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Hydrology and Earth System Sciences Discussions

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

Anonymous Referee #3

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This paper argues that, by increasing transpiration and contributing to the hydrological cycle, both land-based and ocean-based life increases entropy production. It further argues that when this entropy production, rather than a Darwinistic search for survival, is viewed as the main function of life, the existence of several evolutionarily disadvantageous aspects of life can be explained.

The idea that the entropy production of life is mediated by the water cycle is intriguing, and many of the general claims made in the paper are certainly potentially very important. However, several errors, short-cuts, and poorly substantiated claims made in the manuscript (detailed below), as well as the somewhat confusing structure of the paper make it difficult to interpret the arguments as anything more than suggestive that life contributes significantly to entropy production. I have several major concerns about the

argument beign made.

The consideration of maximum entropy production in the earth sciences and for plant function in particular, is not new. See, for example, Dewar et al. 2010, or Kleidon et al., 2010. One significant problem with previous work along these lines is that it has not yet clarified the scales at which this occurs (see Pauluis Volk, 2010, for a discussion of this issue). This manuscript also fails to consider this problem. That is particularly worrisome here for at least two reasons:

a) Few actual calculations of entropy production are performed (with the exception of that on pages 1101-1102, which also fails to correctly discern the effect of life, specifically, by not allowing for any other 'inorganic' variation between Earth and Mars and Venus that would lead to different entropy production due to different temperatures, see comment below).

b)The thermodynamic function proposed is framed repeatedly as superseding Darwinian evolutionary principles, and is specifically used to try to indicate why certain possibly expected evolutions, such as the elimination of photorespiration, have not occurred. However, although some mention is made of the Gaia hypothesis, the methods by which the thermodynamic function would act to influence evolution is not given. This specifically raises the issue of the scales at which thermodynamic maximization acts. Life as it exists today has several characteristics that seem to counter the idea that dissipation of entropy through water loss is an evolutionary driver, including the fact that plants try to limit water losses (e.g. stomatal closure) and the fact that a variety of life exists that does not confirm to the evidence used by the author (e.g. C4 and CAM plants do exist, adaptations have been made to minimize photorespiration, etc.). The manuscript does not mention why so much variety of life exists when, at least in the context of the analyses of the manuscript, there is little reason for such variation.

The author's argument about the role of the water cycle is also unclear. If the argument is that the presence of water aids entropy production performed by life on earth, how

does the hydrologic cycle as a whole contribute to entropy production (section 5)? I do not see evidence presented anywhere in the paper that the water cycle is an integral part of (rather than simply contributing to) life's ability to produce entropy, yet this seems to be a conclusion of the paper (see page 1116).

Although many parts of the paper are well-written, the overall structure of the paper makes it difficult to fully understand the author's theory. The argument could be significantly strengthened by an improvement in the writing structure on the paragraph level, the sectional level, and on a paper-wide level. The paper contains several examples of individual sentences or paragraphs that bear little relation to the text following or preceding it (see, for example, lines 11-22 of 1105, which provide a number of statements about hydrology, but whose relation to the rest of the argument is unclear). There also seems to be little organization of or connection between the multiple arguments in each section.For example, although section 5 is titled "evidence for evolutionary increases in the hydrologic cycle", the arguments of more than half of the section (all of pages 1112 and 1113) concern only energy and heat, and make no connection to water or the hydrologic cycle. On a paper-wide level, I would suggest re-grouping the sections so that all arguments made about photon absorption, all arguments about the characteristics of life, and all arguments about the hydrological cycle are more closely connected. As it is, the section on "life catalyzing the hydrologic cycle" is followed by one on "entropy production by photon dissipation", which makes no mention of the hydrologic cycle, and only refers to life very generally, which in turn is followed by a section titled "quantifying the importance of life to the hydrological cycle". Moving the section on "entropy production by photon dissipation" to either the very beginning or the very end of the paper would probably be clearer

I realize the arguments made in the paper are very wide in scope and that organizing a simple linear paper structure may not be possible. Nevertheless, it is this very wideness of scope that makes it critical that the paper is well-structured so that each of the connections between the characteristics of plant life, water availability, and entropy

production can be clearly followed. Indeed, despite having read the paper at least once with the sole purpose of figuring out where those connections are meant to be made, I may still have missed several. It therefore seems unreasonable to expect that this paper would be sufficiently clear for the general reader.

