Linked from below: The impact of shallow groundwater dynamics on the spatial variability of soil moisture along hillslopes.

P. W. Bogaart[1,*] A. J. Teuling[1] and P. A. Troch[1]

Introduction

On this poster we investigate the hypothesis that the lateral water movement on hillslope scale that is caused by perched groundwater table dynamics, does affect soil moisture spatial variability. The context being that area-averaged hydrological fluxes (Q, E) are sensitive to this variability because of their nonlinear dependence on soil moisture.

Methodology

Models are built from the following elements:

- A one-dimensional daily water balance model for the unsaturated zone [*Teuling and Troch*, submitted]:

$$\frac{\mathrm{d}\theta}{\mathrm{d}t} \propto (T - R - q - S) \qquad (1)$$

  where $T = f(P, \mathrm{LAI})$ is throughfall, $R = f(\theta)$ surface runoff during saturation, $q = f(\theta)$ is downwards drainage towards the groundwater, and $S = f(\theta, \mathrm{LAI}, E_{\mathrm{pot}})$ root water uptake.
- The semi-distributed 'hillslope storage Boussinesq' model [*Troch et al.*, 2003] to calculate perched groundwater dynamics on the hillslope scale:

$$f\frac{\partial S}{\partial t} = \frac{k\cos\alpha}{f}\frac{\partial}{\partial x'}\left[\frac{S}{w}\left(\frac{\partial S}{\partial x'} - \frac{S}{w}\frac{\partial w}{\partial x'}\right)\right] + k\cos\alpha\frac{\partial S}{\partial x'} + fNw \qquad (2)$$

  where $S(x)$ is storage, f is drainable porosity, k hydraulic conductivity, $w(x)$ hillslope width, α slope angle, and N recharge rate.
- An empirical method that relates soil moisture θ to flat-surface soil moisture θ_0 by means of a wetness factor:

$$\theta = K_w\theta_0 \qquad (3)$$

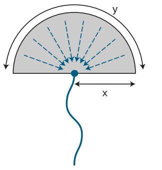
  where the wetness factor K_w is itself a function of hillslope form and aspect, and position within that hillslope [*Svetlitchnyi et al.*, 2003].

Using these basic approaches, 3 models are built.

Unconnected: A hillslope-field of 51 contour-wise rows each having 40 unconnected soil columns with random soil properties, each modelled with Eqn (1).

Connected: The same field, but now average drainage of each array is fed as recharge into the corresponding node of the hsB (Eqn (2)) model. For hsB-nodes that saturate, drainage in the corresponding soil column array is shut down, enabling surface saturation.

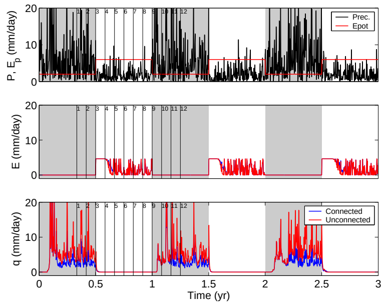
Topography-corrected: As in the 'unconnected' case, but soil moisture is corrected for topography by applying Eqn (3). Four aspects are applied: North, East, South, West.



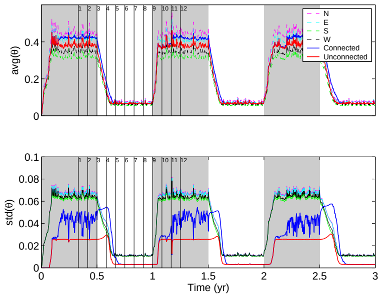
Plan view of the amphitheater-shaped, source-draining hillslope used in this study. Parameters are: L=250 m., α = 0.15, D = 1.0 m, f = 0.3, k = 0.2 m/h.

Climatology is a block-wave type climate: Wet,cold ($\bar{P}$ = 6 mm/d, E_p = 2 mm/d, no vegetation) seasons alternating and dry, warm ($\bar{P}$ = 2 mm/d, E_p = 6 mm/d, full vegetation)) seasons.

