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Reply to RC1

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Author comment on "Flood generation: process patterns from the raindrop to the ocean" by Günter Blöschl, Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2022-2-AC2, 2022

I would like to thank RC1 for the thought provoking questions and the opportunity to expand on them. Below I will share some of my thoughts, noting that the topic deserves fuller discussion, perhaps in the format of a future workshop.

The Digital twin concept (Rigon et al., 2022) is very relevant to the context of this paper. I would think that one can speak of "Weak Digital Twins" and "Strong Digital Twins". In the weaker sense they are really hyperresolution models with the appropriate data assimilation and user interfaces, e.g. following the definition of Bauer et al. (2021, p. 80): "A digital twin of Earth is an information system that exposes users to a digital replication of the state and temporal evolution of the Earth system constrained by available observations and the laws of physics." In the strongest sense, the connections between the physical and digital systems are fully implemented which goes beyond a user interface and, following the original idea from manufacturing, fully integrates water management processes, ideally with water-human feedbacks (Sivapalan et al., 2012). The perspective of Rigon et al. (2022), I think, is slightly more oriented toward science than to management and emphasises the potential of forging a more coherent science community, something I consider extremely important (Blöschl et al., 2019). So, in response to the question posed by RC1, a digital twin will perhaps not in itself resolve the scale issue, but it may help hydrologists do more coordinated research and thus also address the scale issue. I will add a comment in section 2 of the paper to refer to digital twins.

The question of how this journey through scales has helped improve flood design, flood forecasting and flood risk assessment is, again, a very good one. I feel very strongly about the synergies of theory and practice. Good science will lead to more accurate practical methods, and practice may provide data and direction for promoting science progress (Sivapalan and Blöschl, 2017). I believe that the scales perspective can indeed help practice. For example, flood design has benefitted from process patterns such as those in Fig. 6 (runoff generation) and Fig. 7 (flood types) through the flood frequency hydrology approach (Merz and Blöschl, 2008), which is also recommended in the German and Austrian flood estimation standards (DWA, 2012; ÖWAV, 2019). Flood forecasting has benefitted from using observed snow and soil moisture patterns as well as preferential flow representations in the soil (Blöschl et al., 2008; Blöschl, 2008). And risk assessment of spring contamination has benefited from observed patterns of evidence on surface runoff (Reszler et al., 2018). Again I will add a comment on my perspective on this in the conclusions section.

Regarding the concept of "trading space for time", I believe we can learn a lot about the time evolution in one catchment from comparisons with other catchments. Hydrology is not a unique case in the spectrum of science disciplines to use comparative methods. For example ethnologists learn about the cultural evolution of music by comparing different ethnicities at the same time (Schneider, 2006), and chronosequences are the classical case in Earth science (Walker et al, 2010). However, such a space-time similarity does not necessarily imply that the cases compared are exact carbon copies shifted by a fixed time of e.g. 50 years. The learning is more about the underlying cause-effect relationships. In the case of flood generation processes, for example, Perdigão and Blöschl (2014) have suggested, that trading space for time is possible provided coevolution is taken into account through characteristic celerities that reflect the spatiotemporal symmetry. In practical terms their study has shown that "the spatial sensitivity of floods to precipitation exceeds that over time, in such a way that, given a 10% spatial increase in precipitation, there is a corresponding 23% increase in flood peaks, whereas given a similar 10% increase in precipitation over time, the flood peaks increase only about 6%." They conclude further that "the interchangeability is found to be legitimate in regions with hydrogeological stability that have had the time to span the whole state space (thus enabling the ergodic hypothesis) or systems that, even not in equilibrium, are evolving at a similar pace (enabling the Taylor hypothesis). On the other hand, regions with transient hydrogeological activity do not comply with such hypothesis, therefore measures of coevolution or relative characteristic celerities have to be taken into account in the space-time trading." I should add that this is only one case study and an evaluation of whether these findings are more widely applicable is still needed.

The statement on the potential of scale research as a unifying framework was not specifically intended to relate to uncertainty but more generally to hydrology. The idea is to explore phenomena at commensurate scales (e.g. explaining regional scale flood patterns by regional scale climate and soil patterns, rather than soil preferential flow) and to establish cross scale links that may be similar, e.g., for floods and droughts (Blöschl, 2001, 2006). I will add an explanation to better bring out the idea of the quote. In fact, I believe that the entire paper is an example of how a scale perspective can help organise one's thinking and thus contribute to progress.

Scale issues in time have been the subject of Sivapalan and Blöschl (2015). There are plans for a paper on flood changes in HESS (Blöschl, 2022). A paper on how one could learn from the temporal scales of floods is still to be written and could revolve around the propagation of information between time scales. An example of how the seasonal and event scales interact is discussed in Sivapalan et al. (2005).

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