Environmental Modelling

Daisyworld: A Simple Biospheric Feedback Model

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Introduction

- *Daisy World* model intended to illustrate possible mechanism through which — according to the Gaian hypothesis — biota (specifically plants) might optimize their abiotic (specifically climatic) environment by means of negative feedback
- Model does not attempt to describe all the possible mechanisms and feedbacks between plants and climate
- It is an *heuristic* model — one that seeks to describe ways in which these mechanisms *might* work

Introduction

- Original model developed by Watson and Lovelock (1983)
- Subsequently extended and adapted by Lovelock and others
- Heated debate about the general validity of the model (teleological)
- Nevertheless, shows what can be achieved using a comparatively simple model

Objectives

- To test the hypothesis that ‘there exist mechanisms through which biota can influence the planetary environment’
- To implement and test a mathematical model describing the possible influences of biota on an abiotic (climatic) system

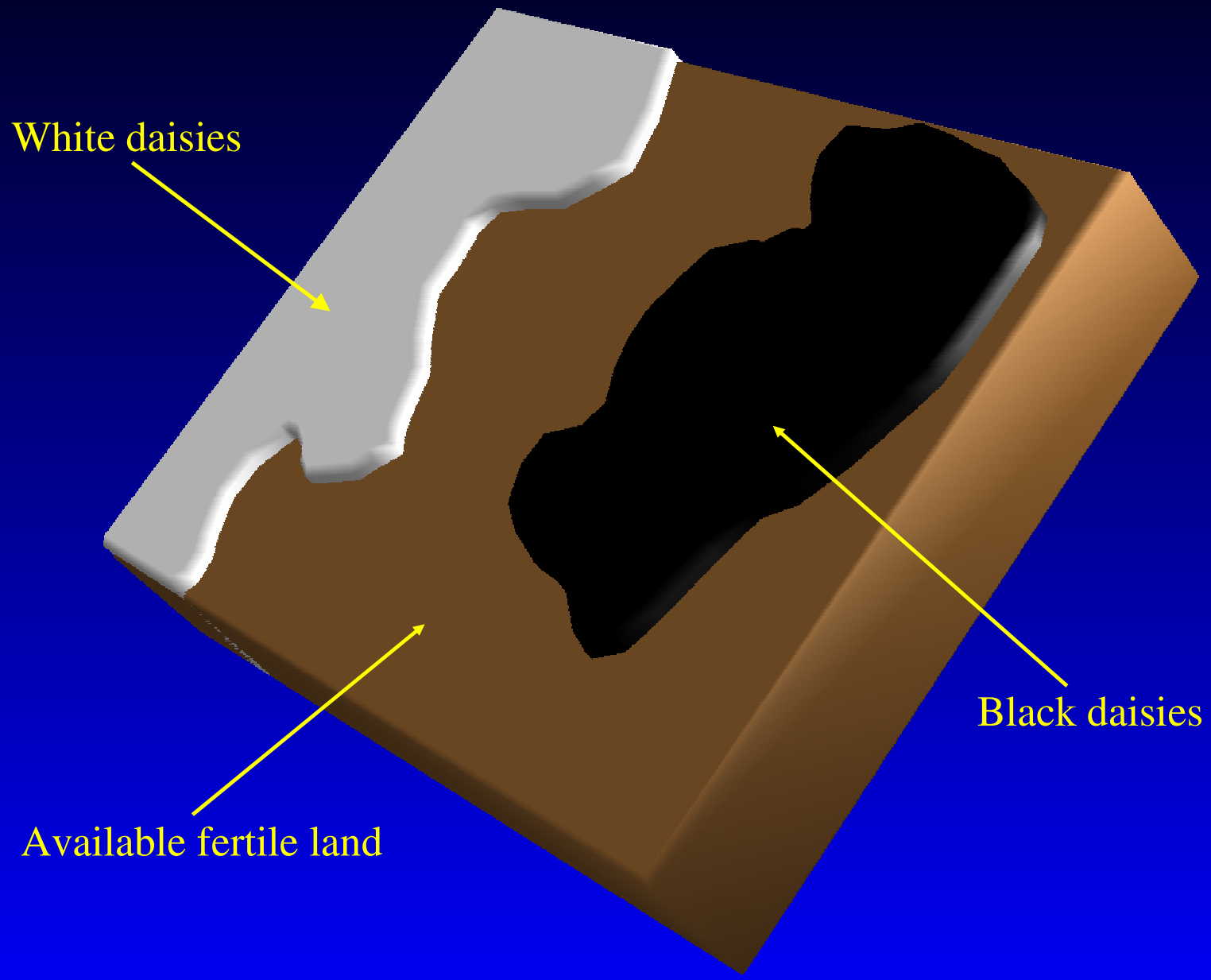
Daisyworld: Description

- Imaginary planet illuminated by an imaginary sun
- Transparent atmosphere, free from clouds and greenhouse gases
- Flat — no latitudinal, longitudinal or topographic effects:
  - No seasonality in climate
  - Changes in surface temperature solely result of changing solar luminosity (energy from the sun) and surface albedo
- Only two species of biota:
  - Black daisies — dark in colour, lower albedo than soil substrate
  - White daisies — light in colour, higher albedo than soil substrate

Daisyworld: Description

- Species of herbivore:
  - Graze daisies in a non-selective manner (i.e. no preference for black or white daisy)
  - Recycles organic material
  - Exert no other measurable effect on the system
- Conditions suitable for growth of daisies over the entire surface of the planet

