Daisyworld Dynamics and Resilience

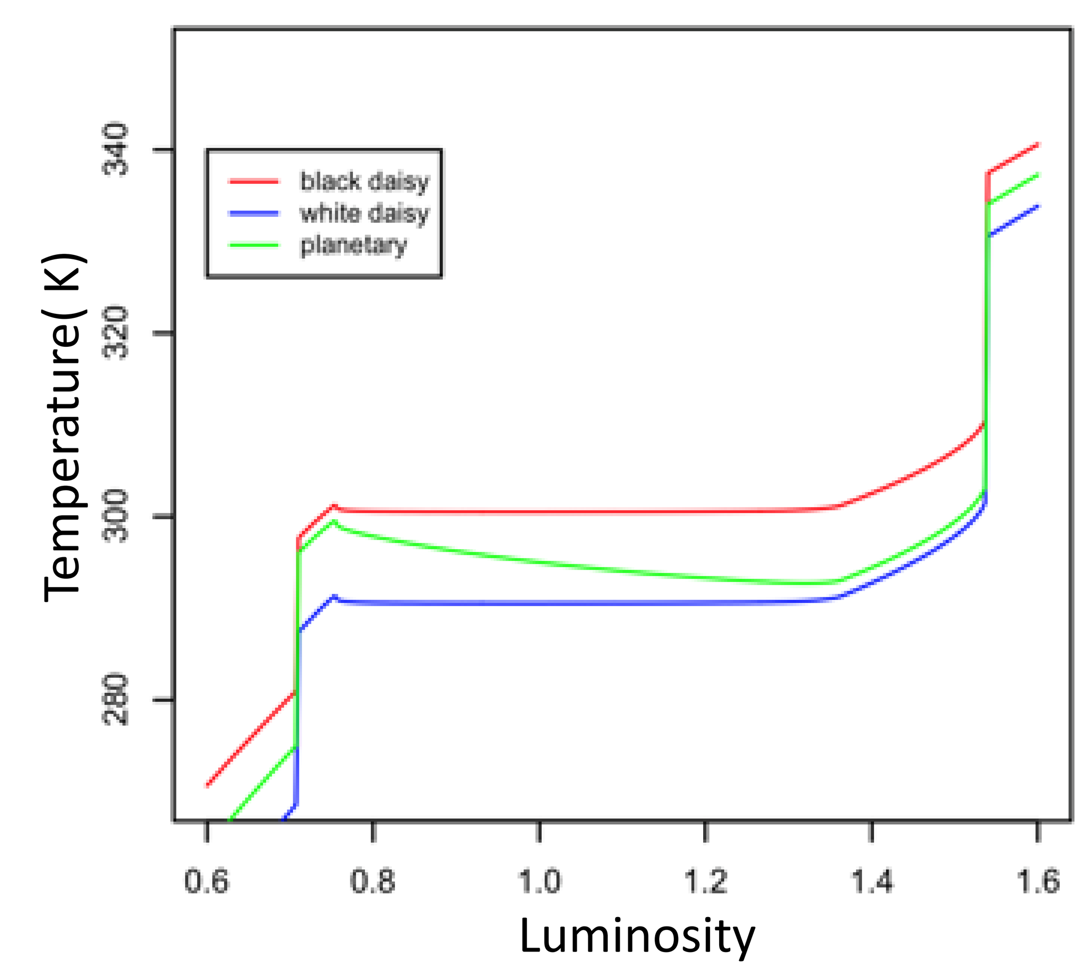
Studying Complex Ecosystem Stability as Rein Control Far from Equilibrium

