

## **Revision of MS "Working on the limit: A review of thermodynamics and optimality of the Earth system"**

Dear Editor,

I would like to submit the revised version of my manuscript for possible publication in Earth System Dynamics. In this revision, I have accommodated the constructive comments by the reviewers, as well as those made by a few other colleagues who have commented on the original manuscript that I shared with them. The changes in text in the manuscript are either highlighted in blue (to address reviewer comments) or in red (to address comments by colleagues).

The revised version of the manuscript includes mostly clarifications and additional text to explain things to address the reviewer comments. Specifically, I addressed the reviewer comments as detailed further below (and as described in more detail in the replies).

Best regards,  
Axel

### **Reviewer #1:**

- Added a brief description of the entropy budget to the introduction. To support this description, I moved the old Figure 6 to make it Figure 1 and modified it to complement this description.
- Added some of the criticisms about MEP to the introduction, including the references mentioned by the reviewer.
- Clarified the forms of entropy and its relevance in Section 2.1.
- Clarified the description of free energy in Section 2.2 and its budgeting by including Eq. 1.
- Clarified the two cases of the Carnot limit in Section 2.3, supplemented with its derivation in the new Appendix A.
- Clarified the difference to Pauluis and Held's work in Section 2.4.
- Added the reference to Held (2005) at the beginning of Section 3.
- Clarified the level of agreement and discrepancies in Section 3.1.
- Added a table (new Table 1) with the entropy budget in Section 3.1.
- Clarified link to Lorenz Energy Cycle, material entropy production, and added reference to Lucarini et al. (2014).
- Clarified that phase transitions play practically no role in entropy production in hydrologic cycling (because they proceed at saturation) at the beginning of Section 3.2 and the discussion at the end of Section 3.2.
- Provided more detail of how the limit on carbon uptake is estimated and described some uncertainty in Section 3.3.

### **Reviewer #2 (Remi Tailleux):**

- Clarified description of free energy and its relation to exergy in Section 2.2, and the link to APE at the end of Section 3.1.
- Clarified the use of generation and dissipation in Section 2.2, including a new equation (Eq. 1) to illustrate this budgeting.

- Added a discussion on how the description of the hydrologic cycle of the manuscript relates to the work of Laliberte et al. (2015) at the end of Section 3.2.
- Added a note on the Curzon-Ahlborn limit at the end of Section 2.3.
- Minor comments addressed as described in the reply to the review.

**Reviewer #3 (Jonas Nycander):**

- Clarified throughout the manuscript that the manuscript does not claim that there is one general thermodynamic optimality principle for Earth system science, but that it requires a more differentiated view of direct vs. indirect manifestations of thermodynamic limits.
- Added a new Section 2.5 to provide a possible mechanism of how a state of maximum power is achieved by feedbacks. This is not new work, but summarizes previously published work in Kleidon et al. (2013) and Kleidon (2016). I also included that this line of research would need more work to be substantiated.
- Added an evaluation plot in Figure 6 in Section 2.4 regarding the evaluation of the max. power limit.
- Added text and a new Figure 8 to clarify that external radiative fluxes and heat transport between the tropics and the poles are not independent from each other.
- Added text and reference to Pascale et al. (2013) about the role of planetary rotation rate in Section 3.1 and in the discussion (Section 4.1).
- Clarified the level of agreement and discrepancies in Section 3.1.
- In evaluation of evaporation (Section 3.2), I separated humid from arid regions to clarify that evaporation are not only shaped by precipitation (see also modified Figures 12 and 14). I also added the link to potential evaporation, a well established concept in hydrology.
- Extended the description on how optimality links to vegetation activity using this thermodynamic interpretation at the end of Section 3.3, specifically regarding the effect of rooting depth and stomata.