Authors response and revised version of Jackisch et al. "In situ investigation of rapid subsurface flow: Identification of relevant spatial structures beyond heterogeneity"

We again thank all five reviewers for their critical and constructive comments on our manuscript and Ross Woods for organising the open review process. Your comments have been the basis to fundamentally restructure and to rewrite the manuscript. To help the review of the revised version, we will highlight how we addressed the raised concerns.

Stand-alone companion manuscripts:

The two companion MS deal with the in situ characterization of rapid subsurface flow. We now refer our studies to the interplay of form and function. The associated MS (Angermann et al.) specifically addresses the aspect of function in a top-down approach with a focus on dynamics. This MS (Jackisch et al.) uses a bottom-up approach on the aspect of form and a focus on the identification and characterisation of flow-relevant structures. The common link between the two is a hillslope-scale irrigation experiment which uses distributed TDR profiles and time-lapse GPR in trench-like transects to detect lateral flow structures and the response dynamics. Both MS come to the conclusion that form and function are mutually paired in hydrological systems.

In order to clarify these aspects, we changed the title into:
Form and function in hillslope hydrology: In situ identification and characterization of flow-relevant structures

Moreover, we changed most of the rationale of the MS in order to substantially consolidate it and to make it stand-alone. The presented approaches are framed under the following hypothesis and research questions:

The rationale of this study is to infer flow-relevant subsurface structures in a qualitative and quantitative sense. Specifically, we hypothesize that a combination of quantitative field methods and in situ imaging of subsurface response patterns with time-lapse GPR at three scale levels provides the missing link between form and function of flow paths and rapid subsurface flow.

We test this hypothesis by addressing three main research questions:
Q1 What kind of information on flow-relevant structures, their characteristics and their distribution can be inferred from direct measurements using a large set of soil core profiles, soil core samples, permeameter measurements and a GPR survey?
Q2 How do salt tracer data, dye tracer patterns, and soil moisture responses from plot- and hillslope-scale irrigation experiments compare with localized imaging with 2D and 3D time-lapse GPR?
Q3 How do identified flow-relevant structures and estimates of vertical response velocities compare between the different methods?

This deviates from the proposed plan outlined in the reply to the revisions. However, it has been found much more appropriate. The overlap between the earlier versions of the

two companion MS has been highly reduced. Besides the form and function reference the quantification of response velocities at the hillslope-scale (Angermann et al.) and at the plot- and Darcy-scale (Jackisch et al.) is seen as a common binder.

Consistency and generality of the presented experiments:

In the MS at hand one major concern was a lack of consistency and generality of the presented experiments. This also gave rise to related issues in terms of scientific quality and reproducibility. We addressed these issues by a throughout revision of the set of presented methods and clear focus on each of the respective scales. As such we now include a much more detailed description of the exploration with Darcy-scale measurements. Moreover, the plot-scale experiments became central in the overall MS. For the hillslope-scale experiment we shifted the focus towards the structure identification. More process- and hillslope related aspects were moved to the companion MS (e.g. the piezometer responses).

Besides the full description of the methods we also clarified the link between them: Starting from the coincidence of silty, cohesive soils with high porosity and saturated hydraulic conductivity (which contradicts the common perception), we used apparent velocities throughout the study as quantitative binder of the methods and scales. As such figure 9 (and figure 11 bottom right) condensate much of the findings.

Another general aspect of the study is the inter-comparability of the employed methods. Through the use of time-lapse GPR in 2D and 3D we were able to assess the findings from point-based and snapshot measurements, respectively. This gave rise to a specific discussion of the different methods as means to assess structures and responses in heterogeneous systems.

Reference to related studies and selection of literature

Again, we apologise to have caused the image of biased referencing. Much of the concerns have been caused by a too fuzzy introduction and a lack of clarity about the intentions of the MS and the specific methods and analyses. This has been addressed by restructuring and rewriting of almost the whole MS. Furthermore, the discussion has been rewritten and includes much more specific reference to related studies.

All the other concerns raised by the reviewers have been carefully addressed too along the argumentation lines of the reply. To avoid repetition and confusion in the rewritten MS, we refrain from a line to line and argument to argument comparison.

Thank you for the support and constructive criticism.
Conrad Jackisch