RC1: 'Comment on egusphere-2025-4424', Anonymous Referee #1, 13 Oct 2025

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Response: We thank the reviewer for taking the time to read and comment on our manuscript. We will provide our responses in blue directly in the text below.

I have read the manuscript multiple times, but I'm still not quite sure what to make of it. Not being a catchment hydrologist, I admit that I don't see the complexities the authors do, and I have trouble seeing the points the authors hope to make. If I'm the only one missing the point, I'm happy to be ignored.

My understanding is that subsurface storm flow (SSF) is a useful concept to illustrate some middle member of a continuum of runoff depths and paths from a hillslope, from surface runoff, perched saturated flow (is this SSF?), and groundwater flow below the water table that discharges to local streams, and deeper flow bypassing the local stream and discharging in higher-order streams downgradient. If this is roughly correct, then the necessary condition for SSF to occur would be the formation of a temporarily perched zone of saturation above the permanent water table and a reasonably steep slope. As we have pretty good handle on the precipitation or snowmelt regimes, the bottle-neck would be to identify pedogenic or geologic strata that has lower permeability than above and below, to stop infiltration and to divert it laterally downslope. Candidates include soil B-horizons and fresh bedrock surfaces. In other words, knowledge of the critical zone (CZ) structure would be the top priority to nail down the places that may generate SSF. But I did not see any discussions on this obvious knowledge gap and the concerted effort of the past 25 years by the CZ community to do exactly this.

Response: We agree that it would be helpful to include a more detailed definition of the term subsurface stormflow as well as a discussion on the importance of critical zone structure. We will do so in the revised manuscript.

Overall process concept: Generally, SSF develops in vertical structured soils where the bedrock or a less permeable soil layer is overlaid by a permeable soil layer and vertically percolating water is deflected more or less in a lateral downslope direction due to the slope inclination (e.g., Rinderer et al. 2017, Blume & van Meerveld 2015, Rinderer et al. 2014, Moldenhauer et al. 2013, Bachmair & Weiler, 2011). Subsurface flow can also occur when groundwater levels rise into more permeable layers and water flows laterally through the more permeable layers to the stream ("transmissivity feedback mechanism"; Bishop et al. 1990).

Definition: Different terms for SSF exist in the hydrological literature such as shallow subsurface runoff, interflow, throughflow, lateral flow, or soil water flow. This multitude of terms reflects the different underlying process concepts developed in various experimental studies in different environments by using different experimental approaches at different spatial and temporal scales (Weiler et al. 2005). After intensive discussion within the consortium, we have established the following definition: SSF is a direct subsurface response to a precipitation event, contributing to streamflow generation. SSF is thus all subsurface flow reaching the stream during an event, including near-stream saturation-excess overland flow triggered by SSF and return flow.

Critical Zone structure in the here described experimental effort is investigated a) through the drilling of observation wells and b) through geophysical measurements. We will highlight the importance of structural controls and their investigation in the revised manuscript.

It is admirable that the authors have dug 12 large trenches to capture and monitor SSF, with example time series shown in Figure 2. However, it is not clear at what depths the flow is considered SSF, which must be prior knowledge in order to dig the trenches not too shallow or too deep. Is the “top flow” in Figure 2 considered SSF or the “bottom flow”, or both? What separates them? Is there a pedogenic/geologic boundary between? What are the logics for selecting the 4 catchments? Do they represent different snowmelt regimes, or pedogenic or geologic environments? Does each of them offer unique insights on the combinations of climate, vegetation, soil, geology, topography etc that can help us piece together a bigger picture of the places and times where SSF is an important flow path? Without such discussions, it is difficult to see why digging 12 large trenches in a narrow geographic range can pave the way forward.

Response: These are all good questions and in our revised manuscript we will clarify these points. Depth of SSF occurrence depends on local conditions. As these depths are unknown prior to trench installation all trenches were dug roughly to a depth of 3m. Trenches are shallower in those locations where bedrock prevented us from going deeper. SSF at each trench is captured at two depths and the collectors will capture all lateral flow generated above the depth of the respective collector. Between surface and upper collector for the so-called “top flow” and between the upper and the lower collector for “bottom flow”. The “top flow” collector is roughly placed at pedogenic boundaries, while the lower collector is mostly located at the bedrock interface or inside the weathered bedrock. The two collectors allow us to study under which conditions lateral flow is happening over one or both of these “depth segments”. Both depth segments contribute to SSF.

Research sites were spread across Germany and Austria to capture different climatic, topographic, and geological settings. However, as three catchments are situated in different low-mountain ranges in Germany, there are also certain similarities among them. Prior to trench installation, we conducted a GIS-based topographic analysis to quantify and compare potential subsurface flow volumes across possible hillslopes within the four catchments and selected sites with higher probabilities for SSF occurrence according to this topographical analysis. As to the narrow geographic range – instrumenting as well as maintaining these four sites was and is already a considerable logistical challenge. While we agree that it would be valuable to have more sites distributed across Europe this was simply not feasible in terms of the logistical effort. However, we strongly welcome collaborations with groups doing or planning similar work at other sites.

I suggest that the authors sharpen their messages. First, an explicit definition of SSF is needed, i.e., what it is and how it differs from other flow paths, and how we know it is occurring and it is important. Second, present a synthesis of what we know on the site conditions where SSF has been observed and known to be important, highlighting the climate and substrate drivers of SSF. Third, what we don’t know and should know, e.g., is SSF only important in humid midlatitudes on shallow bedrocks? How about the tropics where the soil is deep? How about forested slopes/catchments vs. cropped or pastured land covers? And fourth, provide some pointers to move forward, e.g., select climate-substrate combinations across the wide world and get funding to instrument the slopes and catchments via an international consortium, followed by some community-level synthesis workshops, to evaluate the conceptual models such as fill and spill, and to come up with new models.

Response: We agree with the reviewer that providing an explicit definition of SSF is necessary and we will do so in the revised manuscript (see also answer above). As to the second part: this brief communication is not meant to be an exhaustive review, but rather aims at informing the hydrological community of this ongoing research effort. As to a global overview we point to McMillan et al. 2025 "Global patterns in observed hydrologic processes." (Nature Water), a recent meta-study on hydrological processes observed in 400 catchments around the globe which found that subsurface stormflow was widely reported across almost all biomes.

We agree to provide a short outlook in the revised manuscript, also including our planned efforts for international catchment intercomparison and synthesis.