

The Maximum Entropy Production Principle

What is it? Is it Useful?

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Feel Free to Ask Questions





Those of a thermodynamically sensitive nature may find some aspects of this presentation disturbing

Talk Overview



1 Entropy and Energy

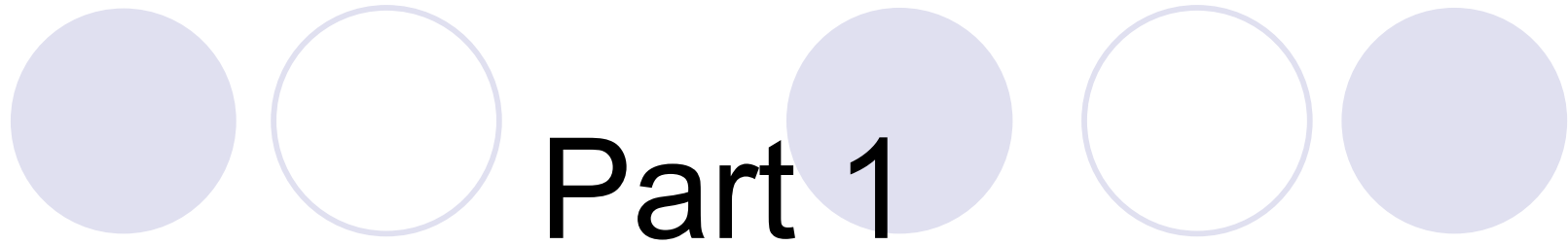
- A bit of classical thermodynamics
- A definition of entropy

2 The Maximum Entropy Production Principle

- What the MEPP is
- Objections and support

3 Recent Research

- MEPP and Daisyworld
- Related and future work



Entropy and Energy



Formulations of Entropy

- Carnot - heat engines
- Boltzmann-Gibbs - statistical mechanics
- Shannon & Weaver - information theoretic

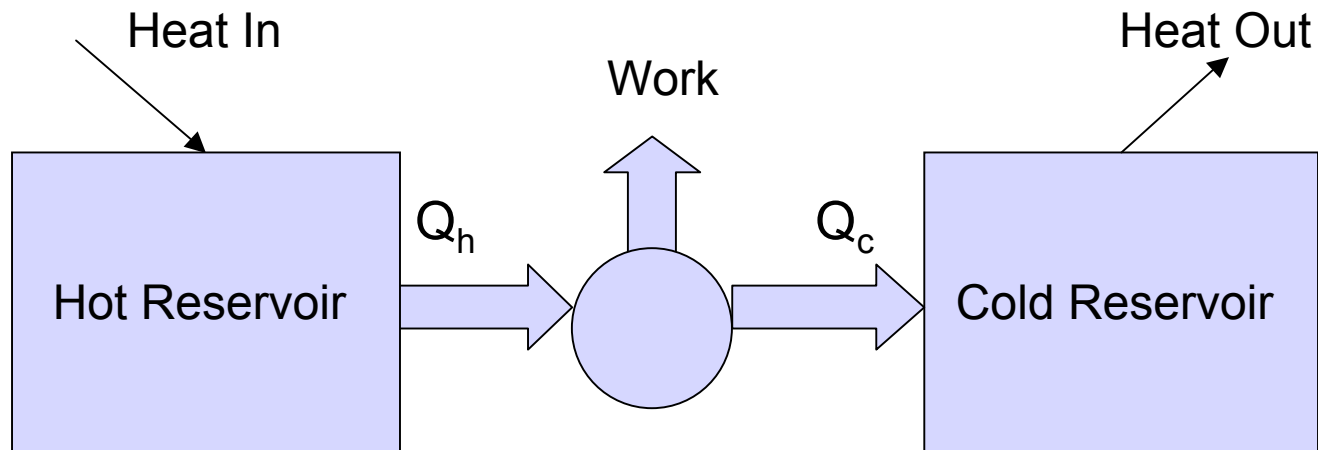
Concentrate on Heat Engines & Entropy



- Different formulations of entropy are related - need to be careful
- Recent work on information theoretic formulations very relevant here
- But... limit scope here to provide necessary framework for MEPP discussion

Carnot's Heat Engine

- Flow of heat, drop in temperature produces work



Work and Efficiency



- Idealized Carnot engine would be 100% efficient.
- Remember - much motivation from industrialists...
- ...who were a bit disappointed to learn 100% efficiency impossible
- Although some still try!

