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Understanding the Information Content in the Hierarchy of Model Development Decisions: Learning From Data

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Process-based hydrological models seek to represent the dominant hydrological processes in a catchment. However, due to unavoidable incompleteness of knowledge, the construction of "fidelius" process-based models depends largely on expert judgment. We present a systematic approach that treats models as hierarchical assemblages of hypotheses (conservation principles, system architecture, process parameterization equations, and parameter specification), which enables investigating how the hierarchy of model development decisions impacts model fidelity. Each model development step provides information that progressively changes our uncertainty (increases, decreases, or alters) regarding the input-state-output behavior of the system. Following the principle of maximum entropy, we introduce the concept of "minimally restrictive process parameterization equations—MR-PPEs," which enables us to enhance the flexibility with which system processes can be represented, and to thereby investigate the important role that the system architectural hypothesis (discretization of the system into subsystem elements) plays in determining model behavior. We illustrate and explore these concepts with synthetic and real-data studies, using models constructed from simple generic buckets as building blocks, thereby paving the way for more-detailed investigations using sophisticated process-based hydrological models. We also discuss how proposed MR-PPEs can bridge the gap between current process-based modeling and machine learning. Finally, we suggest the need for model calibration to evolve from a search over "parameter spaces" to a search over "function spaces."