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Earth System Dynamics Discussions

Interactive comment on "Thermodynamic origin of life" *by* K. Michaelian

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"Thermodynamic origin of life" by K. Michaelian contributes to the important discussion of what is life and its role in shaping the environment on Earth. In our opinion, the work is particularly valuable in highlighting the role of solar energy capture as an essential feature of life.

The solar energy flux maintains the various complex processes on Earth, including life. The flux of solar radiation is reasonably well described by the blackbody radiation at temperature $T_S = 6000$ K. Thermal radiation of the Earth surface can be characterized by the blackbody radiation at $T_E \sim 300$ K. Mean energy of photons that are sent by the Sun to the Earth is kT_S, where k is Boltzmann's constant. Mean energy of thermal photons emitted by the Earth is kT_E. Thus, every solar photon dissipates on Earth into $n = kT_S/kT_E \sim 20$ thermal photons. This increase in the number of particles repre-

sents the major quantitative measure of entropy production on Earth; it characterizes the processes of decay and information loss (Gorshkov et al. 2002).

The decay of one solar photon into 20 thermal terrestrial photons is the outcome of inelastic interactions of solar photons with molecules of the Earth's surface; the states of these molecules change in the course of such interactions. (During elastic collisions when the states of molecules do not change, solar photons do not change either. They are reflected away from the Earth contributing to the planetary albedo. Such reflected solar photons are effectively lost and cannot generate any ordered processes on Earth.) Namely inelastic collisions, i.e. absorption of solar photons by molecules of the Earth, bring about all the complex chemical reactions that take place on Earth, including the photosynthesis. In these reactions there appear various excited states with different lifetimes. These excited states ultimately relax to the ground states, with twenty thermal photons emitted per each absorbed solar photon. If the Sun had been sending the same amount of energy to Earth, but this energy had been coming in the form of the long-wave radiation, the Earth surface would have been warm, but life and any other ordered processes of comparable intensity would be impossible.

The continuous flux of solar radiation maintains the molecules on Earth in a complex state when they participate in various processes of dissipation in a correlated manner. These processes are perceived as ordered and can be characterized as the work produced by solar radiation. If the flux of solar energy disappears, the excited states of molecules relax to the ground states, thermal photons are emitted and the ordered processes discontinue.

The lifetimes of the excited states range widely, from instantaneous decay to decay over a time period comparable to the existence of Earth. For example, fossil fuels represent a longlived state. Fossil fuel burning by humans accelerates the decay of this state and emission of thermal photons and speeds up the entropy production. On the other hand, many of the most complex life processes have a negligible rate of entropy production. Such are the processes of embryogenesis (organism development from the fertilized eggcell in the pre-conditioned internal biological environment of the egg), where in many organisms heat losses and, consequently, entropy production are practically zero (Makarieva et al. 2004). The egg is transformed into a chick with minimum entropy production. But as soon as the chick has hatched and finds itself in an external environment, the chick begins to actively consume food and energy from the environment and to actively produce entropy – its metabolic rate increases sharply upon hatching (Makarieva et al. 2004; 2009). Thus, we can conclude that entropy production is not a property of the life macromolecules like DNA or RNA. Rather, it is associated with, and necessitated by, the existence of living organisms and life as a whole in an external environment and programmed into their behavior. Why in this environment is it not possible to organize biochemical processes with similarly low rates of entropy production as during embryogenesis? Because the external environment of life is not stable. Without life actively shaping and controlling this environment, the latter would rapidly degrade to a state unfit for life. To maintain the environment in a suitable for life state a huge work of the entire ecological community of autotrophs and heterotrophs is needed – and this is inevitably accompanied by entropy production. Life has claimed solar power as it allows one to perform maximum work on environmental control.

RNA and DNA molecules represent the genetic memory cells where the information of life is written. To understand what life is it is necessary to understand what information is coded in these memory cells, rather than to understand the biochemical or thermodynamic properties of the memory cells (information carriers) themselves. The wealth of this information, as it is becoming increasingly clear, is the ecological information about interaction with the external environment (including other species in the ecological community) and its control. These are very important and exciting issues to study, and the *Earth System Dynamics* can be congratulated on taking this topic on board with the work of Dr. Michaelian.

This is a joint comment written by Anastassia Makarieva and Victor Gorshkov.

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