Entropy and Efficiency



- Can never convert all added heat to work
- Quality of energy always decreases - 'exergy'
- Entropy understood as amount of energy in system unable to 'do work'

Classical Thermodynamics & Entropy

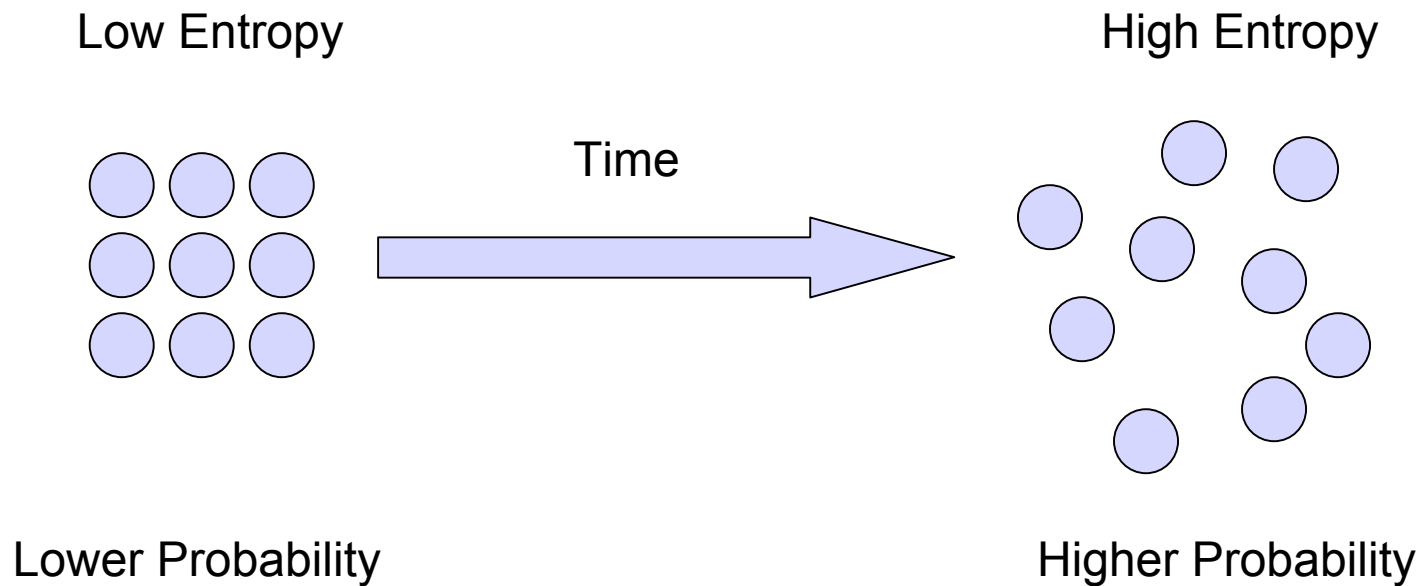
- $dS=dQ/T$
- Change in entropy described as the heat added per unit temperature
- Related to 'Clausius Inequality' and 'Carnot Efficiency'
- Entropy can only ever increase in 'realistic' closed system

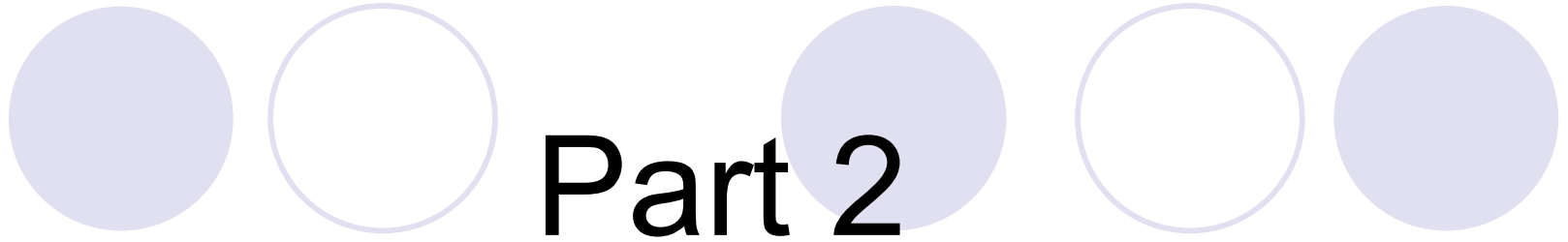
Three Laws of Thermodynamics

- You cannot win (you cannot get something for nothing, because matter and energy are conserved)
- You cannot break even (you cannot return to the same energy state as no process 100% efficient)
- You cannot get out of the game (because absolute zero is unattainable)

Statistical Mechanics & Entropy

- $S = k \ln(\Omega(E))$
- k - Boltzmann's constant
- Ω - possible microstates for energy E





