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Technical note

Spatial patterns of soil moisture from two regional monitoring networks in the United States

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ABSTRACT

Understanding soil moisture spatial variability (SMSV) at regional scales is of great value for various purposes; however, relevant studies are still limited and have yielded inconsistent findings about the primary controls on regional SMSV. To further address this issue, long-term soil moisture data were retrieved from two large scale monitoring networks located in the continental United States, including the Michigan Automated Weather Network and the Oklahoma Mesonet. To evaluate different controls on SMSV, supporting datasets, which contained data on climate, soil, topography, and vegetation, were also compiled from various sources. Based on temporal stability analysis, the results showed that the mean relative difference (*MRD*) of soil moisture was more correlated with soil texture (e.g., negative correlations between *MRD* and sand fraction, and positive ones between *MRD* and silt and clay fractions) than with meteorological forcings in both regions, which differed from the traditional notion that meteorological forcings were the dominant controls on regional SMSV. Moreover, the results revealed that contrary to the previous conjecture, the use of soil moisture temporal anomaly did not reduce the impacts of static properties (e.g., soil properties) on soil moisture temporal dynamics. Instead, it was found that the magnitude of soil moisture temporal anomaly was mainly negatively correlated with sand fraction and positively with silt and clay fractions in both regions. Finally, the relationship between the spatial average and standard deviation of soil moisture as well as soil moisture temporal anomaly was investigated using the data from both networks. The field data showed that the relationship for both soil moisture and soil moisture temporal anomaly was more affected by soil texture than by climatic conditions (e.g., precipitation). The results of this study provided strong field evidence that local factors (e.g., soil properties) might outweigh regional factors (e.g., meteorological forcings) in controlling regional SMSV.

1. Introduction

Soil moisture plays a key role in terrestrial water cycles by linking various land surface and subsurface processes across scales. At local scales, soil moisture partly determines the partitioning of precipitation (*P*) and incoming radiation into different components (Bronstert and Bárdossy, 1999; Vivoni et al., 2008; Evaristo et al., 2015). At regional scales, soil moisture interacts with land surface processes in complex feedback mechanisms (Koster et al., 2004; Jung et al., 2010; Taylor et al., 2012). Meanwhile, owing to the complex interactions with surrounding environments, soil moisture generally exhibits significant spatiotemporal variability (Martinez-Fernandez and Ceballos, 2003; Famiglietti et al., 2008; Brocca et al., 2010; Joshi and Mohanty, 2010; Vanderlinden et al., 2012; Vereecken et al., 2014; Wang, 2014; Wang et al., 2015a). It is thus critical to evaluate the factors that affect soil moisture spatial variability (SMSV) at different scales. Based on previous studies (e.g., Vinnikov et al., 1996; Robock et al., 1998; Entin et al., 2000), Seneviratne et al. (2010) separated the controls on SMSV into two spatial scales. At the scale less than 20 km, local factors (e.g., soil, topography, and vegetation) mostly affect SMSV; whereas, at the regional scale between 50 and 400 km, meteorological forcings (e.g., *P* and radiation) play more important roles in controlling SMSV.

Although numerous efforts have been made to elucidate the impacts of local factors on SMSV (Mohanty and Skaggs, 2001; Jawson and Niemann, 2007; Vanderlinden et al., 2012; Vereecken

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et al., 2014), studies on regional controls on SMSV are still limited. More importantly, existing studies have yielded inconsistent findings about the primary controls on regional SMSV. For instance, by adopting a statistical model that was based on a first order Markov process with added white noise, Vinnikov et al. (1996) found that the spatial scale of the red noise component of soil moisture from Russia was roughly 500 km. Entin et al. (2000) expanded the work of Vinnikov et al. (1996) to include soil moisture data from China, Mongolia, Russia, and the United States. The authors also showed that for all regions, the spatial scale of the red noise component of soil moisture was about 500 km, and thus suggested that meteorological forcings were the dominant controls on regional SMSV. Based on temporal stability analysis (*TSA*), Cho and Choi (2014) examined the regional SMSV from the Korean Peninsula. The results revealed that the spatial distribution of mean relative difference (*MRD*; an indicator of the relative wetness condition at a location) of soil moisture was mostly controlled by *P* over the Korean Peninsula.

However, recent studies have shown that local factors might outweigh meteorological forcings in controlling regional SMSV. For example, using Empirical Orthogonal Function (EOF), Joshi and Mohanty (2010) investigated the spatial pattern of soil moisture from the Soil Moisture Experiment 2002 in Iowa at three spatial scales. The authors found that at the regional scale, the primary spatial structure of soil moisture, which explained over 70% of the total spatial variance of soil moisture, was more correlated with sand and clay fractions than with *P*. Using EOF analysis, Wang et al. (2017a) further demonstrated the dominant control of soil texture on regional SMSV in three regions of the United States. Based on the data from Utah and the Southeast United States, Wang and Franz (2015) showed that *MRD* in both regions was highly correlated with the residual soil moisture content, while no significant correlations were found between *MRD* and meteorological forcings. Contrary to previous work, the above three studies suggested that the impacts of local factors, particularly soil properties, might override the impacts of meteorological forcings on regional SMSV. Therefore, the inconsistent findings from existing studies still warrant further investigations of the mechanisms that control regional SMSV.

