Daisy world mini-project

The goal of this project to gain understanding in how a simulation works and to start getting familiar with programming. The Daisyworld model was used by Watson and Lovelock to exemplify how the biosphere could foster 'homeostasis' (or equilibrium) within the Earth's climate following the Gaia hypothesis. While we are not interested in the original idea in the Gaya hypothesis, suggesting that the biosphere behaves like a single super-organism aiming -intentionally- at obtaining a self- regulatory effect on the Earth's environment. We recognize that the Daisyworld model is a nice example illustrating the potential role of the biosphere in controlling/ modifying local and global climate.

With the following equation you can write a code which is able to find the equilibrium temperature of the hypothetical planet exposed to a certain amount of solar radiation. The equilibrium temperature will depend and the planets albedo, which will change due to the birth and death of black and/or white daisies.

Goal: find the equilibrium temperature for a range of radiations ($St \cdot L$).

Daisy world equations:

$$T_{planet} = \left(\frac{St \ \cdot L\left(1-\alpha_{planet}\right)}{\sigma}\right)^{\frac{1}{4}},$$

where, L [-] is luminosity, St is the solar constant [Wm^{-2}], σ is Stefan-Boltzmann constant ($5.67 \cdot 10^{-8}$ Wm^{-2}K^{-4}). α_{planet} is the albedo of the Daisy World, defined as,

$$\alpha_{planet} = A_g \cdot \alpha_g + A_b \cdot \alpha_b + A_w \cdot \alpha_w,$$

where, area and α stand for the area in [m^{-2}] and the albedo [-]. The subscripts *(g, b and w)* denote *(barren) ground, black daisies and white daisies*, respectively. The area barren ground (A_g) is defined as,

$$A_g = A_{planet} - (A_b + A_w).$$

For simplification, the total area of the planet (A_{planet}) is set to 1 m^{-2}, such that the 3 types of area's (barren, white daisies, black daisies), also match the ratio of the planet. For example, if $A_w = 0.25$, then 0.25 m^{-2} (and 25%) of the planet is covered with white daisies. The change in area of daisies is determined by the birth and death-rate, where we keep the death rate constant. The birthrate is depended on the local temperature,

$$T_w = q * \left(\alpha_{planet} - \alpha_w\right) + T_{planet},$$

where, T_w [K] is the white daisy local temperature, q [K] is the horizontal insulation, which is a measure of the heat advected across the white daisy area.

$$T_b = q * (\alpha_{planet} - \alpha_b) + T_{planet},$$

where, T_b [K] is the black daisy local temperature. As said, the birth rate of daisies depends on the *state* variable (i.e. non-constant variables) temperature,

$$B_w = 1 - \left(R_{growth} * (T_{opt} - T_w)^2\right),$$

where, B_w is the birth rate in [$m^{-2}t^{-1}$], R_{growth} [$m^{-2}T^{-1}t^{-1}$] is the growth rate parameter, T_{opt} [K] is the optimal growing temperature of the daisies. This birth rate is plugged into the equation for the change in area of white/black daisies [m^2t^{-1}], below given for the white daisies.

$$\frac{dA_w}{dt} = A_w(A_g \cdot B_w - D_w),$$

where, D_w is the death rate [t^{-1}]. The change in are is simply given by the simple forward Euler integration, i.e. $y_{t+1} = y_t + \frac{df}{dt} \cdot dt$. In our equation, setting the time step (*dt)* at 1 is sufficient to get stable results. Thus, the area after one time step is given by,

$$A_{w(t+1)} = A_{w(t)} + \frac{dA_w}{dt} \cdot dt.$$

We now have all the formulae's to perform the simulation. If the updated area ($A_{w(t+1)}$) is different from $A_{w(t)}$, it will alter the albedo of the planet (α_{planet}) and will lead to a different temperature (T_{planet}).

Default settings

Initializing

Define initial black/white daisy areas, e.g. 0.1 m^2 for both.

Default parameters

Global parameters

$A_{planet} = 1$ [m^2]

St = 1000 [Wm^{-2}]

- α_g = 0.5 [-]

σ = $5.67 \cdot 10^{-8}$ $Wm^{-2}K^{-4}$

Luminosiy range = np.arange(0.5, 1.7, 0.002) [-] (Python syntax)

Daisy parameters

$q = 20$ [K]

$D_w = D_b = 0.2$ [t^{-1}]

$\alpha_w = 0.75$ [-]

$\alpha_b = 0.25$ [-]

$T_{opt} = 22.5 + 273.15$ [K]

$R_{growth} = 0.003265$ [$m^{-2}T^{-1}t^{-1}$]

Code Reproducibility

To answer the following questions, I want you to have a code which is **reproducible**. I would like to be able to open your notebooks and generate all output is needed to answer the questions listed below. We will change some parameter settings, and re-run the code. In order to re-use the code, we will create a function.

To learn about functions, please go through the *definitions_and_classes* notebook on https://github.com/VU-IVM/Learning_Python.

I want you to create a function which has all the default parameter defined, also make functions for the two plots. Perhaps you would like to make nicer plots, e.g. see link. After this function is working, we can easily adapt one of the parameters (and keep all the others default) for a certain question. This way, you should be able to generate output for each question without have a very long script where the code is copied again and again. Please make the Notebook clear, you can write text with Markdown syntax by using the dropdown window and select Markdown (instead of code).

Some example Markdown syntax:
this is a header
Subheaders:
this is a subheader
this text is italic
__this text is bold__

Daisy World questions:

1. In the code, I commented (using '#') the area of black and white daisies after *'# initializing start values of daisies'*. Plot the results when we re-initialize the area of daisies (uncomment) and comment it. Can you explain the difference, which one do you think is a more realistic simulation?
2. Change albedo of white and black daisies. And how does results depend on the ground albedo?
3. What happens if white and black daisies don't have the same optimal temperature?
4. Can you show hysteresis happening in this system?

   Perhaps you need to have a look at the slides again for the following questions.

5. What other processes could be implemented to make the model more realistic?
6. What are other physical/biophysical real-world processes that can lead to significant feedbacks at the local and global scale?
7. Can you think of other types of feedbacks leading to a stabilization of the Earth's local or global climate (homeostasis)?

Hand in

Please document these results clearly, and provide detailed explanations of what you see, and how you can explain the results. You will have to hand in a working and neat code and the document (one hand in for each team).