Application of a new hydraulic conductivity model to simulate rapid ground water fluctuations in the Eel River Watershed in Northern California

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(1) Introduction

At a small ($\sim$ **4000**m^2) steep ($\sim$ **30** degrees) hill–slope in the Eel River watershed (lat.: **39°43′44″**N, long.: **123°38′39″**W) in Northern California, the fluctuations of several water tables have been monitored continuously, at less than 30 minute intervals, since **2007** (Figure 1). The fast rise and slow recession of the water table suggests preferential flow through fractures.

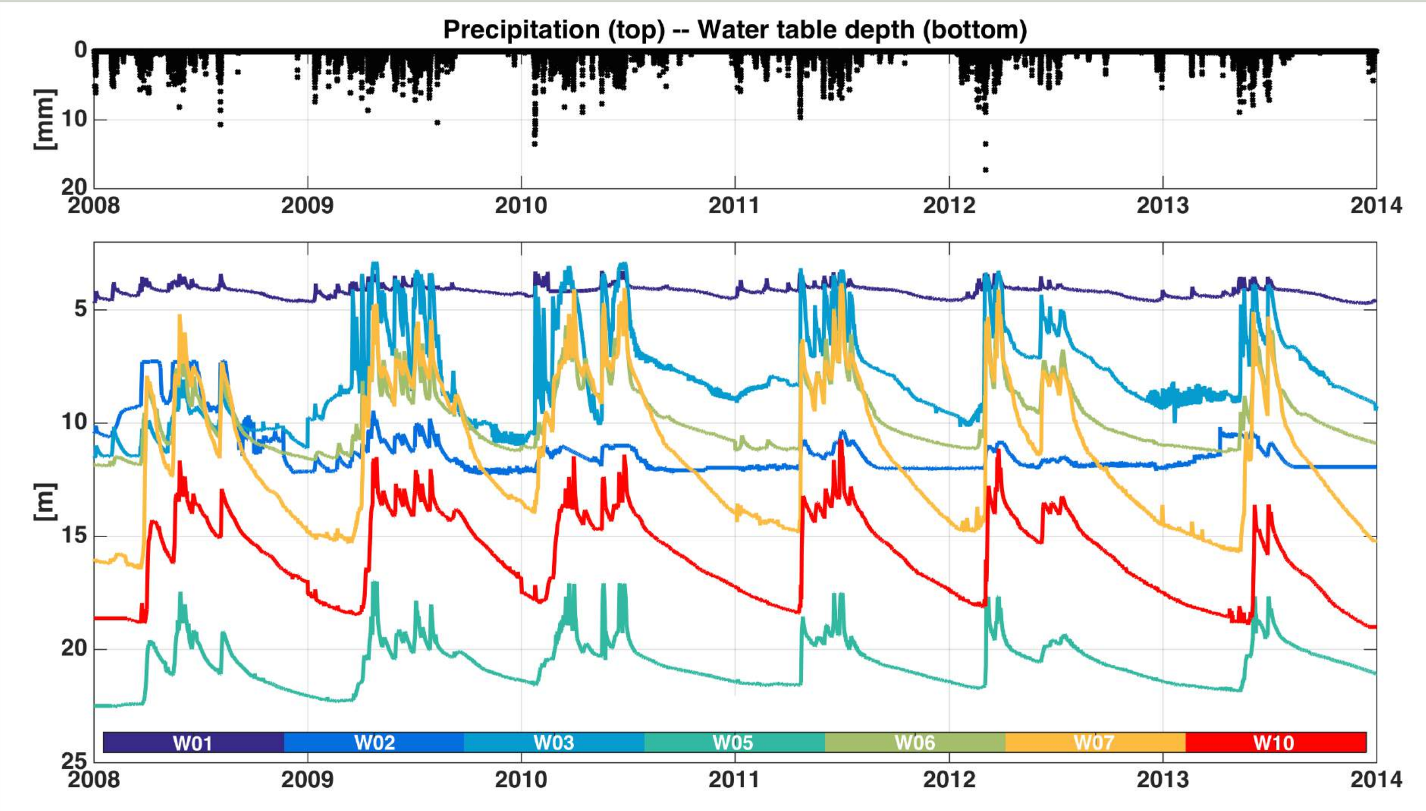

Figure : (1) Top panel presents the precipitation [mm] for six years. Bottom panel contrasts the measured water table depth values [m] for the seven well locations of the present study. Plots are presented at 30-min time intervals.

