Maximum Entropy Production and the Carbon Cycle

Ryan Pavlick
MET0658
March 28, 2006

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:

$$S = \frac{J}{K}$$

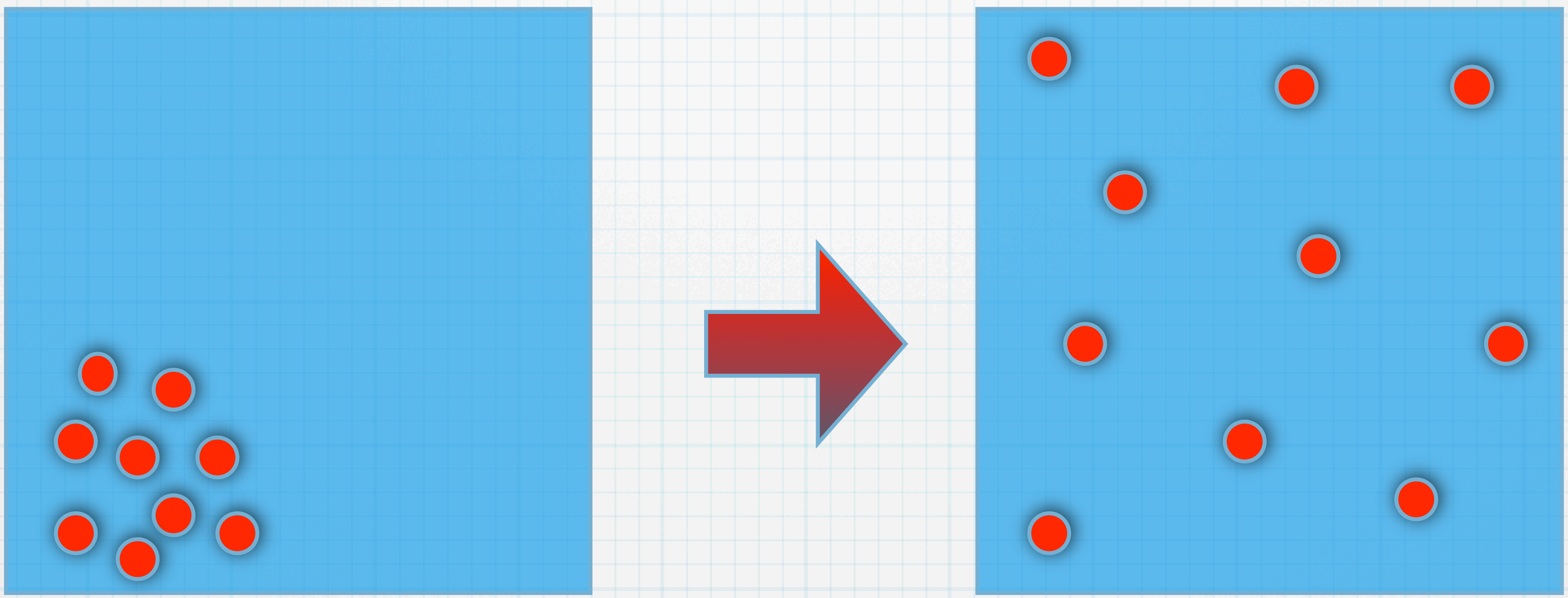
What is Entropy Production ?

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

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

Thermodynamics 101

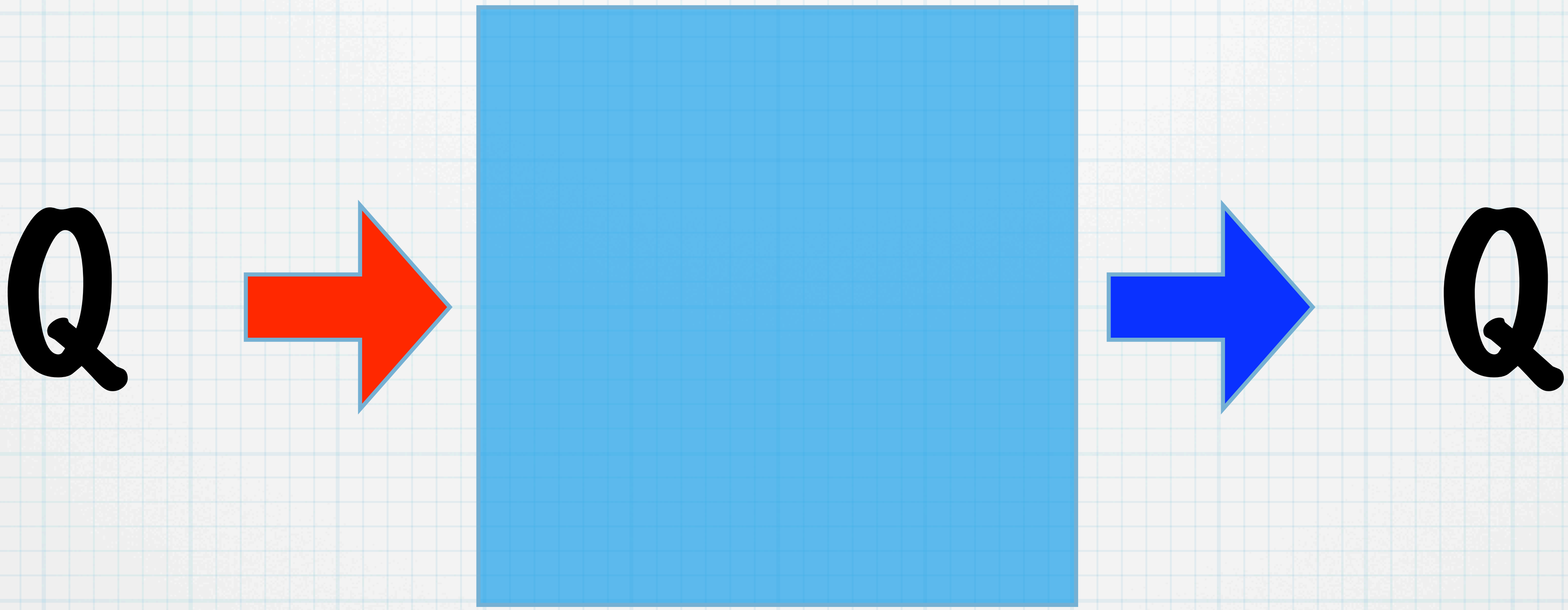
$\frac{dS}{dt} > 0$ $S = max$



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

(Carnot 1824, Clausius 1850)