Moreover, Mittelbach and Seneviratne (2012) proposed to use soil moisture temporal anomaly for studying regional patterns of soil moisture. By decomposing soil moisture spatial variance into time-invariant and time-variant components, the use of soil moisture temporal anomaly was conjectured to reduce the impacts of static properties (e.g., soil properties) on soil moisture temporal dynamics and thus thought to primarily reflect the impact of climatic conditions (Brocca et al., 2014). However, to the authors' knowledge, no attempts have been made to examine the conjecture made by Mittelbach and Seneviratne (2012) using field observations, which still deserves further investigation.

The goals of this note were twofold: (1) to elucidate primary controls on regional SMSV and (2) to test the assumption that the use of soil moisture temporal anomaly reduces the impacts of static properties on soil moisture temporal dynamics. To this end, long-term soil moisture data were retrieved from two large scale monitoring networks, namely the Michigan Automated Weather Network (MAWN) and Oklahoma Mesonet (OK Mesonet), located in the continental United States. Comprehensive datasets (e.g., climate, soil, topography, and vegetation) were compiled from various sources. To examine the impacts of different factors on regional SMSV, the *TSA* method was used as a diagnostic tool. In addition, the relationship between the spatial average and standard deviation of soil moisture as well as soil moisture temporal anomaly was also investigated. The results of this study offer additional insights into understanding the mechanisms that control SMSV at regional scales.

2. Method and materials

2.1. Datasets

With the development of sensor technology, regional scale automated soil moisture monitoring networks have become increasingly available around the globe (Ochsner et al., 2013). In this study, two monitoring networks (i.e., the MAWN from Michigan and the OK Mesonet from Oklahoma) were chosen (Fig. 1). At the MAWN sites, volumetric soil moisture content is measured using water content reflectometers (model CS615 or CS616, Campbell Scientific Inc., Logan, Utah; Xu et al., 2015). At the OK Mesonet sites, soil matric potential is first measured using heat dissipation sensors (model 229, Campbell Scientific Inc., Logan, Utah; Scott et al., 2013) and then converted to volumetric soil moisture content. Daily soil moisture data spanning from 2008 to 2010 at the MAWN and OK Mesonet stations were acquired from the North American Soil Moisture Database (NASMD; http://soilmoisture.tamu.edu/), which archives soil moisture data from national and state monitoring networks across North America. Soil moisture data from the NASMD have been quality controlled and extensively used for soil moisture related studies (e.g., McPherson et al., 2007; Illston et al., 2008; Quiring et al., 2016; Ford et al., 2017). In the following analysis, soil moisture data at 4 and 10 cm from 38 MAWN stations and at 5 and 25 cm from 65 OK Mesonet stations were used (Fig. 1). Note that missing soil moisture data (<3% of the total records for the selected stations) were linearly interpolated. In addition, to minimize the freezing effect at the MAWN stations, soil moisture data were limited between April 1 and October 31 of each calendar year in the following analysis.

For meteorological forcings, annual *P* and potential evapotranspiration (ET_p) were obtained from the MAWN (https://mawn.-

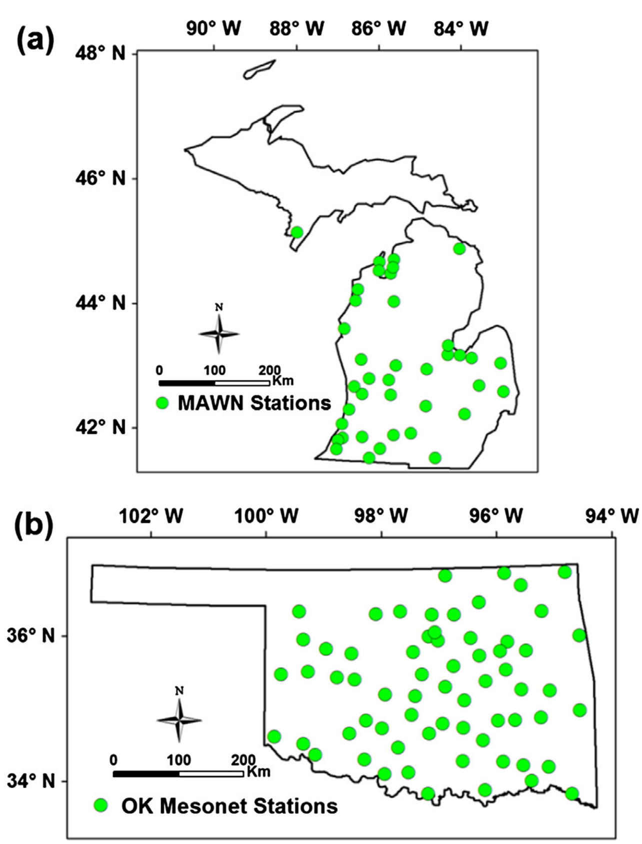

Fig. 1. Location map of the stations from the Michigan Automated Weather Network (MAWN) and Oklahoma Mesonet (OK Mesonet).