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Understanding land surface-atmosphere interactions at the diurnal scale from energetic and thermodynamic constraints

Axel Kleidon[1], Maik Renner[1,2], Annu Panwar[1], and Sarosh Alam Ghausi[1]
[1]Max-Planck-Institut für Biogeochemie, Jena, Germany (axel.kleidon@bgc-jena.mpg.de)
[2]Landesamt für Umwelt, Frankfurt/Oder, Germany

Land-atmosphere interactions are typically evaluated using numerical simulation models of increasingly greater complexity. But what are the key, major constraints that determine the first-order controls of the land-atmosphere system? Here, we present an alternative approach that is solely based on energetic and thermodynamic constraints of the coupled land-atmosphere system and show that this approach can reproduce observations at the diurnal scale very well. The key concept we use is that turbulent heat fluxes are predominantly the result of an atmospheric heat engine that is driven by the heat input from the surface and that operates at the thermodynamic limit of maximum power. This provides a closure for the magnitude of turbulent fluxes in the surface energy balance. Interactions enter this approach mainly in two ways: First, the cooling effect of turbulent heat fluxes on surface temperature lowers the engine's efficiency, thereby setting the maximum power limit, and second, by heat storage changes in the lower atmosphere, which represent an entropy term inside the heat engine and alter the thermodynamic limit for power output. Both effects are, however, well constrained by energy balances, yielding analytical solutions for energy balance partitioning during the day without the need for empirical parameters. The further partitioning into sensible and latent heat fluxes is obtained from the assumption of thermodynamic equilibrium at the surface where heat and moisture is added to the atmosphere (if sufficient soil water is accessible). We then show that this approach works remarkably well in reproducing FluxNet observations over the diurnal cycle. What this implies is that these physical constraints determine the first-order dynamics of the land-atmosphere system, enabling us to derive simple, physics-based estimates of climate, the dominant effects of vegetation, and the response of the coupled system to global climate change.