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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

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## 1 Summary

The paper is thought provoking, reads very well and reminds me in parts of Douglas Adams' "The Hitchhiker's Guide to the Galaxy" by the level of surprise and the ingenuity with which the author draws together different lines of evidence to come to unusual conclusions (e.g. Section 6).

However, the paper leaves a number of open questions unaddressed and contains some confusing or misleading statements that need clarification. In fact, parts of it do indeed more resemble science fiction than science. I would recommend a major



revision to focus the paper more on the open questions already raised in the literature and clarify the many issues I raised below.

## 2 General comments

In the paper entitled "Biological catalysis of the hydrological cycle: life's thermodynamic function" K. Michaelian proposes that photosynthesising biota enhance the planetary entropy production rate by the conversion of shortwave radiation to heat and by driving the hydrologic cycle. He goes as far as proposing that "the basic thermodynamic function of a plant is to increase the global entropy production of the Earth" (p. 1098, l. 10–12) and that this function is superimposed over natural selection and individual fitness. To justify this view, the author reviews an interesting body of literature with a particular focus on the role of cyanobacteria and organic molecules floating at the surface of oceans and lakes in enhancing the hydrological cycle.

The proposition that biota maximise entropy production is not new and there is a significant body of literature that argues about this view or whether maximum entropy production (MEP) is the aim or a side-effect of something else (e.g. Kleidon, 2004; Volk, 2007; Kleidon, 2007, 2009, 2010b,a; Volk and Pauluis, 2010; Dewar, 2010). At least two questions emerged in the discussions that seem relevant to this paper:

1. What is the mechanism that selects for biota that contribute more to planetary entropy production over such that contribute less but invest more e.g. into reproductive success?

2. If maximisation of entropy production is the rule of the game and not maximisation of fitness as defined traditionally, why do plants not produce black carpets that simply absorb solar radiation and convert it directly to high entropy long-wave radiation?

The paper contains some material that could be used to discuss these questions, but the material is primarily used to convince the reader that biota enhance the hydrological cycle and thereby planetary entropy production. However the link between the latter two is not explained convincingly.

I would recommend to the author to put this paper more into the context of the existing literature mentioned above, summarise the current state of the discussion and state how this paper contributes to the open issues. In particular, it would be interesting to juxtapose the examples given here with the counter-examples given by e.g. Volk (2007); Volk and Pauluis (2010).

One question raised in the literature is whether "MEP theory itself can meet the challenge of becoming more explicit about where to draw system boundaries and what fluxes from which components would be expected to become maximized" (Volk and Pauluis, 2010). The paper by K. Michaelian would greatly benefit from a step in this direction itself, as it is quite nebulous about what is meant by entropy production, where this entropy is produced and how. In particular, it is not clear how evaporation contributes to the planetary entropy production, whereas the majority of the article argues that biota enhance evaporation and the hydrologic cycle. This and a number of misleading statements make it difficult for the reader to follow the line of argument in detail (see below).

I was very puzzled by the results presented in Table 2 of the paper and the accompanying discussion on page 1110. It seems to me that both the data in Table 2 and the explanation contradict the established understanding of the greenhouse effect (see below). This is in dire need of clarification, and so are a few other points that seem to ignore or contradict generally accepted knowledge.



## 3 Specific comments

1. 1196, 15–18: Any light absorbing body, whether dead or alive, converts low-entropy sunlight into higher entropy long wave radiation and thereby contributes to the global entropy production of Earth. The sentence implies that this is a special feature of photosynthetic life, which is misleading. In order to explain the special role of life, the author should discuss what would be the entropy production in the absence of life and what life can do in this respect that abiotic structures could not.

2. 1196, 22–29: The statements here appear a bit misleading, as the process of evapotranspiration transfers a part of the free energy from sunlight to the potential energy of water by lifting water up from the soil to the surface. This suggests that the entropy production at the surface could be higher if all the solar radiation was converted to longwave radiation and sensible heat flux in the absence of water. In order to assess whether evapotranspiration increases entropy production in comparison to abiotic light absorption, the author would have to distinguish clearly between free energy transfer processes and entropy producing processes, such as the diffusion of moist air into dry air or the release of heat to space after condensation in the upper atmosphere. This seems much less straightforward than the view presented in this section.

3. 1197, 3–6: A threefold increase of the evaporation rate from the oceans by the agitation of the surface water by zoo-plankton seems very surprising to me, given that surface winds agitate the surface water, anyway. This would need a good explanation or relevant references to convince the reader.

4. 1197, 23 – 1098, 8: Transpiration is generally regarded as a diffusive process dissipating the concentration gradient of water vapour between the leaf and the atmosphere. The little free energy expressed in this gradient is sufficient to drive

transpiration. I would not call this process "extremely free energy intensive", particularly not in comparison to photosynthesis, which in fact cannot run in the absence of the extremely free energy-rich shortwave radiation. In this context, the argument made here that plants lose free energy to transpiration that could otherwise be used for photosynthesis appears unsupported. This would imply that plants could increase photosynthesis if they reduced transpiration, but the opposite is the case according to our current knowledge, as photosynthetic rate increases with opening stomata due to reduced resistance to the influx of CO2. Therefore, maximisation of transpiration is often translated to maximisation of CO2 uptake and productivity.