Thermodynamics 101

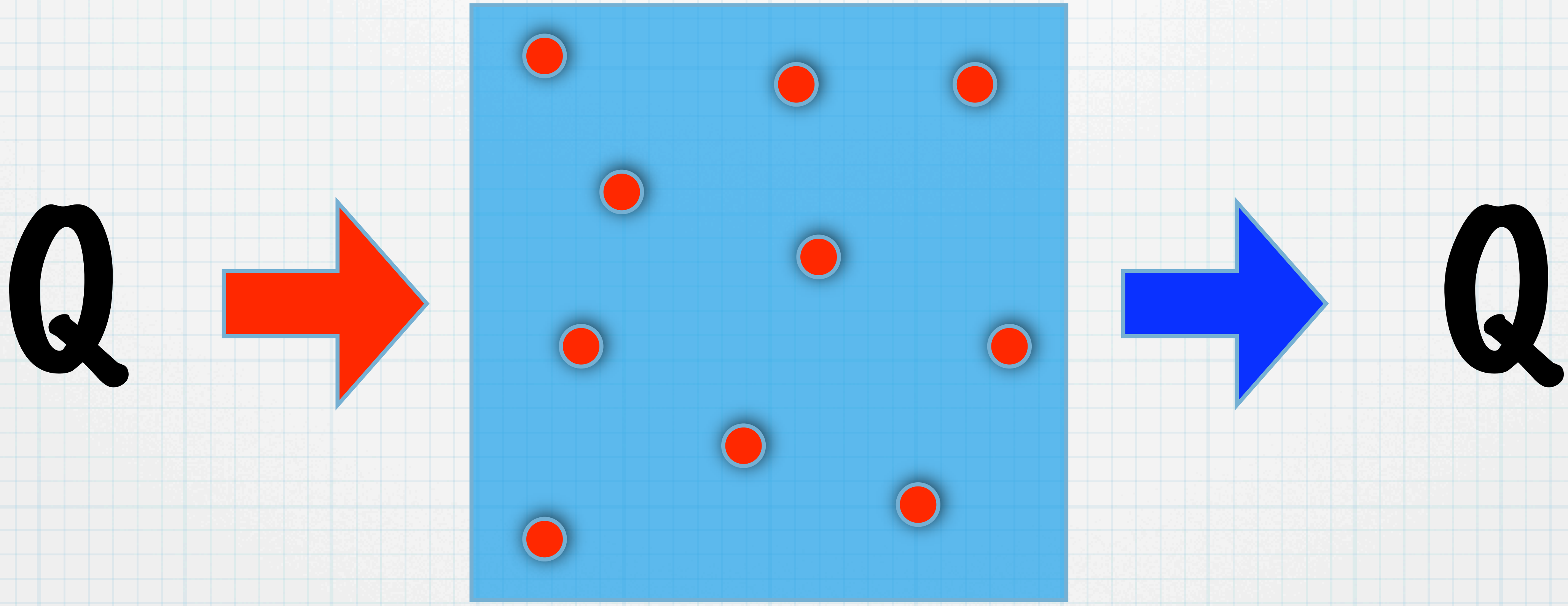


$$\frac{dS}{dt} = \frac{dS_I}{dt} + \frac{dS_E}{dt}$$

(Prigogine 1962)

Maximum Entropy Production

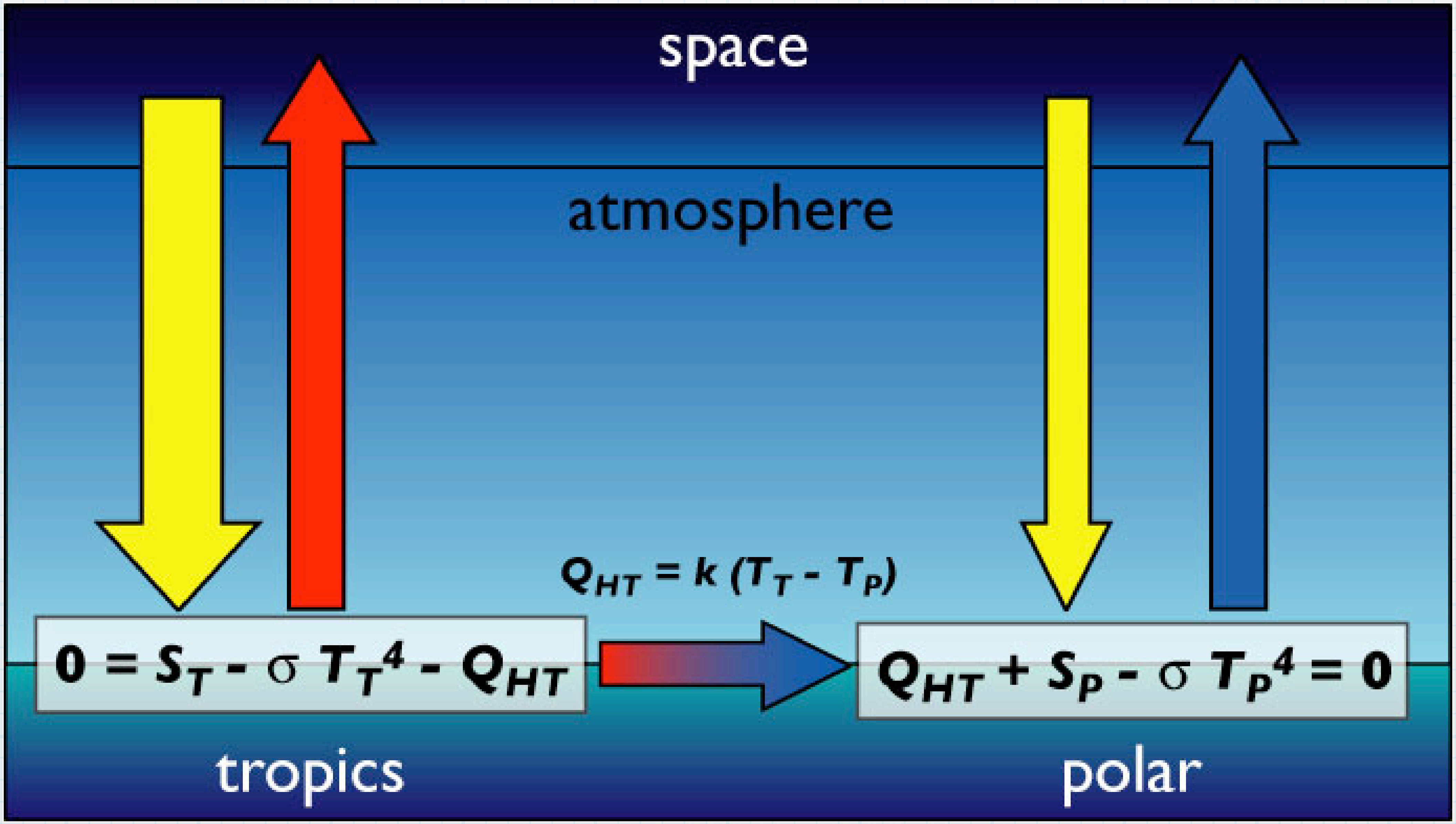
Fourth "rule": You are going broke as fast as possible.



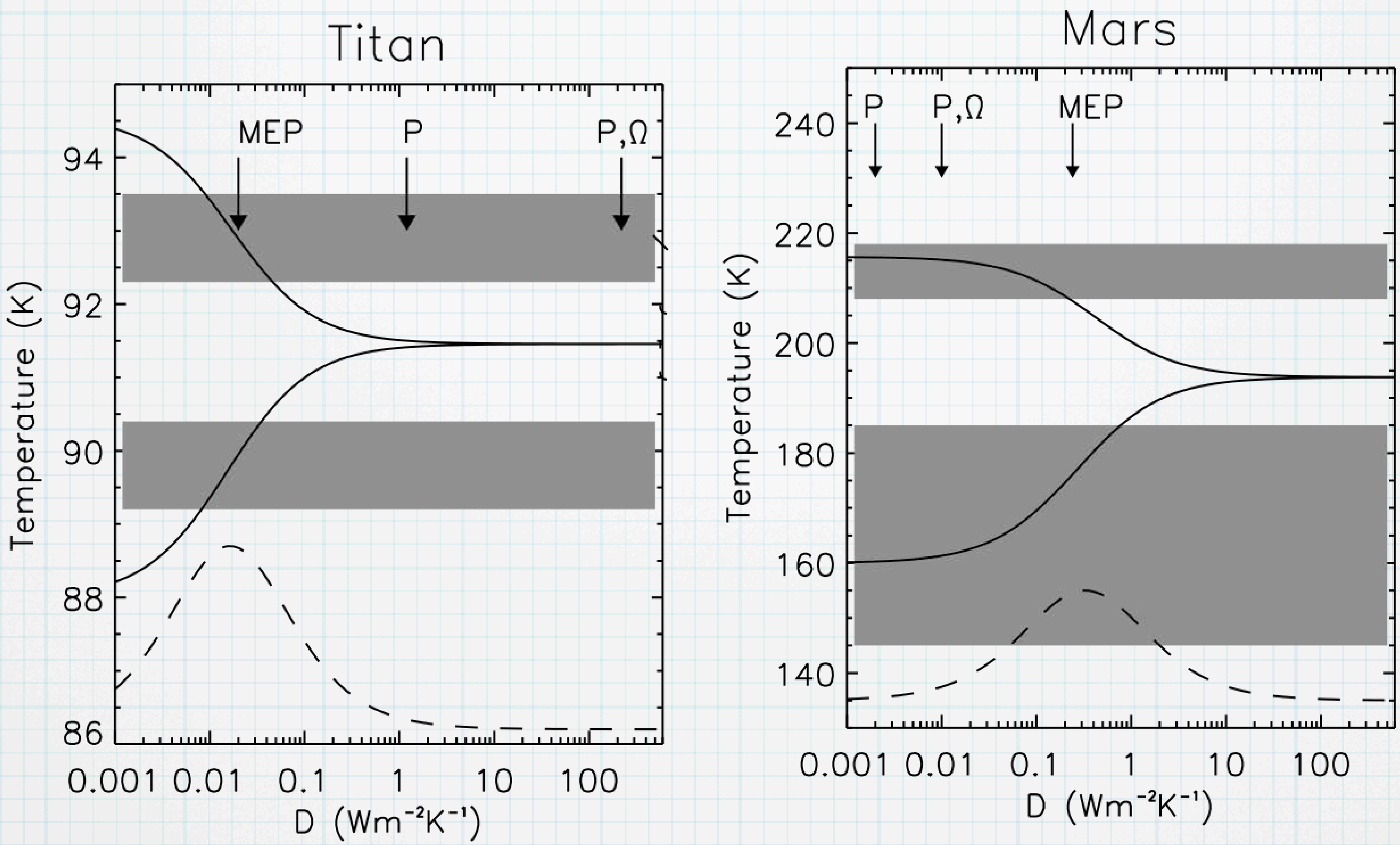
"complex dissipative systems in steady-state produce entropy at maximum possible rate"

