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Equifinality and Earth and Environmental Systems Models: Theory and Application

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All models are wrong, all data are erroneous, our knowledge of real-world processes is fallible, and all model evaluations are incomplete. Despite these limitations, there is room to improve models and evaluation schemes, and due to these limitations uncertainty is an inalienable property of scientific modelling. At the heart of uncertainty lies the concept of 'equifinality', i.e. a given outcome (*finality*) can be reached *equally* through distinct developmental pathways. Equifinality is a characteristic property of open complex systems such as Earth and environmental systems. A review of the literature reveals that despite the widespread use of the term, equifinality is mostly used inconsistently and understood/implemented in terms of parameter equifinality/uncertainty. Therefore, in the first part of this study, we present a conceptual history of equifinality in science, and propose a theoretical framework—based on a meta-synthesis of literature from biology, hydrology, uncertainty, system theory, and philosophy of science—to disentangle equifinality and uncertainty, characterising various facets of equifinality and its relationship with uncertainty. The framework has fundamental implications in process understanding, hypothesis generating/testing, and model evaluation. To illustrate this, in the second part, we present a new model evaluation approach called 'Flux Mapping' within which equifinality of model fluxes are examined. We demonstrate, for a number of conceptual rainfall-runoff models, how Flux Maps can give new insights into the model behaviour that cannot be captured by conventional model evaluation methods. We discuss the advantages of flux space, as a subspace of the model space that is not usually examined, over parameter space. We demonstrate how the proposed theoretical framework and its application in model evaluation (i.e. Flux Mapping) can connect the dots between model performance, uncertainty, and realism. Flux Mapping is an approach to evaluate process-representation of scientific models extendable to any field of scientific modelling dealing with complex systems in the face of uncertainty.