ENTROPY OF SOLAR IRRADIANCE OF THE EARTH

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Reference: Daniel V. Schroeder, *An Introduction to Thermal Physics*, (Addison-Wesley, 2000) - Problem 3.13.

If an amount of heat Q flows into a substance at a constant temperature T, the change in entropy is

$$\Delta S = \frac{Q}{T} \tag{1}$$

We can estimate the entropy created by the heat transferred from the Sun to the Earth using this formula by looking at the energy received in 1 square metre on the Earth's surface from direct sunlight. The maximum solar flux is

$$F_S = 1365 \text{ W m}^{-2} \tag{2}$$

which is the energy received when the sun is directly overhead. This energy is received only by regions near the equator, where the day length doesn't vary much from 12 hours over the course of a year. If we say that the average amount of energy received by a square metre in this region is about half this (allowing for the sun's varying altitude in the sky over the course of each day), then over the course of a year, the total amount of energy received by a square metre is

$$Q = \frac{1}{2}\,(1365)\,(12 \times 3600)\,(365.25) \approx 10^{10} \text{ J} \tag{3}$$

The surface temperature of the sun is around 6000 K so the entropy lost by the sun in providing this energy is

$$\Delta S_{sun} = -\frac{10^{10}}{6000} = -1.8 \times 10^6 \text{ J K}^{-1} \tag{4}$$

The entropy change of the Earth in receiving this energy at a temperature of around 300 K is

$$\Delta S_{earth} = +\frac{10^{10}}{300} = 3.6 \times 10^7 \text{ J K}^{-1} \tag{5}$$

Thus the net entropy change is

$$\Delta S = 3.4 \times 10^7 \text{ J K}^{-1} \tag{6}$$

The argument that grass growing on this square metre violates the second law of thermodynamics since it is converting this solar energy, water and disordered chemicals from the soil into ordered life isn't really valid, since the entropy reduction due to the biochemical reactions would be vastly smaller than this. We've seen that the entropy reduction in freezing 30 g of water at 25° C to an ice cube at 0° C is around -15 J K^{-1} so even if the ordering of molecules in a square metre of grass resulted in a reduction in entropy several orders of magnitude greater than this, it would still be a lot less than the entropy generated by transferring the energy from the Sun to the Earth in the first place.