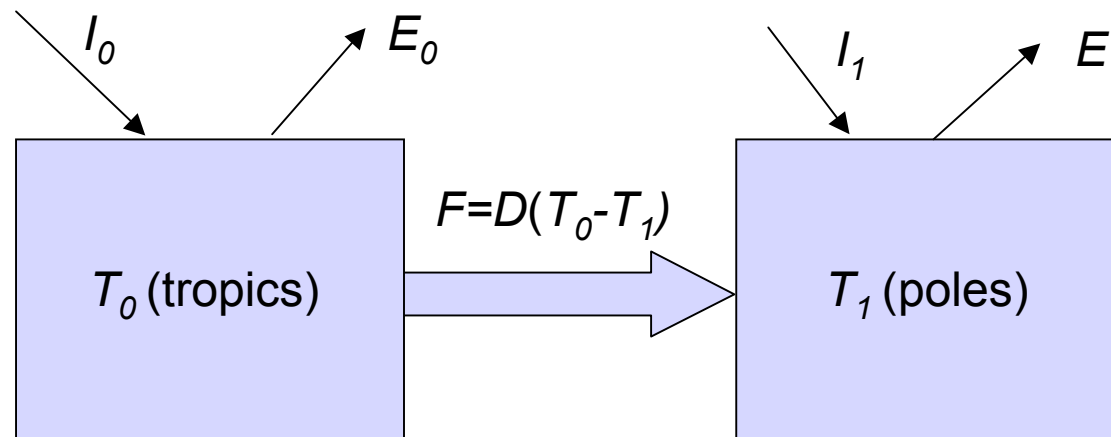
Maximising Entropy

Heat Engines Not Only Steam Engines

- Hot equator
- Cold poles
- Heat flow produced work
- Open system



Energy Balance Climate Model



I - insolation
 E - emission
 D - diffusivity
 F - heat flow
 T - temperature

$$I_0 - E_0 - F = I_1 - E_1 + F$$

Entropy Via Latitudinal Heat Flow

- $dS = F/T_1 - F/T_0$
- Greater heat flow, greater temperature drop, greater rate of entropy production

Earth and the MEPP



- Paltridge 1970/80s - maximum energy dissipation in Earth's climate
- Diffusivity 'selected' to maximise entropy
- So improbable that the Earth must maximise entropy production



Objections

- Not a general principle - example of one
- 'Just so' story
- No plausible account of why Earth 'chooses' maximising diffusivity
- Sounds a bit like Gaia - where are the crystals and wood nymphs?

Empirical Support

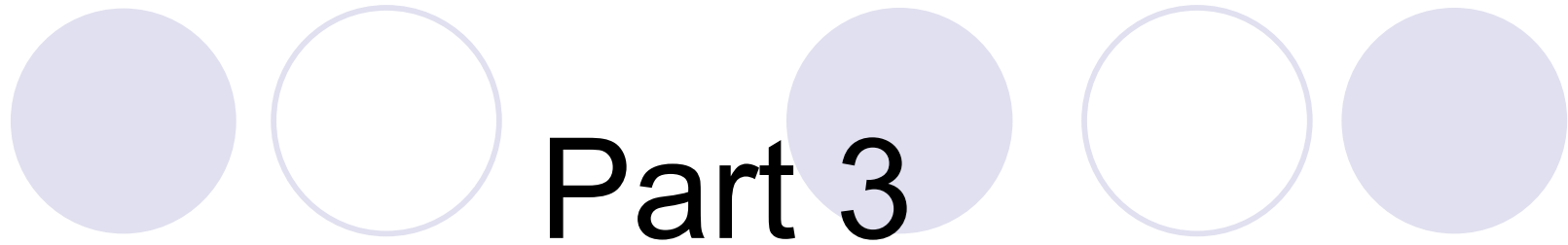


- MEPP can be applied to other planets: Lorenz et al (2001)
- MEPP prediction of heat flux more accurate than pressure scaling
- ‘Black box’ application of MEPP

Analytical Support



- Dewar (2003) derived MEPP, SOC and fluctuation theorem from Jaynes formalism
- MEPP the most probable outcome for certain complex systems
- Non-equilibrium statistical mechanics
- Open dissipative systems



