

Interactive comment on “Biological catalysis of the hydrological cycle: life’s thermodynamic function” by K. Michaelian

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Like Dr. Gorshkov, I welcome the attention to the planetary function of life, see, e.g., my recent comment on Dr. Michaelian’s work here <http://www.earth-syst-dynam-discuss.net/1/C10/2010/>. However, I find the basic equations in the present manuscript incorrect and inconsistent with the few quantitative claims that are made in the paper. I list my specific comments below.

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1 Basic equations

On page 1102 Dr. Michaelian states¹ that his “Eq. (3) with Eq. (4) gives as an approximation for the net entropy production of the Earth of $1.19 \times 10^{-4} \text{ J cm}^{-2} \text{ s}^{-1} \text{ K}^{-1}$ ”. This statement is incorrect. Equation (3) of Dr. Michaelian does not have any physical meaning in the planetary context.

Indeed, using Eq. (4) in Eq. (3) and $T_{rad} \equiv T_E$, $T_{in} \equiv T_S$ and performing elementary integration we obtain

$$P = \frac{k}{h} \int_0^\infty (I_{rad}(\nu) - I_{in}(\nu)) \frac{d\nu}{\nu} =$$

$$\frac{k}{h} \frac{2h}{c^2} \left(\int_0^\infty \frac{\nu^3}{\exp[h\nu/kT_E] - 1} \frac{d\nu}{\nu} - \int_0^\infty \frac{\nu^3}{\exp[h\nu/kT_S] - 1} \frac{d\nu}{\nu} \right) = C(T_E^3 - T_S^3), \quad (1)$$

$$C \equiv \frac{2k^4}{h^3 c^2} \int_0^\infty \frac{x^2}{e^x - 1} dx = 6.7 \times 10^{-9} \text{ J m}^{-2} \text{ K}^{-4} \text{ s}^{-1}.$$

Now putting Dr. Michaelian’s numbers, $T_S = 6073 \text{ K}$ and $T_E = 287 \text{ K}$, into the above equation we obtain

$$P = -1500 \text{ J m}^{-2} \text{ K}^{-1} \text{ s}^{-1} \quad (2)$$

instead of the value $1.19 \text{ J m}^{-2} \text{ s}^{-1} \text{ K}^{-1}$ that Dr. Michaelian claims his Eqs. (3) and (4) yield. Note that P (2) is negative! It is not clear therefore where the quoted figure comes from. It looks like it was taken by Dr. Michaelian from (Aoki, 1983) without checking whether it conforms or not to the derivations presented in the manuscript.

The error made in Equation (3) consists in the following. This equation corresponds to the case when the Earth’s surface were put infinitely close to the surface of the Sun. Then, if all Sun’s energy were captured in some form not allowing the Earth’s temperature to grow, the entropy of Earth would be diminishing at a high rate – reflecting that

¹Note the misprint in the original text: it should be cm^{-2} , not cm^2 .

solar energy would be accumulating on Earth in a form allowing for performing useful work. In other words, Equation (3) of Dr. Michaelian neglects the distance between the Earth and the Sun, i.e., the fact that the solar radiation diverges while spreading in space. When solar radiation reaches the Earth, its flux per unit area is thousands of times lower than the flux of blackbody radiation at temperature T_S .

In my opinion, the comments of Dr. Gorshkov² provided a good opportunity for Dr. Michaelian to check his derivations. Instead, Dr. Michaelian characterized Eq. (1) of Dr. Gorshkov for entropy production

$$\dot{S} = \dot{S}_E - \dot{S}_S = I_s \left(\frac{1}{T_E} - \frac{1}{T_S} \right) (1 - A) \quad (G1)$$

as being "not valid since it fails to take into account the frequency transformations between the incident and outgoing radiation"³.

