have conducted several field campaigns to better understand the underlying processes controlling the spatio-temporal variations of soil moisture using multiple ground, air, and space-borne sensors. In this effort, we will present characteristics spatio-temporal variabilities, time stability, as well as their geophysical controls at different measurement support scales (point-scale, airborne, to space borne remote sensor footprints) in different hydro-climatic regions. The data used in the analyses consist of *in-situ* and passive microwave remotely sensed soil moisture data from Southern Great Plains hydrology experiments 1997 and 1999 (SGP97 and SGP99) conducted in Little Washita (LW) watershed, Oklahoma, and Soil Moisture Experiments 2002 and 2005 (SMEX02 and SMEX05) in Walnut Creek (WC) watershed, Iowa. Results show that in both the regions soil properties (i.e., percentage silt, percentage sand, and soil texture), and topography (elevation and slope) are significant physical controls jointly affecting the spatio-temporal evolution and time stability of soil moisture at both point- and footprint-scale. In Iowa, using point scale soil moisture measurements, WC11 field was found to be more time stable than the WC12 field. The common time stable points using data across the 3-year period (2002-2005) were mostly located at moderate to high elevations in both the fields. Further, the soil texture at these locations consists of either loam or clay loam soil. Drainage features and cropping practices also affected the field-scale soil moisture variability in the WC fields. In Oklahoma, the field having a flat topography (LW21) showed worst time stable features compared to the fields (LW03 and LW13) having gently rolling topography. The LW13 field (silt loam) exhibited better time stability than LW03 field (sandy loam) and LW21 (silt loam) field. At the remote sensing footprint-scale, the ANOVA tests show that the percentage clay and percentage sand are better able to discern the time stable features of the footprints compared to the soil texture in Iowa.

The best soil indicator of soil moisture time stability is the loam soil texture. Further, the hilltops (slope ~ 0-0.45%) exhibited the best time stable characteristics in Iowa. On the other hand, in Oklahoma, ANOVA results show that the footprints with sandy loam and loam soil texture are better indicators of the time stability phenomena. In terms of the hill slope position, footprints with mild slope (0.93-1.85%) are the best indicators of time stable footprints (*Fig. 1*). Also, at both point- and footprint-scale in both the regions, land use/land cover type does not influence soil moisture time stability.

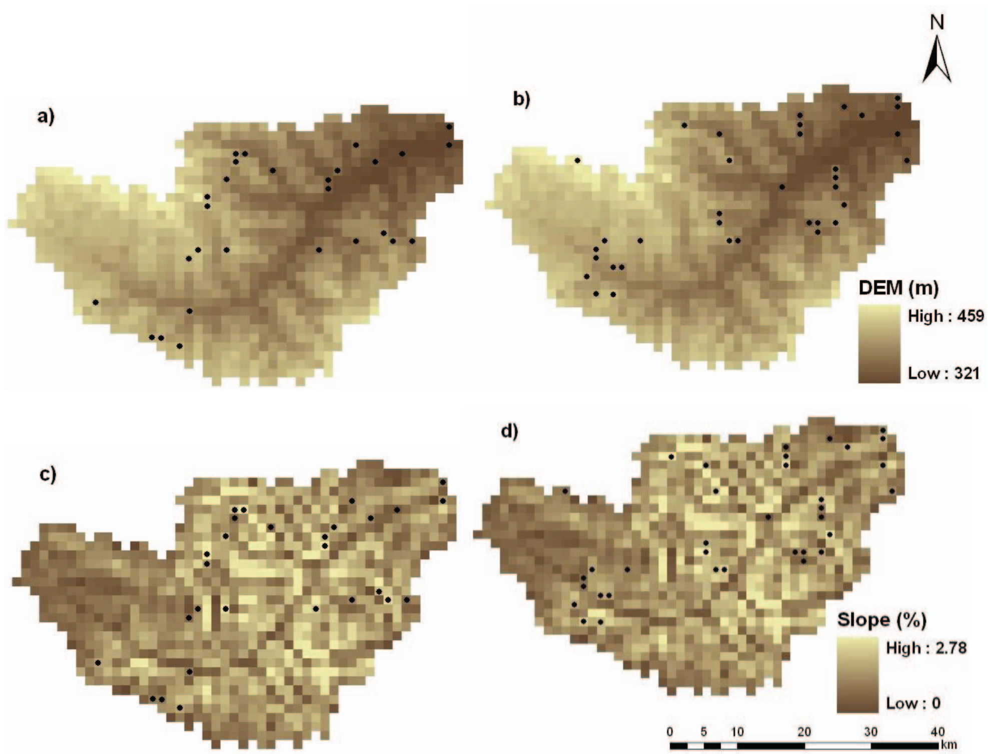

Figure 1. (a) & (b) DEM, and (c) & (d) slope of LW watershed (Oklahoma) showing the location of time stable pixels estimating the watershed mean soil moisture within ± 1 % VSM during SGP97 and SGP99, respectively, for the Electronically Scanned Thinned Array Radiometer (ESTAR) dataset.