This work [1] presents a new parameterization of hydraulic conductivity that captures the preferential flow and is easy to implement in global climate models. The parameterization represents the hydraulic conductivity as a product of the effective saturation and a background hydraulic conductivity, drawn from a log–normal distribution.

(2) Governing Equations

Our problem involves the numerical solution of Richards' PDE, which describes the movement of liquids in unsaturated porous media and is given by:

$$\mathrm{C}(\psi)\frac{\partial \psi}{\partial t} = \frac{\partial}{\partial z}\left[\mathrm{K}(\psi)\left(\frac{\partial \psi}{\partial z} - 1\right)\right] + \mathrm{S}(z, \psi)\,, \qquad (1)$$

where z is the vertical space dimension [L], t is the time dimension [T], ψ(z,t) is the pressure head (suction) [L], C(ψ) is the specific moisture capacity [1/L], K(ψ) is the unsaturated hydraulic conductivity [L/T] and S(z,ψ) is a sink term [1/T] (here [L: cm] and [T: hrs]).

- Initial Conditions: $\psi(z, t = 0) = \psi_0 \in \mathbb{R}^D$,
- Top Boundary: $\mathrm{K}(\psi)\left(\frac{\partial \psi}{\partial z} - 1\right)\Big|_{z=0} = q_{\mathrm{rain}}(t)$,
- Bottom Boundary: $\mathrm{K}(\psi)\left(\frac{\partial \psi}{\partial z} - 1\right)\Big|_{z=z_{fb}} = \mathbf{0}$, for $t \geq \mathbf{0}$.

(3) Formulation of K(Θ)

We propose a **stochastic** parameterization with $\mathrm{K}(\Theta) = \Theta^{\lambda}\mathrm{K}_{\mathrm{bkg}}$, where $\lambda > 0$, $\mathrm{K}_{\mathrm{bkg}} \sim \mathrm{LogN}\left(\nu(z, \Theta), \Lambda(z, \Theta)\right)$ and $\Theta \in [0, 1]$ is the effective saturation. Here $\langle \mathrm{K}_{\mathrm{bkg}} \rangle = \mu(z)$, $\mathrm{Var}[\mathrm{K}_{\mathrm{bkg}}] = \eta(1 - \Theta)$.

