

Interactive comment on “The effect of spatial throughfall patterns on soil moisture patterns at the hillslope scale” by A. M. J. Coenders-Gerrits et al.

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Summary and Evaluation:

This is interesting study that explores concurring controls of spatial throughfall, soil depth and bedrock topography on spatial variability of soil moisture and subsurface storm flow (SSF) at the Panola experimental watershed. The authors transfer a stationary through-fall pattern observed at the Huewellerbach /Luxembourg to drive a 3 D numerical model of the Panola hillslope and explore temporal dynamics of the soil moisture patterns by means of a variogram analysis. They clearly show that effective

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range of soil moisture is in early stages of the simulation close to the value range of the through fall, but evolve towards the much longer range of bedrock topography during later stages of the numerical experiment. The proposed study is based on sound methods, a sound data set and provides potentially interesting insights in concurring controls on soil moisture variability. Nevertheless, despite my sympathy for the study, I suggest that a few major points that should be addressed to extract the optimum from the study, important technical points to improve methodological rigour and minor technical points.

Major points:

- I have problems with changing the slope and assuming the spatial pattern of interception and through-fall stay the same. Trees grow upright with respect to the gravity vector, not with respect to inclination angle of a slope. Steepening you slope means to reduce the angle between the stem and the slope, this affects the correlation structure and the range of the through-fall pattern. You could account easily for this by transforming the length scale by multiplying the lag distances in your variogram calculations with the cosine of the slope angle. In fact this will reduce the range by the same factor.

It is indeed true, that the correlation structure and range of the throughfall pattern will be different when the slope angle is changed. This effect was not included in the study. In the revised manuscript, we will take this effect into account by multiplying the lag distances by the cosine of the slope angle as suggested. As a consequence, Figure 11b and c will change. We will no longer show the ‘Equilibrium soil moisture range’ and ‘Effective range of 2nd peak’ in [m], but now we will show the range as percentage of the (corrected) throughfall range to explain our point to study the relative importance of either the bedrock or the throughfall pattern.

- The proposed way to scale the through-fall pattern to the Panola hillslope is a quick

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fix! You have the range, the mean and the variance. So you could easily employ geostatistical simulation method (Turning Band, Sequential Gaussian) to generate input patterns, including several possible realizations. This way you could account for the change in correlation length with changing slope. If you want to fix part of the pattern, you can assume virtual observations of interception and condition your simulated input fields to these locations. From a methodological point of view this is a weakness of the study.

We could indeed have used a geostatistical simulation method to map our initial throughfall pattern (21x22 meter) from the Huewelerbach on the Panola hillslope (28x48 meter), which would indeed have been a better approach in the sense that we would have been more flexible to play with different patterns. However, we choose a different (more simple) method by mirroring our initial spatial throughfall pattern in different ways on the Panola hillslope (see SUPPLEMENT for details). The result of our chosen methodology is that the generated pattern represents less the observed throughfall pattern and thus our study becomes more a numerical experiment and less a virtual experiment. Nonetheless, for the base case scenario ($R=63\text{mm}$, $A=13^\circ$, $S=0.62\text{m}$), the final pattern (UR2.1) does not geostatistically differ much from the initial pattern as can be seen in Table 3 of the SUPPLEMENT for the percentage throughfall of precipitation. Hence, we think that our study still represents the throughfall observations well enough to call our study a virtual experiment.

In the last part of our study, where we changed the slope, the suggested methodology would indeed have additional benefits. However, we corrected this mistake by adjusting the range by the cosine of the slope as explained in comment 1.

We also would like to stress that our main scope is not to study different throughfall patterns, but our main scope is to investigate how a (certain) throughfall pattern influences soil moisture and its relation with different hillslope controls. We agree, that

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the current description of our research scope might be confusing and misleading. In the revised manuscript we will clarify our scope.

We added this information and a discussion on this limitation in the manuscript and in the SUPPLEMENT.

- How would temporal dynamics of the effective range change, when using a different realisation of the through-fall pattern? When regarding the ranges of the throughfall pattern, the bedrock topography pattern and the extent to the model domain, I doubt that you already reach ergodic conditions (which would justify a single realisation study). Again this could easily be explored when using a sound method for generating the through-fall pattern.

A different throughfall pattern could possibly result in a different (temporal) balance between the throughfall pattern and the bedrock topography. This could have been explored by running different throughfall patterns (e.g., the eight patterns in the SUPPLEMENT or by generating new patterns with a geostatistical method) through the semi-variogram analysis to create the 'geo-statistical hydrograph'. However, we chose to look at a single throughfall pattern to keep focus on our three objectives, where we could inter-compare the results (that is why the differences between throughfall patterns is in the SUPPLEMENT and not in the main manuscript). The analysis in our paper focusses on the interaction between a throughfall pattern and the bedrock topography, and tries to answer how this interaction changes with different storm sizes, slope angles, and soil depths. We agree that the scope of the paper might not be well described in the Introduction, which might mislead the reader. In the revised manuscript we will emphasis this better.

- In principle you find what you put into the experiment, as soil hydraulic properties are assumed to be homogeneous. This is a very strong and questionable assumption:

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both ksat and porosity are known to be spatially variable, also in forests. Correlation lengths are often short (e.g. Zimmerman et al. 2008). This could be easily explored with Hydrus and would affect the "balance" of controls. Maybe the authors can explain why they neglected this aspect in the revised manuscript?

