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Comment

Spreading the power
Comment on "Life, hierarchy, and the thermodynamic machinery of planet Earth" by A. Kleidon

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Kleidon's ambitious review [1] of the thermodynamic machinery of Earth starts out as an accessible primer in non-equilibrium thermodynamics (this is necessary because entropy is probably the least understood and most central concept to the physics of life). He then builds a comprehensive model of how solar power spreads around the Earth through a hierarchy of levels – a trophic pyramid of power. Such a comprehensive analysis integrating various components into one big picture of our planet is refreshingly holistic and overdue. Usually ecologically-minded scientists analyse *either* ocean currents, *or* solar radiation, *or* erosion, *or* the hydrological cycle, *or* wind speeds, *or* cloud cover, *or* transpiration. Kleidon considers them all.

The Earth is in a state of disequilibrium. Winds blow, the mantle convects, continents drift, rivers flow and life grows. To keep all of these processes going requires an input of power from the Sun and from the interior heat of the Earth. Kleidon quantitatively follows the input power as it spreads through the thermodynamic machinery of the Earth, maintaining a steady state of disequilibrium which powers all these processes. Solar radiation on the spherical Earth maintains an equator to pole temperature gradient and evaporates (desalinates) the ocean. This temperature gradient drives winds ("momentum gradients"), which transport humid ocean air up and over the continents ("potential gradients"). The resulting rain erodes mountains, carves river beds and dumps everything into the sea ("geochemical gradient"). All this takes a lot of power. And Kleidon uses a lot of accounting and math to keep track of the spreading power, just as one might keep track of a trail of laundered money, or the branching ratios of decaying particles.

Ever since Lovelock introduced a Gaian world view, climate scientists have been wrestling with teleology, homeostasis, optimality (e.g. [3]) and the maximum entropy production principle (MEPP). Kleidon has been at the leading scientifically-respectable edge of the Gaian apologists and the MEPP advocates [2]. Kleidon's new review contributes constructively to the Gaian and MEPP debate: "Using thermodynamics, we should be able to quantify the extent to

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which life contributes to disequilibrium. To do so, we need to first understand the power transfer in the dominant hierarchy of Earth system processes." ([1], Section 1.3).

Possibly the most important aspect of Kleidon's analysis is that it exposes the larger question: where are the best, ecologically sound places to tap into the hierarchy of power distribution? The Aswan Dam extracts the potential energy of the waters of the Nile, but in doing so, uses the energy that would have transported sediments to refertilize the Nile Delta. Similarly, windmills extract the kinetic energy of the winds, but that energy cannot then be used to transport humid air from the oceans to the land and drive the hydrological cycle. Putting up a windmill then reduces the rainfall on continents and slows continental erosion. How many windmills can we put up before the reduction of wind and rain become a problem? The more we understand about the Earth's power hierarchy, the more we will be able to estimate the ecological consequences and costs of tapping into it.

Kleidon explains how biology affects the hierarchy of power. When a photon hits the Earth, it can either hit a molecule of chlorophyll, excite an electron and do some useful work for life. Or it can hit a rock, and get dissipated into waste heat. Kleidon describes the former as "free energy generated by photosynthetic life". But it is the Sun that generates the free energy. Photosynthesis "extracts" the free energy of sunlight and converts it to chemical free energy by splitting water and CO_2. Thus, photosynthesis transfers power to the rest of the biosphere. This leads Kleidon to the interesting suggestion that phototrophic life "generates" power while other forms of life dissipate power.

Kleidon also argues reasonably but not completely successfully for the idea that life produces entropy at the maximum rate allowed by the constraints of the system. This is called the Maximum Entropy Production Principle and is a hot, controversial idea (e.g. listen to Eric Schneider's views at http://mitworld.mit.edu/video/529).

Kleidon reviews the field with clarity and authority, gives the reader entrance into the best literature in the field, and constructs a comprehensive, provocative and power-full model, that the rest of us can try to patch up, tear down or build upon.

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