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Optimality theory: a path to calibration-free models?

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Hydrological understanding is commonly synthesised into more or less complex mechanistic models, some of which have become "as inscrutable as nature itself" (Harte, 2002). Most of these models contain a number of unknown parameters, which have to be calibrated on past observations. This approach often leads to "equifinality" issues (Beven, 1993; Beven and Freer, 2001), which result from an ill-posed problem, where the information content in the calibration data set is insufficient to filter out a single parameter set from all possible sets. The consequence is that we cannot identify the "correct" parameter set that produces the right results for the right reasons.

Optimality theory suggests that natural systems self-optimise following certain goal functions (or "objective functions" in the mathematical sense). The great potential of optimality principles lies in the fact that they allow prediction of system properties that would otherwise have to be obtained through direct observations or calibration. This means that models built around optimality principles require less data for calibration, leaving more data for model testing.

The present review illustrates the utility of optimality theory for building falsifiable models and the potential to learn from such models. As a concrete example, it uses the development and testing of the Vegetation Optimality Model (VOM). The development of the VOM started off with the assumption that maximization of the net carbon profit (NCP) is an organizing principle that drives the adaptation of vegetation to its environment. To formulate a falsifiable hypothesis based on this principle, the authors had to identify some important degrees of freedom that vegetation has to adapt to its environment and their associated costs and benefits in terms of the NCP. Then, the hypothesis was formulated that the organizing principle in conjunction with the proposed degrees of freedom and their costs and benefits would allow to predict certain canopy features and CO2 fluxes at a given site. The hypothesis was tested using site-specific observations and found to be falsified during the dry, but not during the wet season (Schymanski et al. 2007). This led to the conclusion that the costs for deep roots might be limiting canopy cover in the dry season. Rooting depth and the associated costs and benefits were included in the following version of the VOM, which led to a satisfactory reproduction of the rooting depth, canopy cover dynamics and seasonal fluxes of CO2 and water vapour over several years (Schymanski et al., 2009).

Clearly, the radical reduction of calibration needs by the inclusion of a proposed organizing principle resulted in a falsifiable model. From the partial falsification in the first step, the authors learned enough to construct a model with a clear potential for multivariate prediction.

The present version of the VOM is currently being tested on a number of sites in a range of different climates, without any calibration or parameter tuning. Preliminary results give an indication of the predictive accuracy and generality of the model, again suggesting falsification of the model under certain conditions.

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