Geophysical Research Abstracts
Vol. 20, EGU2018-5709, 2018
EGU General Assembly 2018

Reconciling the Paltridge and Lorenz thermodynamic selection criteria for climate steady states

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Forty years ago Paltridge used a simple zonally-averaged energy balance model (EBM) to show that the steady-state format of meridional heat flow in the Earth's atmosphere and oceans appears to maximise the associated thermal entropy production [1]. This finding opened up the possibility that climate and climate change might be predicted without requiring a detailed model of the internal dynamics of the system.

In apparent conflict with this result, a more recent study using a low-resolution general circulation model (GCM) suggested that realistic values of two key model parameters (cloud droplet-to-rain conversion rate, convective entrainment rate) are consistent with Lorenz's principle of maximum kinetic energy dissipation, but do not maximise the material entropy production [2]. In the absence of a physical understanding of either the Paltridge or the Lorenz conjectures, the interpretation of these two contrasting results remains unclear.

Here, the Paltridge and Lorenz conjectures are reconciled within the framework of a more general Maximum Entropy Production (MEP) principle derived theoretically from non-equilibrium statistical mechanics. In this framework, entropy production (EP) is defined as a generic measure of distance from equilibrium, in terms of the relative probability of forward and reverse microscopic trajectories. Then, among all the possible climate states compatible with steady-state global energy balance, the climate state of maximum mean EP emerges as the most probable one within an approximation that neglects non-Gaussian fluctuations in EP. The mean EP may be interpreted physically as the sum of contributions from both thermal and kinetic energy dissipation; previous EBM- and GCM-based results separately supporting the Paltridge and Lorenz principles [1,2] may then be interpreted as approximations to this more general MEP principle.

The generic statistical explanation of MEP proposed here is not specific to climate systems, and may provide a rationale for applying MEP to non-equilibrium systems more generally.

[1] Paltridge GW. The steady-state format of global climate. 1978. Q. J. R. Meteorol. Soc. 104, 927-945.
[2] Pascale S, Gregory JM, Ambaum MHP, Tailleux R. 2012. Clim. Dyn. 38, 1211-1227.