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Temporal stability of surface soil moisture in the Little Washita River watershed and its applications in satellite soil moisture product validation

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Abstract

The concept of temporal stability can be used to identify persistent soil moisture patterns and estimate the large scale average from select representative sensor locations. Accurate and efficient estimation of large-scale surface soil moisture is a primary component of soil moisture satellite validation programs. However, monitoring the soil surface at large grid scales is difficult. As part of the aqua satellite advanced microwave scanning radiometer (AMSR) Validation Program, a soil moisture sensor network was installed in the little Washita river watershed in Oklahoma, USA in 2002. Along with data from the soil moisture experiment 2003 (SMEX03), this network will provide a valuable dataset for satellite soil moisture product validation. Analysis shows that most of the network sensors are temporally stable at multiple scales and four sites are identified as representative with negligible bias and small standard deviation to the watershed mean. As part of this analysis, the protocols established for large-scale soil moisture sampling campaigns such as in the soil moisture experiments (SMEX) are validated. This analysis showed that basing grid scale estimates on six sampling points is reasonable and accurate. Temporal stability is shown to be a valuable tool for soil moisture network analysis and can provide an efficient means to large-scale satellite validation.

Keywords: Temporal stability analysis; Time series analysis; Surface soil moisture; Soil Moisture experiment 2003 (SMEX03); Little Washita river watershed

1. Introduction

Estimating spatial soil moisture has long been a challenge using conventional technologies. New options are emerging that utilize remote sensing and modeling (Njoku et al., 2003; Robock et al., 2003). However, these techniques still require validation using conventional methods. Here, the primary interest is in the validation of passive microwave observations, such as those provided by the advanced microwave scanning radiometer (AMSR) for estimation of surface soil moisture. These measurements are made over large footprints or pixels (the area on

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the ground that the sensor measures) on the order of 10–50 km in diameter. Few current monitoring networks are either dense or extensive enough to estimate the footprint scale surface soil moisture with a good degree of accuracy. The mismatch in scale between satellite footprints (>10 km) and ground sampling (∼5 cm) makes most attempts at statistical sampling difficult.

Warrick et al. (1977) and Russo and Bresler (1980) demonstrated that by using soil moisture scaling theory, moisture field averages could be accurately estimated using only point observations. Some recent studies have focused on approaches to scaling at large resolutions, including geostatistical analysis (Western and Bloschl, 1999), probability density function analysis (Avissar and Pielke, 1989), and fractal analysis (Rodriguez-Iturbe et al., 1995). Each of these approaches assumes some knowledge of the surface soil moisture distribution at finer resolutions, as a result of intensive sampling campaigns over long periods of time (Chen et al., 1995; Kachanoski and De Jong, 1988; Yoo, 2002). Other geostatistical analyses, such as kriging (Delhomme, 1979; Burgess and Webster, 1980) and semivariogram analysis (Cosh and Brutsaert, 1999) require a dense sampling network to capture the spatial character of the soil moisture field. Vinnikov et al. (1999) studied the impact of increasing the number of point samples in a study region, to identify the threshold number of sites for accurate (low error) estimation. This point theory approach carries the burden of bias. Random selection within a domain can result in the selection of a point with high bias, which can significantly alter the large-scale estimate.

As a solution to this dilemma, Vachaud et al. (1985) proposed the method of temporal stability to determine representative locations within a field, thus improving sampling efficiency while maintaining accuracy. Their study estimated large-scale soil moisture in a 2000 m^2 grass field by determining which sampling locations within the study region maintain a low bias relationship to the spatial average and also have low variability. By extending this concept to a temporally stable soil moisture sensor network, it may be possible to create a dataset of considerable quality for validation of large-scale estimates.

Grayson and Western (1998) extended the work of Vachaud et al. (1985) by examining small watersheds with significant relief ranging in size from 0.1 to 27 km^2. These included the Tarrawarra catchment (Australia), mostly dryland grazing, Chickasha, OK, USA, mostly pastures and winter wheat, and Lockyersleigh (Australia), mixed grazingland and woodland. The limitation of these watersheds was the small scale. Kachanoski and De Jong (1988) argued that spatial scales must be considered in temporal stability analysis. These scales could include the correlation length scale, which they applied to a small grassland field in Canada. Mohanty and Skaggs (2001) expanded this work by studying how various surface parameters, such as soil type, slope, and vegetation cover, affected the spatio-temporal stability of grassland and winter wheat near Chickasha (OK, USA). In another investigation, Cosh et al. (2004) studied a temporary network of surface soil moisture sensors near Ames, Iowa as part of the Soil Moisture Experiment 2002 (SMEX02). These sensors were located throughout a small agricultural watershed dominated by corn and soybean fields. Temporally stable sites were identified and moisture patterns were shown to be persistent for a short time period, though they concluded a longer time period is necessary.

As these studies demonstrate, large-scale estimation of surface soil moisture can present a difficult task for hydrologists and climatologists. The process requires a dense network of moisture probes located throughout a region, which is difficult to install and maintain. One approach to this problem is to utilize temporal stability in hopes of identifying representative as well as anomalous sites. If a site is temporally stable with regard to surface soil moisture, it has a persistent relationship with the well-defined large-scale average for a long period of time. Using this information, sampling schemes can be made more efficient by reducing the number of monitoring sites, while maintaining the accuracy of the network based estimate. In this investigation, the following concepts are explored. First, the integrity of a large-scale network of soil moisture sensors located near Chickasha, OK is analyzed through temporal stability analysis for a 21-month study period. This analysis identifies sites that are not representative of the footprint scale. In addition, the network representativeness is assessed using the SMEX03 Field Experiment data from the summer of 2003. Also, the impact of two different time scales, seasonal