Planet-Civ Update

Ethan Savitch

Janurary 2020

Current Model

1 Model Variables/Constants and Units

- T = Average Global Temperature (Kelvin)
  - T_{eq} = Equilibrium (initial) Temperature, calculated with the energy balance model ($Kelvin$)
  - ΔT = Temperature Range in which humans can survive (higher values correspond to lower fragility)[1]
  - D = Orbital Distance (AU)
- P = Global Carbon Dioxide Partial Pressures (ppm)
  - P_0 = Initial Carbon Dioxide Partial Pressures (ppm)
  - ϵ = Annual Per-Capita[2] Carbon Footprint ($\frac{ppm}{10^6 ppl*yr}$)
  - ΔP = A proportionality factor between the birth rate and changes in pCO_2. (higher values correspond to less technologically efficient civilizations (ie: must burn more fossil fuels in order to increase the birth rate))[3]
- N = Global Population ($x10^6$ ppl)
  - N_0 = Initial Global Population ($x10^6$ ppl)
  - N_{max} = Maximum Allowed Global Population ($x10^6$ ppl)
  - $\alpha_{birth,0}/\alpha_{death,0}$ = Initial Per-Capita[2] Birth/Death Rates ($1/yr$)
  - $\alpha_{birth}/\alpha_{death}$ = Current Per-Capita[2] Birth/Death Rates ($1/yr$)
- $\Lambda = \frac{\alpha_{birth,0}\Delta T}{\epsilon N_{max}\frac{dT}{dP}} = \frac{Rate\ of\ Temperature\ Change}{Maximum\ Climate\ Forcing}$
  - $\Lambda >> 1 \implies$ Corresponds to a civilization having a low risk of an Anthropocene
  - $\Lambda << 1 \implies$ Corresponds to a civilization having a high risk of an Anthropocene
  - $\Lambda = 1 \implies N_{avg,max} = 32,232$

1.1 Linear Regressions of Temp vs pCO2

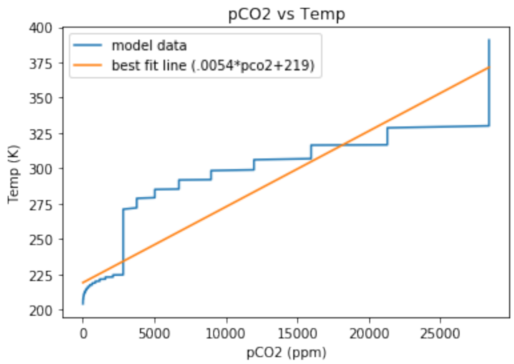
1.1.1 As a function of pCO2

$$T = 5.4 * 10^{-3}\left(\frac{P}{ppm}\right) + 219$$

[1] $\Delta T = \sqrt{\frac{\alpha_{death,0}}{F_r}}$

[2] Per-Capita Meaning Per-Million People

[3] $\Delta P = \frac{\alpha_{birth,0}}{E_n}$



1.1.2 As a function of Distance and pCO2[4]

$$T = 1.137 * 10^{-3}\left(\frac{P}{1\ ppm}\right) - 407.2\left(\frac{D}{1\ AU}\right) + 685.5$$

2 Model Outline

First, let the energy balance model reach an equilibrium between incoming and outgoing radiation, this gives us the equilibrium temperature. The model continues by setting the initial temperature to this equilibrium value, as well as setting the birth and death rates to their initial values. The main loop now begins, where each loop represents one year.[5]

i) Call[6]: $\frac{dT}{dt} = EBM(P)$

ii) $\alpha_{birth} = \alpha_{birth,0}\left[1 + \frac{P - P_0}{\Delta P}\right]$

iii) $\alpha_{death} = \alpha_{death,0}\left[1 + \left(\frac{T - T_{eq}}{\Delta T}\right)^2\right]$

iv) Call: $\frac{dN}{dt} = min(\alpha_{birth}N,\ \alpha_{death,0}N_{max}) - \alpha_{death}N$

v) Call: $\frac{dP}{dt} = \epsilon N$

   a) If time has reached the end, program is finished

   b) If time hasn't reached the end, go back to the first step.