(Dewar 2003, 2004,2005)

Example for the meteorologists ...



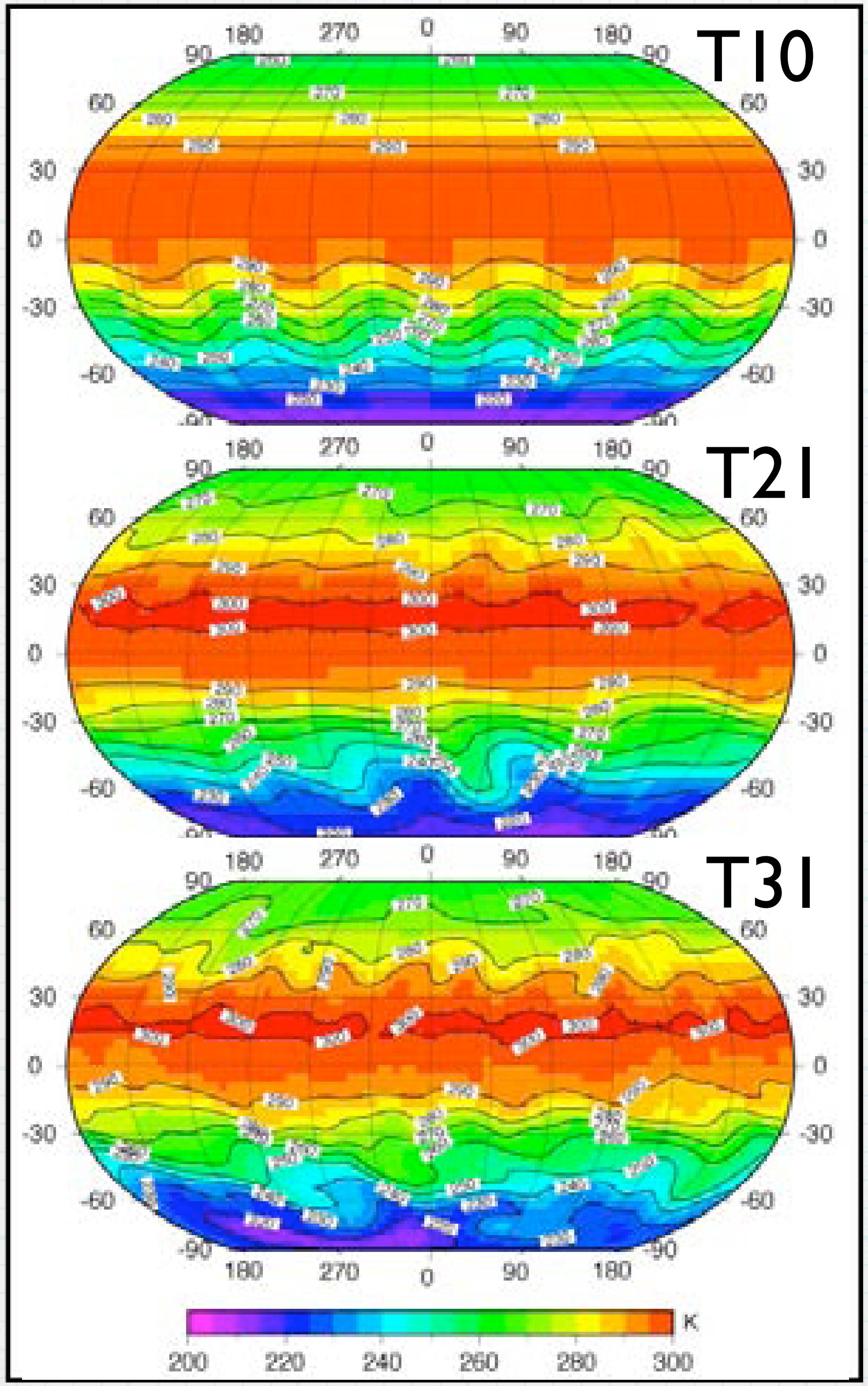
(Paltridge 1975, 1978; Lorenz et al. 2001)



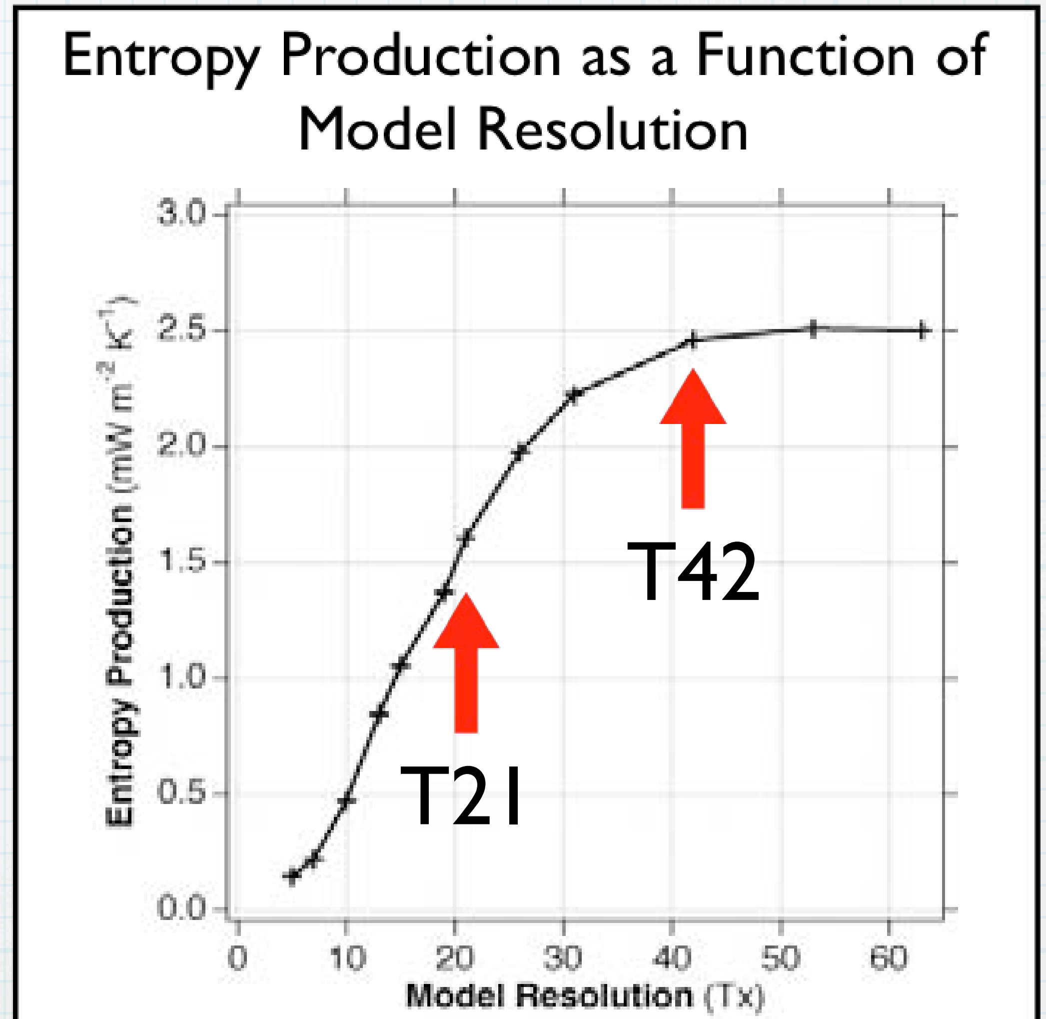
MEP is a general and powerfully predictive.