We agree that in reality the soil hydraulic properties are highly spatially variable. Macropores would indeed have a very important influence on soil moisture patterns. If we would like to include the effect of macropores, we should define a spatial macropore distribution based on field observations (e.g. the small core soil data by Tromp-van Meerveld et al., 2008 for the Panola hillslope). However, an intensive 3D physically based modelling study on Panola hillslope by James et al (2010) showed that using field observed soil core data (to estimate macropores) did not lead to reasonable model performance. This was also showed by the study of Hopp and McDonnell (2009). They showed that the simulated distributed response of state variables (pressure head time series) agreed very well with measured pressure head dynamics, indicating that the model could reproduce hydrologic behaviour satisfactorily. For clearness, although the soil hydraulic properties are in the horizontal plane homogenous, they change in the vertical direction, based on field observations by Tromp-van Meerveld (2006a, 2007) and others.

We will add this reasoning in the revised manuscript. We would also like to stress that we do see the importance of macropores and other neglected processes (e.g., transpiration, antecedent soil moisture). These processes are shown in Figure 12 by the dashed blocks and are topics for further research.

Minor technical points:

- Page 8632 Eq. 3, this could be named as *through-fall anomaly*.

Ok, we will rename the 'normalized spatial data' into 'anomaly'. With N being either spatial throughfall, soil moisture, or bedrock data.

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- Page 8633: *I do not understand why neglecting the nugget saves computation time, please explain this.*

We used an optimization algorithm to fit the ‘best’ exponential model (Equation 4) through the data points of the semi-variogram. Equation 4 has three freedom parameters: the sill c , the range r , and the nugget n . By forcing the nugget equal to zero, the search space reduces, resulting in a shorter computation time. We verified this assumption by a visual check on the semi-variograms, where indeed the nugget was close to zero. We will add this information to the manuscript.

- Figure 4a, lower left panel: *Please use a larger line width.*

Ok, we will improve Figure 4 by using a thicker line width.

- Figure 5: *y- and x axis of the pseudo colour plots have no units, I assume this is meter and they mark the upslope and lateral extent of the plot? If so, please mention this in the figure caption. Please explain what 5h, 10h ? 25 h means, as the figure shall be understandable without referring to the text.*

We agree and we will clarify Figure 5 (and 7) by improving the captions in such way they can be understandable without reading the text. The y and x axis are indeed the upslope and lateral extent of the hillslope. The hours indicate the time of the snapshot of the soil moisture pattern.

- Figure 6: *maybe it is more appropriate to show the confidence intervals for the mean values instead of the standard deviation within the entire domain.*

Ok, we will change the standard deviation for the confidence intervals.

- Page 8637 and Figure 9: *I am not sure what panel 2 b shows: the correlation*

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structure of vertically averaged soil moisture for each time step? Does average mean vertically averaged in this passage?

Figure 9b indeed shows the semi-variograms of the mean soil moisture over layer 5 to 10 (thus in the vertical) for each time step. For clarity, we will improve the figure in such way that only the semi-variograms at $t=0\text{h}$, 5h, 23h, 25h, 56h, and 190h (similar to Figure 5 and 7) are shown.

- Wouldn't it be interesting to define an anomaly in bedrock topography, by defining an average at a constant upslope distance. This is an indicator for the deviation of a "uniform slope". I expect this to be highly anti correlated with soil moisture at the bedrock interface.

This is what we actually did. The 'bedrock irregularity' is defined as the deviation from a plane slope (P8633, L8). The soil moisture is indeed anti-correlated with the bedrock irregularity as also shown by the semi-variogram analysis. For clarity, we will replace the term 'bedrock irregularity' for 'bedrock anomaly', since this is a better naming.

- Page 8638: I do not think that an increasing range of the soil moisture with increasing storm depth is an inherence of a method. Maybe it reflects that the precipitation pattern exerts a more and more dominant control on the soil moisture pattern, with increasing storm depth?

This is indeed what we meant. We will change the text in such a way that we properly refer to Zehe et al (2010).

- Figure 8: I am wondering whether the temporal dynamics of anisotropy in soil moisture at the bedrock interface could be related to different parts of the SSF hydrograph?
Yes, the anisotropy of the soil moisture is reflected in the bedrock topography (dry state) or in the throughfall pattern (during storm).

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- *Figure 11. Sorry but I find these figures very difficult to interpret. What is the colour code, the effective range in meter?*

We realize that Figure 11 is difficult to interpret, but we think these cubes are the best way to show the inter correlation of the different controls. The colour code in Figure 11a is the 'performance, R2', in 11b the 'range of the soil moisture in the equilibrium state', in 11c the 'range of the second peak' and in Figure 11d the 'time to the second peak'. In the revised manuscript we will improve our explanation of these response cubes.

- *Please explain how you derived the R2 to estimate the variogram performance? Is this the averaged sum of the squared residuals?*

The R2 is calculated as $1 - ss_{err} / ss_{tot}$. With ss_{err} the residual sum of squares and ss_{tot} the total sum of squares.

$$R^2 = 1 - \frac{\sum_i (y_i - f_i)^2}{\sum_i (y_i - \bar{y})^2}$$

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 9, 8625, 2012.

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