Nan Ding, Bowdoin College, nding@Bowdoin.edu

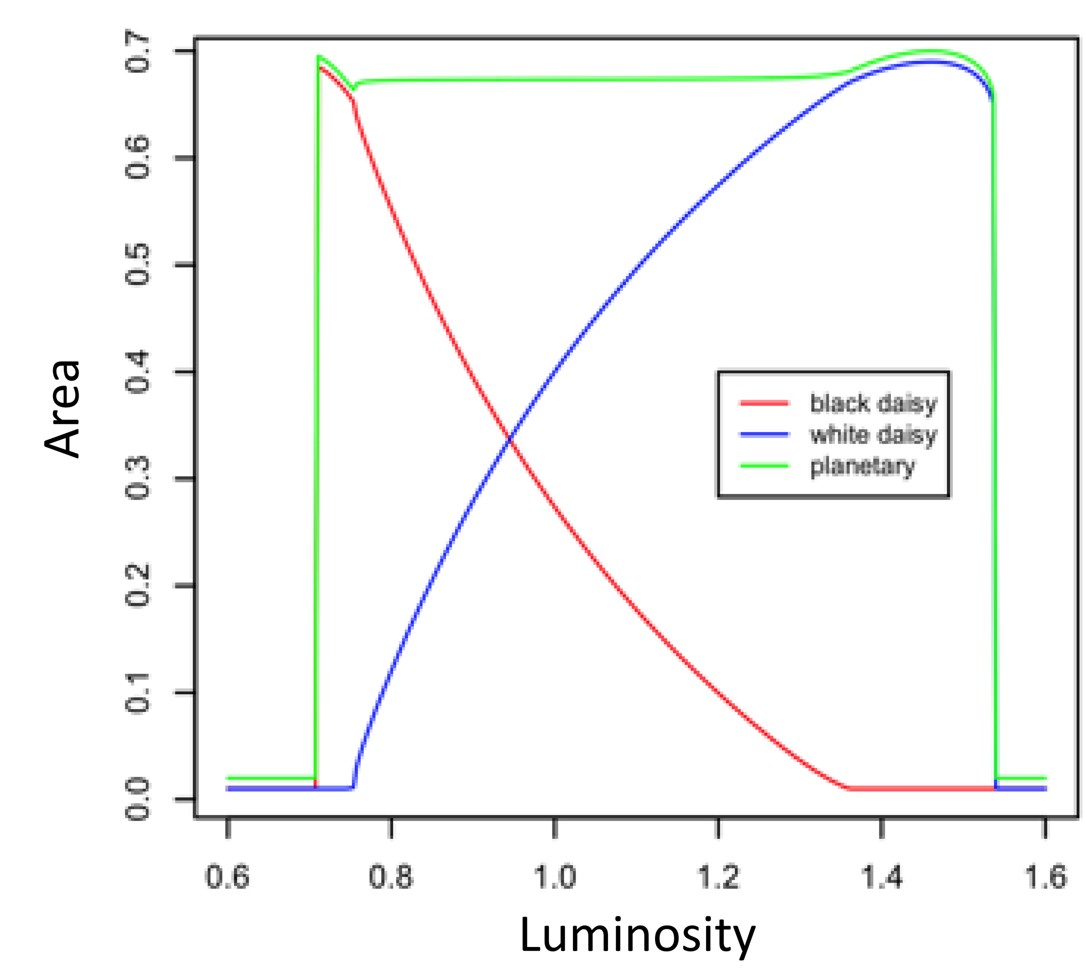
Introduction

Daisyworld is a simplified model of planetary climate that captures the dynamics of homeostasis between a system of biotic components and their environment. The original form, introduced by James Lovelock, characterizes a simple planetary system in which the environment is reduced to temperature, and the only species being black and white daisies. The growth rates of the daisies are solely determined by the local temperatures, which are dependent on the planetary temperature through heat transmission. The planetary temperature is dependent on surface albedo, which, in turn, are affected by the areas of black and white daisies. This simple model of coupled biota and environment displays a rein control system with a stable regime of planetary temperature and area covered by daisies. Although this model has been applied to various biological and ecological problems, the homeostasis of the original abstract model has not been studied sufficiently. This research project is concerned with arriving at a more sophisticated understanding of the original model and generalizing it beyond its original specific ecological setting.