3 Example: Modeling Earth ($t_0 = 1820,\ P_0 = 284,\ N_0 = 1,129$)

- $N_{max} = 13,000$
- $\alpha_{birth,0} = 0.019$
- $\alpha_{death,0} = 0.015$
- $\Delta T = 1.73$
- $\Delta P = 6.3 * 10^{-5}\ Bar = 63.3\ ppm$
- $\Lambda = 2.48$

[4](sklearn.linear_model.LinearRegression)

[5]Note: made population have a minimum of 1 million people, to avoid values of 10^{-100}

[6]$EBM(P) = \frac{\psi(1-A) - I + \nabla \cdot (\kappa \nabla T)}{C_v}$

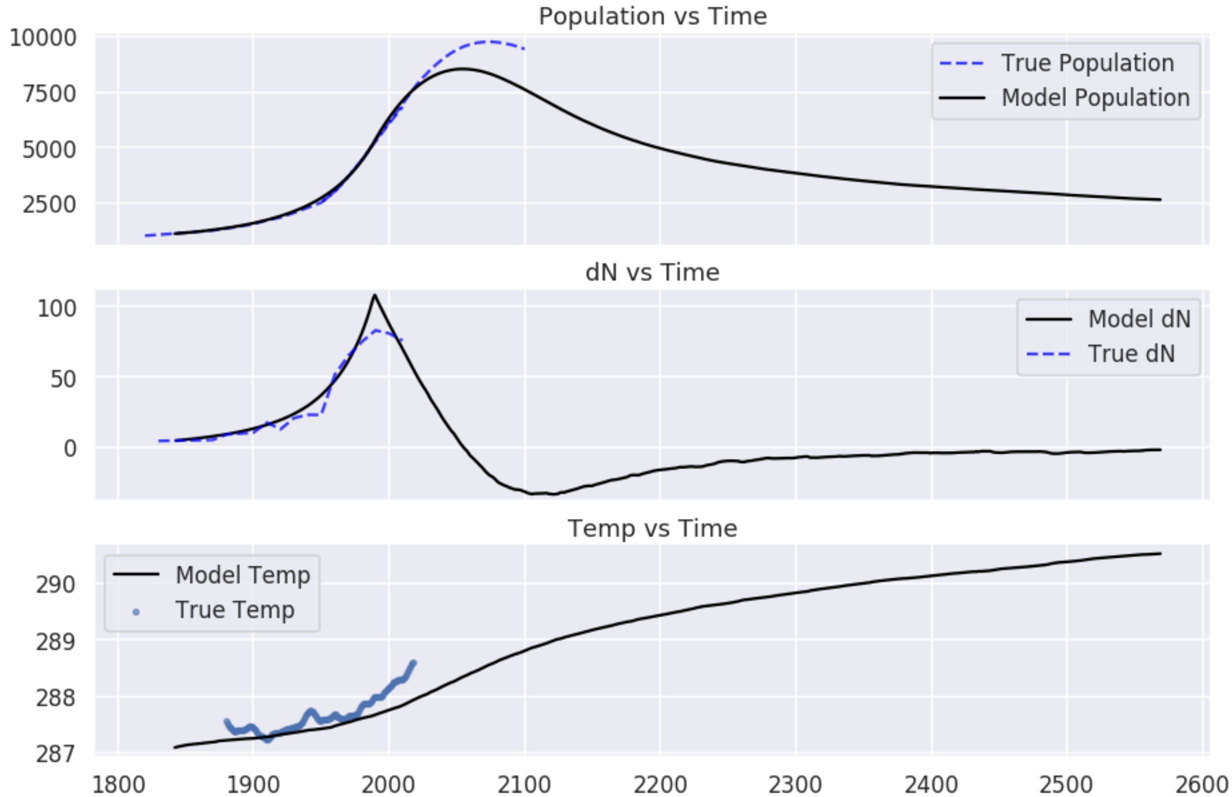


Figure 1: Model Output (solid black line) vs Real Global Data (dotted blue line) for 750 Years