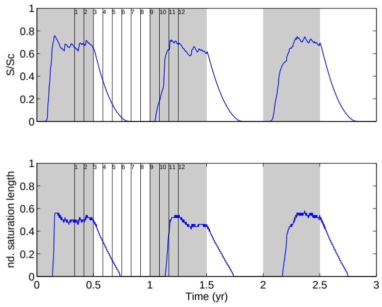
Results



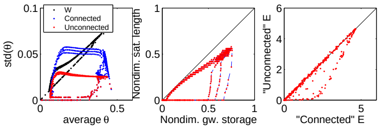
Vertical fluxes within the models. **Top:** Daily precipitation and potential evapotranspiration rates. **Middle:** Field-averaged root water uptake, which is used as a proxy for field-averaged actual evapotranspiration rate. **Bottom** Field-averaged downward drainage from the root zone, which is used as recharge rate for the perched groundwater model (in the 'connected' case).



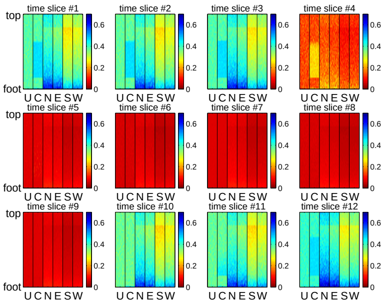
Evolution of field-averaged root-zone soil moisture statistics. There is little difference between the various models. **Top:** mean soil moisture content. **Bottom:** soil moisture spatial variability. 'connected' variability is twice that of 'unconnected'. This variability is maintained during the early summer. 'corrected' variability is still higher but is not maintained during early summer.



Evolution of total storage in the perched-groundwater system that underlies the 'connected' root zone field. **Top:** total nondimensional storage (S/S_c). The maximum fill of 70% is reached midwinter and emptying occurs during the first half of summer. **Bottom:** Uphill length of surface saturation. At maximum the lower half of the hillslope is saturated. Surface saturation appears suddenly during winter, but disappears gradually.



Left: field-averaged soil moisture vs. soil moisture variance. Both the 'connected' and 'unconnected' models have highest variability for intermediate values of average soil moisture. The 'corrected' models (only aspect 'west' shown) show a different relationship: almost linear dependent on average soil moisture. **Middle:** internal dynamics of the groundwater system, indicated by the total perched groundwater storage, versus the length of surface saturation. Line segments point in the direction of the next state, indicating counter-clockwise hysteresis. **Right:** Comparison of root water uptake (actual evapotranspiration rates) for the 'connected' and 'unconnected' cases. This suggests that 'unconnected' E is underestimated, *if* the 'connected' model is more close to reality.



Soil moisture patterns for 12 selected time slices spanning a complete annual cycle. Soil moisture fields for the 6 model cases are next to each other: 'Connected', 'Unconnected', 'North', 'East', 'South', 'West'. It can be clearly seen that in the 'connected' case, field-scale spatial variability mainly stems from the appearance and disappearance of perched ground-water caused near-surface saturation on the footslope. Spatial patterns are also present in the 'corrected' soil moisture fields, but they are prescribed.

Discussion

The 'connected' model provides a process-based method to quantify dynamic, perched groundwater table influenced, soil moisture variability on the hillslope scale. As expected, the main source of this variability is due to saturated areas. It was found that saturated area extent has a clear relationship with total groundwater storage. This enables the construction of simple, yet physically based transfer functions for soil moisture variability prediction.

---

[1] Hydrology and Quantitative Water Management Group [*] patrick.bogaart@wur.nl

References: **Svetlitchnyi**, A. A., S. V. Plotnitskiy, and O. Y. Stepovaya (2003), Spatial distribution of soil moisture content within catchments and its modelling on the basis of topographic data, *J. Hydrol.*, *277*, 50–60. **Teuling**, A. J.,and P. A. Troch (subm.), Improved underrstanding of soil moisture variability dynamics, *Geophys. Res. Lett.*, subm., 4 pp. **Troch**, P. A., C. Paniconi, and E. E. van Loon (2003), Hillslope-storage Boussinesq model for subsurface flow and variable source areas along complex hillslopes: 1. Formulation and characteristic response, *Water Resour. Res.*, *39*(11), 1316, doi:10.1029/2002WR001728.