Comment on K. Michaelian and A. Simeonov (2015) “Fundamental molecules of life are pigments which arose and co-evolved as a response to the thermodynamic imperative of dissipating the prevailing solar spectrum”.

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Abstract. This is a comment on: “Fundamental molecules of life are pigments which arose and co-evolved as a response to the thermodynamic imperative of dissipating the prevailing solar spectrum” by K. Michaelian and A. Simeonov, Biogeosciences, 12, 4913–4937, 2015. Michaelian and Simeonov formulate the leading thought in their article: “The driving force behind the origin and evolution of life has been the thermodynamic imperative of increasing the entropy production of the biosphere through increasing the global solar photon dissipation rate”. I doubt that their reasoning is correct.

1 Introduction: Do living systems reduce the albedo of Earth?

Already in the first sentence of their abstract Michaelian and Simeonov formulate the leading thought in their article “The driving force behind the origin and evolution of life has been the thermodynamic imperative of increasing the entropy production of the biosphere through increasing the global solar photon dissipation rate”. I doubt that the reasoning that follows regarding the role of pigments is correct.

As long as light travels freely in space, there is no change in the entropy associated with it. If it is scattered, entropy is increased. If we consider only the non-absorbed fraction of the light, a surface reflecting light in a diffuse way (i.e., non-specularly), will increase entropy by scattering, not by changing the photon number; there is, in principle, no difference between non-living substances (e.g., pure sand) and organisms in this respect. Thus we can focus on absorption. An absorbing surface on Earth will eventually cause incident radiation to be converted to diffuse radiation of an increased number of less energetic photons, and thus increase entropy more than a reflecting surface (see, e.g., Delgado-Bonal, 2017), although processes such as photosynthesis can cause a considerable time-delay in entropy production. Thus, it appears that if Michaelian and Simeonov are correct, one would expect organisms, in particular phototrophic organisms, or the biosphere), to be less reflecting and more absorbing than dead matter. They explicitly state: “Living systems reduce the albedo of Earth”. Is this correct?

Although the Moon may look bright against a dark night sky, it does, in fact, absorb a greater proportion of incident sunlight than plants do. As far as we know there is no life on Mars; nevertheless the reflectivity (albedo) is very low even in brighter locations on Mars such as Syrtis Major, although during dust storms, the albedo increases (Vincendon et al., 2015). The low reflectivity holds particularly for short wavelength (422 nm), but even red rocks reflect less than 10% of incident 733 nm and 1009 nm radiation over most angles (Johnson et al., 2021). Early phototrophic organisms on Earth are thought to have evolved in water, and I shall therefore concentrate on aquatic life, but start with the situation on land. Let us compare the optical properties of ground with and without organisms.

2 Vegetation compared to bare ground

What is important in the context of what we are dealing with here is of course not what things look like. We must extend our interest into the infrared, a spectral region to which much of the solar radiation belongs (the ultraviolet is of less interest in this context). And the quantity we should consider as far as data are available is the hemispherical reflectance, not reflectance in a single direction. Unfortunately, in most cases values of hemispherical reflectance are not available. Directional reflectance spectra (Figure 1) seem to indicate that vegetated areas may reflect more light throughout the daylight spectrum. The kind of terrestrial life most similar to the newcomers on land may be "biocrusts". As shown by the example in Figure 2, these crusts can have albedos exceeding that of the bare ground they inhabit, with an exception only for a very dry state, with less biological activity. As shown in Figure 3 with data from Rutherford et al. (2017), ground albedo increases with the proportion of cyanobacteria cover (compared to cover by cyanobacteria, moss, and lichen). There are also cases in which even simple organisms decrease the albedo, one reason being the production of pigments protecting them from sunlight (e.g., Couradeau et al., 2016). This fact does not prove that pigments are formed due to a "thermodynamic imperative" for increasing entropy. Moss strongly decreases soil surface albedo, while lichens often have de opposite effect (Blanco-Sacristán, 2019; Xiao and Bowker, 2020)

We shall not go into details of the complications associated with evaporation and other phase transitions; just point out that forests have a tendency to increase cloudiness, and thereby cause increased reflectance by the atmosphere (e.g., Teuling et al., 2017), and thereby counteract entropy increase.