Daisyworld & MEPP

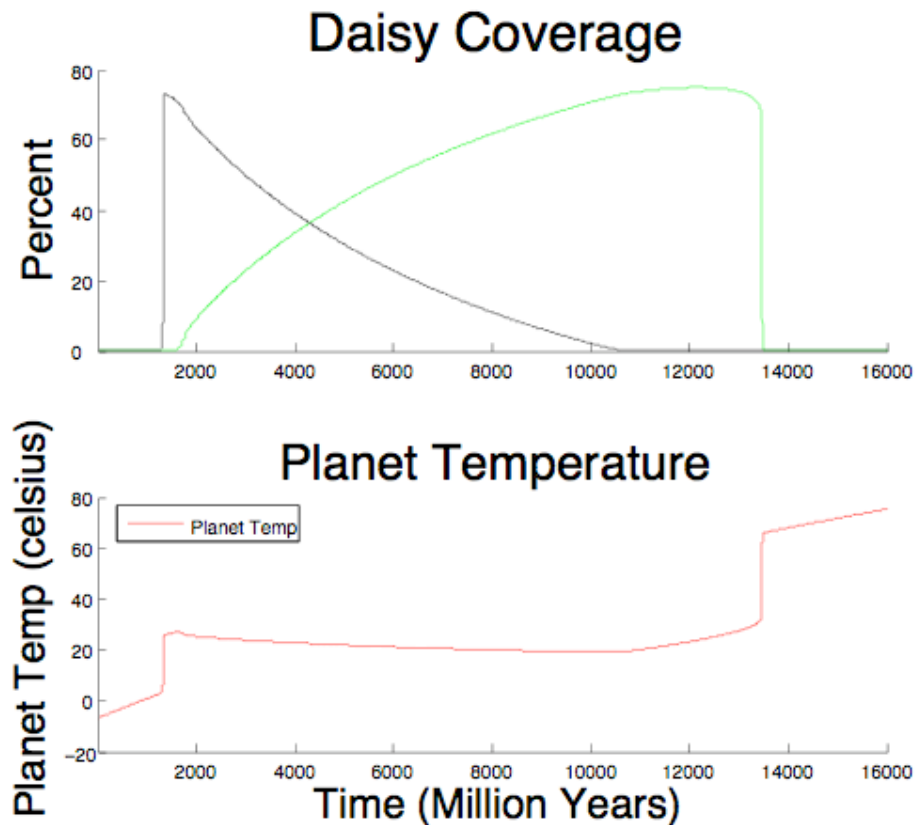
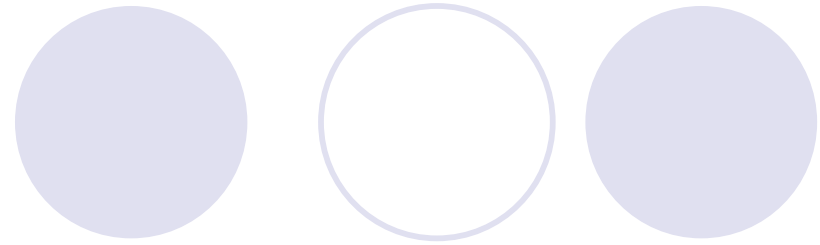


Biotic-Abiotic Feedback

- One (comparatively non-controversial) element of Gaia theory is life affects environment
- Lovelock's atmospheres far from equilibrium
- What effect would MEPP have on life?

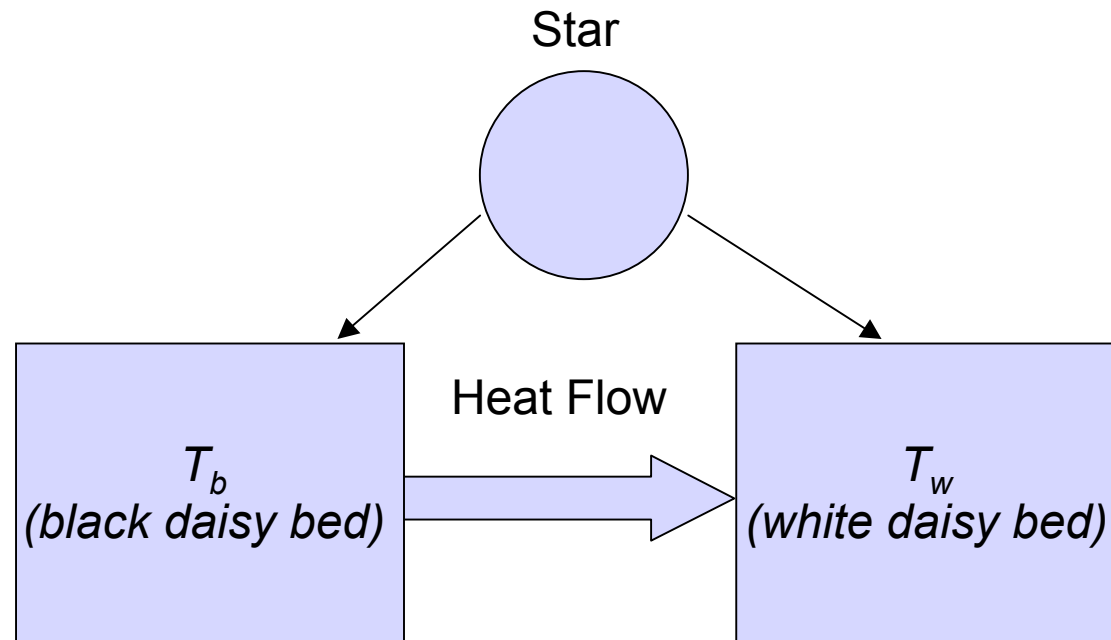
Daisyworld

- Proof of concept for regulation of abiotic environment by biota
- Black & white daisies regulate temperature to within 'preferred' range