Daisyworld: Visualization



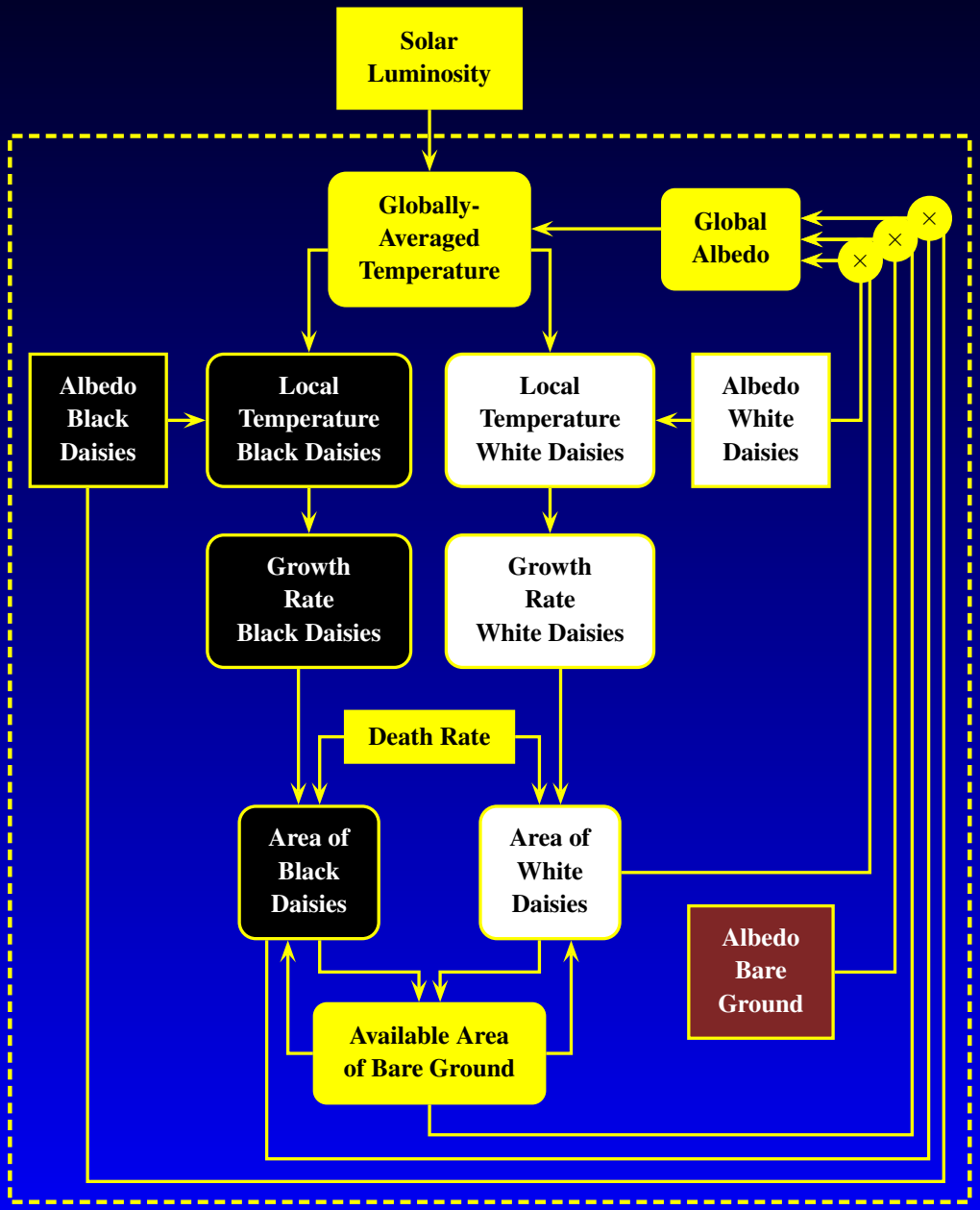
Assumptions

- Rate of population growth/decline for each species of daisy depends on
  - Death rate for that species
  - Potential birth rate for that species,
  - Amount of fertile land available for daisy growth
- Birth rate for each species of daisy depends on the local surface temperature
- Local surface temperature depends on
  - Difference between global and local albedo
  - Global temperature

Assumptions

- Global tempearature depends on
  - Luminosity (brightness) of the sun
  - Planetary albedo
- Planetary albedo is the sum of the albedo of the black and white daisies, and of bare ground, weighted by their relative areas
- Amount of fertile land available for further growth of black and white daisies depends on
  - Total amount of fertile land (fixed)
  - Current coverage of the two species of daisy

Graphical Representation



Daisyworld: Formulation

- Amount of land available for daisy growth:

$$x = P - (a_b + a_w) \tag{1}$$

where

x proportion of land available for further growth

P proportion of land suitable for the growth of daisies (default $P = 1.0$)

a_b proportion of land currently occupied by black daisies ($a_b = 0.2$ initially)

a_w proportion of land currently occupied by white daisies ($a_w = 0.2$ initially)

Example GAWK Code

```
1  BEGIN{
2
3      #  Initialize  variables
4
5      P=1.0;
6      areaBlack=0.2;
7      areaWhite=0.2;
8
9      # Calculate area of land available for further daisy growth
10
11     availLand=P-(areaBlack + areaWhite);
12 }
```

$$x = P - (a_b + a_w) \tag{1}$$

Daisyworld: Formulation

- Total (average) albedo for Daisyworld:

$$A = x(A_g) + a_b(A_b) + a_w(A_w) \tag{2}$$

where

A albedo of Daisyworld

A_g albedo of bare ground (default $A_g = 0.5$)

A_b albedo of black daisies (default $A_b = 0.25$)

