Hydrological modelling at the catchment scale: Trusty Friend or Devious Foe?

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Abstract: Hydrological modelling – despite its seeming well-defined aim of predicting environmental water flows – is growing to employ a staggering array of models and modelling techniques. It is helpful to view the process of model development and application as a series of decisions, which highlights that the reliability and trustworthiness of the overall modeling chain depends critically on the individual steps. However, making transparent and justifiable choices at each modeling step is far from straightforward.

Even if we limit ourselves to a discussion of model development for catchment-scale streamflow predictions, there are entire schools of thought to choose from – with the historical distinctions between conceptual versus physically based, and lumped versus distributed becoming increasingly grey as broader choices such as black-box models and neural networks, data mining, and others are considered.

As we go from model development to model application, a hydrologist will face further choices, such as those related to parameter estimation – from a priori estimation, to manual calibration, to deterministic optimization to fuller probabilistic uncertainty analyses. As before, each category here is a field of research in its own right, with its own set of orthodoxies and inevitable controversies.

The origins of such a wide gamut of modelling approaches are arguably rooted in the challenging combination of modelling and data analysis tasks facing hydrologists, and environmental modellers in general. Data uncertainty arising from the sparse and imprecise measurements of environmental variables, the nonlinearity and heterogeneity of hydrological systems (both at the surface and in the subsurface), the difficulty in establishing physically realistic constitutive relationships, and other factors are all widely recognized and are continuing to attract major research attention.

Are we as a community making progress? The published literature suggests clear advances, yet, at least sometimes, there is also a sense of slow progress – for example, as evidenced by sessions at major conferences being titled “Why can’t we do better than TOPMODEL?”, and workshops such as the “Hydrological Court of Miracles” where many examples of model failures were exhibited.

One of the difficulties is that, while we are seeing numerous and diverse modelling applications, the studies have tended to use their own sets of models and metrics, and efforts to carry out a meaningful large scale interpretation and attribution of results have been hampered by the myriad of uncontrolled major and minor differences between different models – especially once we get down to the level of actual computing software. And to confound matters further, many current hydrological models do not take advantage of modern numerical techniques, and their trustworthiness is often undermined by major numerical artefacts.

Is there a way of making sense of all this real and perceived “complexity”? Are we in danger of building a Modelling Tower of Babel, where hydrologists speak with each other and their users in a thousand non-transparent technical dialects – or is this an inevitable price of research diversification? Are we any closer to a Grand Unified Theory of hydrological modelling? Should we even be looking for such a theory, or do most modelling contexts demand their own model? Can defensible research-based recommendations be made to model users, and what might some of these recommendations look like? What might be some of the practical challenges and opportunities awaiting the next generation of hydrological model developers and users?

This talk will provide the authors’ perspectives on these and other questions. Examples will be provided, including development, application and integration of inference methods and diagnostics, robust time stepping schemes and flexible hydrological models, with the aim of encouraging a debate and discussion.

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