3 The temporal aspect

We can also put a temporal aspect on this. If sunlight is absorbed by dead matter, it is usually converted to heat and reradiated as heat radiation of ambient temperature within a short time. If it is absorbed by a photosynthetic system, much of the energy is retained for a long time, before eventually being radiated as heat, sometimes after having been processed through several steps in the food chain. Thus, the living system delays entropy increase. Some trees that had collected solar energy sank into swamps more than two hundred fifty million years ago, and their reduced carbon was preserved until the present era, when mankind started to burn coal and thereby generate entropy. Thus, entropy production was delayed, i.e. the rate of production

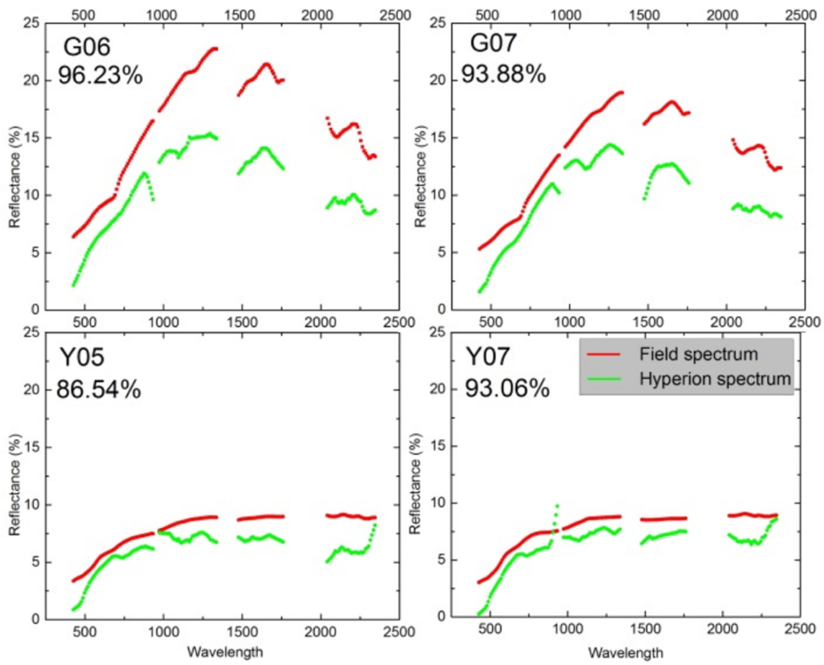

Figure 1. Reflectance spectra from the volcano Teide on Tenerife, one of the Canary Islands. The spectra were recorded on the ground (red) or remotely from satellite (green). The percent values indicate the agreement between the red and green curves. Top left (G06) is from a site with heavy lichen cover but no plants, top right (G07) heavy lichen cover and some plants. Bottom panels show spectra of bare lava (no vegetation). From Li et al. (2015). Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/).

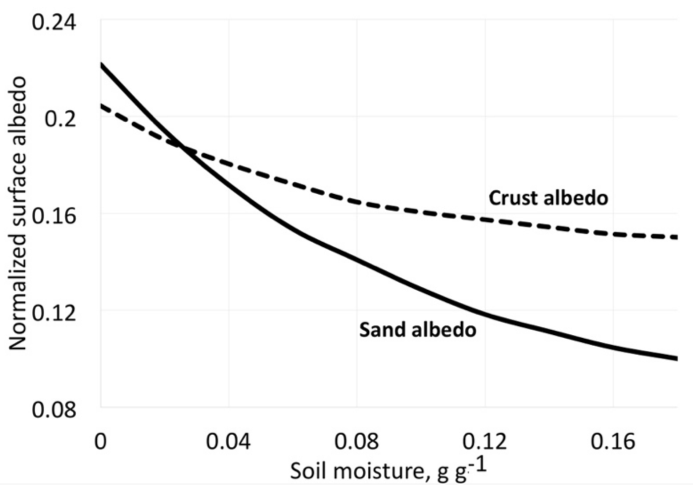

Figure 2. Albedo for desert dune sand with and without biological soil crust organisms (BSC) at different moisture contents. Redrawn and simplified from Zang et al. (2013).

