Comment on the paper „Field observations of soil moisture variability across scales” by Famiglietti et al.

Vereecken H.(1), T. Kamai(2), T. Harter(2), R. Kasteel(1), J.W. Hopmans(2), J.A. Huisman(1), and J. Vanderborght(1)

[1]Agrosphere (ICG-4), Institute of Chemistry and Dynamics of the Geosphere (ICG), Forschungszentrum Jülich GmbH, D-52425 Jülich, Germany

[2]Department of Land, Air and Water Resources, 113 Veihmeyer Hall; University of
California, Davis, CA 95616-8628

1. Abstract

In a recent paper, Famiglietti et al. (2008) analyzed more than 36,000 ground-based soil moisture measurements to characterize soil moisture variability across spatial scales ranging from 2.5 m to 50 km. They concluded that the relationship between soil moisture standard deviation versus mean moisture content, $\sigma_\theta(\langle\theta\rangle)$, has a convex upward behaviour with maximum values occurring at mean moisture contents of 0.17 cm^3/cm^3 and 0.19 cm^3/cm^3 for the 800 m and 50-km scale, respectively. Based on these data, they derived empirical relationships between the coefficient of variation and the mean soil moisture content in order to estimate the uncertainty in field observations of mean moisture content. The authors are to be commended for providing this valuable database to the scientific community. We agree with the authors that such data are important in improving our understanding about the importance of sub-grid moisture variability in the parameterization and simulation of land surface processes. However, the authors limited themselves to an empirical description of the observed data by fitting exponential relationships to the mean moisture content versus CV data. We feel that this is a missed opportunity and would like to argue that an interpretation based on established theories and concepts in soil hydrology and upscaling theories could provide alternative methods and new insights for interpreting such data sets.

2. Soil hydraulic properties and soil moisture variability

It can be shown from soil physical concepts that for a homogeneous soil, the shape of the moisture retention curve can largely explain observed variations in surface soil moisture, at any specific observation scale. For heterogeneous soils, stochastic upscaling theories may be used to relate $\sigma_\theta(\langle\theta\rangle)$ to spatial variability in soil hydraulic properties. These theories can be used to predict $\sigma_\theta(\langle\theta\rangle)$ and to examine the sensitivity of this function with respect to soil hydraulic properties.

To better illustrate the potential contributions of the soil water retention curve on spatial variations of surface soil moisture for homogeneous soil, we present the hysteretic soil water retention curves across a range of soil textures in Fig. 1. The soil water retention curve defines the unique relation between soil water potential, expressed by soil water pressure head (h, cm) and soil water content (θ, cm^3 cm^{-3}), as determined by the soil's pore size distribution. The functional relationships used to describe the curves were introduced by van Genuchten (1980), with corresponding parameters listed in Table 1, representative for a sand, silt and clay, as determined by Carsel and Parrish (1988). We chose to present the curves using a logarithm scale, to better illustrate the soil's water retention in the dry range. As shown in Fig.1, soil water content variations are expected to be the largest for intermediate values of soil water content, θ, thus providing for a simple soil physical explanation for the upward concave shape of Fig. 1 of Vereecken et al. (2007), and of Fig. 6 in Famiglietti et al. (2008). Variability in h for a uniform soil may result from spatial variations in the soil moisture regime, such as by plant water uptake, evaporation/infiltration and fluctuating water tables.

In this comment, we like to further impress the notion that observed spatial variations in field soil water content can be partially explained by the shape of the soil water retention curve, with the dependence partly determined by the slope of the retention curve, dθ/dh, also known as the soil water capacity, C (cm^{-1}). For the van Genuchten relationship, it is given by

$$\frac{d\theta}{dh} = (\theta_s - \theta_r)\left[1 + (\alpha|h|)^n\right]^{\left(\frac{1}{n}-2\right)}(\alpha|h|)^{n-1}\alpha(n-1) \qquad , [1]$$

Conceptually, this situation would occur in a homogeneous soil with spatially variable infiltration.