MEP is not very skilled at explanation.

(Lorenz et al. 2001)



Higher resolution = more degrees of freedom

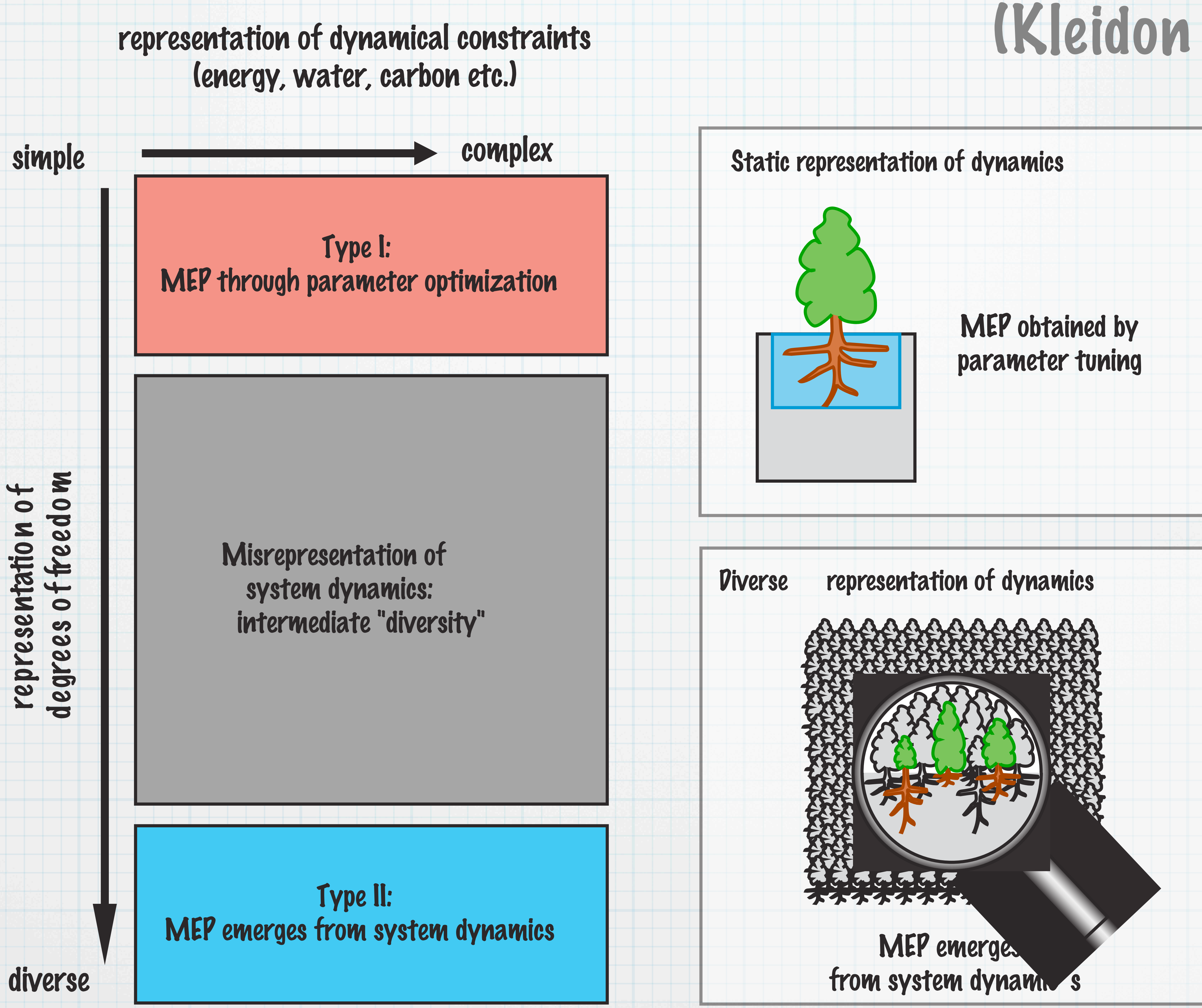


Kleidon, Fraedrich, Kunz, Lunkeit (2003)

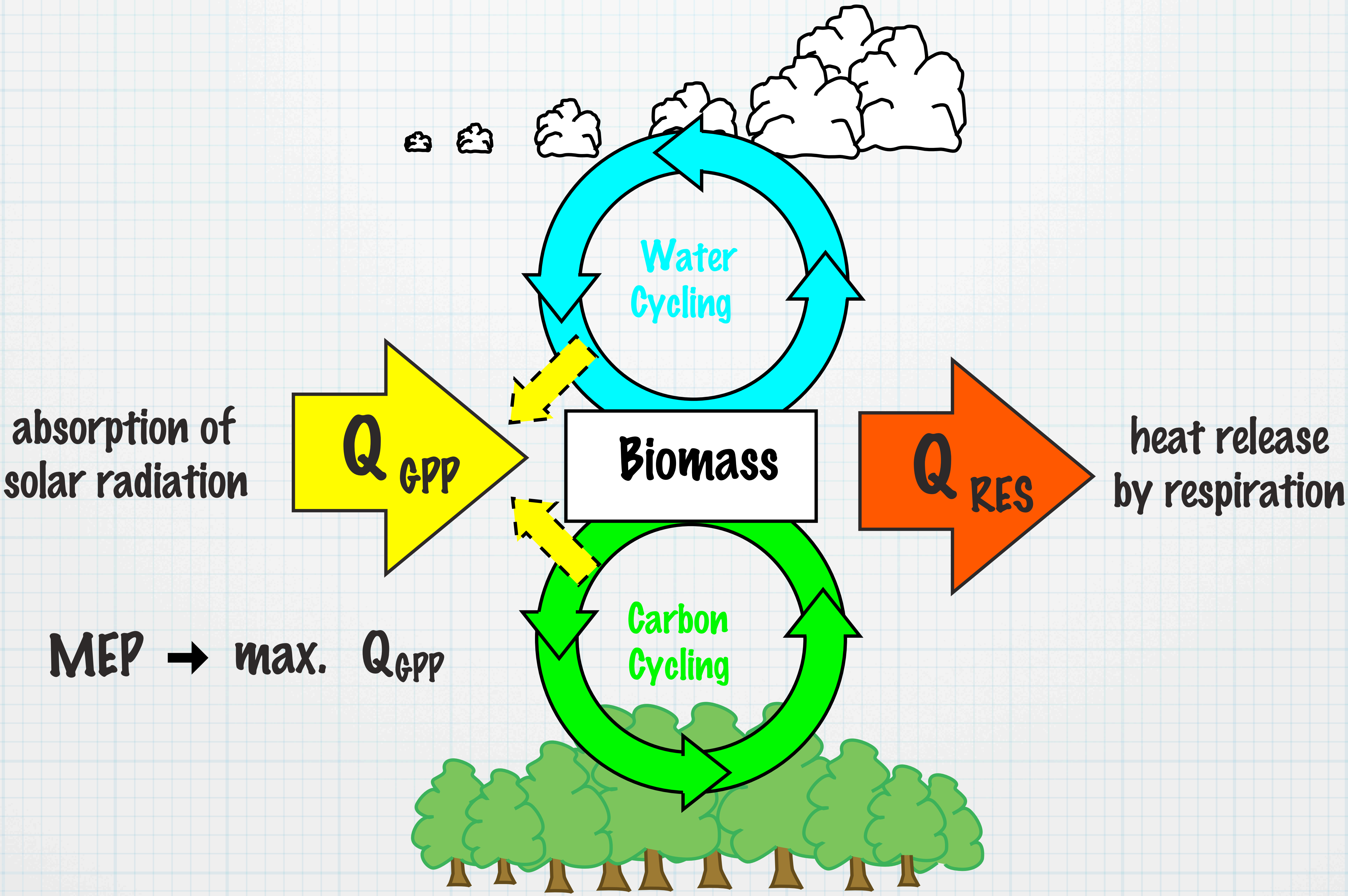
(Kleidon 2003)

