Introduction to Earth System

Daisyworld & feedback mechanisms

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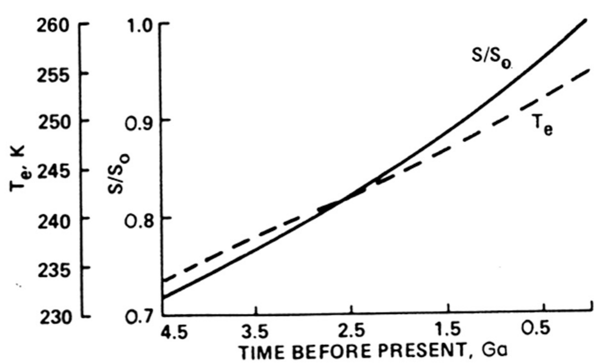
Question

- Why has the temp of the Earth's surface remained in a narrow range for the last 3.6 billion years when the heat of sun has increased by 25%?



EBM-0D → ? Temperature

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Faint Sun paradox

Solar Irradiance increases by 25 to 30% over 4.5 Gy. Forcing: 100 Wm^{-2}

What did happen?	What should have happened?
Water (liquid) and life existed ~ 4Ga	**Water frozen for ~2 Gy**
Low-latitude glaciation 750, 600, and 300 Ma	Earth → out of ice age conditions by 700 Ma
Earth appears to have cooled over past 60 My	Warm up of Earth over time

What else happened?

- GHG concentration
- Tectonics
- Milankovitch cycles
- etc.

Gaia Hypothesis

James Lovelock, 1970s

Biota co-evolves with their environment: **biota might optimize their abiotic environment by means of negative feedback**

Abiotic factors determine biological possibilities ⟷ Biotic factors feed back to control abiotic factors

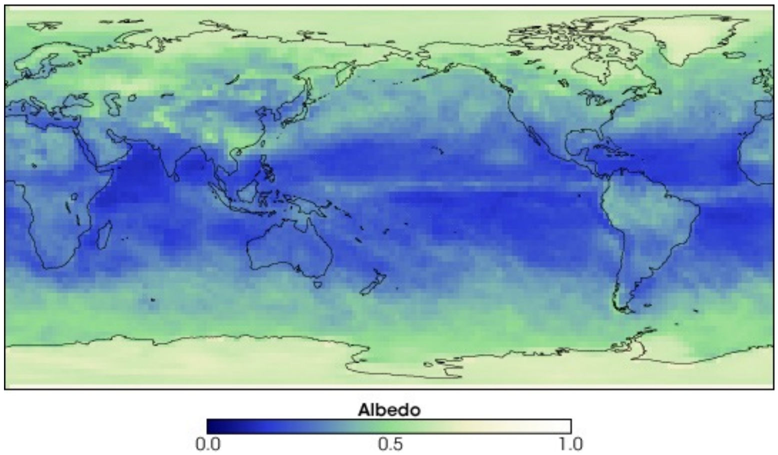
e.g. T increase → sparser vegetation, more desertification → increase albedo → reduce temperature (a negative feedback loop)

Earth can't be understood without considering the role of life

→ Daisy World model: a simple biospheric feedback model

Albedo

Earth's average albedo for March 2005



NASA image http://visibleearth.nasa.gov/view_rec.php?id=17177

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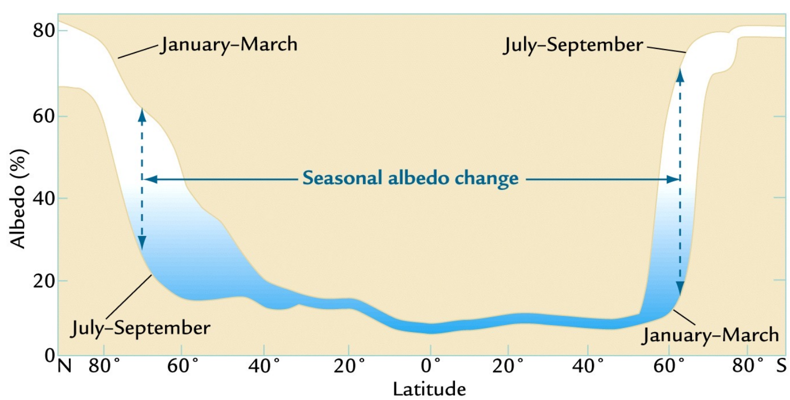
Albedo



