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Hydrology and Earth System Sciences Discussions

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Interactive Comment

Interactive comment on "Biological catalysis of the hydrological cycle: life's thermodynamic function" *by* K. Michaelian

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I thank both Prof. Schymanski and an anonymous referee for their through and thoughtful reviews of my manuscript. I also thank them for their particularly encouraging and engaging initial comments. To promote discussion within the allotted time window of the journal, before responding to the specific comments of each referee individually (which will take more time) I present here a clarification addressing what I consider to be the most important concern of both referees, regarding the foundations of the thermodynamic formalism on which my hypothesis of life catalyzing the hydrological cycle is based.

I have been careful in the manuscript not to use phrases, and much less employ principles, of the likes of which I am presently accused by both referees; for example that “biota maximize entropy production”. Furthermore, nowhere in the manuscript do I refer to “maximum entropy production”. I am, in fact, in agreement with the general consensus in the community that the maximum entropy production principle (MaxEP) is still without a rigorous statistical mechanical basis. Although some extremum principles in non-equilibrium thermodynamics can be used, and have been generally accepted, these require specific system thermodynamic conditions, constraints and kinetics to be valid [1]. For the particular case treated in the manuscript, concerning the global entropy production of the Earth in its solar environment, without these considerations, a phrase such as “biota maximize entropy production” would imply that we somehow have a priori knowledge of all (almost infinite) possible couplings of irreversible processes that could occur on Earth, and that we are confident enough to suggest that among all possibilities “biota maximizes entropy production”. This, most certainly, is not the case and NOT what I am suggesting in the manuscript. In fact, in the concluding sentence of my manuscript I emphasize that “Life, as we know it, is an important, perhaps even inevitable, but probably not indispensable, catalyst for the production of entropy on Earth.”

What I do employ in the manuscript, however, is based on much more established non-equilibrium thermodynamics;

1) All irreversible processes produce entropy. Stated more emphatically from the thermodynamic or statistical mechanics viewpoint, entropy production is the source of macroscopic irreversible processes.

2) Often irreversible processes couple, for example an electric current in a bimetallic circuit will cause the emission or absorption of heat at the bimetal junction (Peltier effect). The application of a temperature gradient in a gas mixture will cause a flow of mass in addition to the flow of heat (Soret effect).

3) The overall entropy production in situations where a coupled irreversible process arises is always greater than the irreversible process conjugate to the applied thermo-

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dynamic force (gradient). In other words, irreversible processes arise and couple to remove impediments to greater entropy production (see Onsager [2], and also Morel and Fleck [3]).

In the manuscript, I am suggesting that biological processes arose and coupled with abiotic irreversible processes (such as, for example, the water cycle) to augment the global entropy production of Earth in its interaction with its solar environment. Of course, the biological production of photon dissipating organic pigments in water is not the only irreversible process imaginable that could have arisen. Our Earth under its impressed solar environment could also have taken a completely different route, which could have led to an even greater, or lesser, entropy production than today. Initial conditions (even microscopic), variations in the external conditions, and microscopic fluctuations seem to be determinant of the particular dynamics chosen by a complex very non-linear system [1] (consider, as a simple analogy, the chaotic pendulum – the path and final resting position of a metal pendulum swung over three fixed magnets is very dependent on the precise initial condition and subsequent (even microscopic) perturbations).

Given that irreversible processes couple, and that when they do they augment the global entropy production of the system in its interaction with its external environment, the next important question to be asked is whether there exists a principle of Nature in which the number of coupled irreversible processes or the number of imbedded hierarchies of these increases over time, and as to whether this tendency can be discerned in the evolutive history of a planet. The evolutive history of Earth suggests that this indeed is the case (see Zotin [4]); life has evolved ever more the atmosphere of our planet so as to be transparent to the most intense region of the solar spectrum and life has evolved metabolic processes to produce organic pigments that dissipate ever more completely the solar photon spectrum reaching the surface. Ecosystems too have evolved to become ever more complex (many hierarchal levels involving the coupling of ever more biotic and abiotic irreversible processes; see, for example, Lovelock

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[5]). It therefore seems that the Earth is becoming ever more a black-body (absorbing more) of lower temperature (dissipating more completely), i.e. the entropy production of Earth in its solar environment is increasing over time.

Looking at our neighboring planets, Venus and Mars, the answer does not seem to be as obvious, perhaps because being organic creatures we still do not adequately appreciate non-biotic irreversible processes and their coupling (we have only recently discovered how intense biotic-abiotic coupling is on Earth (Lovelock [5])) and perhaps because we have a much more limited understanding of the histories of these planets. I believe, however, that here too the answer is yes. Venus today has a high visible albedo but also has a great southern vortex and complex, poorly understood, convection mechanisms operating within clouds containing of an array of inorganic (and perhaps organic) pigments [6]. These pigments would have required a period of UV and visible light photochemical interactions on the more basic primordial atmospheric gasses, and thus the complex convection mechanism operating in the clouds on Venus also has an evolutive history. Mars has a very low albedo, in part due to complex interactions of solar radiation, winds, and dust [7]. The external conditions over Mars also have appeared to change drastically when it's molten core solidified and it lost its solar wind protective magnetic shield. These evolutive histories of the planets are clearly very distinct and most likely determined by particular initial and external conditions, as well as by perturbations [1], but there is also tentative evidence in these other planets of evolution towards complex coupled irreversible processes. However, the whole content of these last two paragraphs is only relevant to the last phrase made in the conclusions of the manuscript.

What was written in the manuscript is completely consistent with what I have expressed above. However, it has become evident from the concerns expressed by the referees that the matter was not made sufficiently clear. I am now working on a revised version of the manuscript that makes it more explicit that my proposal is based on established non-equilibrium thermodynamic principles verified by experiment. Since my manuscript

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does not pretend to investigate the postulated more general non-equilibrium thermodynamic principles and is only oriented towards providing evidence for how biology is catalyzing the hydrological cycle, and to demonstrate that this is in accord with established thermodynamic principle, it would not be prudent nor relevant for me to re-orient my paper towards addressing the more general "open questions".

A revised version of the manuscript and a full response to all of the comments and criticisms made by the referees is in process.

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 8, 1093, 2011.