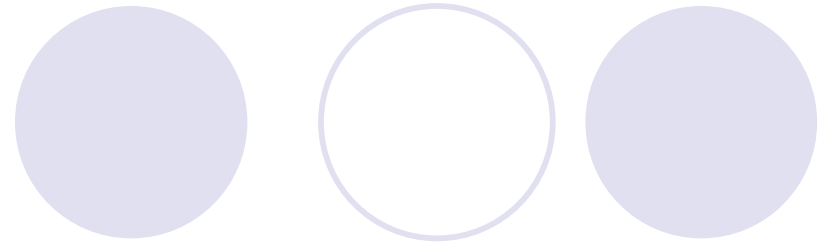


Harvey Two-Box Daisyworld

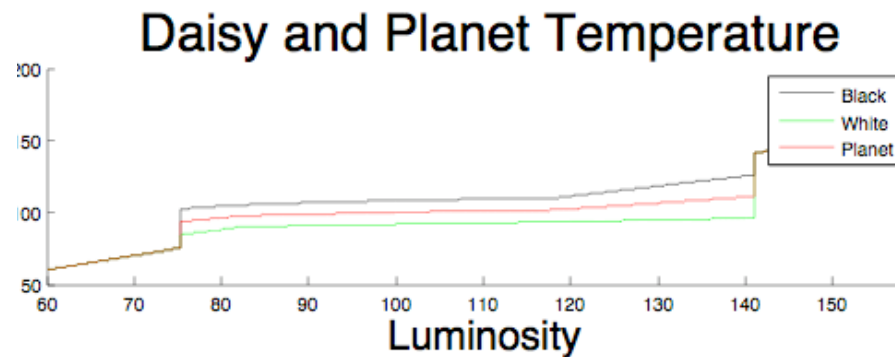
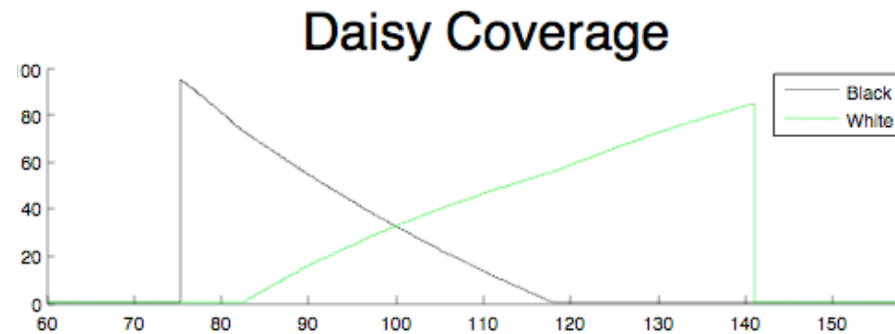
- A number of simplifications including separate daisy beds so no space competition



Two Box Results

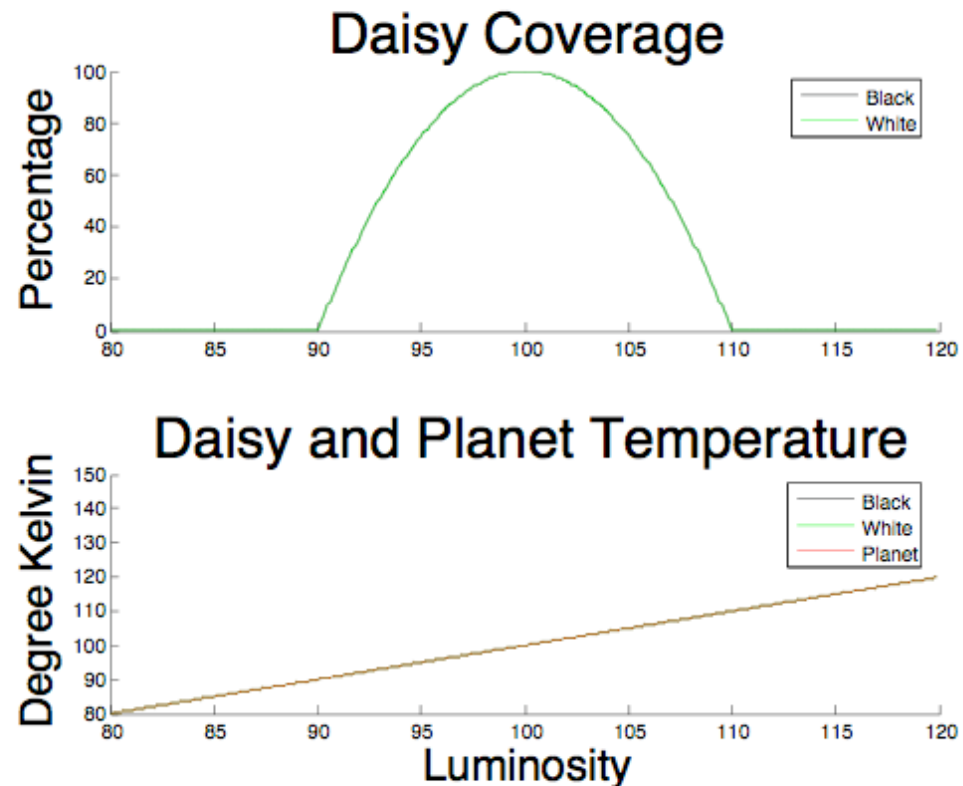


- Same homeostatic behaviour observed
- Highlights importance of 'coupling'