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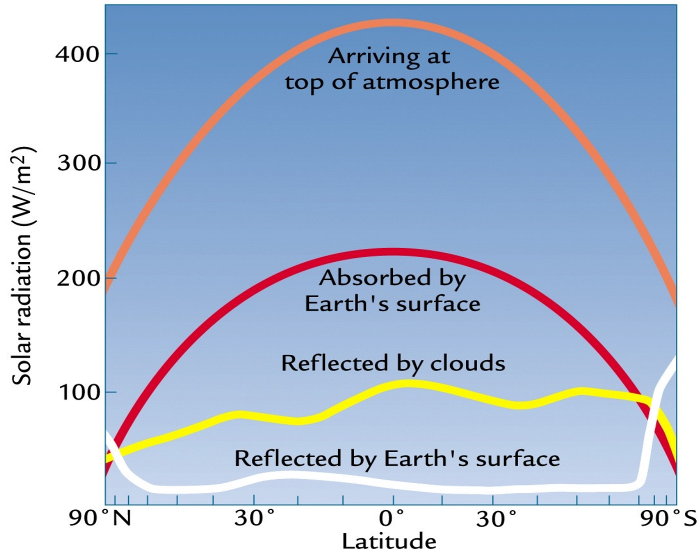

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Albedo values of different surfaces and clouds

Earth surface	(%)	Clouds	(%)
Oceans, Lakes	8	Shallow broken clouds Cu, Ci, Cs, Cc	30 35
Land Surfaces	14-18	St	40
Sand, Desert	27	Thick clouds (Cs)	74
Ice and Snow		Ac, As, Sc	68
Sea ice	35	Cu	75
Old snow	59	Ns	85
Fresh snow	80	Cb	90

Kishtawal (2003)

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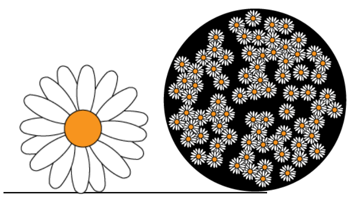
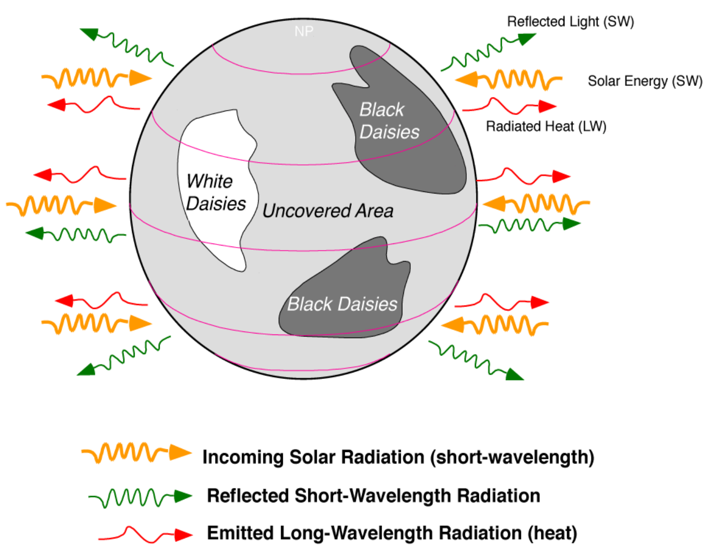
Daisy world

