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Pattern formation through spatial interactions in a modified Daisyworld model

Tommaso Alberti (1), Leonardo Primavera (1), Fabio Lepreti (1,2), Antonio Vecchio (3,1), Vincenzo Carbone (1,4)

(1) University of Calabria, Department of Physics, Arcavacata di Rende (CS), Italy (tommasoalberti89@gmail.com), (2) CNISM Unità di Cosenza, Ponte P. Bucci 31C, 87036 Rende (CS), Italy, (3) INGV Istituto Nazionale di Geofisica e Vulcanologia, Sede di Cosenza, Rende (CS), Italy, (4) ISAC/CNR Lamezia Terme (CZ), Italy

The Daisyworld model is based on a hypothetical planet, like the Earth, which receives the radiant energy coming from a Sun-like star, and populated by two kinds of identical plants differing by their colour: white daisies reflecting light and black daisies absorbing light. The interactions and feedbacks between the collective biota of the planet and the incoming radiation form a self-regulating system where the conditions for life are maintained. We investigate a modified version of the Daisyworld model where a spatial dependency on latitude is introduced, and both a variable heat diffusivity along latitude and a simple greenhouse model are included. We show that the spatial interactions between the variables of the system can generate some equilibrium patterns which can locally stabilize the coexistence of the two vegetation types. The feedback on albedo is able to generate new equilibrium solutions which can efficiently self-regulate the planet climate, even for values of the solar luminosity relatively far from the current Earth conditions. The extension to spatial Daisyworld gives room to the possibility of inhomogeneous solar forcing in a curved planet, with explicit differences between poles and equator and the direct use of the heat diffusion equation. As a first approach, to describe a spherical planet, we consider the temperature $T(\theta, t)$ and the surface coverage as depending only on time and on latitude θ ($-90^\circ \leq \theta \leq 90^\circ$). A second step is the introduction of the greenhouse effect in the model, the process by which outgoing infrared radiation is partly screened by greenhouse gases. This effect can be described by relaxing the black-body radiation hypothesis and by introducing a grayness function $g(T)$ in the heat equation. As a third step, we consider a latitude dependence of the Earth's conductivity, $\chi = \chi(\theta)$. Considering these terms, using spherical coordinates and symmetry with respect to θ, the modified Daisyworld equations reduce to the following set of equations

$$\frac{\partial \alpha_w}{\partial t} = \alpha_w \left[(1 - \alpha_w - \alpha_b)\beta(T) - \gamma\right] \tag{1}$$

$$\frac{\partial \alpha_b}{\partial t} = \alpha_b \left[(1 - \alpha_w - \alpha_b)\beta(T) - \gamma\right] \tag{2}$$

$$\frac{\partial T}{\partial t} = \frac{1}{\rho c_p}\left[1 - A(\theta, t)\right] R(\theta) - \frac{\sigma}{\rho c_p} g(T) T^4 + \frac{1}{r_E^2 \cos\theta} \frac{\partial}{\partial \theta}\left[\kappa(\theta) \cos\theta \frac{\partial T}{\partial \theta}\right] \tag{3}$$

where $\alpha_{w,b}$ are the daisy coverages of each species, $\beta(T)$ and γ are the growth rate and the death rate per unit of time of daisies respectively, $A(\theta, t)$ is the albedo of the Earth, $R(\theta)$ describes the incident radiation, ρ is mass density of the atmosphere, c_P is the heat capacity, $\kappa = \chi/\rho c_P$, $r_E \simeq 6.37 \times 10^8$ cm is the Earth's radius and in which we use the expression of the Laplace operator in spherical coordinates. We found that, at variance with previous results, the system is able to self-regulate even in presence of values of the incident luminosity which are far from the current Sun-Earth conditions. In particular, the mutual exclusion of the two vegetation types, observed in previous models, is never observed in our case. Of course the model can be further enriched by considering, for example, more realistic conditions, e.g. the dependence of c_p and κ on temperature, more realistic greenhouse effect and different initial conditions of daisies, which are currently under investigation.