ESTAR- and model-derived multiscaling characteristics of soil moisture during SGP'97, Washita '92 and Washita '94

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***Abstract*-Using a spatially distributed water and energy balance model, we investigate the spatial structure of surface fluxes and states for the Washita '92 field experiment and the August campaign of the Washita '94 field experiments. For Washita '92, the model is validated against gravimetric and remotely-sensed soil moisture, and for Washita '94, the model is validated against gravimetric soil moisture and measured energy fluxes. The model is shown to reasonably represent land-atmosphere interactions during the experimental periods. Scaling analysis of soil moisture and latent heat flux is indicative of multiscaling behavior. The multiscaling behavior of soil moisture and latent heat flux is hypothesized as a relationship that is a function of average soil moisture, and this relationship seems to fit the data quite well. Similar scaling analysis of important land surface properties indicates simple scaling for porosity, field capacity and leaf area index, and multiscaling for residual soil moisture and the soils-topographic index. This is consistent with model results, which indicate a transition from simple scaling to multiscaling with dry-down. It is hypothesized that this transition is governed by the scaling properties that in wet conditions control infiltration (porosity, field capacity, leaf area index) to properties that in dry conditions control drainage (residual moisture content and soils-topographic index).**

INTRODUCTION

There has been considerable interest of late in the scaling properties of soil moisture, given its importance in land-atmosphere interaction, as well as agricultural, hydrologic and ecological applications. This endeavor has been given a sense of urgency as scientists seek to employ the forthcoming satellite-based soil moisture products in models and analysis which seemingly require more spatial detail.

One of the earliest works to suggest that remotely sensed soil moisture is a multiscaling field was that of [1], who analyzed the Washita '92 [2] 200m resolution airborne ESTAR L-band soil moisture products from June 11, 14 and 18. In addition, they, along with [3,4] studied the scaling properties of porosity in order to investigate the logical causal link between the scaling properties of porosity and soil moisture. Later analyses with the same data have provided strong evidence for multiscaling which changes with moisture condition [5,6]. [5] applied a spatially distributed water and energy balance model and found that the model did not reproduce the moisture-dependent scaling behavior of the ESTAR soil moisture fields. [6] provide sound empirical evidence for the multiscaling behavior, and decompose the fields to identify simple scaling behavior for the small-scale components. In addition, they question the results of [3], in which scaling analysis of the model-derived soil moisture fields for the same period show an upward-concavity which increases with dry-down. This counter-intuitive behavior seems to have been partially corrected in [5] who apply essentially the same model to the same period with the modifications of a thin soil layer and soil resistance parameterization as described by [7].

As [8] notes, the progress in scaling of hydrologic remote sensing and scaling of hydrologic processes at the 10^3 km^2 scale has been minor due to lack of reliable datasets as well as deficiencies in field experiment design. Quantifying the spatial structure of surface fluxes and states is critical for comparisons with and incorporation of remotely sensed measures of these quantities in land-atmosphere models. In addition, it may be important for "sub-grid" turbulence parameterizations in numerical weather prediction and climate models to represent the buoyant production of turbulent kinetic energy due to latent and sensible heat flux variability. Thus, if simple relations between small- and large-scale statistics of soil moisture and/or surface latent and sensible heat fluxes can be found, small-scale variability in the flux might be inferred from a coarser resolution model.

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In this work, we employ a spatially distributed water and energy balance model to investigate the scaling properties of surface soil moisture for three experimental periods in the Southern Great Plains (SGP): i) the June 12-18 Washita '92 [2] campaign; ii) August Washita '94 campaign [9], and iii) the SGP'97 Hydrology Experiment [10]

TOPLATS-GIS MODEL VALIDATION

The model applied in this work to simulate land surface water and energy fluxes and states is the explicitly distributed TOPmodel-based Land-Atmosphere Transfer Scheme (TOPLATS-GIS) as described in [7,11].