A_w albedo of white daisies (default $A_w = 0.75$)

Example GAWK Code

```
1  BEGIN{
2
3      # Initialize variables
4      P=1.0;
5      areaBlack=0.2;
6      areaWhite=0.2;
7      albedoGround=0.5;
8      albedoBlack=0.25;
9      albedoWhite=0.75;
10
11     # Calculate area of land available for further daisy growth
12     availLand=P-(areaBlack + areaWhite);
13
14     # Calculate total planetary albedo
15     albedoTotal=(availLand*albedoGround)+(areaBlack*albedoBlack) + \
16             (areaWhite*albedoWhite);
17 }
```

$$A = x(A_g) + a_b(A_b) + a_w(A_w) \tag{2}$$

Daisyworld: Formulation

- Globally-averaged temperature of Daisyworld:

$$T_e = \left(\frac{SL(1-A)}{s} \right)^{0.25} - 273 \qquad (3)$$

where

T_e globally-averaged temperature of Daisyworld

S solar constant (the amount of energy from the sun reaching Daisyworld; default $S = 1000$)

L solar luminosity (expressed as the proportion of the present-day value; 0.7 initially, but increasing in steps of 0.025 as a function of time)

s Stefan's constant (5.67×10^{-8})

Daisyworld: Formulation

- Local temperatures for populations of black and white daisies:

$$T_b = (q(A - A_b) + T_e) \tag{4a}$$

$$T_w = (q(A - A_w) + T_e) \tag{4b}$$

where

T_b local temperature of black daisies

T_w local temperature of white daisies

q constant used to calculate local temperature as a function of albedo (default $q = 20$)

Daisyworld: Formulation

- Growth rate of the populations of black and white daisies:

$$B_b = \left\{1 - \left[0.003265\,(22.5 - T_b)^2\right]\right\} \tag{5a}$$

$$B_w = \left\{1 - \left[0.003265\,(22.5 - T_w)^2\right]\right\} \tag{5b}$$

where

B_b	growth rate for black daisies
B_w	growth rate for white daisies
1	constants such that growth occurs
0.003265	between $5°C$ and $40°C$
22.5	and peaks at $22°C$

