

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

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In the paper by Dr. Michaelian "Biological Catalysis of the Hydrological Cycle: Life's Thermodynamic Function" the main life property pertaining to its interaction with the environment is considered to be the increase of the rate of entropy production. It is stated that the dissipation of solar radiation by organic molecules in the course of water turnover is the main process of entropy production on Earth. The paper presents a discussion of published papers which, in the author's opinion, carry evidence in favor of the latter statement.

Flux of entropy per unit Earth surface is equal to $\dot{S} = (dQ/dt)/T$, where dQ/dt (W m^{-2}) is the flux of heat, T is absolute temperature. The entropy flux of solar radiation to Earth is equal to $\dot{S} = I_s/T_s$, where $I_s \equiv dQ_s/dt$ is the solar constant, $T_s \approx 6000$ K is the

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temperature of the Sun. The entropy flux with the outgoing thermal radiation emitted by the Earth to space is $\dot{S}_e = I_e/T_e$, where $I_e \equiv dQ_e/dt$, $T_e \approx 300$ K is the Earth surface temperature. The energy conservation law relates I_e and I_s as $I_e = I_s(1 - A)$, where albedo A is the share of solar energy reflected back to space by the planet (mostly cloudiness). Entropy production on Earth \dot{S} is determined by the difference $\dot{S}_e - \dot{S}_s$:

$$\dot{S} = \dot{S}_e - \dot{S}_s = I_s \left(\frac{1}{T_e} - \frac{1}{T_s} \right) (1 - A). \quad (1)$$

Neither the solar constant I_s nor temperature T_s can be changed by life. Temperature of the thermal radiation emitted to space, called the effective planetary temperature, is determined by the distance of Earth to Sun and cannot be changed by life either. Life can only affect the value of the albedo, which is not discussed in the paper of Dr. Michaelian. The only way of increasing entropy production \dot{S} is by decreasing the albedo. The modern value of Earth's albedo is 31%. Decreasing the albedo by 1% corresponds to an increase in Earth surface temperature by more than 1 K. Having invaded land life extended the cloud cover over land and increased (not decreased) the planetary albedo by about one third. Therefore, rather than increasing the entropy production rate life diminished it by a considerable magnitude on a global scale.

Entropy production has a clear physical meaning. Temperature of the radiation is unambiguously related to the mean energy ε of the emitted photon $\varepsilon \approx kT$, where coefficient $k \approx 1 \times 10^{-23}$ J/K coincides with the Boltzmann's constant. Photons of Earth radiation have $T_s/T_e \approx 20$ times lower energy than solar photons. This means that entropy production on Earth consists in the conversion of each solar photon into 20 chaotically distributed thermal photons. This is mentioned by Dr. Michaelian in his paper. Flux of radiation energy is $I = \varepsilon N = kTN$, where N is the flux of the number of photons. Consequently, the entropy flux $\dot{S} = I/T = kN$ is proportional to the flux of the number of photons. We thus have for the rate of entropy production on Earth:

$$\frac{\dot{S}}{k} = (N_e - N_s) \approx N_e, \quad N_e = \frac{I_e}{kT_e}, \quad \frac{T_s}{T_e} = \frac{N_e}{N_s} \approx 20. \quad (2)$$

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Photons like any other particles (atoms and molecules) represent the information memory cells, as first pointed out by an outstanding physicist L. Brillouin (1956). Chaotically distributed thermal photons of the thermal radiation of Earth corresponds to complete loss of information and entropy production. However, life, as well as the human civilization, is able to use the process of solar photon decay in an ordered way, accumulating information and delaying the ultimate entropy production for a long period of time.

It is namely the ordered, non-chaotic routing of the processes of solar photons decay over the molecular memory cells of the living cells that accounts for the observed diversity of all the biotic processes on Earth. It follows from the last relationship in Eq. (2) that the number of solar photons that undergo decay per unit area of the Earth surface is of the order of 10^{23} photon $m^{-2} s^{-1}$. Earth surface area is 5×10^{14} m^2 . The total number of acts of solar photons' interaction with molecules in the environment is therefore of the order of 10^{38} act s^{-1} . Assuming that each act of solar photon interaction leads to formation of one molecule in the excited state we can posit that every such act corresponds to one bit of information received. Consequently, the information flux received by the Earth from the Sun is 10^{38} bit s^{-1} . The biota of Earth uses one hundredth part of this flux – 10^{36} bit s^{-1} – on evaporation (transpiration and intercept) and one thousandth part of this flux – 10^{35} bit s^{-1} – on photosynthesis. For comparison, modern civilization with all our computer facilities processes no more than 10^{16} bit s^{-1} (Gorshkov et al., 2000, Sec. 7.2, 7.3).

Any information is prone to decay (loss). A stationary store of information is maintained by continuous information flow from solar radiation that compensates for the on-going decay. Life, including our civilization, slowly accumulates information at the expense of the incomplete decay of solar photons. This slightly (by a relative magnitude of about 10^{-4}) diminishes the rate of entropy production on the planetary surface. The information is accumulated in the dead organic matter of sediments, including fossil fuels, as well as in the DNA of living organisms. All the accumulated information of the civilization could be accommodated in the Internet. The complexity of informational

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fluxes in life, including evolutionary processes, are not determined by the laws of thermodynamics and do not maximize entropy production. Entropy production on a planet where life stationarily exists remains the same as it would be on a lifeless planet. I got the impression, from reading the paper, that speaking about the unique rate of entropy production by life on Earth Dr. Michaelian might have been keeping in mind, in fact, the rate of information production – which is a notion opposite to the notion of entropy production.

All these are complex issues that are currently poorly understood. I welcome the discussion of the role of the biospheric processes in shaping the Earth's environment, to which publication of the paper by Dr. Michaelian contributes.

References

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