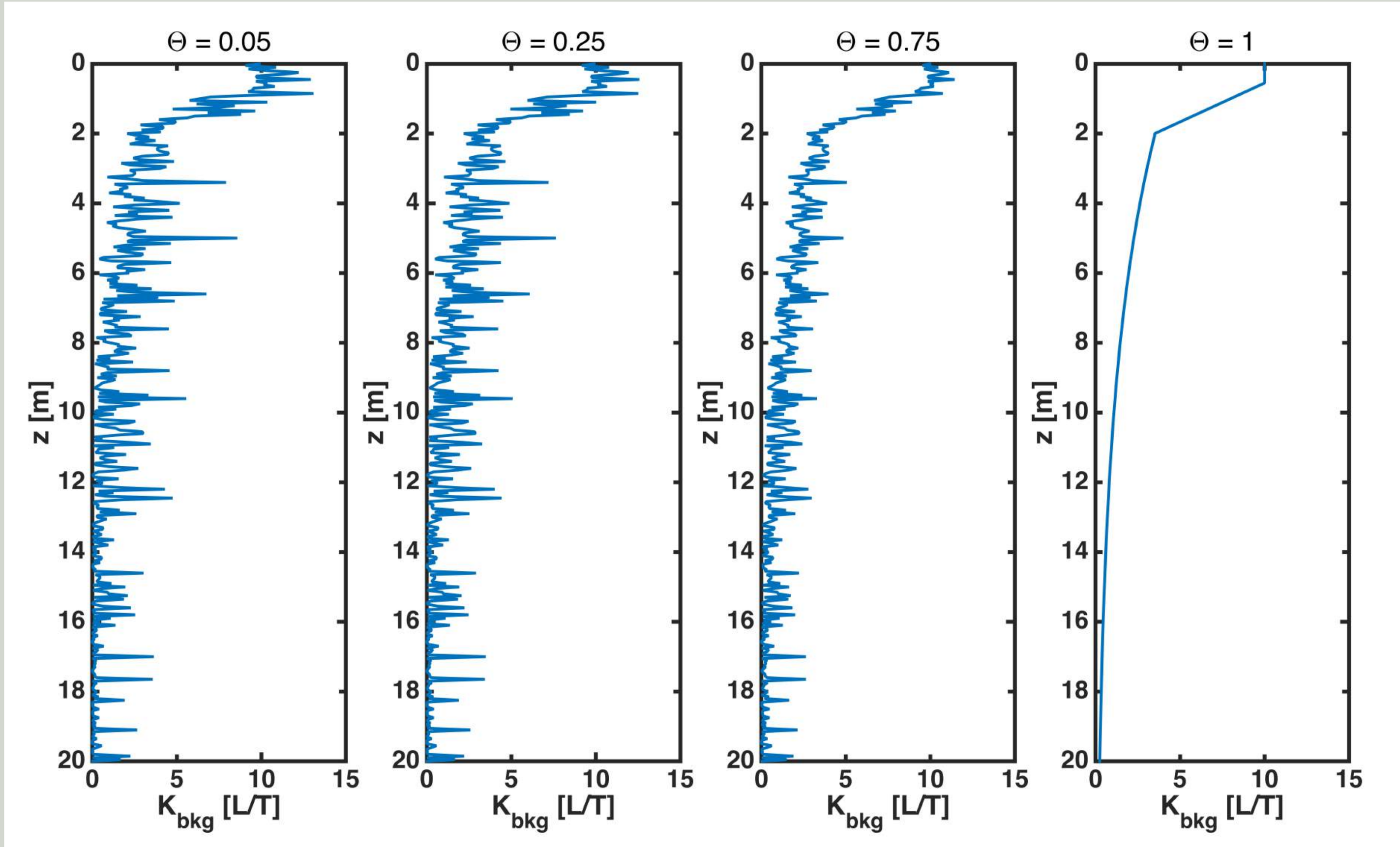

Figure : (2) A typical example of the stochastic vector $\mathrm{K}_{\mathrm{bkg}}$, as function of depth z with different values of effective saturation $\boldsymbol{\Theta}$. From left to right the degree of saturation increases from **0.05%** (almost dry), to **100%** (full saturation).

(4) Determination of Optimal Model Parameters

In total **256** $\times$ **42** numerical simulations, from seven wells and six years, was used to derive the site "optimal" parameters $\hat{\eta}$ and $\hat{\lambda}$.