where θ_r and θ_s denote the residual and saturated soil water content, and α and n are curve meters (van Genuchten, 1980). In addition to presenting the soil water capacity in id line), we show two additional curves that can partly explain the typical concave ociated with spatial variations of surface soil moisture. The second curve in Fig. 2, y the dashed lines, shows $\Delta\theta/\Delta h$ as a function of θ, computed numerically, with Δh equal to h, and centered around h. For example, at h = -1000 cm, the range of Δh is between -500 and -1,500 cm, with a corresponding $\Delta\theta$ that is associated with these h-values. This increase in Δh with h is typically observed in the field where the largest spatial variations in soil water potential occur in the dry range, and it results in a shift of the curves to the left, with maximum variation values depending on soil texture. To further illustrate the relevance of the soil moisture retention curve, we added a third curve (dashed-dotted lines), to show the additional effect of hysteresis of soil water retention (drying curve) on spatial water content variation. These curves show the difference in h between the main drying and wetting curves, Δh-hysteresis, as a function of the mean soil water content, and illustrate that spatial variations in soil water content are expected to show an upward concave curve, caused by spatial variations of the wetting or drying regime of the surface soil. We hope that the presented illustration makes a clear case that soil physical concepts can be used to explain riations in surface soil moisture across spatial scales even for a homogeneous soil.

Again, conceptually this situation may occur in a homogeneous soil with spatially variable infiltration.

of heterogeneous soils, it is well known that also the variability in the parameters ture retention characteristic play an important role in determining soil moisture (e.g. Vereecken et al., 2007a). Numerical simulations of soil moisture variability at different degrees of saturation in heterogeneous unsaturated porous media were performed by Roth (1995) and Harter and Zhang (1999) amongst others. Their results show that soil moisture variability peaks at medium soil moisture content values. Closed form expressions for the relationship between soil moisture variance and the statistical properties of soil hydraulic parameters were derived by e.g. Russo et al. (1998) for steady state unsaturated flow using the Gardner-Russo model of the moisture retention characteristic. An overview of the state of the art in using stochastic methods for unsaturated flow in heterogeneous soils was given by Zhang (2002). Recently, Vereecken et al. (2007) used results from stochastic analysis of unsaturated flow in heterogeneous soils obtained by Zhang et al. (1998) to predict the observed convex upward shapes of $\sigma_\theta(\langle\theta\rangle)$ also reported by Famiglietti et al. (2008). Using this relationship for eleven textural classes, Vereecken et al. (2007b) showed that the standard deviation of soil moisture peaked between 0.17 and 0.23 cm^3/cm^3 for most textural classes. In addition, the parameter describing the pore-size distribution of soils controlled the maximum value of the soil moisture standard deviation. The mean soil moisture values at which the maximum soil moisture variability occurs are in very good agreement with the values obtained by Famiglietti et al. (2008) from their very large database. This indicates the potential value of stochastic theories of soil water processes in explaining and predicting the observed spatial variability of soil moisture across scales. In this respect, we would like to argue that $\sigma_{\theta}(\langle\theta\rangle)$ can be considered as a fundamental property of a heterogeneous soil, which is related to the spatial variability in the moisture retention characteristic. Perturbations of the $\sigma_{\theta}(\langle\theta\rangle)$ relationship may be caused by spatially and temporally heterogeneous fluxes and sink/sources such as infiltration, evaporation, root water uptake, evaporation and surface runoff. Taking stochastic theory as a starting point for the interpretation of observed soil moisture variability and integrating and further developing upscaling approaches combined with integrating knowledge from the fields of remote sensing and hydrology may finally lead to a better understanding and a more fundamental interpretation of the role of soil moisture variability in land surface processes across scales.

Have you guys looked at Famiglietti's data to see, whether we can deduce the stochastic parameters from it?