The data used in this work both for verification and model forcings were collected and/or compiled during the June Washita '92 [2], August campaign of Washita '94 [9] and the SGP'97 Hydrology Experiment [10]. For Washita '92, model forcing data are derived from 4 temporary meteorological stations as discussed in [12]. For Washita '94 and SGP '97, model forcing data include USDA/ARS Micronet stations in the Little Washita Watershed in addition to the Oklahoma Mesonet stations. The model was run for the experimental periods at a 30 m resolution with an hourly timestep. All input forcing data were interpolated the 30 m model grid. In addition, georegistered 30-m resolution coverages of spatially distributed soils texture, land cover, and soils-topographic index were input the model, with user-defined lookup tables for the required parameters. More information about the parameters required by TOPLATS-GIS can be found in [7,11].

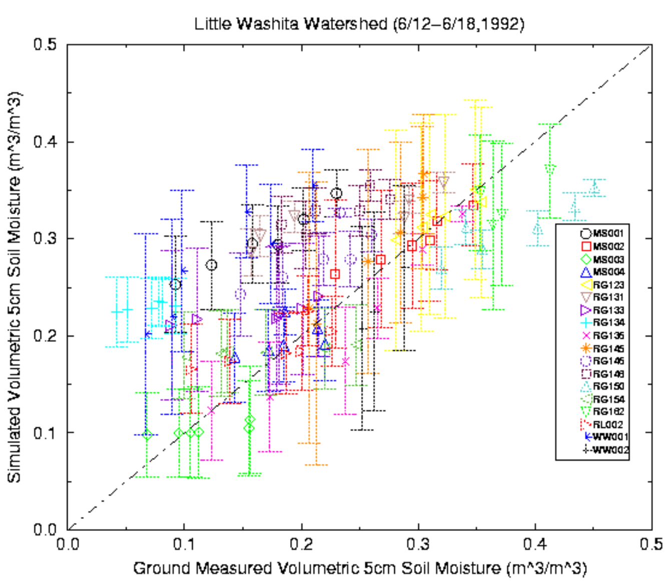

Figure 1. Washita '92 modeled vs. measured 5-cm volumetric soil moisture. Symbols indicate field averages, and errorbars indicate model spatial standard deviation over the field.

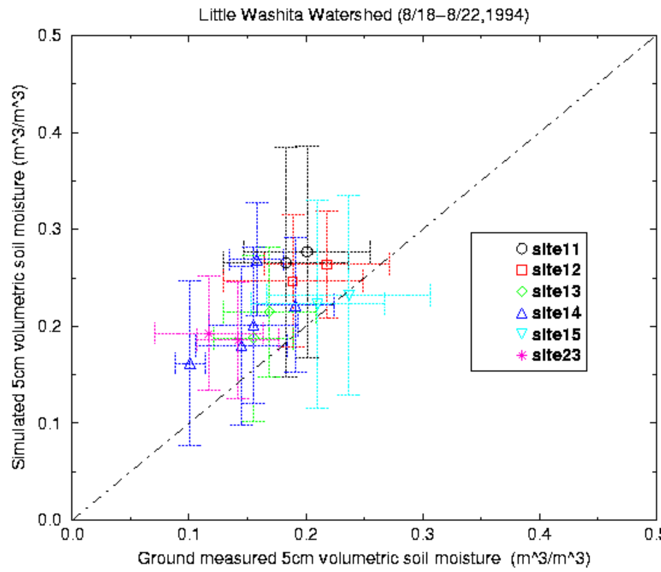

Figure 2. Same as Figure 1, but for Washita '94.

As discussed in [2,10], the airborne ESTAR was flown during Washita '92 and SGP'97, and the derived soil moisture products have been validated against gravimetric measurements on a field-by-field basis. During Washita '94, gravimetric soil moisture samples were taken at 14 sites. The gravimetric data and ESTAR products are used in the current work for comparison with the model-predicted 5-cm volumetric soil moisture.

Figures 1 and 2 show modeled versus measured volumetric soil moisture for the Washita '92 and Washita '94 field campaigns, respectively. The errorbars indicate model and/or sample standard deviations for the fields sampled, as shown by the symbols on the figures. Overall, the figures indicate a reasonable agreement between the model and measurements, with a tendency for the model to be too wet.

