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Discussions

Interactive comment on "Scaling, Similarity, and the Fourth Paradigm for Hydrology" *by* Christa D. Peters-Lidard et al.

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Please find below the comments of R. Maxwell and our replies (preceded by "»").

This manuscript makes the argument for a 4th paradigm, or data-intensive science, as an additional path towards understanding scaling relationships in hydrology. In general this manuscript is clearly written and is of a topic that should be of interest to the readers of HESS and is a good fit for the special issue. I have detailed comments organized topically below that I think the authors should consider in a revised manuscript. I recommend that this discussion article undergo revision prior to publication. Finally, I did find the article to be a bit too concise and while much can be written on the topic and brevity is appreciated, some sections felt like they would benefit from additional discussion (e.g. conclusions and recommendations).

»Thank you for your constructive comments. Agreed. More description and discussion has been added on these points.

Types of scaling relationships. As the authors point out, scaling may be a function of organization or hydrologic inputs and responses. Functional relationships between hydrologic variables may also exist and these may be scale-independent (or often referred to as scale-invariant).

»Agreed. This point is noted in the introduction.

Closure. Closure is still important and a formal closure of these systems need be embraced. All models invoke some form of closure at an REV scale and whether this is appropriately represented by the model resolution is an interesting question. Many of the scaling studies cited in this work point out that topography is fractal and this drives much of the scaling behavior seen in hydrology. This presents a special challenge to closure, similar to the atmospheric sciences, where some sub grid information is always needed no matter what the resolution.

»Agreed. See additional discussion added to the introduction.

Model-data interplay. Increasing model resolution can be for multiple reasons, some of which are pointed out but a critical one not included is to ensure numerical convergence of the underlying PDE solution. This latter reason is in tandem with many of the others mentioned by the authors, datasets and scale of process. An important distinction is models that have parameterizations that represent sub grid processes may not improve with increased resolution, models that have a single column tile / subtile form will only increase as a function of finer / better data. I think the important point here is that data limitations affect all models, but differently. Integrated models with lateral flow of water in surface, subsurface systems that generate runoff directly will have a different spatial sensitivity to the resolution of the input data than more traditional land surface models with no lateral flow and a parametrized runoff generation, which will have a very different spatial sensitivity. The input data matters in all cases, but differently for different classes of model. Spatial resolution matters in all cases, but for some models increasing resolution will have diminishing returns or no effect past a certain point, while for other models these thresholds may not be seen or may be found at different spatial resolutions.

» Agreed. The PDE/truncation issue is now noted in the introduction and additional discussion has been added in Section 5 on modeling framework requirements.

Scaling of process. The sub grid parameterizations in e.g. VIC are an important step to understand how processes, such as runoff production, scale up with heterogeneous parameters. High resolution numerical studies indicate that this may depend upon process, excess infiltration doesn't appear to have an ergodic limit (e.g. Maxwell and Kollet AWR 2008), while excess saturation processes scale with the geometric of subsurface K (e.g. Meyerhoff and Maxwell, Hydrogeology 2011). This is but what I'm sure must be only one (self-serving) example of how model simulations like this can inform how parameterizations may be constructed, tested or scaled. In this type of example, the effects of heterogeneity may decrease with scale for runoff that involves groundwater, diminishing the impact of uncertainty in the framework presented by the authors, while they may not for runoff that is purely surface-flow and connection driven. I would imagine that other examples can be used to extend this idea to other processes, e.g. ET, land energy fluxes.

» These are important points, and we have addressed them along with adding citations in section 2.

Distinctions between input data, observations for model and process validation. The 4th paradigm, or intensive spatial temporal data, is important in hydrology. I think it is worth distinguishing between uses and types. Some of these data will be used as model input, some to compare or validate. Uncertainty and spatial scale / scope is important in these large (e.g. continental) datasets and although published after this article went into discussion, Christensen et al (WRR 2017), provide some novel

approaches for improving the subsurface datasets. Additionally, I think it is important for the so-called 3rd and 4th paradigm to interact in that models can be useful hypotheses generation tools to better inform use of observations in new ways.

» Agreed. We have included this distinction in section 4 data requirements, and have also included a reference to Christensen et al.

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