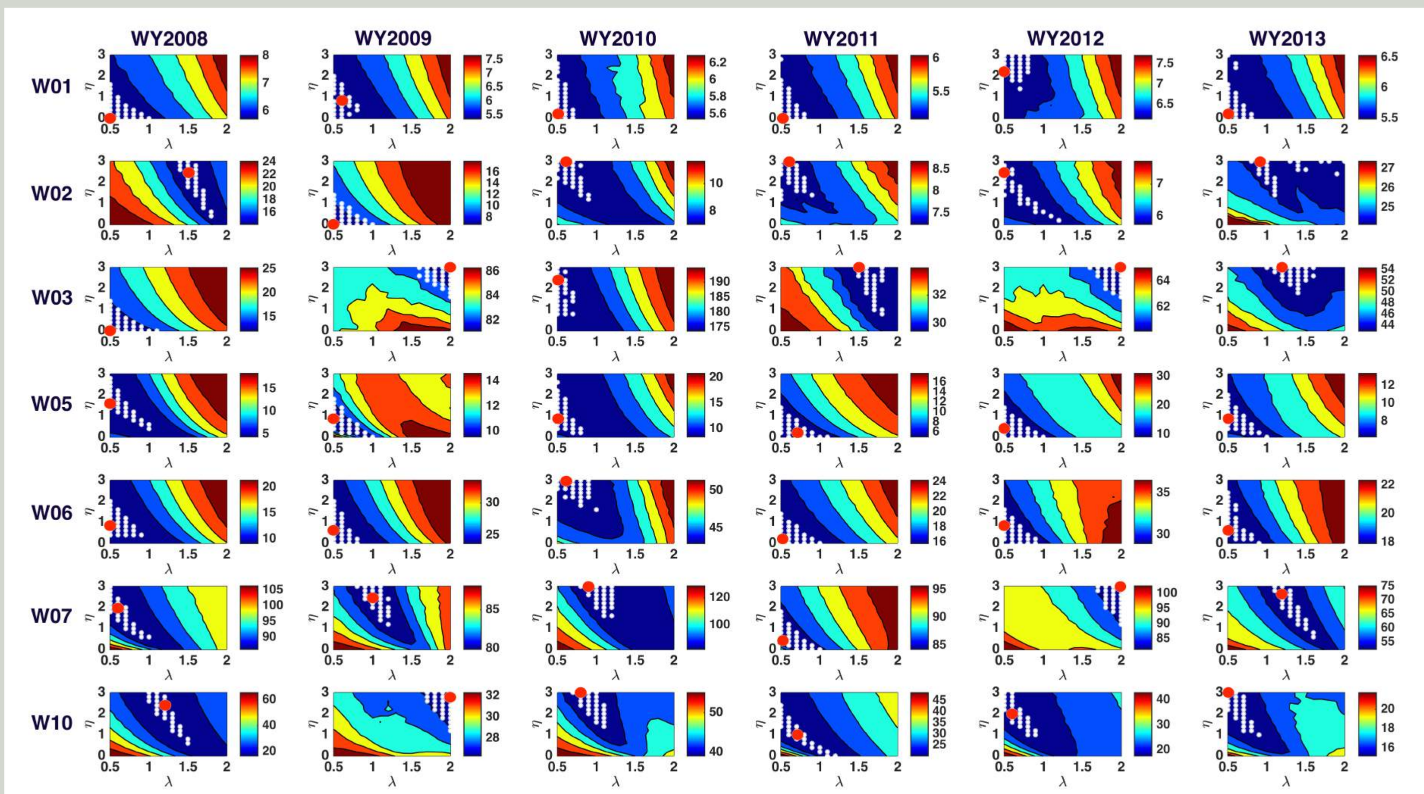

Figure : (3) Mean absolute error results [cm], as function of noise η and exponent λ, for the seven well locations through the six year period WY2008 – WY2013.

References

[1] M. Vrettas and I. Fung, *Towards a new parameterization of hydraulic conductivity in climate models: Simulation of rapid groundwater fluctuations in Northern California.* Journal of Advances in Modeling Earth Systems (accepted – in press), 2015.

(5) Multi-Year Multi-Well Simulations

Over the six years the magnitude (between 1050 and 2100 [mm]) and time of precipitation varied (mid October to mid February). Contrasting the results from a six years simulation, for all seven wells, with the mode values for $\hat{\eta} = \mathbf{2.475}$ and $\hat{\lambda} = \mathbf{0.575}$ shows a good match of the observed vs the simulated water table fluctuation.