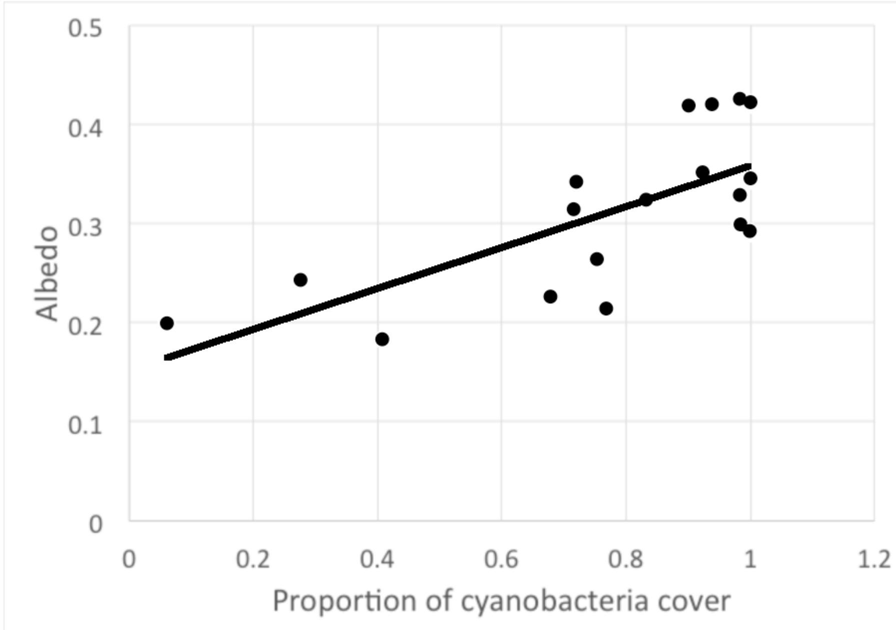

Figure 3. Albedo as a function of the cover of the ground with cyanobacteria (ratio of points intercepting cyanobacteria relative to total biotic cover, i.e., sum total of cyanobacteria, moss, and lichen points). The variation of cyanobacteria coverage was partly natural, partly caused by experimental treatment during several years (watering, heating, or both). The measurements were taken under identical, relatively dry conditions. Data from Rutherford et al. (2017), replotted.

decreased, thanks to the chlorophyll and the photosynthesis of ancient trees that have been preserved as coal. The production and usage of oil is a similar phenomenon. We cannot back from our responsibility for our planet by claiming that we must burn all the coal and oil due to a “thermodynamic imperative”.

4 The aquatic environment

Much of the Earth surface is covered by water, life probably originated in water, and much of life’s evolution has taken place in water. Thus we must also consider the reflectance of water bodies, and how their reflectance is affected by life. In addition, aquatic life is easier to deal with, since we do not have to deal with gases, and processes such as transpiration. A minor effect might arise from increased temperature in the presence of organisms at the surface, and probably some increased evaporation (Kahru et al., 1993).

Aquatic organisms do not decrease the reflectance of the ocean and other water bodies. This is not always as clear as in the data of Qi et al. (2020), who have published numerous reflection difference spectra for various lakes and ocean surfaces where algae are abundant, i.e. spectra that show the difference in reflectivity for water with and without algae. A sample is reproduced in Figure 4. In many other cases algae cause a decrease of reflectance at short wavelengths, and an increase above about 500 nm, both for phytoplankton (Jin et al., 2002, 2011; Bacour et al., 2020,; Li et al., 2021) (Figure 5) and for brown and green macroalgae (Qi and Hu, 2021). However, taking the daylight spectrum into account, one finds that the algae increase the total light reflection. The data in Figure 5 do not extend over a sufficiently wide wavelength range to permit such a