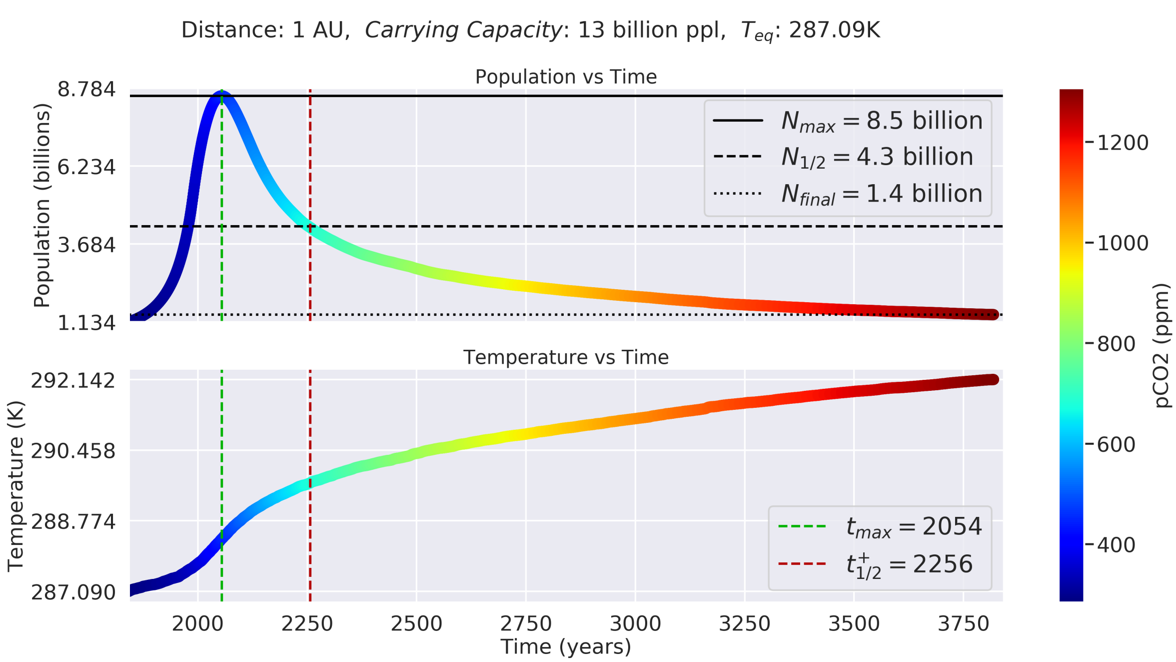


Figure 2: Model Output for 2000 Years

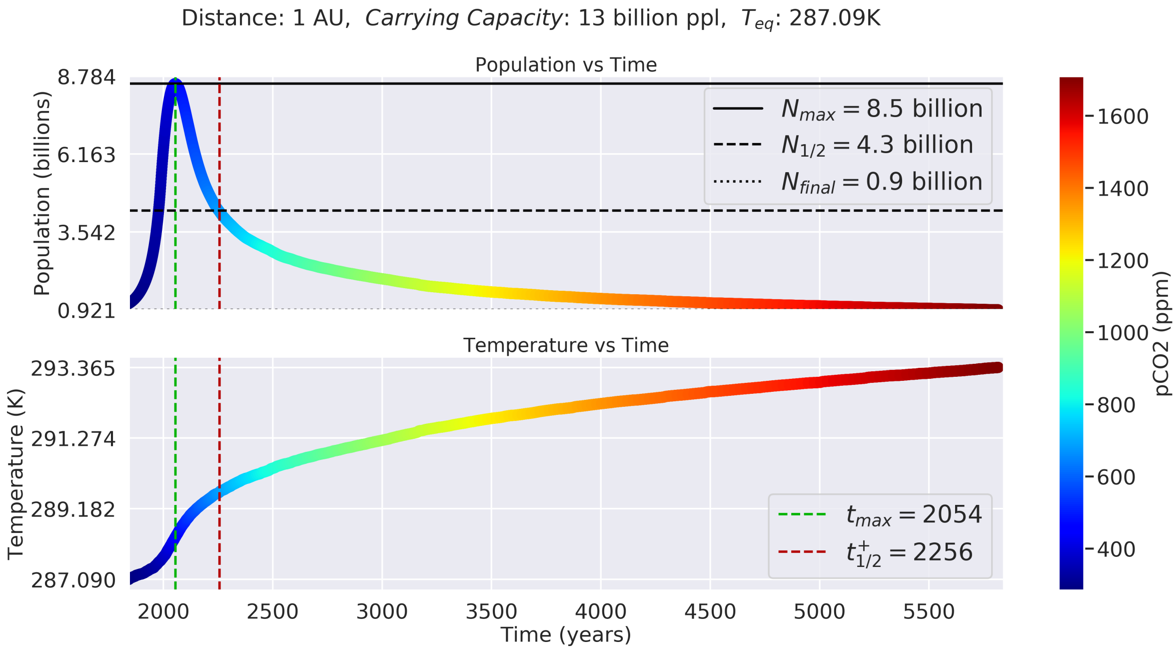