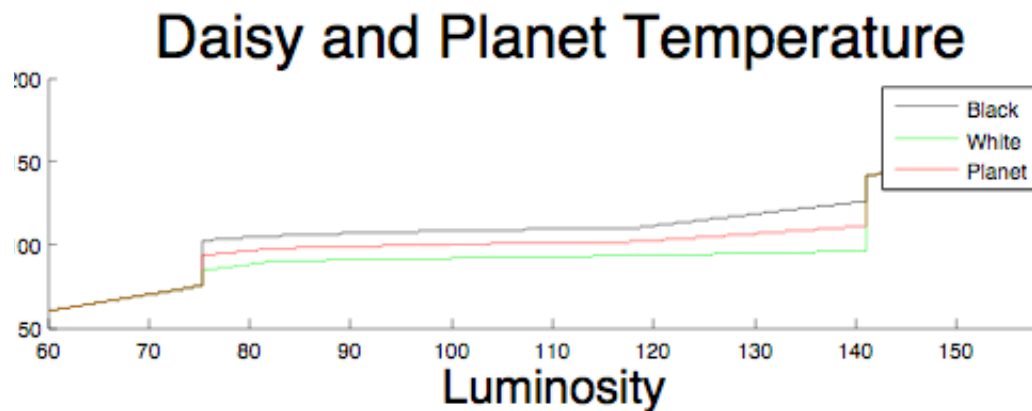
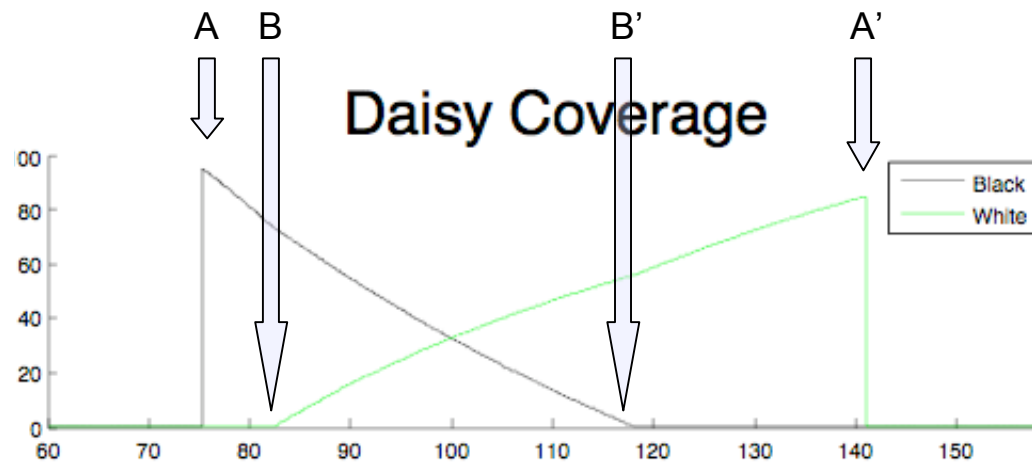
Homeostasis and Diffusivity

- $F = D(T_b - T_w)$
- With maximum diffusivity, no homeostasis



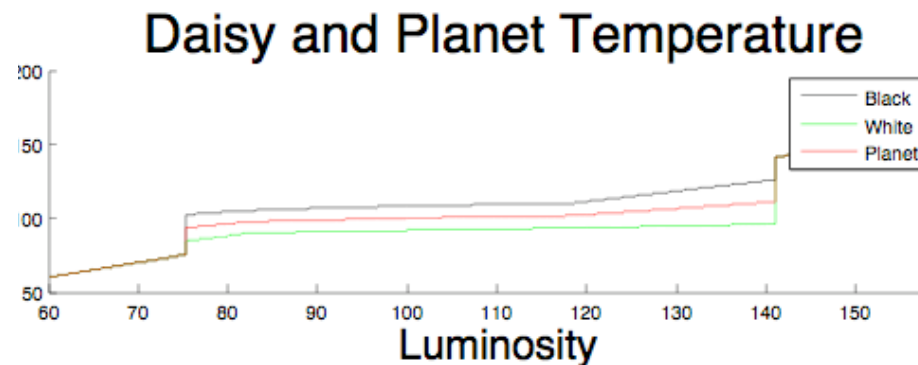
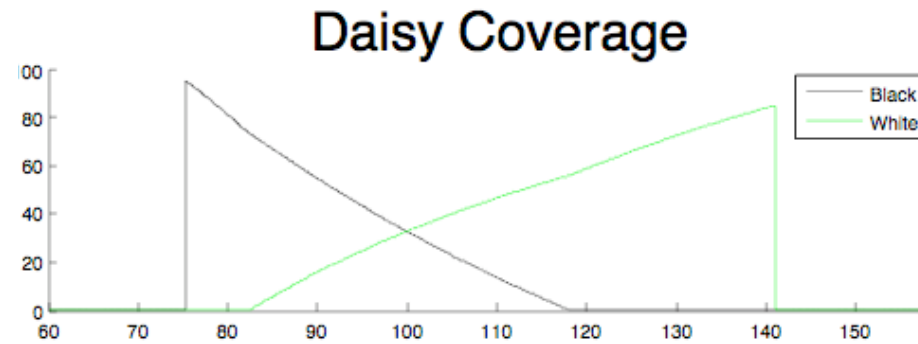
Daisy Ranges