Specific Comments:

Page 1095: The idea that life's shaping its physical environment somehow conflicts with or "is difficult to reconcile" with Darwinian theories needs to be substantiated. It is not clear to me why this fact undermines the ability of evolution to shape the function and form of life, but that seems to be the conclusion the author is making.

Page 1096, sentence starting on line 22, and rest of the paragraph: This argument, that water and evapotranspiration are integral the contributions of life forms to entropy production, is offered as a key idea of the paper in several other parts of the manuscript, but little substantiated beyond this section. The clarity of this section is therefore key, but both its writing and citations could use improvement. In particular,

*"Of all irreversible processes by living organisms, the process generating by far the greatest amount of entropy...". This must be substantiated with additional arguments or citations! No evidence is currently given to support this statement.

*"generating by far the greatest amount of entropy (consuming the greatest amount of free energy". This equivalence between consuming free energy and producing the most entropy must be substantiated. The one-to-one correspondence between maximum entropy production and maximum free energy absorption is not necessarily realistic when compared to other processes in the earth system beyond absorption and re-emission of radiation, particularly ones that involve changes in system temperature. Although I can imagine why the author assumed that the equivalence proposed here is valid in the context of calculating total entropy production on the planet as a whole, those connections must be spelled out clearly.

*In general, some definition of terms (e.g. 'entropy', 'free energy') would probably increase the clarity of the paper

*"...into heat that can be efficiently absorbed by the surface water". This writing is somewhat confusing and vague. It would be clearer to simply note that the heat acts to increase the temperature of the ocean surface.

*"Over 90% of the free energy available in the sunlight captured by the leaves of plants is used in transpiration." A citation is needed for this statement

*" [agitation of water by zooplankton...] increasing by nearly three-fold the evaporation rate from the surface". Is this sentence in reference to the calculations in section 3? If so, where in section 3 is the "three-fold" number calculated? If not, a citation or additional evidence is needed to substantiate this argument.

Page 1099, line 14-15: This is not true. Water vapor rises along with nearby air depending on the exact air motions and the turbulence of the atmosphere. Because of the turbulence, the troposphere is fully mixed. There is no density driven separation mechanism for water to separate from dry air, as implied by this sentence.

Page 1099, line 16: The temperature at which condensation occurs varies widely depending on storm conditions. This sentence seems to implies condensation always occurs at 259K, which is misleading.

Page 1100, first paragraph: This paragraph seems to try to explain how clouds promote surface evapotranspiration. Since clouds are part of hydrological cycle and necessary to allow water to return to the surface, it is not clear why their existence needs to be justified in the context of entropy production by plants. Given that the argument is being made, it would be strengthened by a more quantitative analysis of the total effect of cloud production on entropy production due to its effect on evapotranspiration, and its effect on reducing the available radiation that reaches the surface, even if it was only in the form of illustration using location-dependent estimates of incoming radiation,

temperature and humidity.

Pages 1101-1102: The entropy production rate calculated here is compared to estimates of the entropy production rate of Mars and Venus as an indication of the effect of life. However, because the role of life is not explicitly considered in the analysis, the analysis cannot distinguish between the effect of life on Earth, and the effect of 'natural variability between the planets', i.e. other factors that may differ between Earth and Mars, including the size and atmospheric composition. While the existence of life has modified Earth's atmospheric composition, it differed from that of Mars and Venus even before the absence of life. Rather than comparing to Mars and Venus, the calculation performed here would be more convincing if it compared to global entropy production of the current global average temperature to the entropy production associated with the global average temperature before the advent of life.

Page 1101, eq 1: In the context of radiation, the use of dS(v)/dt=4/3 1/T(nu) dE(nu)/dt is more appropriate. The factor of 4/3 accounts for the contribution of the radiation pressure to entropy production. See Wu and Liu, Rev. Geophys., 2003 for a derivation. This paper also contains a discussion of the the effect of graybody emissivity on the calculation of earth's entropy production, which causes an additional increase in dS/dt and avoids having to use the kT=hv relation. I am unsure whether the one-to-one relationship between frequency and temperature is applicable in this calculation.

Page 1105, lines 19-22: This is not true. Relative humidity is, by its very definition, entirely independent of the presence of condensation nuclei.