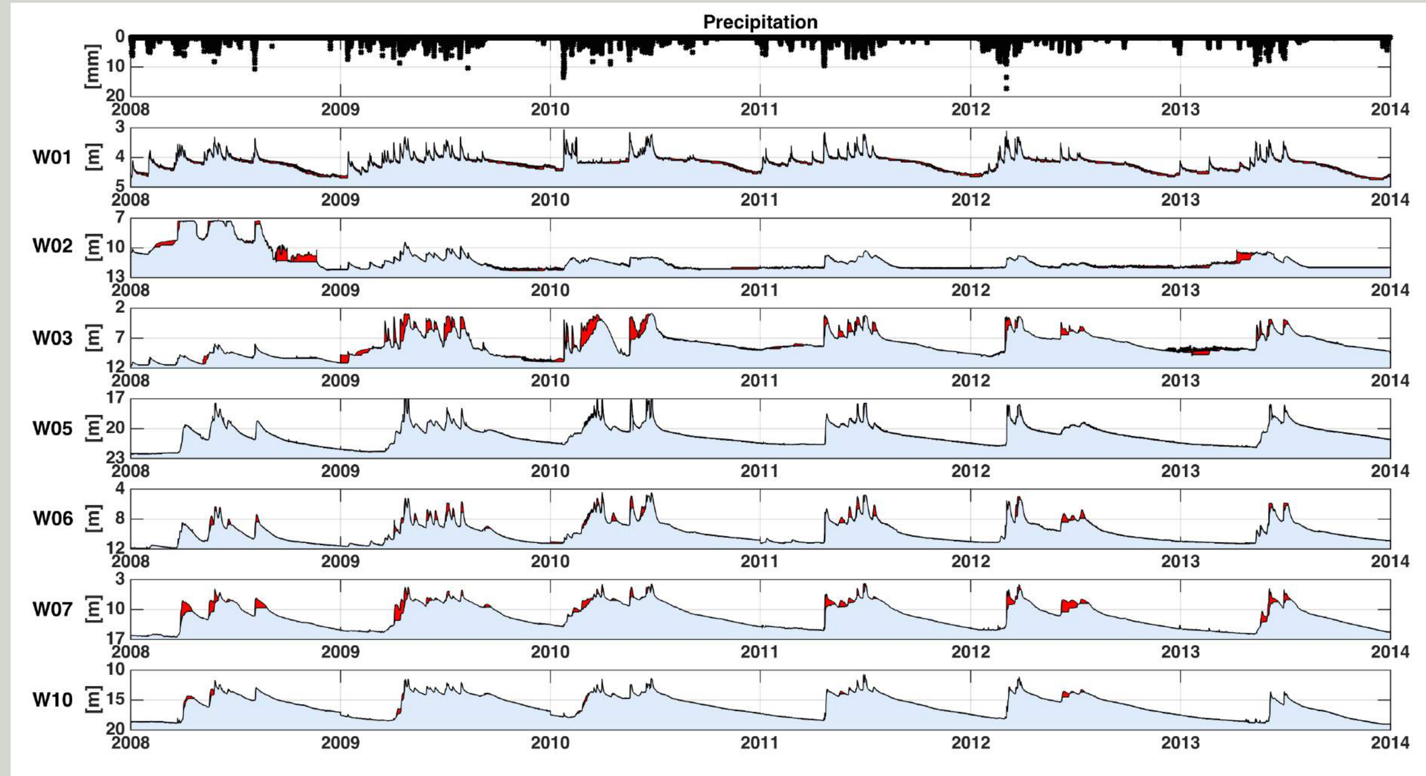

Figure : (4) The light blue area shows the simulated water table while the red shaded area marks its departure from the observed (actual) [m]. Top panel is the precipitation [mm].

(6) Implications for Climate Modeling

- The new stochastic hydraulic conductivity parameterization captures the rapid penetration of rain water to depth.
- This amount of rock moisture ($\sim$ **30%** of the column) is isolated from evaporative demands of the atmosphere, and could be what is needed to sustain transpiration through the dry season and through extended droughts.