Temperature Change Plot



Area Change Plot



Research Goals & Questions

We investigated the rich structure of the system by asking the following questions:

- What conditions give rise to homeostasis of the Daisyworld
- How to reasonably generalize the original set of equations without losing the properties (i.e., the rein control behavior)
- How would the behavior of the system change under different parameter values
- Can we reproduce a Daisyworld-like system without explicitly using the equations of the original model

The System

The black and white daisy abundance change dependent on the growth rate functions:

$$\frac{d\alpha_b}{dt} = \alpha_b(\alpha_g \beta(T_b) - \gamma)$$

$$\frac{d\alpha_w}{dt} = \alpha_w(\alpha_g \beta(T_w) - \gamma)$$

Local Temperatures and dependent on planetary albedo *A* and global temperature *T*:

$$T_w^4 = q(A - a_w) + T^4$$

$$T_b^4 = q(A - a_b) + T^4.$$

T is given by the Stefan-Boltzman equation:

$$SL(1 - A) = \sigma T^4$$

Results & Discussion

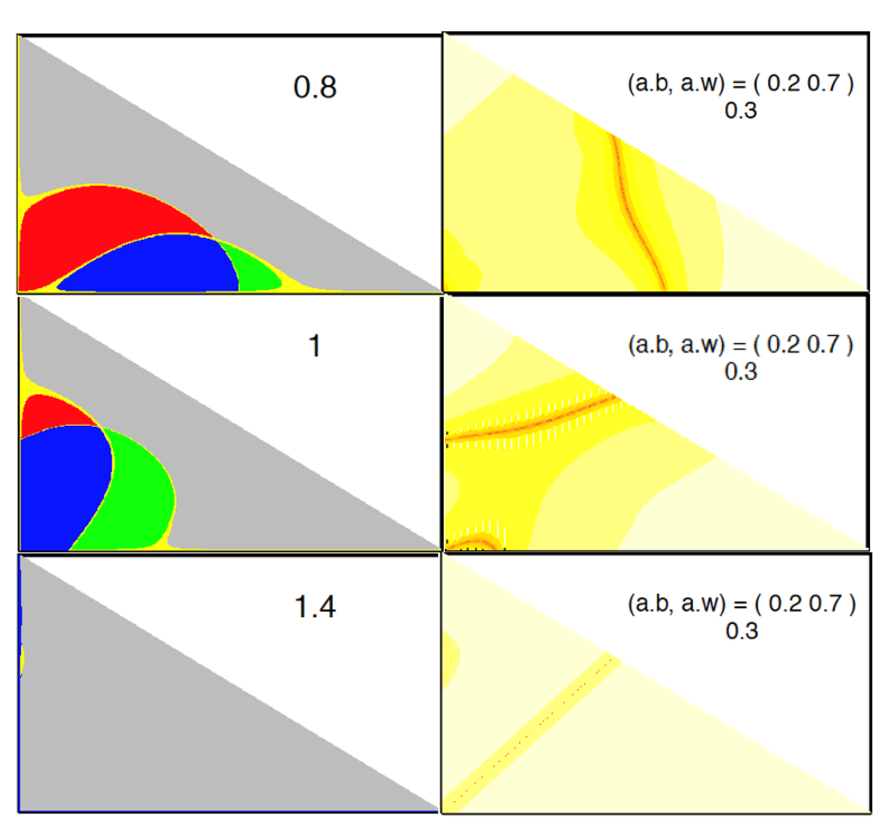
The analytical solutions to the local temperatures are found to be dependent on the areas of black and white daisies:

$$T_b = (\alpha_w - \alpha_b)\left[q^{[\ell]} - 2T_I\right]B + q^{[\ell]}B + T_I$$

$$T_w = (\alpha_w - \alpha_b)\left[q^{[\ell]} - 2T_I\right]B - q^{[\ell]}B + T_I.$$