- Daisyworld is an imaginary planet: transparent atmosphere, free from clouds & greenhouse gases
- Flat planet → similar changes in temperature with changing solar luminosity; does not experience any seasonality in climate
- The planet's biota:
  - Black daisy → low albedo → absorb more energy → warming
  - White daisy → high albedo → reflect more energy → cooling
- Conditions on Daisy World are suitable for the growth of daisies over the entire surface of the planet

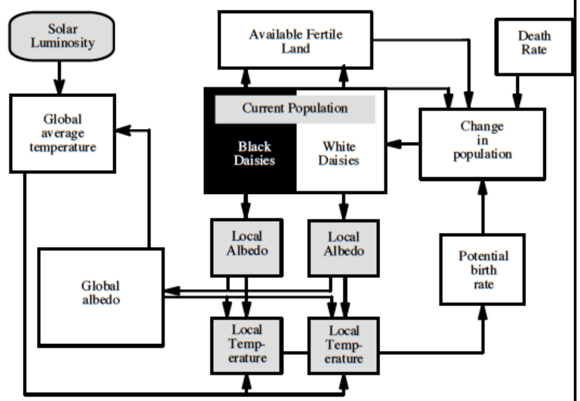


Daisy World – two species



Assumptions

1. The rate of population change → depends on the death rate and the potential birth rate for that species, and the amount of fertile land available for growth
2. The birth rate for both species of daisy depends on the local temperature
3. The local temperature depends on the difference between the global and local albedo, and on the global temperature
4. The global temperature depends on the luminosity of the Sun and the planetary albedo
5. The planetary albedo is the sum of the local albedo components
6. The amount of fertile land available for further growth of the daisies depends on the total amount of land and the current coverage of the two species of daisy



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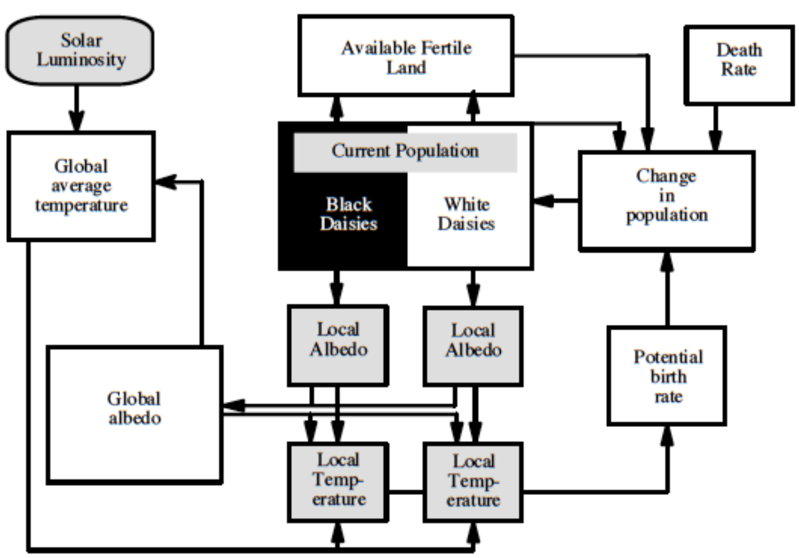
Daisyworld Model: Graphical representation



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Mathematical formulation

1. The amount of fertile land available for daisy growth:

$$x=1-w-b \qquad (1)$$

where: x is the amount of available land; w,b are areas of white & black daisies, respectively

2. The planetary albedo:

$$\alpha_p=w\alpha_w+b\alpha_b+x\alpha_g \quad (2)$$

where: α_w, α_b, α_g are the albedos of white daisy, black daisy & bare ground respectively

3. The planetary temperature:

$$T_e = \sqrt[4]{\frac{S(1-\alpha_p)}{4\varepsilon\sigma}} - 273.15 \qquad (3)$$

Mathematical formulation

4. The **local temperat**ure for populations of black & white daisies:

$$T_b=T_e+q(\alpha_p - \alpha_b) \qquad (4)$$

$$T_w=T_e+q(\alpha_p - \alpha_w) \qquad (5)$$

where: q is the constant used to calculate local temperature as a function of albedo

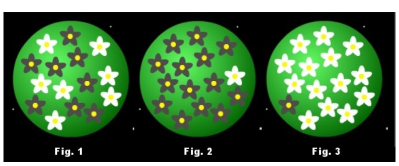


Fig. 1: Equal numbers of white and black daisies. Temperature is 'normal'.
Fig. 2: Mostly black daisies - temperature is consequently high.
Fig. 3: Mostly white daisies - temperature is low.

