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Keeping Earth at work: Using thermodynamics to develop a holistic theory of the Earth system

Axel Kleidon
Max-Planck-Institut für Biogeochemie, Jena, Germany (akleidon@bgc-jena.mpg.de, +49-(0)3641-577217)

The Earth system is unique among terrestrial planets in that it is maintained in a state far from thermodynamic equilibrium. Practically all processes are irreversible in their nature, thereby producing entropy, and these would act to destroy this state of disequilibrium. In order to maintain disequilibrium in steady state, driving forces are required that perform the work to maintain the Earth system in a state far from equilibrium. To characterize the functioning of the Earth system and the interactions among its subsystems we need to consider all terms of the first and second law of thermodynamics. While the global energy balance is well established in climatology, the global entropy and work balances receive little, if any, attention. Here I will present first steps in developing a holistic theory of the Earth system including quantifications of the relevant terms that is based on the first and second laws of thermodynamics. This theory allows us to compare the significance of different processes in driving and maintaining disequilibrium, allows us to explore interactions by investigating the role of power transfer among processes, and specifically illustrate the significance of life in driving planetary disequilibrium. Furthermore, the global work balance demonstrates the significant impact of human activity and it provides an estimate for the availability of renewable sources of free energy within the Earth system. Hence, I conclude that a holistic thermodynamic theory of the Earth system is not just some academic exercise of marginal use, but essential for a profound understanding of the Earth system and its response to change.