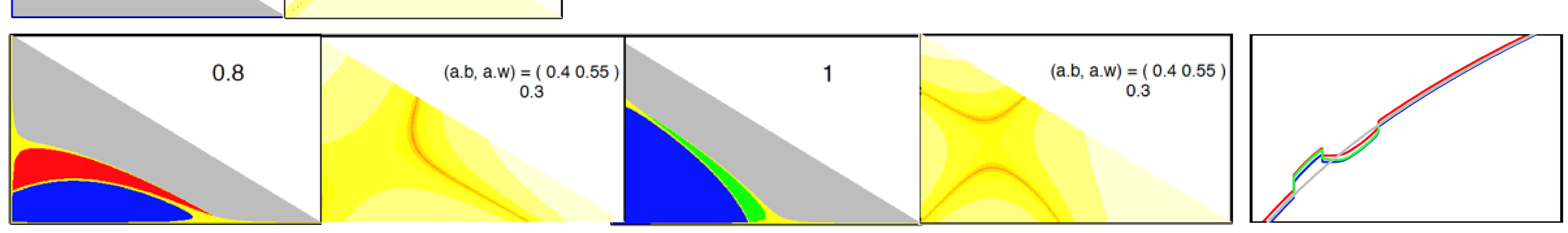
with the only variables being α_w and α_b, the areas of white and black daisies respectively.

To visualize the change in T with respect to daisy areas, we explored the fixed points of α_w and α_b, with an initial exploration of the parameter space of black and white daisy albedos.



Left: The number in the plot is the value of luminosity when evaluated, and the x and y axis are daisy areas; the plot shows the time derivative of α_b and α_w with different initial daisy areas. The yellow area is when both $\frac{d\alpha_b}{dt}$ and $\frac{d\alpha_w}{dt}$ are zero, i.e., stable points; green and red areas are when time derivatives of black and white daisies have opposite signs; grey is when both time derivatives are negative, and blue is when both positive.

Right: This plot shows the time derivative of planetary albedo *A*, with respect to different initial daisy areas. (a.b, a.w) in the figure is the black and white albedo values, with a death rate of 0.3.

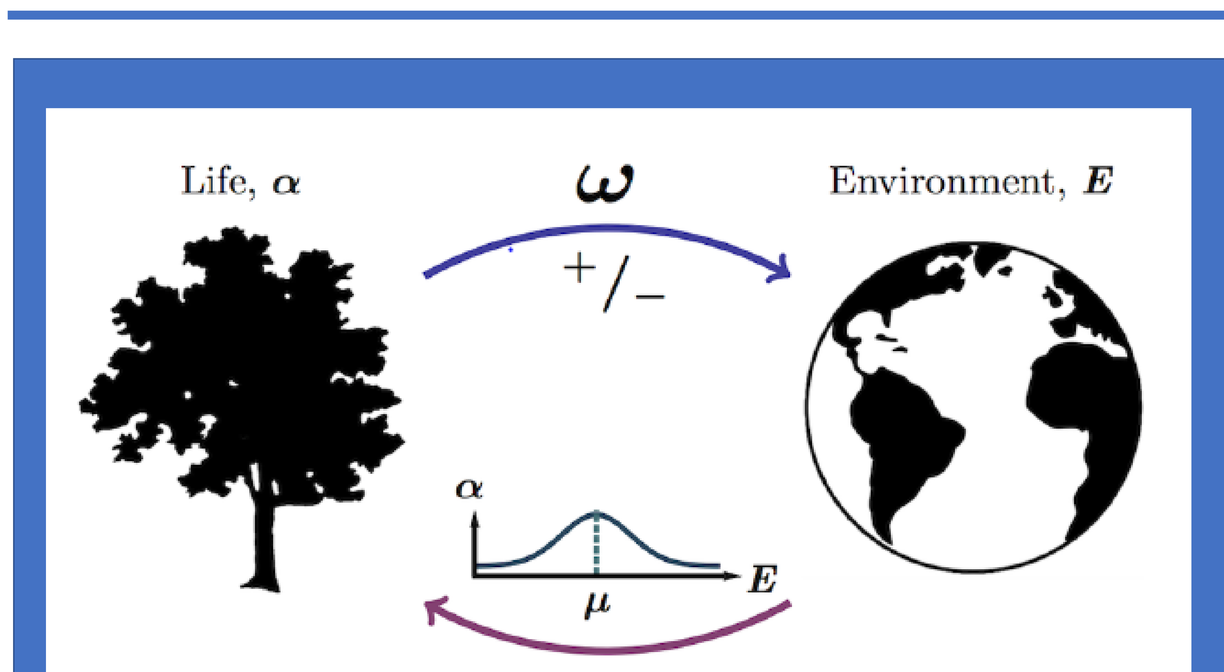


For boundary albedo values (in this case the black daisy albedo), the system might exhibit a different behavior. We created a short animation to trace the evolution of the time derivatives as luminosity increases. We aspire to understand better the dynamics of the model, especially at boundary values.