Mathematical formulation

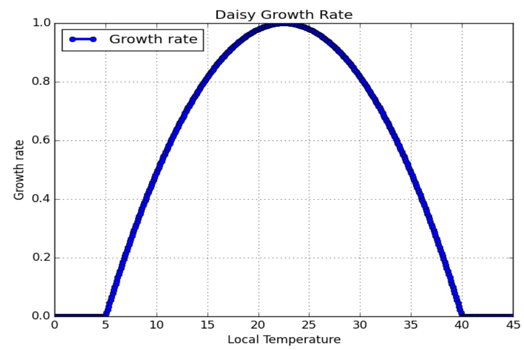
5. The **growth rate** of the populations of black and white daisies:

$$f_b = \max(0, 1 - k(T_0 - T_b)^2) \quad (6)$$

$$f_w = \max(0, 1 - k(T_0 - T_w)^2) \quad (7)$$

where: k and T_0 are constants so that growth occurs within a range of temperature and peaks at T_0.

k=0.003265; T_0=22.5 → growth occurs between 5-40ºC, peaks at 22.5ºC



Mathematical formulation

6. The change in area of black and white daisies over time:

$$db/dt = b(xf_b - d) \quad (8)$$

$$dw/dt = w(xf_w - d) \quad (9)$$

where: d is the death rate; t is time

7. The new area of black and white daisies :

$$b = b + db/dt \quad (10)$$

$$w = w + dw/dt \quad (11)$$

Model parameters

- S: 1000 W/m^{-2}
- ε=0.3*:* emissivity of the atmosphere
- σ=5.67 x 10^{-8}
- α_w=0.75, α_b=0.25, α_g=0.5
- q=20
- k=0.003265
- T_0=22.5ºC
- d=0.1
- At the initial stage → b=w=0.2

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Model outputs

- T_e: ºC, planetary temperature
- α_p: unitless, planetary albedo
- T_w, T_b: ºC, local temperature of white daisies and black daisies
- f_w,f_b: (inverse time) growth rate of white daisies & black daisies
- w,b,x: fraction of the planet's surface covered by white daisies, black daisies and bare ground

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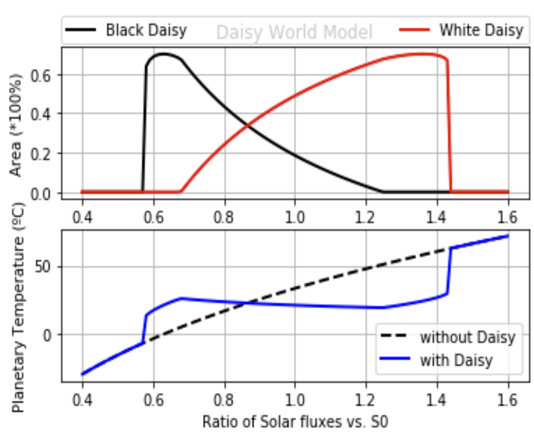
Algorithm

- The algorithm for Daisy World follows the logic of the model equations (1) to (11) above.
- After Eq(11), need to return to step 1, i.e. Eq(1) and repeat until the system reaches **equilibrium** (i.e. model's variables are almost unchanged)

Results



- When planet is cold, any white daisies are cooler than surrounds, hinder their own growth. Any black ones absorb the sunlight, warm up their surrounds, and enhance their growth. In doing so they warm up the whole planet.
- When planet is hot, the reverse happens, and white daisies dominate.