Modeling Dynamics using MEP

(Kleidon 2004)

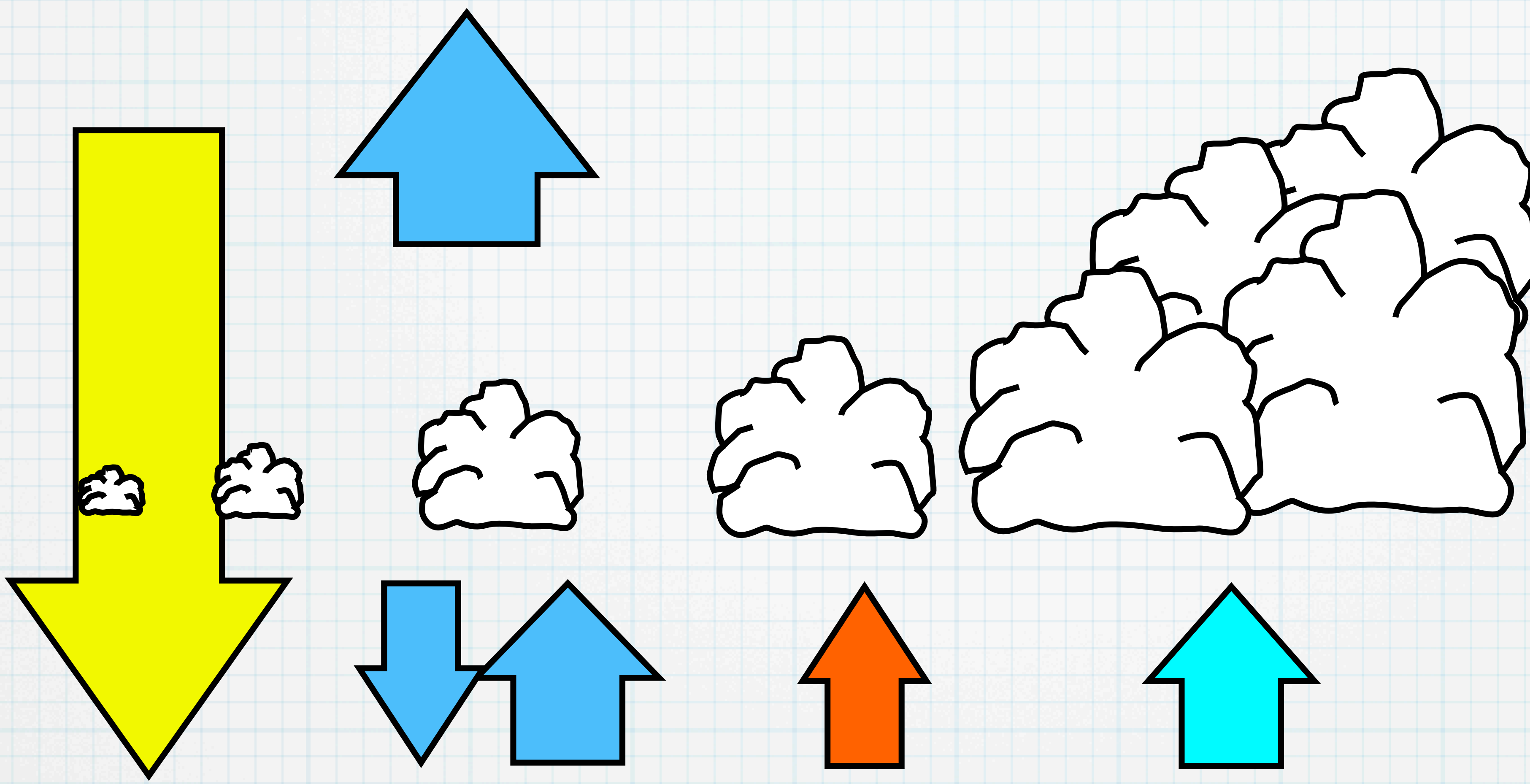


Entropy production: $\sigma = Q_{GPP}\ (1/T_S - 1/T_{SUN})$



MEP → max. Q_{GPP}

(Pavlick and Kleidon 2006)



energy balance constraint

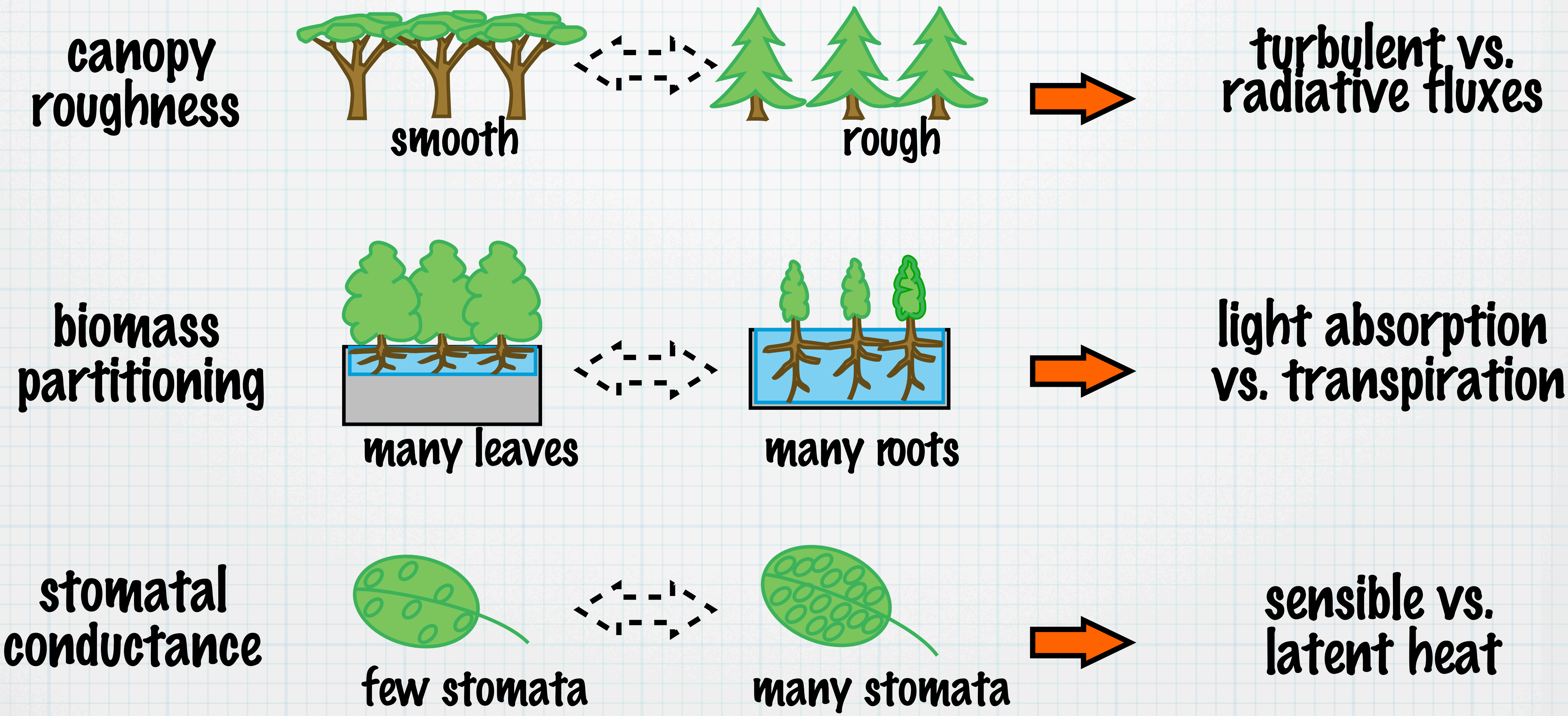
$$Q_{SW} - Q_{LW} - Q_{SH} - Q_{LH} = 0$$