- A: any-daisy range
- B: both-daisy range

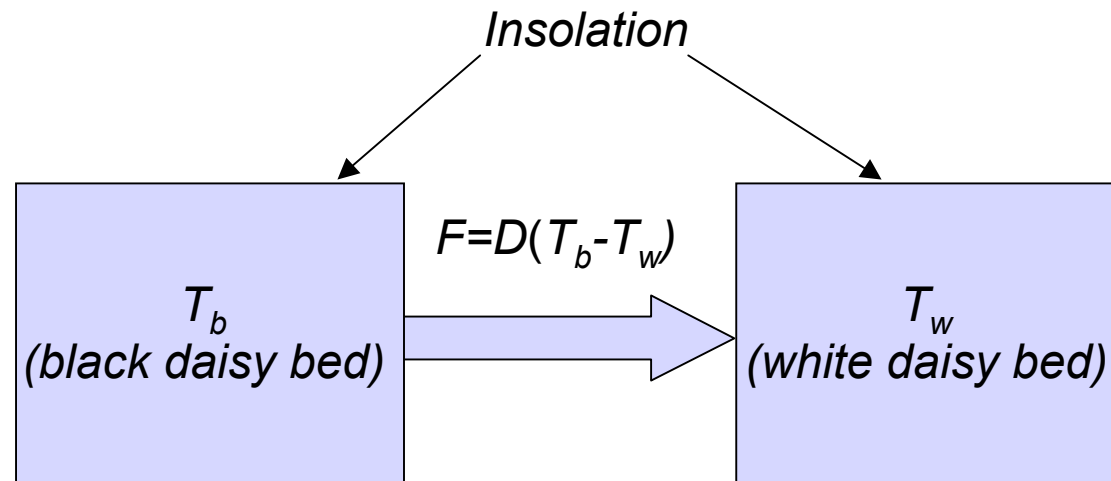


Max Homeostasis With Both Daisies

- Most effective temperature regulation when black and white daisies present



Daisyworld Energy Balance Model



I - insolation

F - heat flow

D - diffusivity

Φ - Steffan-Boltzmann constant

$$\Phi T_b^4 = I(1 - A_b) - F$$

$$\Phi T_w^4 = I(1 - E_1) + F$$

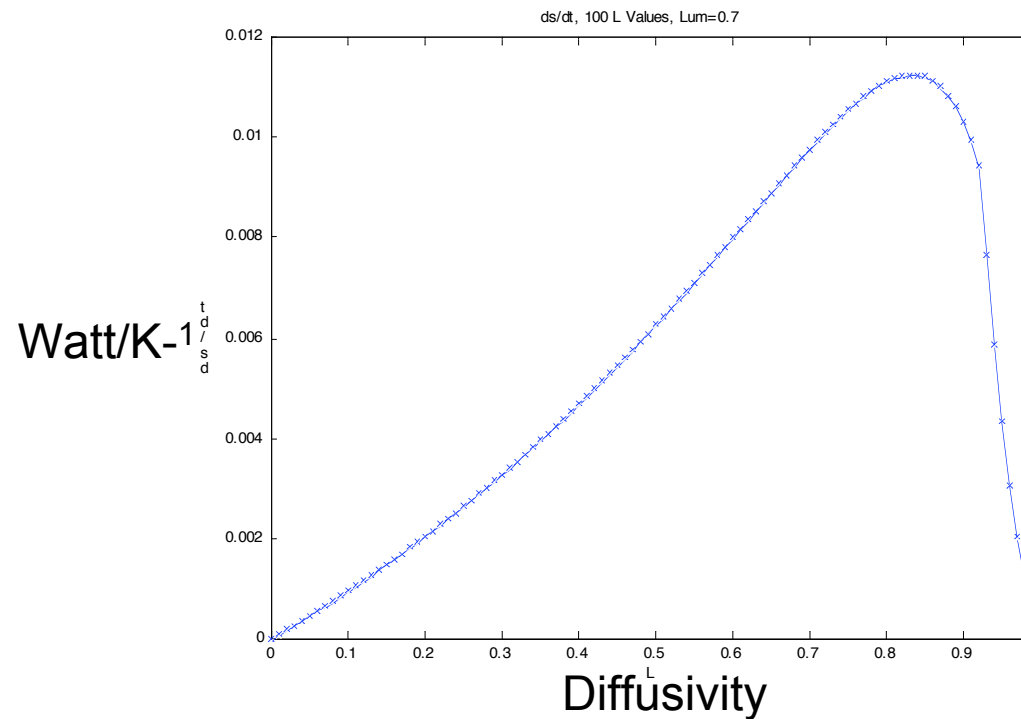
Daisyworld and MEPP



- Rate of entropy production: $dS = F/T_w - F/T_b$
- What if Daisyworld maximised rate of entropy production?