- The daisies, only with their albedo and birthrate, maintain the living planet's temperature at a daisy-friendly 20-30 degrees when the solar input varies

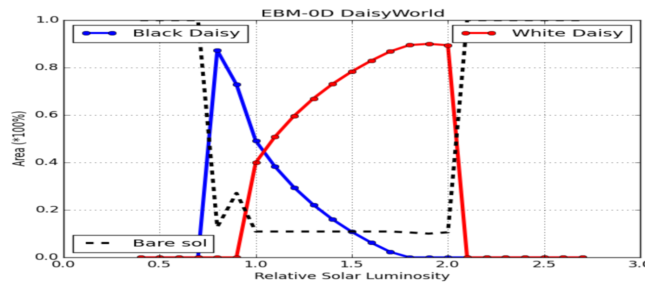
Different initial conditions making different results

- For each incoming solar flux, initial area of black and white daisy area started from a same value (e.g. 0.1)

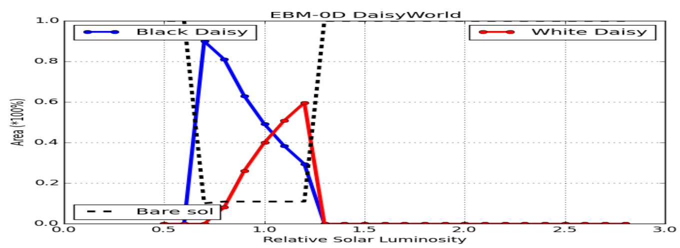
Different initial conditions making different results

- For a given incoming solar flux, the equilibrium area of black and white daisies have been calculated
- Then the incoming solar flux varies, the daisy system needs to adjust to the new change
- Results will be different for the two cases:
  - Increasing solar flux (from low to high values)
  - Decreasing solar flux (from high to low values)

Different initial conditions making different results



S increase --------→



S decrease <--------

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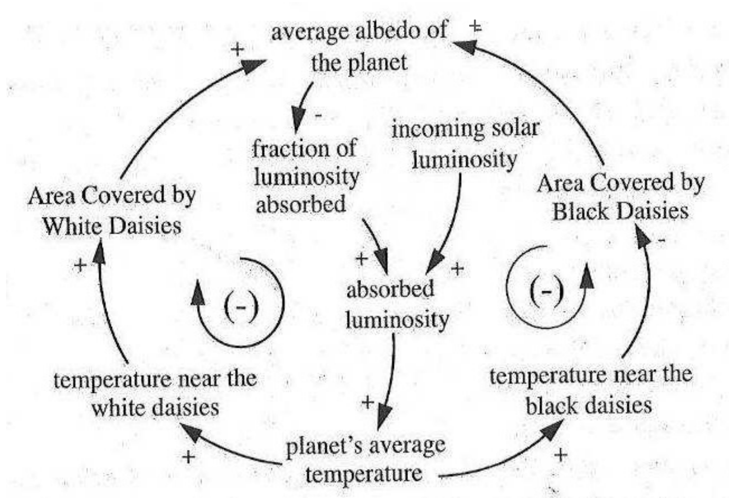
Daisyworld as a feedback system



source: Andrew Ford

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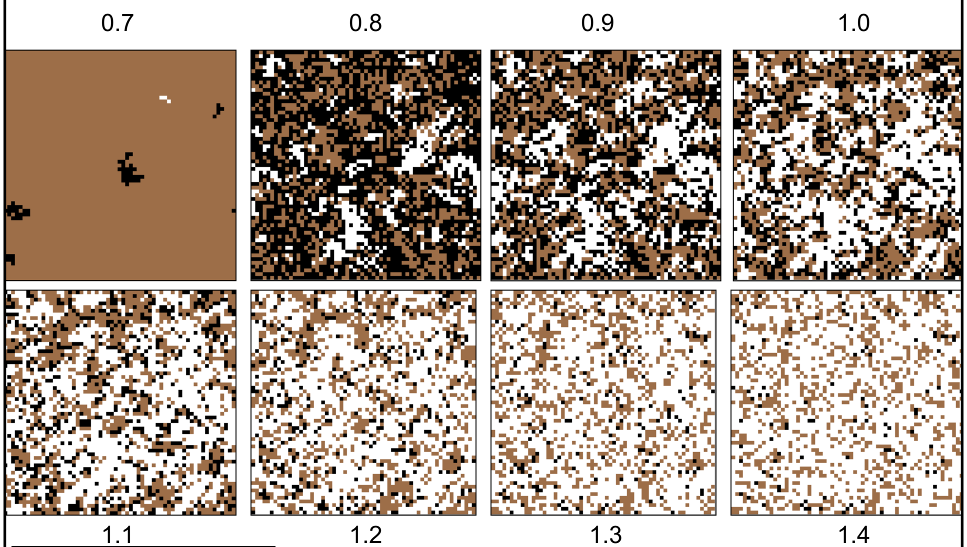
Effects of Solar Luminosity on 2D Daisyworld