carbon balance constraint

water balance constraint

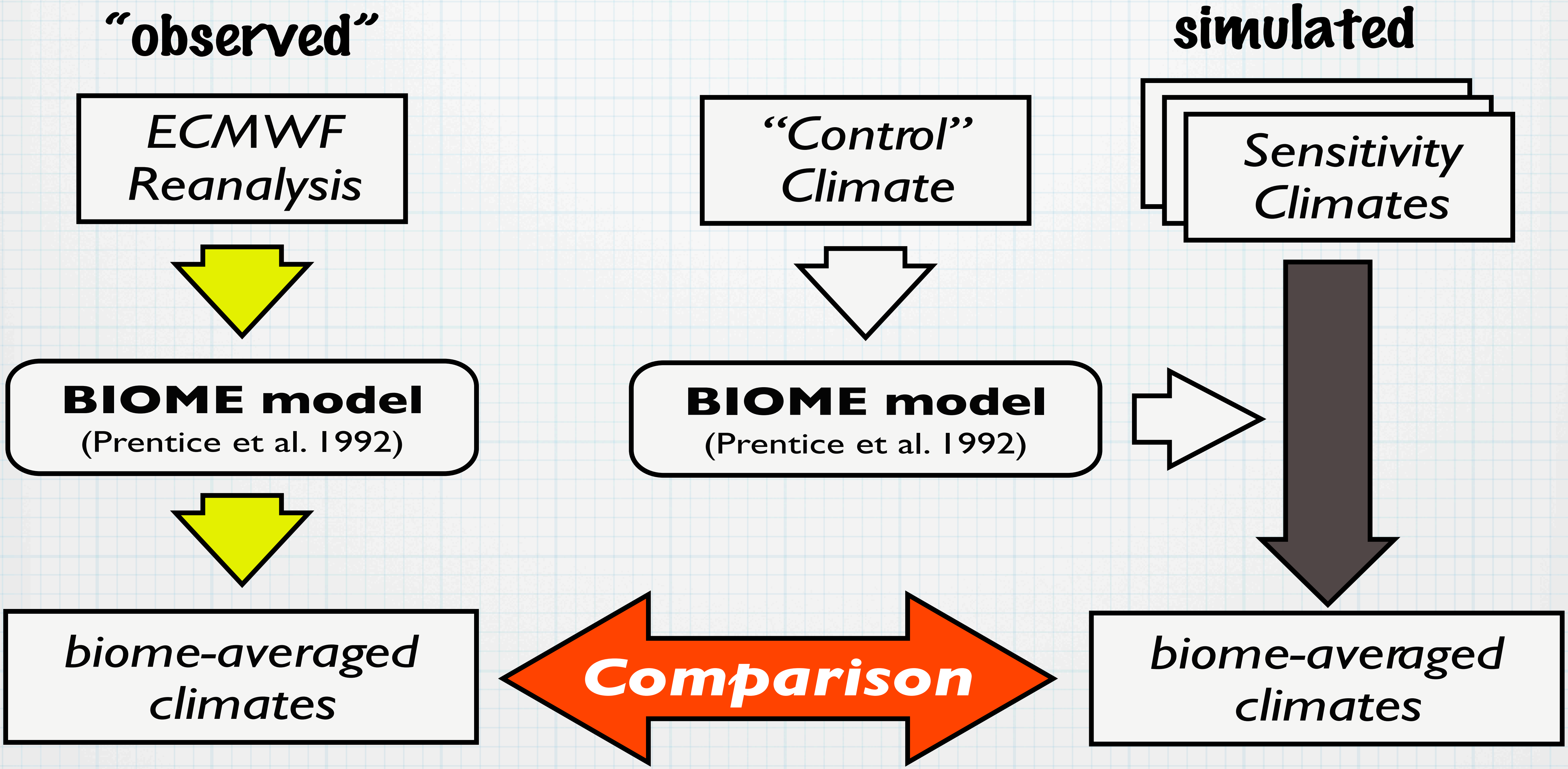
(Kleidon and Pavlick 2005)

Diversity of Possible Vegetation Forms



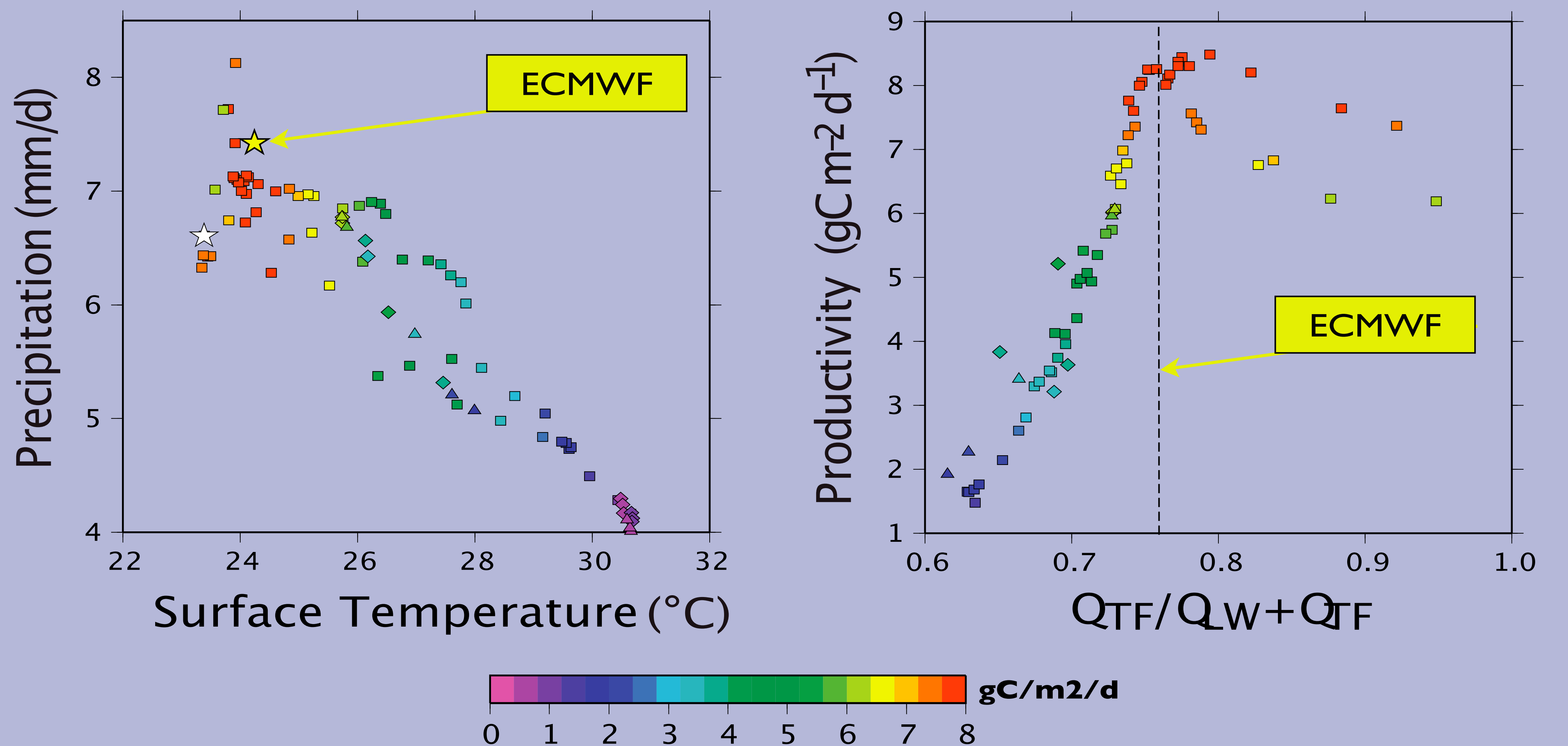
(Kleidon and Pavlick 2005)

