Thermodynamic optimality principles in Earth sciences

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Ecohydrological systems are a result of long-term co-evolution of soils, biota and atmospheric conditions, and often respond to perturbations in non-intuitive ways. Their short-term responses can be explained and sometimes predicted if we understand the underlying dynamic processes and if we can observe the initial state precisely enough. However, how do they co-evolve in the long-term after a change in the boundary conditions? In 1922, Alfred Lotka hypothesised that the natural selection governing the evolution of biota and composition of ecosystems may be obeying some thermodynamic principles related to maximising energy flow through these systems. Similar thoughts have been formulated for various components of the Earth system and individual processes, such as heat transport in the atmosphere and oceans, erosion and sediment transport in river systems and estuaries, the formation of vegetation patterns, and many others. Different thermodynamic optimality principles have been applied to predict or explain a given system property or behaviour, of which the maximum entropy production and the maximum power principles are most widespread. However, the different studies did not use a common systematic approach for the formulation of the relevant system boundaries, state variables and exchange fluxes, resulting in considerable ambiguity about the application of thermodynamic optimality principles in the scientific community. Such a systematic framework has been developed recently and can be tested online at:
https://renkulab.io/projects/stanislaus.schymanski/thermodynamic_optimality_blueprint
In the present study, we illustrate how such a common framework can be used to classify and compare different applications of thermodynamic optimality principles in the literature, and discuss the insights gained and key criteria for a more rigorous testing of such principles.