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Maximum power as Threshold between Matrix Flow and Boil Formation

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Upwelling water in polder areas is often combined with vertical sand transport in the form of sand boils, where these boils act as preferential flow paths. However, it is difficult to predict when and where this happens. In this study, we demonstrate with a lab experiment that the threshold when sand boils start forming coincides with the maximum power principle.

While the well-known Carnot limit sets a limit for the maximum rate of work that can be extracted from a heat engine (having a fixed temperature difference), the maximum power principle predicts this for a system with fixed flux boundary condition. It differs from the Carnot limit by the feedback that the gradient driving the flux is also depleted by the flux. While both, a zero-flux and a very large flux result in no generated power, a maximum occurs at an intermediate flux.

Our experimental setup is an analogue of the simple two-box model of Lorenz et al. (2001), who successfully used this principle to predict latitudinal heat transport on Titan, Mars and Earth. It consists of two connected reservoirs, both draining according to a certain stage-discharge relation. In the first reservoir, water is pumped in at a constant rate. The second reservoir is filled with compacted sand and situated such that water is flowing upwards through the sand bed. For each set of experiments, we stepwise increased the pump discharge until the geopotential increases so much that boils are formed.

After reaching each steady state, power is determined as the product of the observed geopotential over the sand bed and the mass flux through it. The maximum in power is determined by running a numerical model for a range of fluxes through the sand bed and corresponding geopotentials.

Our results show that for a wide range of boundary conditions, the compacted soil states always operates at a lower than optimal mass flux, while observed mass fluxes in the boil state are always higher than the one at maximum power. This indicates that the threshold at which sand boils occur coincides with the maximum power principle.

References:
Lorenz, R. D., Lunine, J. I.,Withers, P. G., and McKay, C. P.: Titan, Mars and Earth: entropy production by latitudinal heat transport, Geophys. Res. Lett., 28, 415–418, 2001.