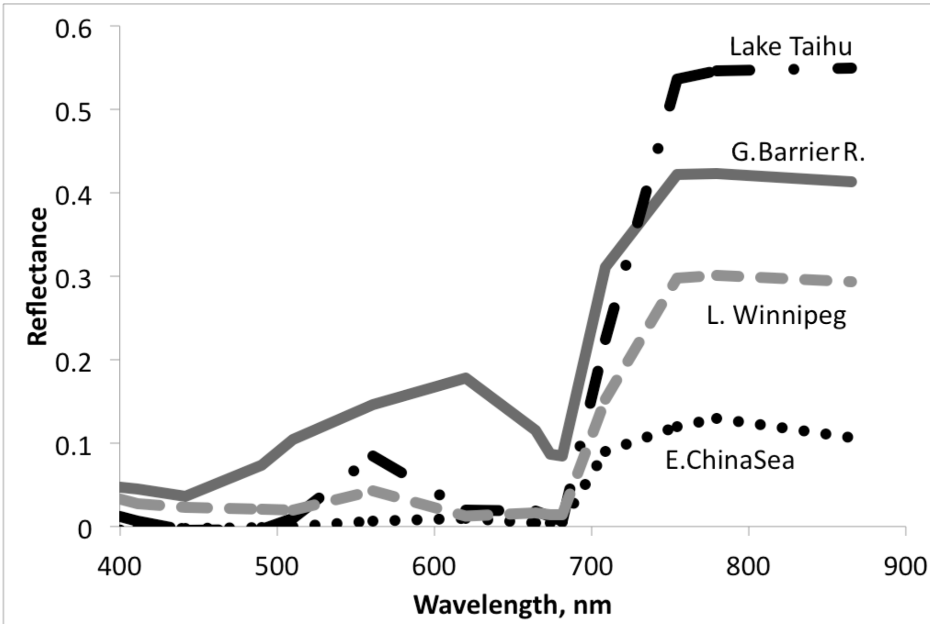

Figure 4. A sample of sea and lake reflectance difference spectra redrawn from Qi et al. (2020). The diagram shows reflectance of waters with algae minus adjacent water without algae. These differences are mostly positive, in some cases with the exception for very small negative excursions at short wavelengths.

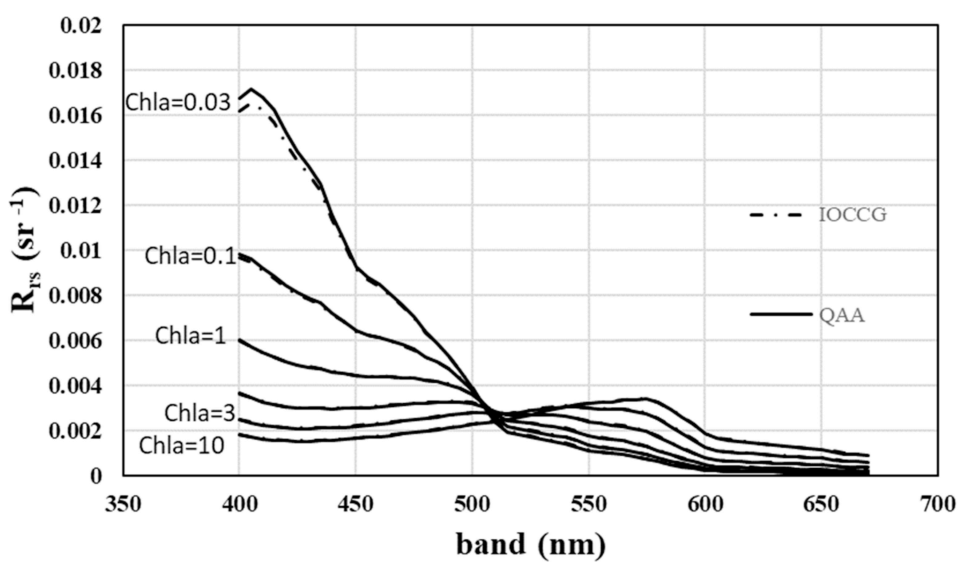

Figure 5. Ocean reflectance over 1 radian according to Li et al. (2021) for various concentrations of chlorophyll *a*-containing organisms. Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

comparison, but we show the calculation for Bacour et al. (2020) and Jin et al. (2002) in Figure 6. Both based on the data of Bacour et al. (2020)and those of Jin et al. (2002) more light is reflected from water containing more algae. This holds on an energy basis, and the increase in reflected light by the algae is even more pronounced when expressed on a photon basis. The light that is not reflected (or emitted as fluorescence) is eventually converted to heat radiation.