Figure 3: Model Output for 4000 Years

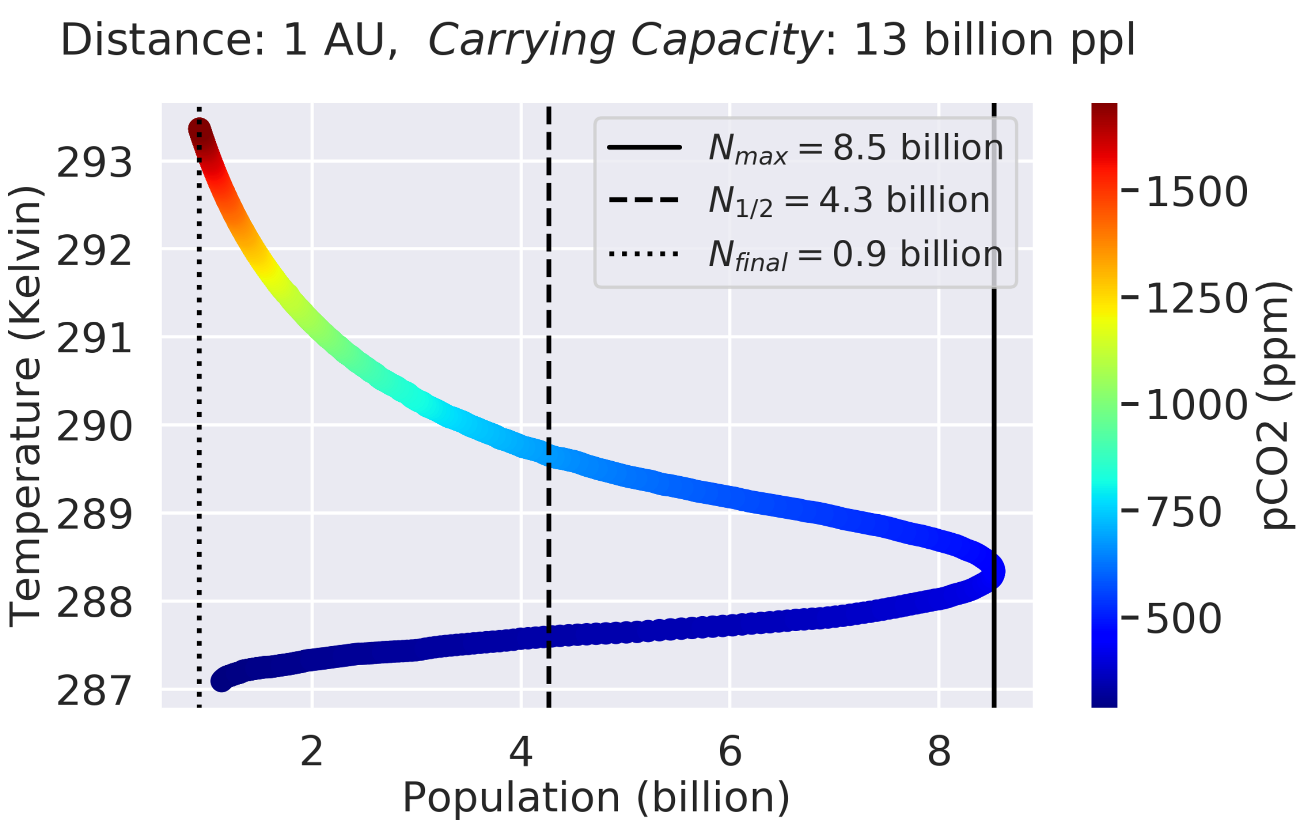


Figure 4: Phase Diagram of Model Output (4000 years)