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Thermodynamic limits set relevant constraints to the soil-plant-atmosphere system and to optimality in terrestrial vegetation

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The soil-plant-atmosphere system is a complex system that is strongly shaped by interactions between the physical environment and vegetation. This complexity appears to demand equally as complex models to fully capture the dynamics of the coupled system. What we describe here is an alternative approach that is based on thermodynamics and which allows for comparatively simple formulations free of empirical parameters by assuming that the system is so complex that its emergent dynamics are only constrained by the thermodynamics of the system. This approach specifically makes use of the second law of thermodynamics, a fundamental physical law that is typically not being considered in Earth system science. Its relevance to land surface processes is that it fundamentally sets a direction as well as limits to energy conversions and associated rates of mass exchange, but it requires us to formulate land surface processes as thermodynamic processes that are driven by energy conversions. We describe an application of this approach to the surface energy balance partitioning at the diurnal scale. In this application the turbulent heat fluxes of sensible and latent heat are described as the result of a convective heat engine that is driven by solar radiative heating of the surface and that operates at its thermodynamic limit. The predicted fluxes from this approach compare very well to observations at several sites. This suggests that the turbulent exchange fluxes between the surface and the atmosphere operate at their thermodynamic limit, so that thermodynamics imposes a relevant constraint to the land surface-atmosphere system. Yet, thermodynamic limits do not entirely determine the soil-plant-atmosphere system because vegetation affects these limits, for instance by affecting the magnitude of surface heating by absorption of solar radiation in the canopy layer. These effects are likely to make the conditions at the land surface more favorable for photosynthetic activity, which then links this thermodynamic approach to optimality in vegetation. We also contrast this approach to common, semi-empirical approaches of surface-atmosphere exchange and discuss how thermodynamics may set a broader range of transport limitations and optimality in the soil-plant-atmosphere system.