Entropy Production of Soil Hydrological Processes and its Maximisation by

P. Porada, A. Kleidon, and S. J. Schymanski

Reply to the comments of anonymous referee 2

We address all concerns raised by the referee and describe the resulting changes to our manuscript. The (summarised) reviewer's comments are in italic text, while our responses are formatted as standard text.

1. *The model scale and resolution should be discussed. The description of hydro- logical processes and the method of quantifying the associated entropy production presented in this study are only appropriate at a large scale, corresponding to a coarse resolution.*

   We will add a description of the model resolution, which corresponds to T42 (global rectangular grid with a resolution of 2.8125 degrees). Since the grid cells of the model have a side length of over 300 km at the equator, only large-scale hydrological processes were considered in our analysis. This is also the reason for using only the largest catchments for the model evaluation. It is true that the relative importance of the different hydrological processes would change on smaller scales. We will add to the discussion section of the manuscript that the resolution is crucial for the assumptions on which the model is based.

2. *It might be nice to have a table listing the 35 basins that form the basis of the results. That way the scale of these basins could be judged by the readers.*

   We will add a list and a map of the basins.

3. *c_{root} and c_{soil} seem to be playing the role of hydraulic conductivities, but the units used in the study are not appropriate for this purpose. If c_{root} and c_{soil} correspond to hydraulic conductivities in the vadose zone, they should not be kept constant.*

   The parameters c_{root} and c_{soil} represent effective conductivities. As described briefly in the introduction, they integrate all structures and processes that have an influence on the speed of water movement from soil to vegetation or the channel network, respectively. They include the effect of hydraulic conductivity (which de- pends on soil water content and soil type), macro- pore density, root density, etc. Since soil and root properties vary strongly spatially (even within a grid cell) and temporally, c_{root} and c_{soil} also represent averages of these properties over space and time. Consequently, c_{root} and c_{soil} are not related in a simple and predictable way to the hydraulic conductivity and they do not have the same units as the hydraulic conductivity. We do not deny that the speed of water flow is determined by a set of soil and vegetation properties at a certain place at a certain time. The crucial assumption, however, is that the relation between the measurable soil or vegeta- tion properties and the "true" effective conductivity for water is so unpredictable on the spatio-temporal scale of our model, that c_{root} and c_{soil} are characterised by

a very large range of values. This is the justification for the MEP-based approach. It is also the reason to assume that c_{root} and c_{soil} are constant, since this is the simplest model possible, given that not much is known about how c_{root} and c_{soil} are related to soil and vegetation properties at the scale of this model. We will add these clarifications to the introduction of the manuscript.

4. *The parameter "Relative soil moisture" is not properly defined in the text.*

   Θ_{soil} is the extractable relative soil water content defined as m^3 extractable water / m^3 soil. It can be written as $\Theta_{soil} = (\theta - \theta_r)$ and the relation to saturation S is: S = Θ_{soil} / $\Theta_{soil,max} = (\theta - \theta_r)/(\theta_s - \theta_r)$ where θ is the volumetric relative water content of the soil in m^3 water / m^3 soil, θ_r is the residual soil water content and θ_s is the water content at saturation as defined in van Genuchten [1980]. In our model, θ_r is 0.065 m^3 water / m^3 soil and θ_s is 0.41 m^3 water / m^3 soil, corresponding to the soil type sandy loam [Carsel and Parrish, 1988]. We will add this information to the text for clarification.

5. *Using only one soil type (sandy loam) for the whole global spatial domain represents a gross simplification of reality.*

   There are two reasons why a globally uniform soil type was chosen for the model: 1. Assigning a particular soil type to each grid cell would represent an increase in model complexity not matched by other parts of the model, e.g. the vegetation model and other parts of the soil model, which also utilise globally uniform parameters. 2. The model is not very sensitive to soil type, only slight changes in the ratio of surface runoff to baseflow can be observed, which can be explained by a small change of average soil moisture depending on the soil type selected. We will add these points to the model description.

6. *How can the soil hydrological model and the vegetation model run independently from each other?*

   By stating that the models are designed to run independently, we mean that each of the models can be coupled to other models and that they do not have to be run together. The soil model, for instance, needs the value of the vegetation water potential to compute root water uptake. It does not matter, however, where this value comes from. It could be computed by any vegetation model or it could be set as a fixed boundary condition. We will clarify the coupling of the two models in the text.

7. *An arrow should be added to figure 1 to represent surface infiltration.*

   We created an improved version of figure 1 (see the author's comment on the first review of this manuscript) which includes infiltration and which will be used for the revised manuscript.

8. *It is not clear that the model represents an improvement over other current global hydrologic or BATS models. Can the authors compare the results to other models?*

The main objective of our study was to test the hypothesis, that MEP can be used as an organising principle in soil hydrology at the global scale. This hypothesis was confirmed by showing that the MEP-based model is in accordance with observational data. The identification of organising principles such as MEP potentially plays a large role for improving hydrological models, since these principles are assumed to be generally valid and independent of changes in the forcing or in the structure of the system [Schaefli et al., 2011]. Using a model as a tool to identify the underlying organising principles is in contrast to tuning a model in order to reproduce a wide range of observations. By tuning a model, it is implicitly assumed that the model is correct and that the uncertainty of the predictions results from unknown parameter values. It is difficult to test the assumptions behind such a model. Hence, comparing the output of models based on organising principles and tuned models may not be useful, since these two approaches differ from a methodical perspective.

References

R. F. Carsel and R. S. Parrish. Developing joint probability distributions of soil water retention characteristics. *Water Resources Research*, 24(5):755–769, 1988.

B. Schaefli, C. J. Harman, M. Sivapalan, and S. J. Schymanski. Hydrologic predictions in a changing environment: behavioral modeling. *Hydrol. Earth Syst. Sci.*, 15:635646, 2011. doi: 10.5194/hess-15-635-2011.

M. T. van Genuchten. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Sci. Soc. Am. J.*, 44:892–898, 1980.