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Estimation of diurnal turbulent heat exchange by the thermodynamic limit of a cold heat engine over contrasting land-cover types

Maik Renner, Luigu Conte, and Axel Kleidon
Max-Planck-Institute for Biogeochemistry, Biospheric Theory and Modelling Group, Jena, Germany
(mrenner@bgc-jena.mpg.de)

Land-cover change not only alters local temperature but also affects the exchange of turbulent heat fluxes. However, the assessment is uncertain because models require a parameterization of turbulent exchange which may not be applicable to the future state and measurements taken over e.g. a grass site cannot be transferred to a forest site.
Here we aim to estimate turbulent heat exchange by the means of thermodynamics limits of a surface-atmosphere heat engine, which converts a temperature gradient into kinetic energy. At the diurnal time scale this requires to take heat storage processes at the surface and in the lower atmosphere into account. We use a modified Carnot limit of a cold heat engine where power is reduced due to heat storage within the engine (Kleidon 2016). This is linked to an estimate of diurnal heat storage requirement where diurnal heat storage fluxes are assumed to balance the diurnal imbalance of absorbed solar radiation at the surface. Using the tradeoff between the temperature gradient and the turbulent heat exchange we maximize the power of the cold heat engine which provides analytical solutions of turbulent heat exchange. We find that it is critical where the diurnal heat storage is being accomplished. If subsurface heat storage is small, then most of the diurnal solar imbalance must be buffered within the lower atmosphere, which is accomplished by enhanced turbulent heat exchange. Land-cover types which have small heat capacity like forests induce a larger turbulent heat exchange with the atmosphere which is consistent with observations of FLUXNET sites across a surface heat storage capacity gradient. We conclude that our thermodynamic approach identified the key controls of land-surface conditions on turbulent heat exchange which enables to project land-cover change based on first-order physical principles.

Reference: A Kleidon, Thermodynamic foundations of the Earth system, Cambridge University Press, 2016