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Hydrology and Earth System Sciences Discussions

Interactive comment on "Searching for the Holy Grail of Scientific Hydrology: $Q_t = H(\overleftarrow{SR})A$ as closure" *by* K. Beven

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I agree with Keith that the discussion of his "holy grail" paper is an excellent example for the value that an online forum on recently submitted papers can offer to the community, not to mention the fun! I also agree with Keith, that our discussion reflects different points of view: mine which is (still) optimistic and Keith's which is, due to his huge expertise and experience, a little sceptical! I think both views are absolutely necessary in a complimentary sense for advancing hydrology in its fundamentals and the closure problem in particular.

Keith is right with his statement that closure in hydrology is a much more complicated and involved problem than closure in e.g. boundary layer meteorology due to the dominance of boundary conditions and sub structures in hydrology, which simply often do

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not know! The dominance of structures is e.g. well reflected by non Gaussian transport behaviour. This is due to a break of symmetry i.e. mixing is not perfect, as slow travelling molecules will never mix with fast ones in preferential flow paths. However, the fact that there are interconnected structures in the subsurface, which lead to non Gaussian transport, is due to my feeling because the generic processes that form these structures in sub-soils are self amplifying in its nature! Otherwise these structures would not exists, average out and spatial heterogeneity would be just white noise. There is structure out there and a due to my believe a part is typical for a landscape Ĕ.. If we succeed in identifying those structures, in understanding how they operate, we are a step ahead towards tackling the closure problem. Again I agree with Keith that the most crucial thing within this context is the development of novel measurement techniques. However, we should carefully think what measurement means? In Quantum Mechanics we often not directly observe i.e. things but just observe traces of e.g. an elementary particle in detector an employ a lot of theory to interpret the observation. In this light, as well never be able to perform direct observation of subsurface fluxes at larger scales, we should in the future combine novel techniques such as tracers and geophysical methods with models, in the sense that the dynamic model aids use to interpret signals (although this might lead to a multitude of possible structures/explanations of the signal).

The discussion about the averaging problem (non-ergodical or ergodical) leads in more general to the question whether we can restrict ourselves to models that just reproduce average dynamics of e.g of subsurface saturation and the related fluxes. The answer is of course no! Closure cannot end with understanding average dynamics. E.g. for transport problems we need the whole spectrum of residence times in the underground, not just the mean. I believe that a) tracer data can help a lot in this context and that i.e. the spectrum of residence times can described in a stochastic manner, which would be one way to allow for subscale variability without letting go the averaging approach, that is the fundament of the REW. However, this spectrum of residence times is of course finger print of the connectivity of the porous media, whether macropores are present,

HESSD

3, S348–S350, 2006

on their structure and whether the macropores penetrate into the saturated zone or not. I agree that these things cannot be decided on a theoretical level but have to be carefully investigated in the landscape of interest and the related soils and aquifers. Again, as optimistic person, I believe that we can access part of this information in a typical catchment in a distinct landscape and may generalise this information into typical closure relations, that have of course to be proven to be valid in independent studies (more thoughts on this may be found in hessd-2006-0006 “Dynamical process upscaling for deriving catchment scale state variables and constitutive relations for meso-scale process models” by Zehe et al., that will pop up shortly in HESSD, has been thoroughly reviewed by Keith and the related response to Keith’s review).

Finally I agree that the right way to tackle the closure problem is that we combine theoretical considerations, our perceptions and empirical approaches. In this sense it would be interesting to start with different zero-order-models how closure functions in a catchment/ landscape, design the right measurements to test those models, and reject and update those approaches. This should be way to go, so lets start together maybe in the frame of PUB?

Erwin Zehe

Literature: Bloeschl and Zehe, 2005: On predictatbility. HP Todays 19, 3923 - 3929

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 3, 769, 2006.