MULTISCALING ANALYSIS

The notation for the multiscaling analysis is identical to that of [5]. For Washita '92, Figures 3 and 4 suggest a nearly monotonic behavior of the scaling exponent K(q) vs. order of moment q during drydown. However, past work on the subject (discussed above) has focused primarily on three days during the experiment: June 11, 14 and 18. Although these days exhibit a monotonic behavior of their scaling exponents with drydown, Figure 3, shows that the behavior of ESTAR-derived scaling exponents is not monotonically decreasing. In fact, there seems to be three distinct regimes from June 10-13, June 13-16, and June 16-18. One might hypothesize that these regimes correspond to transitions from ``atmospheric" (regime 1) to "infiltration" (regime 2) to "drainage/evaporation" (regime 3) control during the interstorm period.

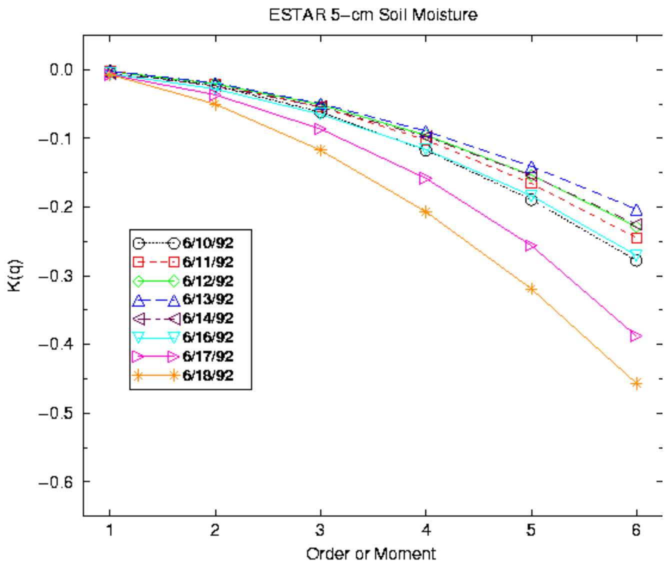

Figure 3. ESTAR-derived scaling exponent K(q) versus order moment q for the June 10-18 drydown period of Washita '92.

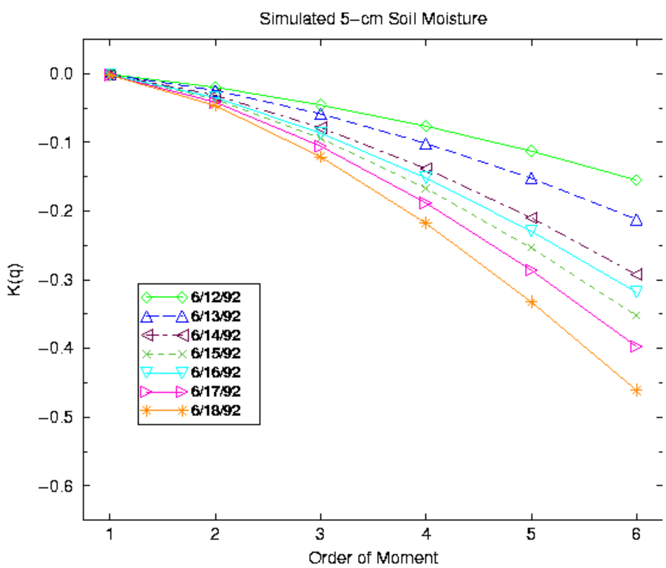

Figure 4. Same as Figure 3, but derived from the TOPLATS-GIS model.

CONCLUSIONS

Scaling analysis of model-predicted soil moisture from all three experimental periods is indicative of multiscaling behavior, which increases with dry-down, consistent with previous analyses of the Washita '92 data. This is the first time, to our knowledge, that a model has been shown capable of representing time-varying scaling properties of soil moisture. The multiscaling behavior of soil moisture is hypothesized as a relationship that is a function of average soil moisture, which seems to fit the data quite well.

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