THE IMPACT OF PLANETARY ALBEDO ON A NONLINEAR CLIMATE MODEL

Kellogg Honors College Capstone Project

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Introduction

By definition, planetary albedo is the fraction of light from the sun that is reflected back into space by the Earth. Light that is not reflected is absorbed by the Earth's atmosphere and surface, providing energy input for the motions of the atmosphere and ocean. If albedo is high, the Earth would have no energy and become extremely cold. If albedo is low, the Earth's temperature would become really hot and further increase the effects of climate change. Hence, by exploring the albedo parameter in the climate model, the appropriate Earth albedo could be discovered to halt or potentially reverse the effects of climate change.

Climate Model

Equilibrium of Glaciation

$$G_e = 1 - \frac{K}{F} \cdot T_e^4.$$

Equilibrium of Average Temperature

$$\begin{aligned} 0 = (T - T_e)[&-R\kappa^2 T^7 - T_e R\kappa^2 T^6 - T_e^2 R\kappa^2 T^5 \\ &- T_e^3 R\kappa^2 T^4 + \kappa(R - R\kappa \cdot T_e^4 + A)T^3 \\ &+ T_e\kappa(R - R\kappa \cdot T_e^4 + A)T^2 + T_e^2\kappa(R - R\kappa \cdot T_e^4 + A)T \\ &- R\kappa^2 T_e^7 + T_e^3 A\kappa + T_e^3 R\kappa - B] \end{aligned}$$

Name	Description	Value	Units
G	Percent of the planet's surface covered by glaciation	$G_e = 9.7$	percent
T	Average temperature of the planet	$T_e = 246$	K
A	Proportional to melting from glacial movement	-0.0049	$1/\text{year}$
B	Proportional to melting from temperature increase	-7.2493×10^{-5}	$1/\text{Kyear}$
C	Planetary constant given by (1)	-0.0183	$1/\text{year}$
c_3	Soft parameter given by (1)	-0.0021	K/year^4
F	Proportional to albedo of bare planet surface	0.43395	K/year
K	Proportional to black-body emissivity	1.07×10^{-10}	$1/K^3\text{year}$
L	Proportional to the latent heat of evaporation	20	K
R	Proportional to evaporation rate	8×10^{-5}	$1/\text{year}$
κ	Used for simplification	2.46572×10^{-10}	$1/K^4$

Table 1: Original parameter values and their descriptions

New Equilibriums

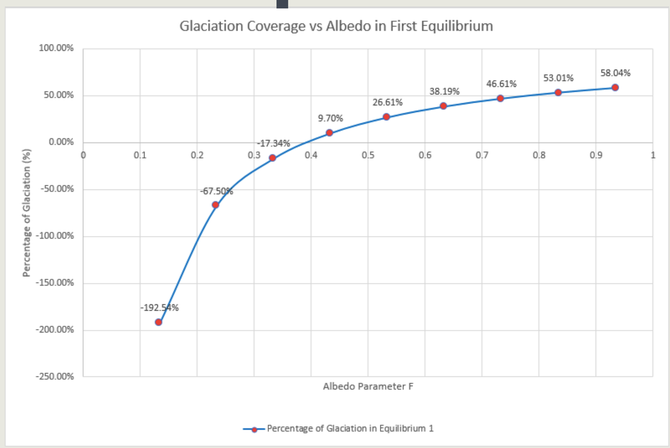

Figure 1: Percentage of Glacial Volume as the Planetary Albedo varies in the First Equilibrium