5. 1198, 14–16: Couldn't the same effect be achieved by porous black minerals floating near the surface, too? Why should the MEP principle only apply to biota and not to the abiotic environment? If it applies equally to both, one has to ask why biota are better at maximising entropy production than any conceivable abiotic structures.
6. 1099, 4–7: This seems like a better example than the above.
7. 1099, 9–13: Natural water surfaces also contain suspended minerals; how would they contribute to the increased evaporation in relation to biotic substances?
8. 1099, 23–27: This is wrong, or at least confusing. If the atmosphere is not part of the biosphere, then the amount of radiation reaching the biosphere is not equal to the total energy radiatiated by the biosphere, as a very large part of the energy is converted to latent and sensible heat flux at the surface of the biosphere. This statement is only true for the top of the atmosphere, where only radiative energy exchange can happen, but it would be very uncommon to include this in the definition of the biosphere. This has to be clarified.
9. 1100, 1–10: This argument is not convincing to me. Clouds indeed reduce the



amount of shortwave radiation reaching the ground. (In this context, the relevance of absorbing infrared radiation is not clear to me.) However, the formation of clouds is an inevitable consequence of the hydrologic cycle, as the water has to condense in the cold layers of the atmosphere where it gives off the energy absorbed during vaporisation. Is there any evidence to suggest that the clouds' positive effect on evaporation by driving local winds near the surface is greater than their negative effect by reducing downwelling radiation?

10. 1101, 9–11: This statement does not seem justified in the perspective of Point 2 above.
11. 1101, 16– 1102, 22: This whole section is very confusing to me. The equations are derived based on the ideal gas assumption, but this assumption is only relevant for black body radiation, i.e. radiation in an enclosed space in equilibrium with the walls. Solar radiation reaching the Earth is far away from equilibrium and furthermore directed, rather than diffuse. Therefore, the Equation $kT = h\nu$, on which the whole derivation seems to be based, is not applicable. Also, what does the author mean by "more efficiently dissipated into heat by organic molecules in contact with liquid water"? The largest entropy production would be achieved if all the high frequency radiation was absorbed by a body of the lowest possible temperature and re-emitted as long-wave radiation of low temperature. Is this what the author would consider "efficient" dissipation? Then he should explicitly include the place of water vapour condensation in his discussion, i.e. the upper atmosphere, where the latent heat coming from evaporation is converted to heat and partly emitted as long wave radiation.
12. 1103, 17–30: Interesting points and new to me, but the question remains why life is necessary to absorb light. There are porous minerals of volcanic origin that float on water, would they not do the job? Or, since the MEP principle is not only applicable to biota, why does the surface of the planet not organise

spontaneously to a highly absorbing structure?

13. 1107, 10: Is the depth range of 1–10 $\mu$m correct? A quick look at the literature revealed zooplankton sizes of 2 – 1000 $\mu$m, so there might be a unit conversion problem here.

14. 1108, 10–12: The data source for Table 1 should be given, or the method how the integrated values were derived from a textbook figure.

15. 1109, 1–: What is the relative contribution of inorganic compounds in the coastal surface waters? Would suspended sediments not influence the results?

16. 1110, 14–: I do not have access to Fig. 8.17 in Gates (1980), but this paragraph sounds wrong to me. Since the Earth's surface converts absorbed solar radiation to infrared radiation, the upwelling longwave is much greater than the downwelling longwave from the sun. Therefore it does not make any sense that a cloud layer or moist air would reduce the downwelling infrared radiation, as the effect of water vapour is to absorb mainly the *upwelling* longwave and re-emit it in all directions, i.e. also backwards to the surface. This means that the amount of longwave radiation should be *greater* under clouds or moist air. This is generally known as the greenhouse effect. I am very puzzled by the data presented in Table 2. How come the infrared reaching the surface is an order of magnitude lower under overcast skies than under clear skies? This does not make any sense to me, nor can I verify the origin of the data, as the text only refers to the same figure in the Gates (1980) text book as the reference given for Table 1. I cannot access this figure, but I cannot imagine that all this data can be extracted from one figure, anyway. If the data in Table 1 and Table 2 is not supported convincingly, I cannot trust any of the results and conclusions in this section.

17. 1111, 23–27: Conifers are gymnosperms, while deciduous trees are angiosperms, which are considered as further developed than gymnosperms, with



a much more complex xylem structure. Therefore this paragraph contradicts itself and is very confusing. The paragraph also neglects the generally accepted explanation that the evolution of more sophisticated water use strategies was a response to decreasing atmospheric CO2 concentrations, which necessitated a greater water use for the same amount of CO2 uptake.

18. 1112, 3–1113, 9: This paragraph did not convince me that the function of UV absorbing pigments is primarily to increase evaporation by converting UV light to heat, rather than protecting the cells from damage. It may not be a selective disadvantage to absorb a larger range of wavelengths than the one known to cause damage, whereas I cannot think of a selective advantage for increasing evaporation. I also find it very little convincing that the complicated photosynthetic apparatus would be necessary just to convert shortwave and UV radiation to heat. Any black stone could do that! I'm sorry, but this sounds really like science fiction.

19. 1114, 11–14: What is the relevance of the absorption peak in the IR spectrum? Please explain.

20. 1115, 1–10: This is a very interesting point!

## 4 Technical corrections

- 1094, 13: 'processes'
- 1095, 29: should be 'touched by water and light'.
- 1096, 22–25: This sentence would benefit from restructuring.
- 1098, 19: I would use K instead of $^o$C here.
- 1104, 23: "would have led"

- 1106, 11: “established”
- 1106, 13 “revolutionized”
- 1109, 22–23: Please clarify if the 30 % increase in evaporation for natural waters is taken from Jones et al. (2005), or give other source.
- 1116, 13: Please delete the semicolon.

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