References:

Wood, A. J., G. J. Ackland, J. G. Dyke, H. T. P. Williams, and T. M. Lenton (2008), Daisyworld: A review, Rev. Geophys., 46, RG1001.

C. Nevison, V. Gupta & L. Klinger (1999) Self-sustained temperature oscillations on Daisyworld, Tellus B: Chemical and Physical Meteorology, 51:4, 806-814.



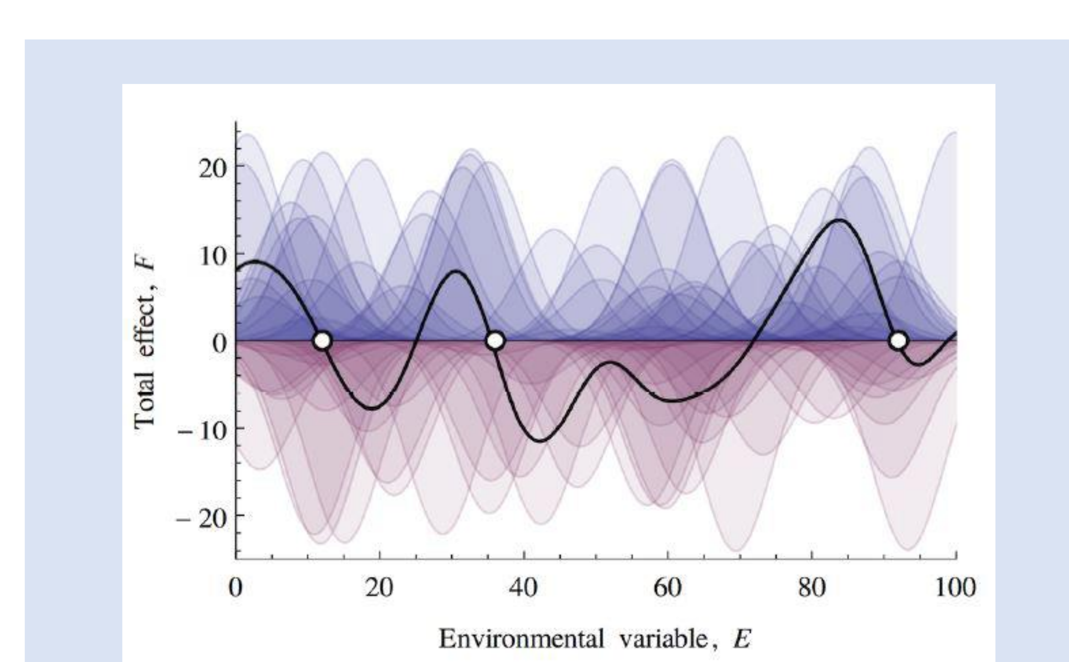
Dyke's model carries three important assumptions:

a) The environment affects on the species
b) The species in turn act on the environment
c) No strong coupling among species or among environmental conditions (i.e., not necessarily competition or predator-prey relationship)

Prospectus

Having its own interesting behaviors, Daisyworld can be best extended to real, complex systems through the metaphor of rein control. We moved on to explore a model proposed by James Dyke in 2009 that carries the most general set of assumptions aspiring to make it applicable to all ecosystems.

We have performed simulations with one environmental condition (e.g., temperature), and we are extending the model to higher dimensions and exploring its resilience under perturbations. In this time of climate change, we believe studying this model and the alike shed great light in management strategies and education.



Acknowledgments:

Thanks Prof. O'Brien and Prof. Mary Lou Zeeman for supervising my project.

This project is supported by CompSustNet NSF award CCS-1521672 and the Mathematics and Climate Research Network