Outline of Methodology



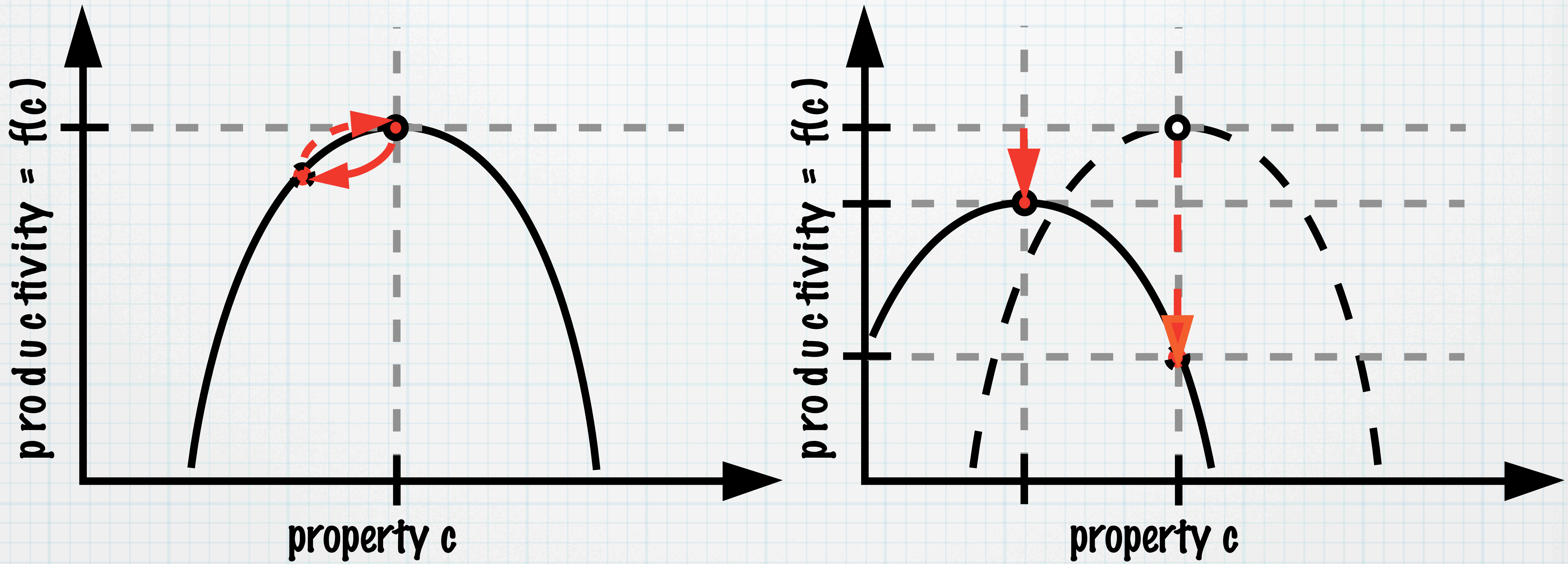
(Kleidon and Pavlick 2005)

Tropical Rainforest



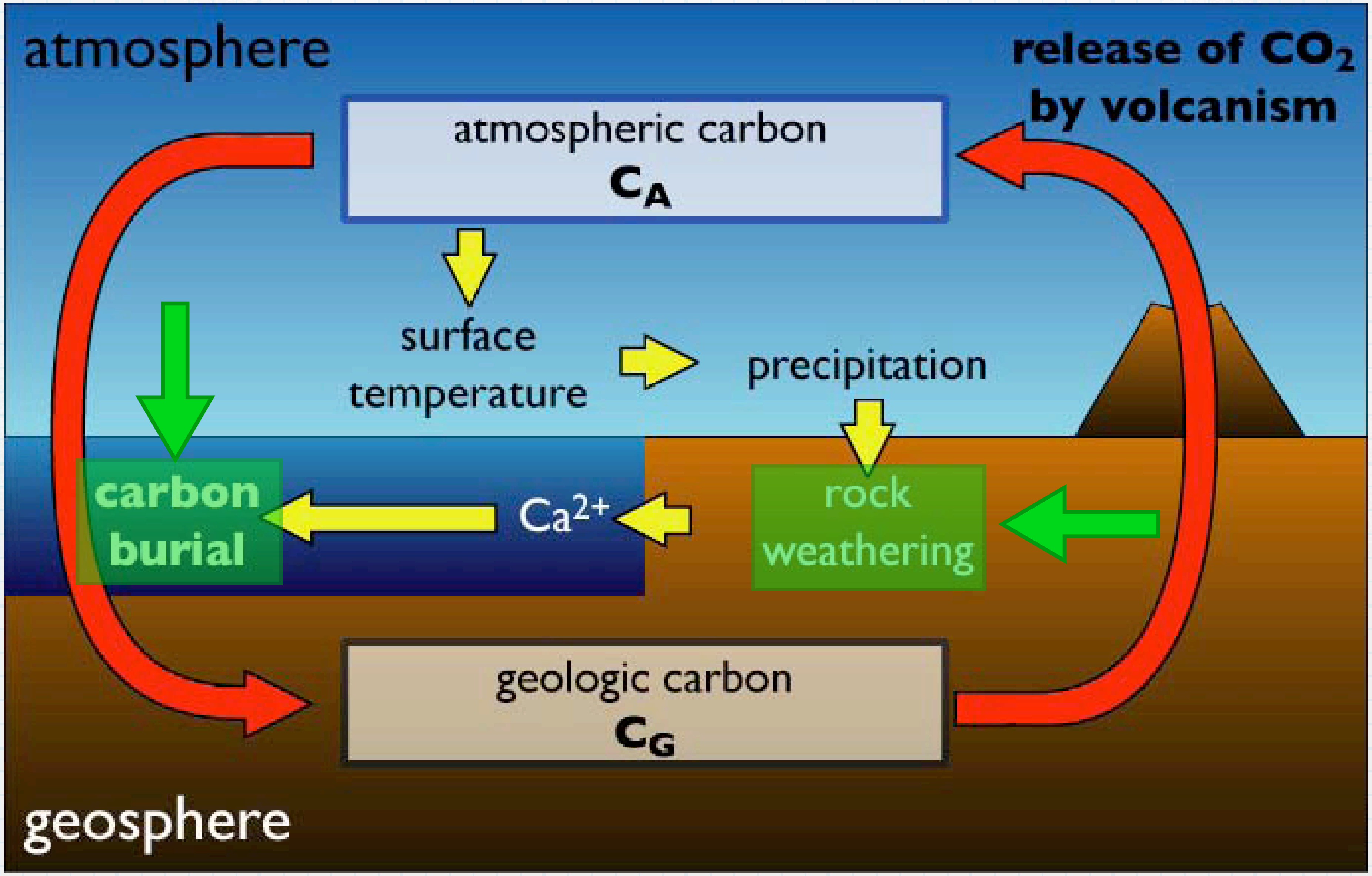
(Pavlick and Kleidon 2006)

How is this important?

