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Effective soil hydraulic conductivity predicted with the maximum power principle

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Drainage of water in soils happens for a large extent through preferential flowpaths, but these subsurface flowpaths are extremely difficult to observe or parameterize in hydrological models. To potentially overcome this problem, thermodynamic optimality principles have been suggested to predict effective parametrization of these (sub-grid) structures, such as the maximum entropy production principle or the equivalent maximum power principle.

These principles have been successfully applied to predict heat transfer from the Equator to the Poles, or turbulent heat fluxes between the surface and the atmosphere. In these examples, the effective flux adapts itself to its boundary condition by adapting its effective conductance through the creation of e.g. convection cells. However, flow through porous media, such as soils, can only quickly adapt its effective flow conductance by creation of preferential flowpaths, but it is unknown if this is guided by the aim to create maximum power.

Here we show experimentally that this is indeed the case: In the lab, we created a hydrological analogue to the atmospheric model dealing with heat transport between Equator and poles. The experimental setup consists of two freely draining reservoirs connected with each other by a confined aquifer. By adding water to only one reservoir, a potential difference will build up until a steady state is reached. From the steady state potential difference and the observed flow through the aquifer, and effective hydraulic conductance can be determined. This observed conductance does correspond to the one maximizing power of the flux through the confined aquifer.

Although this experiment is done in an idealized setting, it opens doors for better parameterizing hydrological models. Furthermore, it shows that hydraulic properties of soils are not static, but they change with changing boundary conditions. A potential limitation to the principle is that it only applies to steady state conditions. Therefore the rate of adaptation of hydraulic properties should be faster than the rate of change in boundary conditions.