Daisyworld: Formulation

- Change in area of black and white daisies over time:

$$\frac{da_b}{dt} = (a_b(xB_b - y)) \tag{6a}$$

$$\frac{da_w}{dt} = (a_w(xB_w - y)) \tag{6b}$$

where

da_b is the change in area of black daisies [a]

da_w is the change in area of white daisies

y is the death rate (default $y = 0.2$)

t is time

[a] Recall that $\frac{da_b}{dt}$ means 'the change in area of black daisies with respect to time' (dt), **not** divide the change in area of daisies by the change in time.

Daisyworld: Formulation

- The new area of black and white daisies:

$$a'_b = \left(\frac{da_b}{dt} + a_b \right) \tag{7a}$$

$$a'_w = \left(\frac{da_w}{dt} + a_w \right) \tag{7a}$$

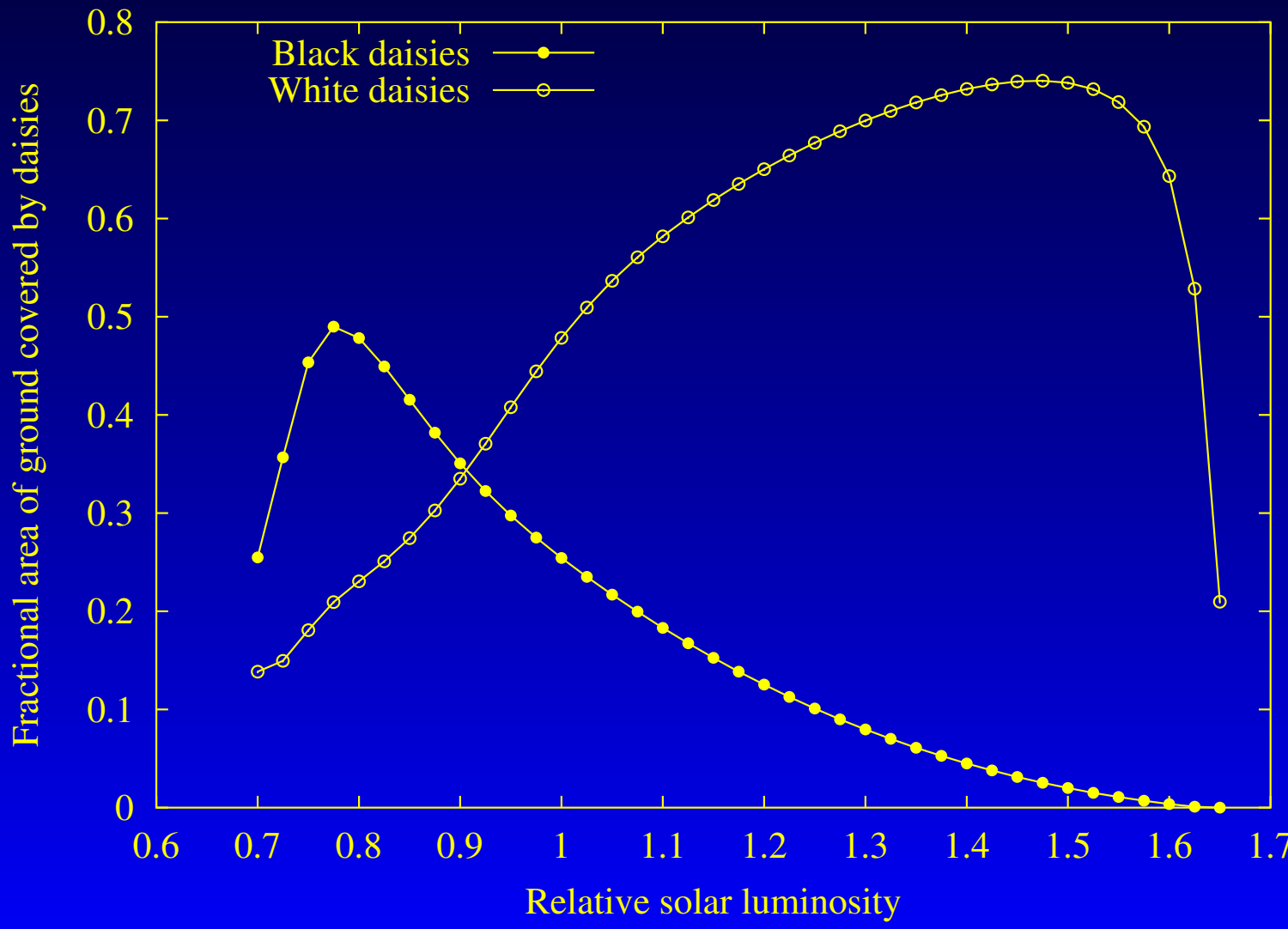
where

a'_b is the new area of black daisies

a'_w is the new area of white daisies

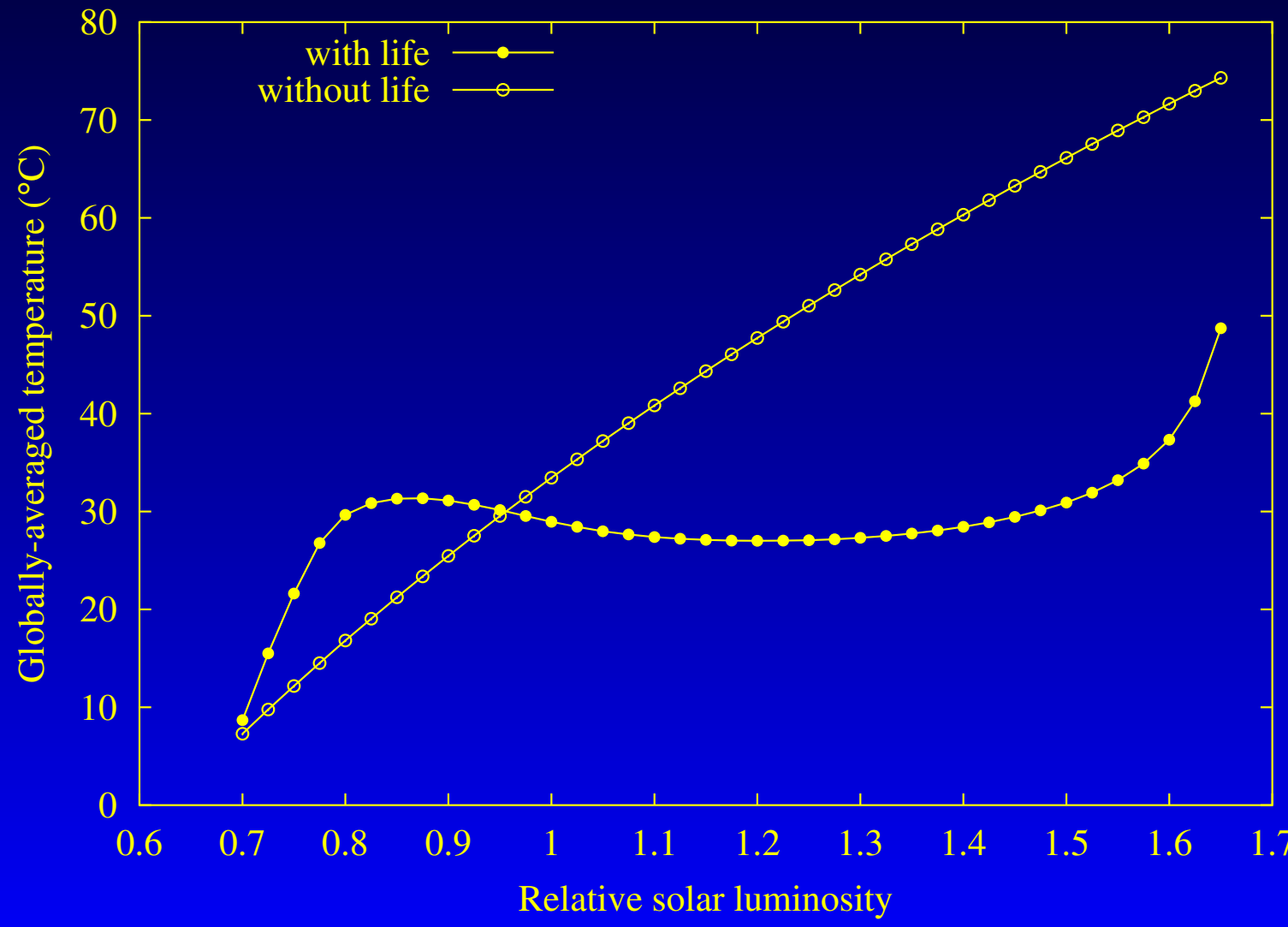
Daisyworld: Evaluation

- Variation in the area of black and white daisy as a function of solar luminosity