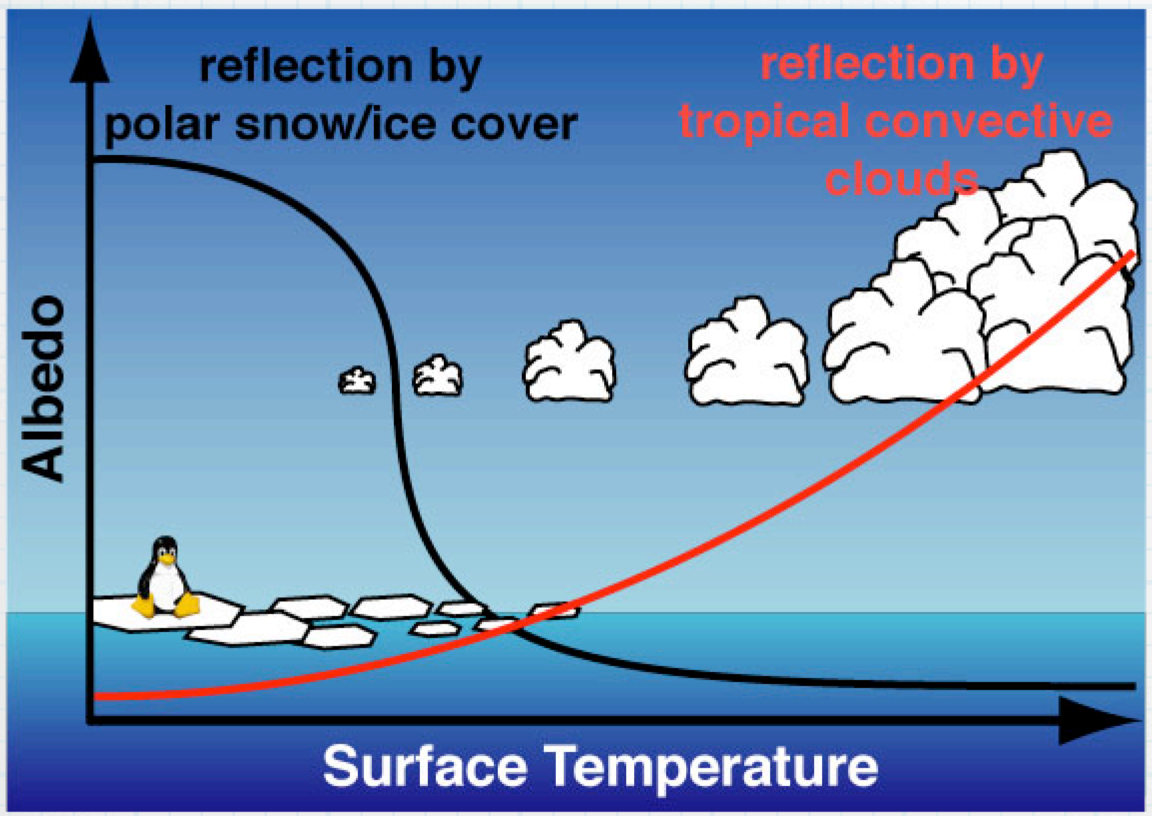


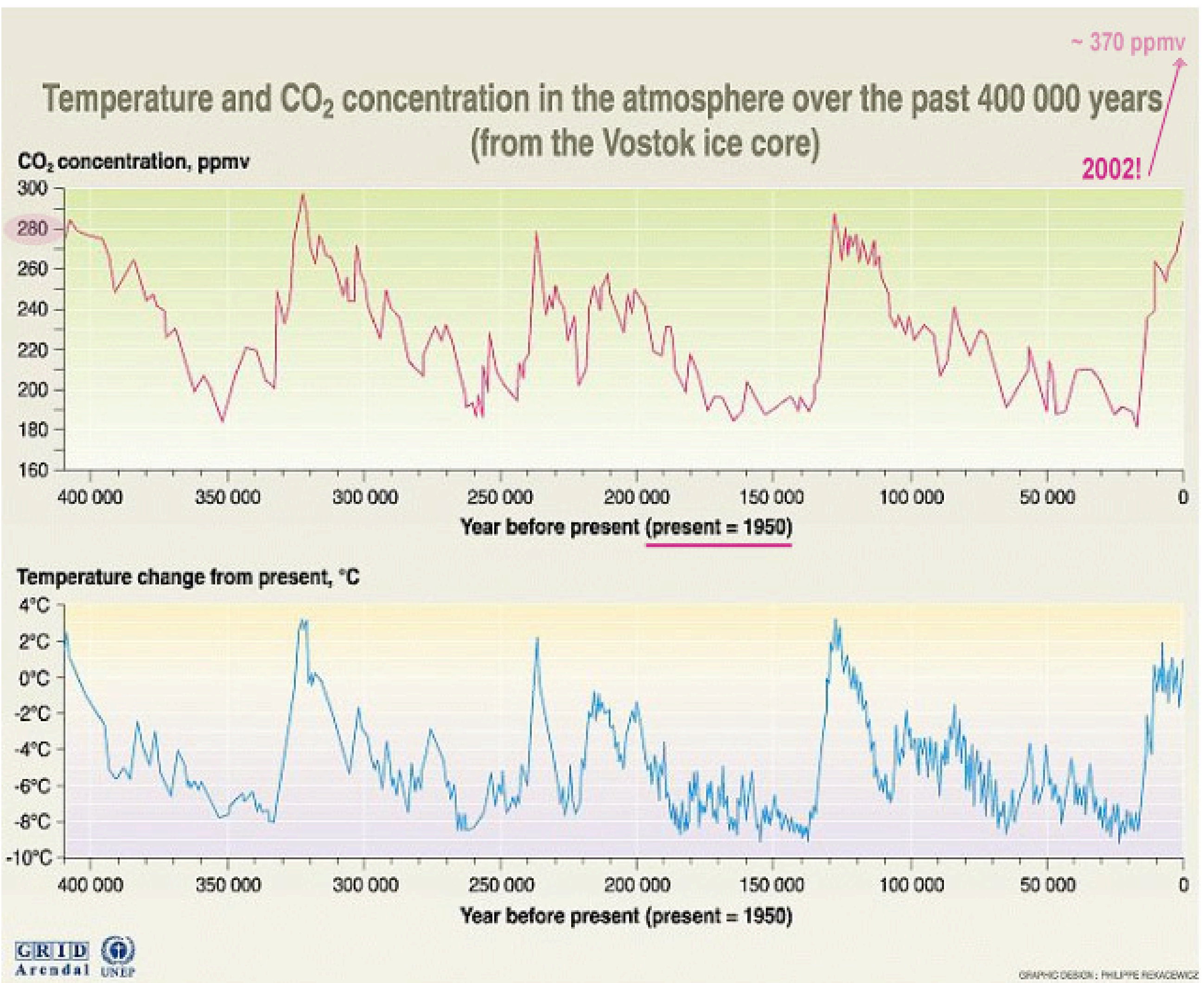
(Kleidon 2005)

MEP and Biotic Enhancement of Rock Weathering



MEP and Glacial-Interglacial Cycles





Source: J.R. Petit, J. Jouzel, et al. Climate and atmospheric history of the past 420 000 years from the Vostok ice core in Antarctica, Nature 399 (3JUne), pp 429-436, 1999.

(Note: 2002 information added to diagram)

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/

Biospheric Theory and Modelling Group
@ the Max Planck Institute for Biogeochemistry

Jena, Germany

http://www.earthsystem.org