A geostatistical analysis (using isotropic semivariograms) was conducted to investigate the evolution of spatial structure and correlation lengths of daily soil moisture fields at different scales. At the field-scale (spherical model), watershed-scale (Gaussian model) and regional-scale (exponential model) provided good fits. The correlation lengths increased with decreasing soil moisture content at the field-scale as well as within the WC watershed. At the SMEX02 regional-scale, the trend is opposite with correlation lengths being higher on wet days compared to the dry days. This is because when the soil moisture content is high following a large storm event, the regional study site is closer to saturation, and hence, the soil moisture variability is lower resulting in higher correlation lengths. On the other hand the nugget variance is highest at the field-scale due to increased micro-heterogeneity compared to the watershed- and the regional-scale. Further, the EOF approach was employed to examine the underlying geophysical patterns for determining the different modes of soil moisture variability and the portion of variance explained by each of the mode. At the field-scale, it took four EOFs to explain about 81% of the total variability, although the primary EOF (or EOF1) was dominant throughout the observation period compared to the rest of the EOF patterns. At the watershed-scale, both EOF1 and EOF2 were dominant (*Fig. 2*), whereas at the regional-scale, EOF1 itself explained more than 70% of the variability. Thus, complex soil moisture patterns can largely be explained by a very

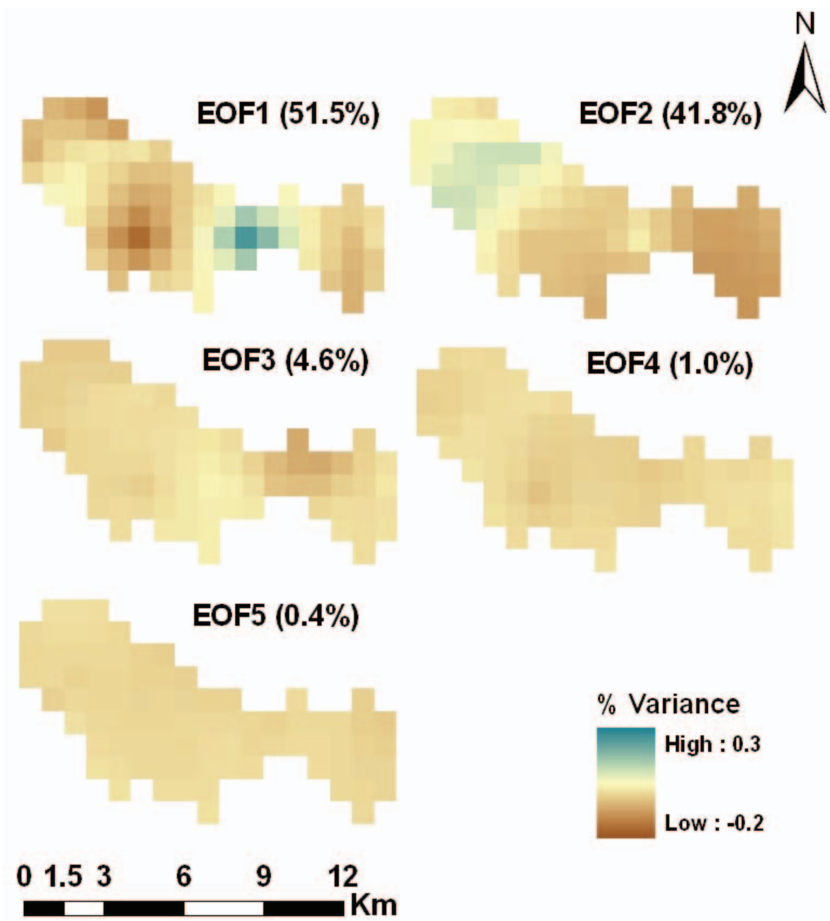

Figure 2. The first five EOFs generated from the spatial anomalies of Polarimetric Scanning Radiometer (PSR) derived soil moisture and the variance explained by each EOF/PC pair at Walnut Creek watershed, Iowa (SMEX02).

small number of underlying orthogonal spatial structures related to the geophysical attributes of the region. At the field- and the watershed-scale, precipitation did not seem to directly affect the primary EOF structure, both when the complete soil moisture dataset was analyzed as well as when the dry, average, and wet days were considered individually. On the other hand, at the regional-scale, precipitation appeared to affect the primary EOF for wet days and average days, though the extent of the effect has not been determined here. Finally, the relationship between various regional characteristics (topography, soil texture, and vegetation) and the EOF patterns was examined to determine the dominant control on the soil moisture variability patterns at the watershed- and the regional-scale. Results of the correlation analysis showed that both topography and soil texture have mixed effects on the variability explained by the dominant EOFs, at both watershed- and regional-scale.

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