Phillipa Sessini (Toronto)



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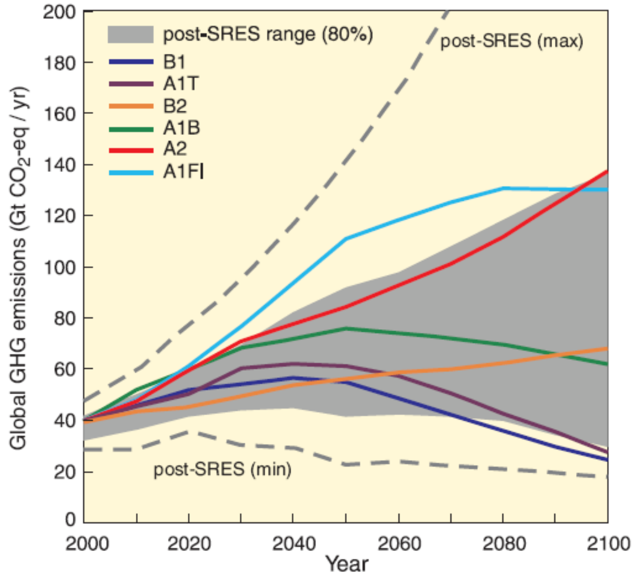
More to think/ and do

- Effects of Solar Luminosity on Daisyworld with two species
- Effects of death rate on Daisyworld
- Your simulations?
- Daisyworld with 4 species of Daisies

CO_2 Increase: can GAIA save the earth?



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Practice#4: Daisy World

Write a program to represent the Daisy World with two species: black and white.

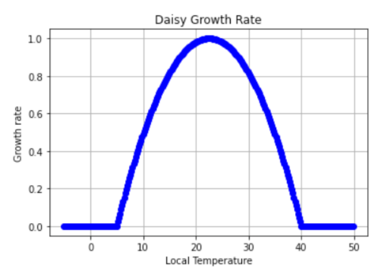
1.Plot the growth rate function f_b & f_w versus temperature

f_b=max(0,1-k $(T_0 – T_b)^2$)

f_w=max(0,1-k $(T_0 – T_w)^2$)

k=0.003265

T_0=22.5ºC



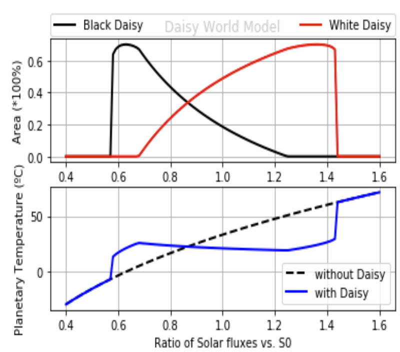
2.S=S_0=1000; at the initial stage b=w=0.2. Find the equilibrium b and w values

3. S/S_0 varies from 0.4 to 1.6

   3.1. Plot the equilibrium daisy black/white area versus S/S_0.

   3.2. Plot the planetary temperature versus S/S_0.

4. Suppose that the Daisy world has only one specie, black daisy. How does the behavior of the system change?



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