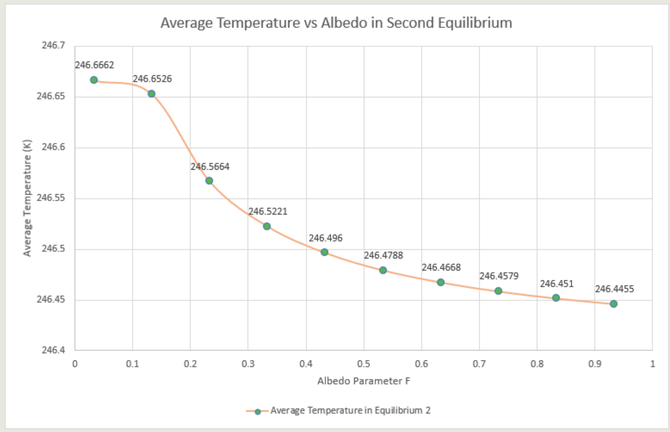

Figure 3: Average Temperature of Earth as the Planetary Albedo varies in the Second Equilibrium

Results & Conclusion

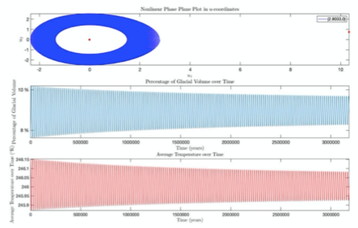

Figure 4: Nonlinear Phase Plane, Percentage of Glacial Volume over Time, and Average Temperature over Time while Albedo is 0.23395

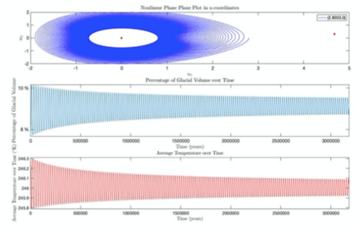

Figure 5: Nonlinear Phase Plane, Percentage of Glacial Volume over Time, and Average Temperature over Time while Albedo is 0.33395

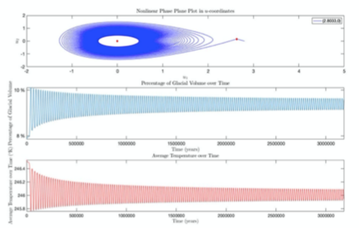

Figure 6: Nonlinear Phase Plane, Percentage of Glacial Volume over Time, and Average Temperature over Time while Albedo is 0.43395

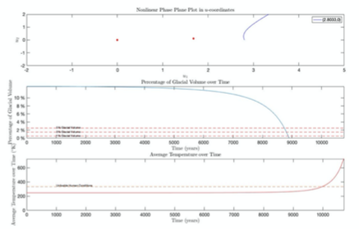

Figure 7: Nonlinear Phase Plane, Percentage of Glacial Volume over Time, and Average Temperature over Time while Albedo is 0.53395

From the figures shown, we can see that unfavorable outcomes will occur if the planetary albedo drastically changes. Figures 4-7 show the concerning pattern of the equilibrium of the percentage of glaciation and the equilibrium of Earth's average temperature shrinking until the cycles are broken at F = 0.53395. These figures suggest that a planetary albedo of 0.53395 is a dangerous albedo, for this would cause glaciation to decrease until reaching 0 percent and average temperature to increase until going past temperatures that would deem Earth inhabitable for Earth's organisms within 10000 years. While it is still debatable if decreasing the planetary albedo to 0.33395 is better for human civilization and the planet, one can see that a change in albedo can drastically affect the fate of our planet. A 0.1 change in albedo appears to decide whether the Earth has an additional 3,000,000 years or only an additional 10,000 years.

Possible solutions: The use of white roofs in urban areas increase long-term solar reflectance and thus, planetary albedo

References: [1] Matthews H. Seto D. Akbari, H. The long-term effect of increasing the albedo of urban area. Environmental Research Letters, 7(2):1–10, 2012. [2] S. Secor. Human impact on a simple climate model. Master's thesis, Cali- fornia State Polytechnic University, Pomona, 2020. [3] A. D. Toner, M. Kirwan Jr. Periodic and homoclinic orbits in a toy climate model. Nonlinear Processes in Geophysics, 1(1):31–40, 1994. [4] M. Toner. Invariant Manifolds of a Toy Climate Model. PhD thesis, Old Do- minion University, Norfolk, Virginia, 1994. [5] S. Twomey. Pollution and the planetary albedo. Atmospheric Environment, 8(12):1251–1256, 1974.