Maximising Entropy in Daisyworld

- Maxwell's daemon adjusts diffusivity to maximise dS



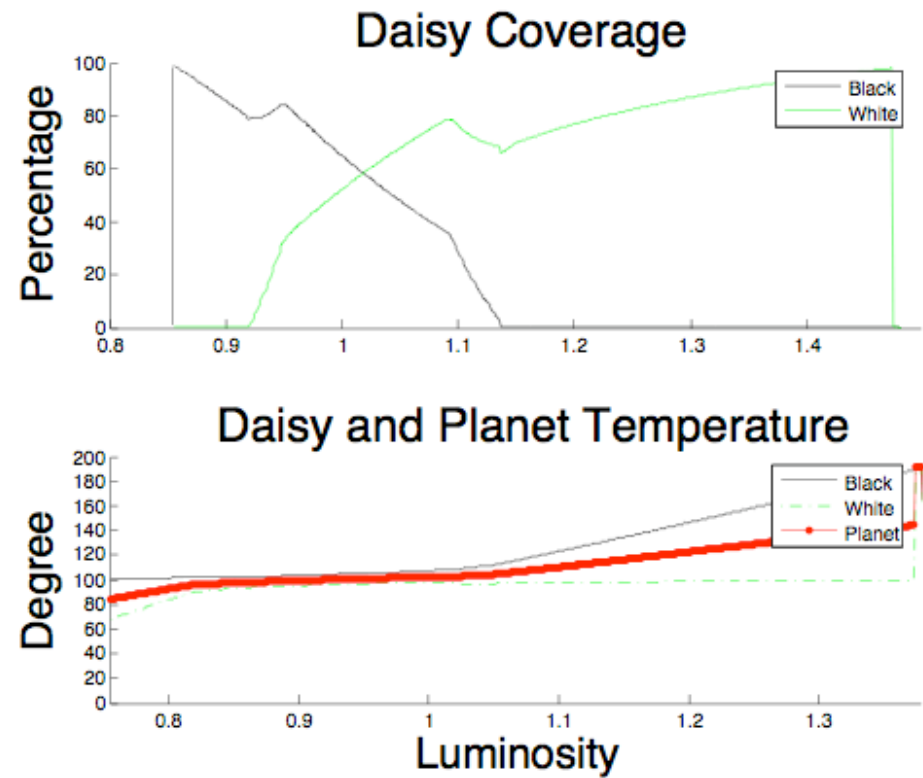
The Experiment

A decorative graphic consisting of six circles arranged in a horizontal line. The first circle is solid light blue. The second circle is hollow with a light blue outline. The third circle is solid light blue. The fourth circle is hollow with a light blue outline. The fifth circle is solid light blue. The sixth circle is solid light blue.

- Model proceeds as per 'normal' two-box Daisyworld but...
- ... for every insolation, diffusivity parameter adjusted to 'find' maximum rate of entropy production

Results

- Any-daisy and both-daisy range maximised
- Temperature maintained within preferred range over max range of solar forcings



Analysis

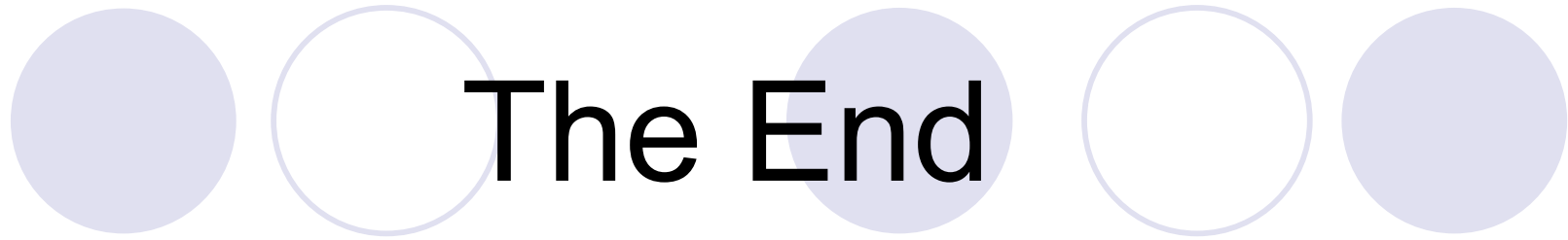


- Any-daisy range: daisies increase temperature difference so increase heat flow
- Both-daisy range: a bit more complex!
 - $dS = F(1/T_w - 1/T_b)$
 - Max heat flow at both-daisy, reduce D , reduces F but increases $(1/T_w - 1/T_b)$
- Recently produced analytic proof for MEPP at any and both-daisy ranges
- Previous work not presented proof for MEPP in Daisyworld



Related and Future Work

- Schneider & Kay: Life as a consequence of thermodynamics, thermodynamics of ecology
- Kauffman: co-constructing biospheres and natural laws
- MEPP 'cabal' Ackland, Lenton, Lorenz, Lovelock, Paltridge, Pujol
- Has MEPP cooled down? No! Need to think how to apply it
- MEPP discussion group?



Thank You!