Page 1106, concluding sentence of top paragraph: There is still much debate about the biotic pump theory (See the 2009 HESS comment by Meesters et al, and the resulting discussion, among others). Although this review comment is not the right forum for this debate, I would recommend that the second half of this paragraph is rewritten to be more cautious about use of this young theory to support this manuscript's conclusions.

Page 1108: The comparison performed should not be between absorption of coastal

turbid water and pure water, but between coastal water with phytoplankton and saline water in which little or no organic material is present.

Page 1108, lines 15-20: It is not clear why the author uses average values for three parts of the electromagnetic spectrum, rather than integrating over the possible wavelengths. Given the non-linearities involved, the quantitative estimates might change non-trivially. They may not, but this should be checked, or some justification should be given as to why a better estimate is not produced. Although I agree that the separation by spectral region in Table I (and II) may be useful to give the reader an idea of how the total energy is distributed spectrally, the calculations should also be performed in full.

Page 1108, line 20: The citation to Chaplin (2009) here appears to refer to an individual researcher's personal website. This source may not be appropriate.

Page 1109, line 19: It would be helpful to estimate how much the evaporation rate increases when water temperature and absorbed energy increase. Using an average value or an average range of values for ocean temperature and radiation and then using the Penman equation would provide a first-order estimate to strengthen the argument about the increased rates of evaporation.

Page 1099, line 21-22: This is not true. Most of the latent heat of condensation goes to warming the surrounding air (see, for example, Iribarne and Godson"s book on Atmospheric Thermodynamics)

Page 1110, top paragraph: It is not clear why the simplification of using only the 10000 nm (peak of the blackbody radiation spectrum at 287K) is used, rather than the full and easily calculated blackbody spectrum. See also my comment on lines 15-20 of page 1108 on the use of spectral regions for the absorbed energy.

Page 1114, lines 14: This absorption peak may simply be an evolutionary adaptation to allow for increased energy absorption. No reason is given why this should be interpreted as related to entropy production.

Page 1116, line 11: I see no specific evidence for this conclusion mentioned anywhere in the text of the manuscript.

Minor comments:

Page 1097, lines 17-20: The mere existence of photosynthesis at high temperatures does not necessarily imply that it is optimal at that temperature, or that processes that act to cool the operating temperature of photosynthesis cannot be beneficial for certain plants under different environmental conditions. The inconsistency mentioned is therefore not an actual inconsistency.

Page 1099, line 7-9: The object of the sentence ("this") is unclear, and the claim needs to be clarified and substantiated. What is the "larger surface area" compared to? The soil surface?

Page 1099, line 26: Universe should not be capitalized

Page 1095, line 23: units would be more accurate as "$10^9 organisms/ml$"

Page 1101, line 25: P is the global entropy production rate

Page 1102, lines 16-17: I do not follow this argument. Please elaborate.

Page 1102, line 19: The albedo of Mars is actually lower than that of Earth. This sentence should be clarified.

Page 1104, line 25-26: It is not clear why this sentence is included. A citation should be added to substantiate the claim.

Page 1106, lines 11-12: establish should be established, spelling of revolutionized

Page 1115, lines 8-10: Clearly death is not the only mechanism by which animals can spread nutrients. Furthermore, 'the short life span' mentioned is not relevant to many animals.

Page 1115, lines 17-18: Citation needed.

References:

R. Dewar (2010), Maximum entropy production and plant optimization theories, Phil. Trans. R. Soc. B, 365, 1429-1435.

A. Kleidon (2010), A basic introduction to the thermodynamics of the Earth system far from equilibrium and maximum entropy production, Phil. Trans. R. Soc. B, 365, 1303-1315.

Volk, T., and O. Pauluis (2010), It's not the entropy you produce, rather how you produce it, Phil. Trans R Soc B, 365, 1317–1322.

Iribarne J.V. And W. L. Godson (1981), Atmospheric Thermodynamics, 259 pp. D. Reidel Publishing Company.

A. G. C. A. Meesters, A. J. Dolman, and L. A. Bruijnzeel (2009), Comment on "Biotic pump of atmospheric moisture as driver of the hydrological cycle on land" by A. M. Makarieva and V. G. Gorshkov, Hydrol. Earth Syst. Sci., 11, 1013–1033, 2007", Hydrol. Earth. Syst. Sci. Discuss., 6, 401-416.

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