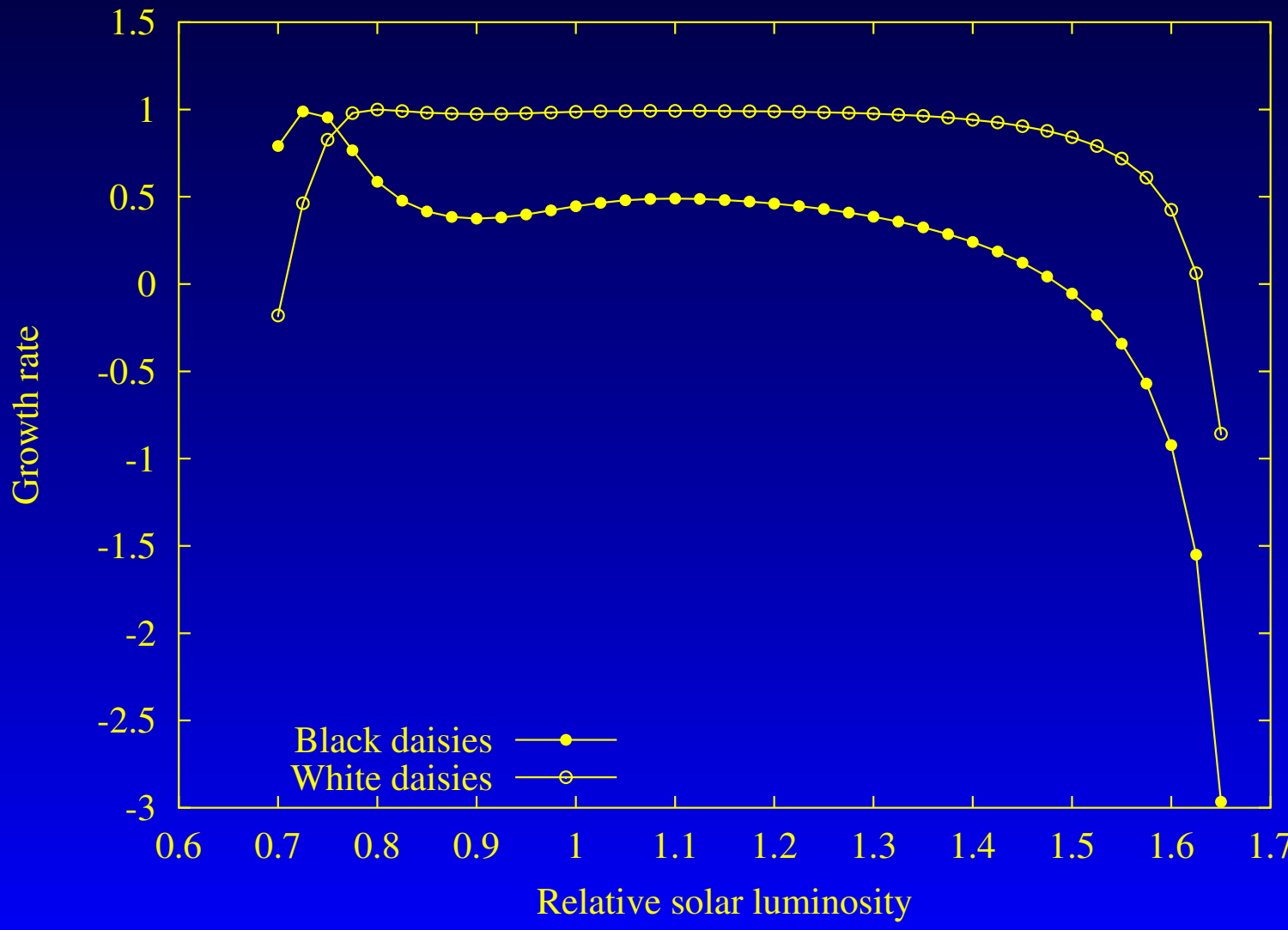
Daisyworld: Evaluation

- Variation in globally-averaged surface temperature as a function of solar luminosity



Daisyworld: Evaluation

- Variation in growth rate of black and white daisies as a function of solar luminosity



Daisyworld: Evaluation

- Variation in local surface temperature over black and white daisies as a function of solar luminosity