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Table 1. Van Genuchten parameters (Carsel and Parrish (1988)

	θr	θs	α_dry (cm^{-1})	α_wet (cm^{-1})	n
Sand	0.045	0.4	0.145	0.29	2.68
Silt	0.034	0.46	0.016	0.032	1.37
Clay	0.068	0.38	0.008	0.016	1.09

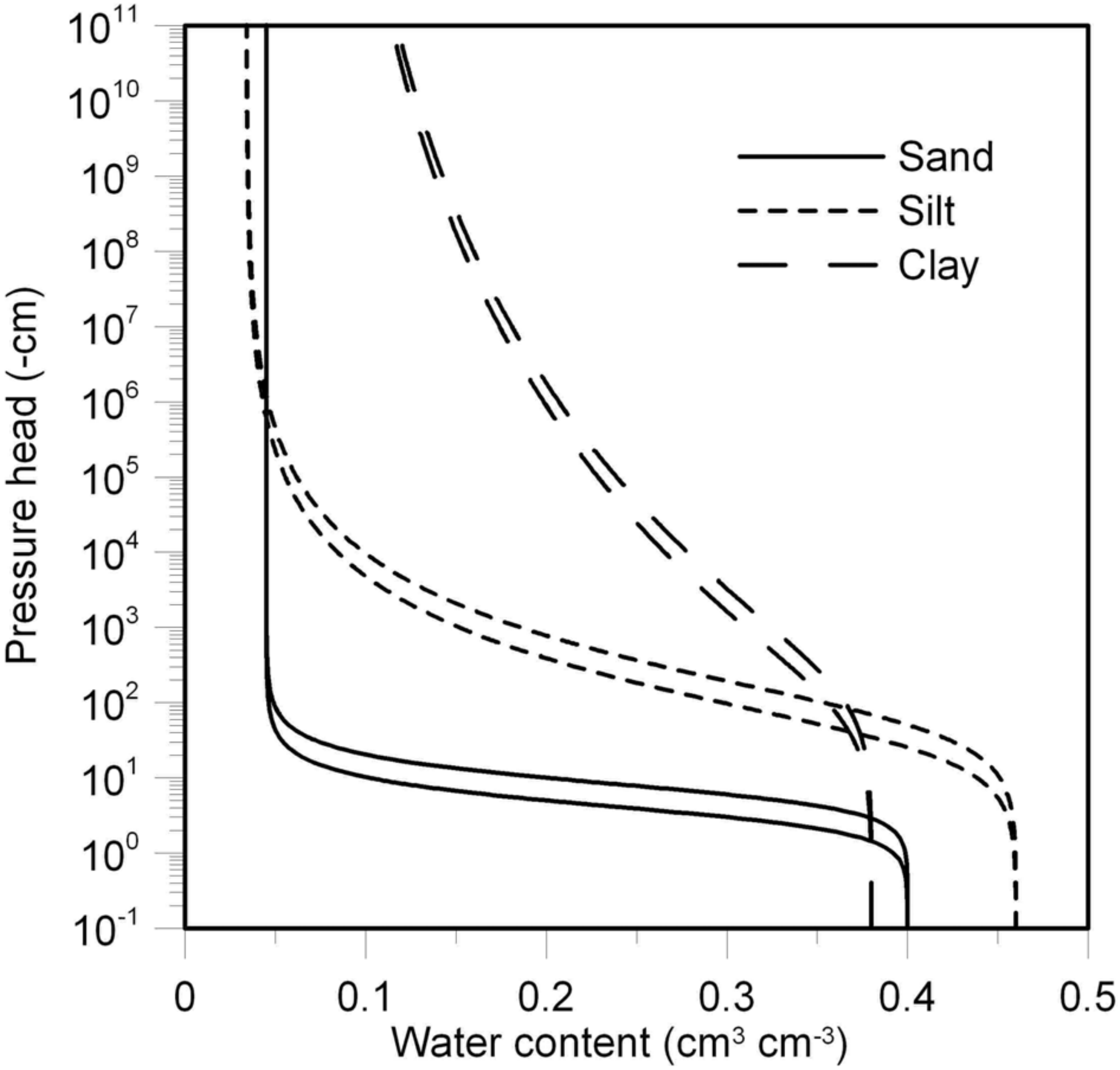

Figure 1. Retention curves with hystersis for the three soils in Table 1. Main drying and wetting curves are represented by top and bottom curves, respectively, for each soil.

