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Thermodynamics and Planetary Habitability

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The relevance of thermodynamics as the driving force for life has long been recognized, for instance by Boltzmann (1886), Lotka (1922) and Schrödinger (1944). Thermodynamics has also been used to characterize planetary habitability. The Earth's atmosphere in a state far from thermodynamic equilibrium, as reflected by its high oxygen content, has been used as an indication for a habitable planet as this state is maintained by the biosphere (Lovelock, 1965). Yet the question remains regarding the fundamental causes that make planet Earth so habitable, or, in other words, what the driving principles are that make the emergence of life an inevitable feature of Earth system functioning.

As an extension to these thermodynamic views, I argue here that the myriad of different biogeochemical processes that we call life act to maximize the planetary rate of entropy production. The possibility to do so exists on Earth because its planetary albedo, and therefore the amount of absorbed sunlight and planetary entropy production, is not a fixed planetary property, but emerges from the dynamics of the climate system and the global biogeochemical cycles that shape the composition of the atmosphere. A dominant effect on the planetary albedo is surface temperature: low temperatures result in more highly reflective snow and sea-ice cover, while high temperatures result in an atmosphere with high moisture contents, low temperature gradients, and likely higher reflective cloud cover. Hence, a minimum planetary albedo should exist for a certain, optimum surface temperature at which the absorption of sunlight and the associated rate of entropy production is maximized. Surface temperature, in turn, can be regulated towards the optimum through the intensity of carbon cycling as it directly impacts the strength of the atmospheric greenhouse effect. Hence, a carbon-cycling biosphere can be seen as the biogeochemical implementation to maximize planetary entropy production.

This thermodynamic perspective views life as an intrinsic planetary property that is the inevitable consequence of non-equilibrium thermodynamic systems to maximize their rates of entropy production to the extent possible (Kleidon 2004). Planetary habitability can then be related to the flexibility of the planetary boundary conditions, that is, the extent to which these can be altered by internal dynamics. In this presentation, I describe this view in more detail and will outline methods by which this view can be tested quantitatively with numerical simulation models of the Earth system.

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