Maximum Entropy Production and the Carbon Cycle

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Outline

* Thermodynamics 101
* Maximum Entropy Production
* Conceptual schematic of MEP and Climate-Vegetation Interactions
* Sample of some of our current work
* Glimpse of future work and topic of my next presentation
* Conclusions and some advertisements
What is Entropy?

* Entropy is a measure of disorder.

* In a thermodynamic context, it measures the disorder of energy:

\[ S = \frac{J}{K} \]
What is Entropy Production?

$$\frac{dS}{dt} = Q \cdot \left( \frac{1}{T_1} - \frac{1}{T_0} \right)$$

Entropy production is a measure of how quickly energy is degraded.
Thermodynamics 101

\[ \frac{dS}{dt} > 0 \]

\[ S = \text{max} \]

First law: You can’t win.
Second law: You can’t break even.

(Carnot 1824, Clausius 1850)
Thermodynamics 101

\[
\frac{dS}{dt} = \frac{dS_I}{dt} + \frac{dS_E}{dt}
\]

(Prigogine 1962)
Maximum Entropy Production

Fourth “rule”: You are going broke as fast as possible.

“complex dissipative systems in steady-state produce entropy at maximum possible rate”

Example for the meteorologists ...

(Paltridge 1975, 1978; Lorenz et al. 2001)
MEP is a general and powerfully predictive.

MEP is not very skilled at explanation.

(Lorenz et al. 2001)
Higher resolution = more degrees of freedom

Entropy Production as a Function of Model Resolution

(Kleidon, Friedrich, Kunz, Lunkei (2003))
Modeling Dynamics using MEP

representation of dynamical constraints (energy, water, carbon etc.)

Type I: MEP through parameter optimization

Type II: MEP emerges from system dynamics

Misrepresentation of system dynamics: intermediate "diversity"

 MEP obtained by parameter tuning

Diverse representation of dynamics

 MEP emerges from system dynamics

(Kleidon 2004)
Entropy production: $\sigma = Q_{\text{GPP}} \left( \frac{1}{T_S} - \frac{1}{T_{\text{SUN}}} \right)$

(Pavlick and Kleidon 2006)
\[ Q_{sw} - Q_{lw} - Q_{sh} - Q_{lh} = 0 \]

(Kleidon and Pavlick 2005)
Diversity of Possible Vegetation Forms

- Canopy roughness
  - Smooth vs. rough

- Biomass partitioning
  - Many leaves vs. many roots

- Stomatal conductance
  - Few stomata vs. many stomata

- Turbulent vs. radiative fluxes
- Light absorption vs. transpiration
- Sensible vs. latent heat

(Kleidon and Pavlick 2005)
Outline of Methodology

“observed”

ECMWF Reanalysis

BIOME model
(Prentice et al. 1992)

biome-averaged climates

“Control” Climate

BIOME model
(Prentice et al. 1992)

Comparison

simulated

Sensitivity Climates

biome-averaged climates

(Kleidon and Pavlick 2005)
Tropical Rainforest

(Pavlick and Kleidon 2006)
How is this important?

(Kleidon 2005)
MEP and Biotic Enhancement of Rock Weathering
MEP and Glacial-Interglacial Cycles
Conclusions

* Complex systems produce entropy at maximum possible rate given constraints.

* Vegetation adds many degrees of freedom to the climate system allowing for many possible steady states.

* The most likely state is the one at which productivity and thus entropy production are maximized.
4th Annual International Meeting on Maximum Entropy Production in Physics and Biology
6th and 7th of July, Split, Croatia

http://www.pmfst.hr/razno/entropy/
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