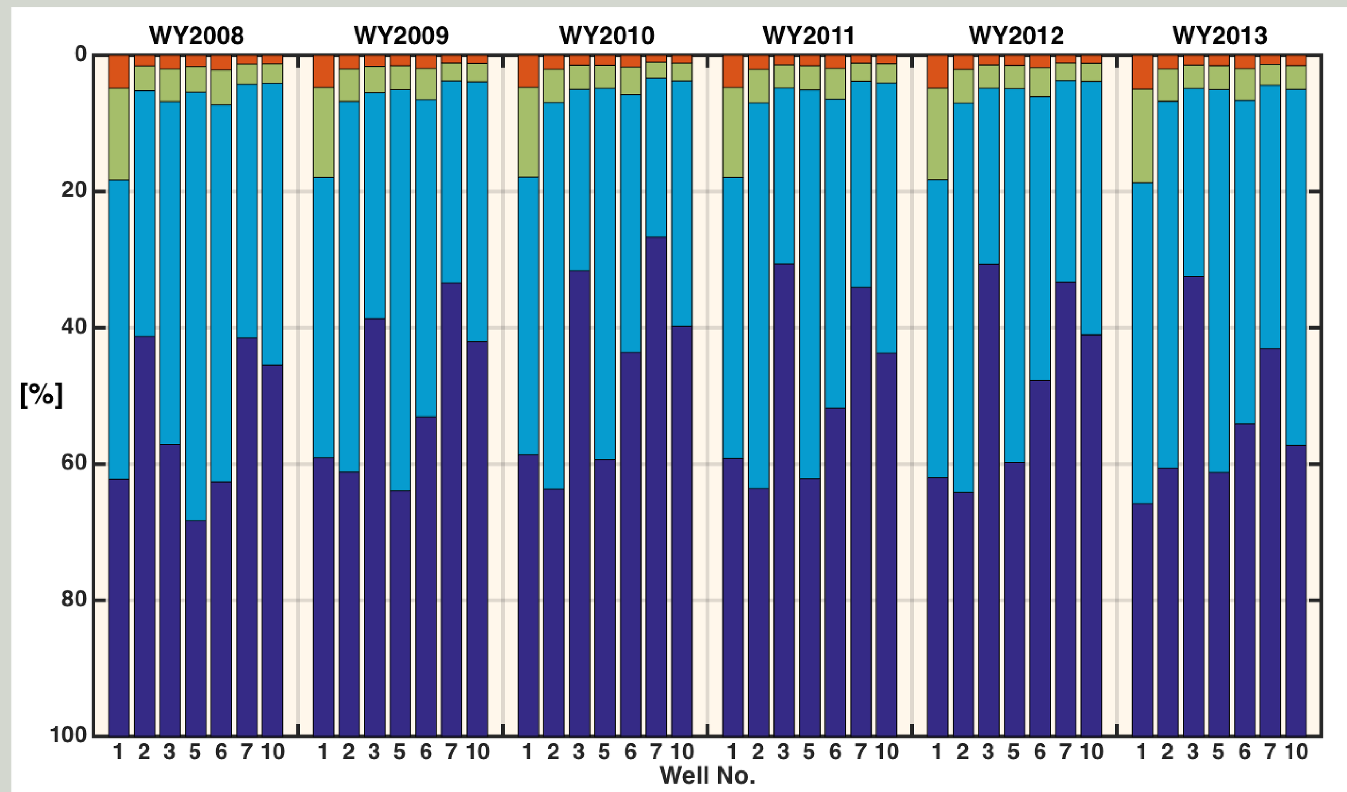

Figure : (5) Averaged partitioning of the water content for each well and water year. The four layers are: (i) soil (orange), (ii) saprolite (light green), (iii) unsaturated weathered bedrock (light blue) and (iv) saturated weathered bedrock (dark blue)

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