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Comment on esd-2022-38

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Referee comment on "Working at the limit: a review of thermodynamics and optimality of the Earth system" by Axel Kleidon, Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2022-38-RC2, 2022

This review provides an interesting perspective on the various optimality principles --- such as maximising or minimising entropy production, power, or dissipation --- that have been proposed as possible macro thermodynamic laws capable of accounting for some of the observed emergent properties of the Earth climate system. Overall, I find the review clearly written and making some valid and important points, such as the need to distinguish whether irreversible entropy production results from the destruction of free energy or just from passive diffusion of heat within the background stratification. Still, I think that some crucial concepts used by the author are imprecise and would benefit from clarification, as indicated in the comments below.

Major comments

Free energy versus exergy versus APE. I find the discussion of the concepts of free energy versus exergy versus APE somewhat confusing and unclear. In Tailleux (2013) cited by the author, I interpreted exergy as the available energy defined relative to a state of thermodynamic equilibrium with uniform temperature, and APE as available energy defined relative to a state of minimum potential energy obtained from the actual state by means of an adiabatic re-arrangement of mass as per Lorenz (1955) theory. In my mind, there is a significant difference between the two, as transforming exergy into useful work cannot be done without simultaneously destroying exergy and creating entropy irreversibly. In contrast, APE can be converted into useful work (kinetic energy) without the need to destroy any of it nor creating entropy irreversibly. In this regard, APE appears to be a `freer' form of free energy than exergy. Can the author try to highlight the differences and inter-relations between the different concepts? Does the author define free energy relative to thermodynamic equilibrium, or does he also consider that APE is a form of free energy? An advantage of the exergy concept is that it provides a clear explanation of where the free energy comes from, i.e., from the convexity of the internal energy. If internal energy was not a convex function of entropy, it would not be possible to transform `heat' into `work'.

Dissipation/generation. It is not clear to me what the author means by 'dissipation' or `generation'. As regards dissipation, does the author mean 'viscous dissipation' or does his definition also include APE dissipation by diffusive processes, which Tailleux (2009) argued should be regarded as an additional form of Joule heating similar to viscous dissipation? The concept of APE dissipation seems important, because for simple fluids, it is proportional to the rate of irreversible entropy production by diffusive fluxes of heat, which means that there is a link between the production of entropy production due to the destruction of APE (viewed as a form of free energy) and the entropy production due to passive or dynamically inert heat diffusion through the background reference stratification. As regards 'generation', it seems to me that it is an ambiguous term. Indeed, I'd like to point out that in the oceans, for instance, oceanographers still do not agree on how to define the power input due to surface buoyancy fluxes as discussed in Tailleux (2010).

On the role of moisture. I believe that the author makes an important point in pointing out that the climate system differs from the kind of heat engines considered in textbooks in that the net heating and cooling are not fixed but to be obtained as part of the solution. Regarding the role of moisture, the author may be aware that Laliberte et al. (2015) have argued that moisture reduces the efficiency of the atmospheric heat engine relative to a dry one. It would be of interest if the author could comment on this and whether he agrees or disagrees from his perspective.

Carnot efficiency versus maximum power efficiency. The author cites a number of studies related to maximum power. Wouldn't it be relevant to cite endoreversible heat engines and the ideas of Curzon-Ahlborn here?

Minor comments

Abstract. I find the first sentence to be particularly obscure. Could the author be somewhat more specific? Second line: what does 'it plays' refer to? If this refers to 'thermodynamics and optimality', plural should be used.

Lines 23-26. Could the author be more specific about the `simplicity' of the examples discussed? This seems to be a bit subjective and left to the appreciation of readers.

Line 87. Might be important that entropy increases irreversibly only in closed systems.

Lines 180. Free energy budgets are important. It seems to me that these are widely used but not called that way. What about APE budgets or the kind of available energy budgets considered by Bannon and co-authors for instance? Could the author be more specific about what he has in mind exactly? What is his definition of free energy?

Line 184: `These all can be formulated in terms of free energy budgets, a concept that is rarely used in Earth system sciences' I am not sure that this is true, as for me, APE budgets or budgets of available energy represent 'free energy budgets' so the author needs to explain what a 'free energy budget' would look like and provide examples.

Line 233 – This derivation of the Carnot limit is general and quite different to common textbook derivations. I am a bit puzzled by this statement, as this is the derivation of the Carnot efficiency I am used to, and the one I was taught as an undergrad.

Line 240 – is given by G = D. This may be the case but because I think that there is no consensus about how to define G and D unambiguously in all cases (see my remarks about APE dissipation above), as is the case in the oceans for instance, it is unclear how to link MEP and ideas of maximum power or dissipation in the most general case.

Lines 275-277. What about endoreversible engines and the Curzon-Ahlborn efficiency?

Lines 376 – Against friction. As well as against APE dissipation may be.

Lines 385-390. This assumes that we understand how to define and quantify both power and dissipation in all possible cases, but I don't think this is true, e.g., discussion in Tailleux (2010) for the oceanic case.

Line 443 – Here the author uses the term 'frictional dissipation' where he only used 'dissipation' before. See the need for clarifying the term 'dissipation' in major comments above.

Line 450 – I agree that this is a particularly important point that I think will need to be more fully recognised and expanded upon in the future.

Line 463 – 'so that these conversions neither generate nor dissipate free energy' This is true only for APE but would not apply to exergy for instance, whose transformation into useful work requires destruction.

Line 527 – GPCP – missing reference

References

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