However, it is Eq. (G1) of Dr. Gorshkov that, unlike Eqs. (3) and (4) of Dr. Michaelian, yields the correct result. Assuming that all solar radiation incident upon Earth, $I_s = 340 \text{ W m}^{-2}$, is absorbed (albedo $A = 0$) and converted to blackbody thermal radiation at Earth's orbital temperature $T_E = 278 \text{ K}$ we have from Gorshkov's equation

$$\dot{S} = 1.17 \text{ J K}^{-1} \text{ s}^{-1} \text{ m}^{-2}. \quad (3)$$

This is practically identical to $1.19 \text{ J m}^{-2} \text{ K}^{-1} \text{ s}^{-1}$ – the number quoted by Dr. Michaelian. Taking into account the planetary albedo will change this estimate (note that T_E is then also changed) but not its order of magnitude.

Dr. Michaelian mistakenly concludes that Eq. (G1) does not take into account the frequency transformations between the solar and terrestrial radiation. It does. When a planet receives high frequency (solar) radiation and emits an equal amount of low frequency (thermal) radiation, all information about radiation frequency transformation is

²<http://www.hydrol-earth-syst-sci-discuss.net/8/C298/2011/>

³<http://www.hydrol-earth-syst-sci-discuss.net/8/C390/2011/>

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contained in the blackbody temperatures of the incident and outgoing radiation, as reflected in Eq. (G1). Entropy production in this case merely corresponds to an increased number of particles (photons) emitted by the planet after having dissipated the low entropy high frequency photons. Dr. Gorshkov explains this physical meaning of entropy production in his comment, see also⁴ (Gorshkov, 1995, Section 2.8 "Correlation distances and information"), (Gorshkov et al., 2000, Section 7 "Energy and information"), (Gorshkov and Makarieva, 2001).

Equation (G1) makes the analysis of the planetary entropy production physically transparent. There is one way of increasing entropy production on a planetary scale – to reduce the planetary albedo, thus allowing for capturing (and, hence, dissipation) of a larger amount of solar radiation.

2 Literature analysis

A salient feature of the present paper is the dominance of qualitative statements with extensive references to published literature from diverse fields. I have not inspected all references present in the manuscript and submitted to the discussion, but from those that caught my attention I got the impression that Dr. Michaelian might consider analyzing in greater depth the works he refers to.

For example, in his last comment⁵ Dr. Michaelian refers to the study of Zotin (1984) to support a very general claim that "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])".

⁴available at <http://www.bioticregulation.ru/pubs/pubs2.php>

⁵<http://www.hydrol-earth-syst-sci-discuss.net/8/C543/2011/>

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Zotin's claims about the evolutionary trends in organisms' metabolism are based on his analysis of the so-called logarithmic intercept a . This is a parameter in the logarithmic dependence of metabolic rate R (W) on body mass M (g), $R = aM^\alpha$, where the scaling exponent α is supposed by Zotin to be universally equal to 3/4. Plotted on a log-log plane, such a dependence has the form of a straight line. Here a has the meaning of metabolic rate of an organism of a unit body mass (e.g., 1 gram). It is also called the metabolic *intercept*, as it is the value the metabolic log-log line takes on the ordinate axis when crossing a vertical line corresponding to unit body mass.

Zotin states that a grows with the increasing evolutionary hierarchy level (i.e., it is larger in mammals than, say, in eukaryotic unicells). However, the absolute value of a which is either characterized by Zotin without reporting the units of measurements at all or incorrectly reported as having the dimension of power (e.g., mW) is misleading. In reality, the value of a is not scale-independent but is determined by the mass units (at which body mass it is measured). Second, the statement that α is universal has been repeatedly refuted by recent research, see, e.g., (Kozłowski and Konarzewski, 2004; Makarieva et al., 2008; Irlich et al., 2009). When α is not universal, the taxonomic group A which has a larger a than group B if measured at some body mass M_1 can have a smaller a when the latter is measured at a different body mass M_2 . This deprives comparison of metabolic intercepts of any meaning.

The scaling of metabolic rate with body mass is a highly controversial area with much active research on-going and a large amount of new data available in the last decade. I appreciate that quoting a paper from 1984 Dr. Michaelian may not be aware of this fact as he comes from a different research area – but the more caution should be exercised when referring to studies from a distant field to avoid misleading the reader.

I believe that to productively tackle such a grand topic as properties of life as a whole it is necessary to advance specific statements and confirm them by quantitative evidence. In the present manuscript, as I argued above, the key quantitative statements are in error.

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