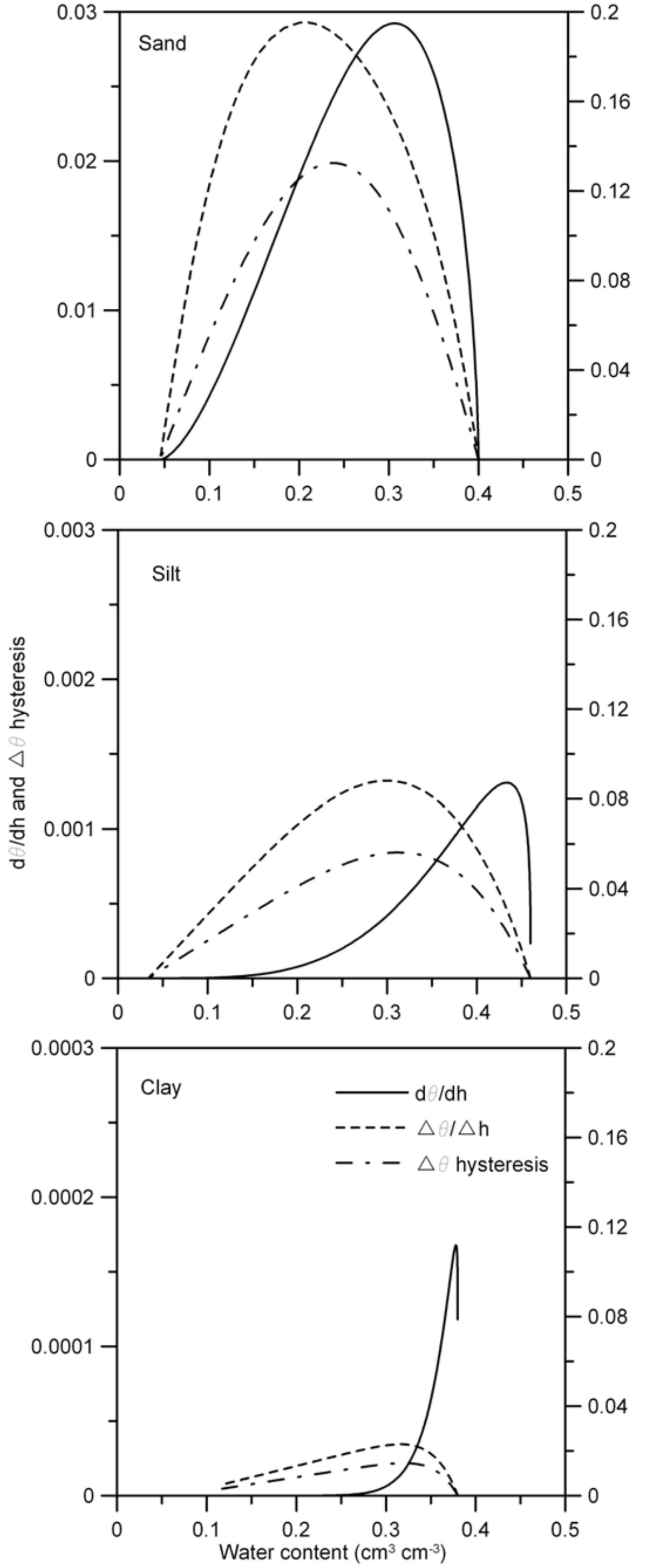

Figure 2. The slope of the retention curve, dθ/dh, Δθ/Δh, and Δh-hysteresis, as a function of
155 mean soil water content, θ. Note the different scales between the left and right vertical axis.