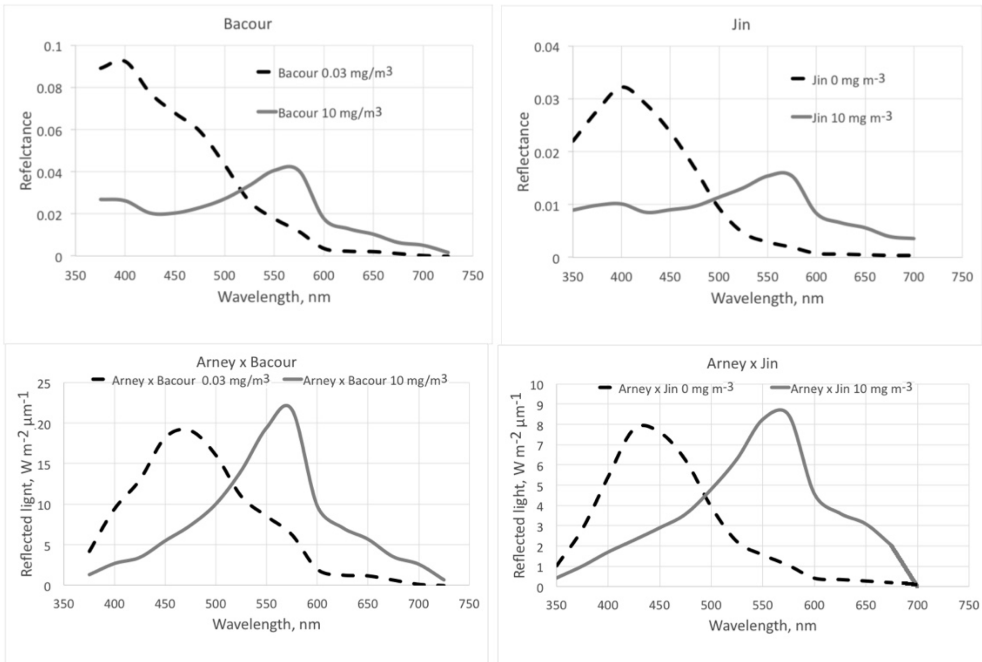

Figure 6. The effect of phytoplankton on reflectance of the ocean surface. The dashed lines are for a low chlorophyll content of the surface layer (0 or 0.03 mg m^{-3}), the solid lines for a high chlorophyll content (10 mg m^{-3}). The top two graphs show the modeled spectra from Bacour et al. (2020) and Jin et al. (2011, diffuse incidence). The geometry is not the same for the two panels, thus the absolute values are not directly comparable. The lower two graphs show the amount of reflected light, assuming an incident Archaean daylight according to the red graph in Fig. 15 (right panel) of Arney et al. (2016).

Thus the presence of algae increases the reflectivity of oceans and lakes, i.e. counteracts the “degradation” of sunlight to diffuse radiation of longer wavelength in all directions (not only from the sunlit side of the planet), and the production of entropy.

5 Conclusion

Michaelian & Simeneov (2015) conclude that they have presented evidence that “supports the thermodynamic dissipation theory of the origin of life (Michaelian, 2009, 2011), which states that life arose and proliferated *to carry out* the thermodynamic function of dissipating the entropically most important part of the solar spectrum (the shortest wavelength photons) prevailing at Earth’s surface and that this irreversible process began to evolve and couple with other irreversible abiotic processes, such as the water cycle, to become more efficient, to cover ever more completely the electromagnetic spectrum, and to cover ever more of Earth's surface."

I cannot agree that they have presented evidence for this conclusion. The biosphere has certainly evolved and is maintained thanks to a production of entropy associated with the conversion of solar radiation to Earth radiation. For details of this entropy production, I refer to Wu and Liu (2010). They compared and discussed various ways of computing entropy fluxes in the Earth system.

7 Final comments

Ultraviolet radiation has played an important role in the prebiotic synthesis of the molecular species that have made the origin of life possible (Björn 2015). But several recent publications explore the possibility that the first life emerged in places without any ultraviolet radiation or visible light, such as submarine hydrothermal vents (Altair et al., 2021) or a geyser system driven by nuclear power (Maruyama et al., 2019).

8 There are no competing interests

9 Acknowledgements

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