Planet-Civ Update

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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)[2]
  - ϵ = Annual Per-Capita[3] 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))[4]
- 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[3] Birth/Death Rates ($1/yr$)
  - $\alpha_{birth}/\alpha_{death}$ = Current Per-Capita[3] Birth/Death Rates ($1/yr$)
- $\Lambda = \dfrac{\alpha_{birth,0}\Delta T}{\epsilon N_{max}\frac{dT}{dP}} = \dfrac{Rate\ of\ Temperature\ Change}{Maximum\ Climate\ Forcing}$
  - $\Lambda >> 1 \implies$ 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
  - $\Lambda = 1 \implies N_{avg,max}$

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]

[1] $\Delta T = \sqrt{\frac{\alpha_{death,0}}{F_r}}$
[2] $x\ ppm * \left(\frac{1Bar}{10^6 ppm}\right) = y\ bar$
[3] Per-Capita Meaning Per-Million People
[4] $\Delta P = \frac{\alpha_{birth,0}}{E_n}$
[5] Note: made population have a minimum of 1 million people, to avoid values of 10^{-100}

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

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

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

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

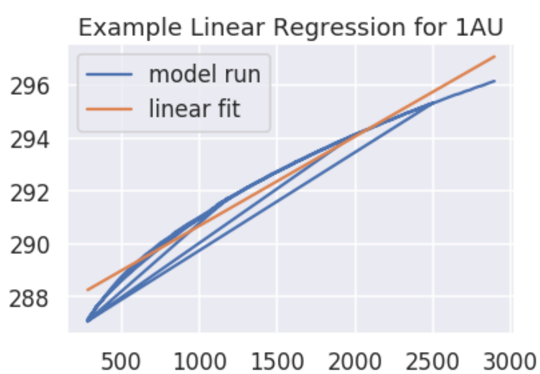
v) Call: $\dfrac{dP}{dt} = \epsilon N$

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 Linear Regressions of Temp vs pCO2 at Various Distances

At each distance, I ran the model for four different values of maximum population (10, 40, 70, and 100 billion people), 2000 years each, then did a linear regression to find the average relationship between temperature and pco2 for that distance.



$$T = 7.967 * 10^{-2}\left(\frac{P}{ppm}\right) + 316.364 \qquad \textbf{\textit{(0.94 AU)}}$$

$$T = 4.94 * 10^{-3}\left(\frac{P}{ppm}\right) + 305.669 \qquad \textbf{\textit{(0.97 AU)}}$$

$$T = 3.378 * 10^{-3}\left(\frac{P}{ppm}\right) + 287.302 \qquad \textbf{\textit{(1 AU)}}$$

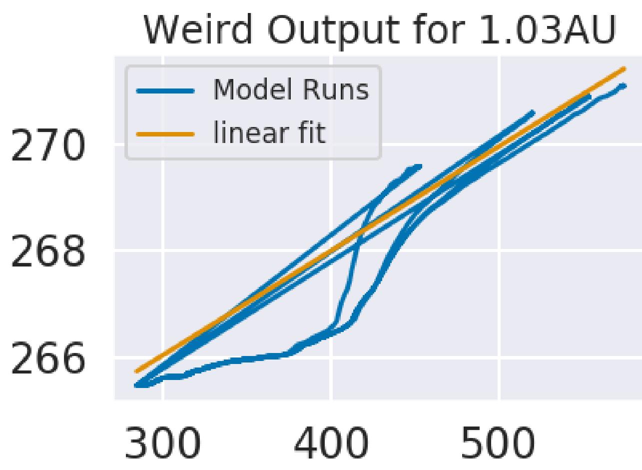
$$T = 1.959 * 10^{-2}\left(\frac{P}{ppm}\right) + 260.164 \qquad \textbf{\textit{(1.03 AU)}}$$

$$T = 6.554 * 10^{-4}\left(\frac{P}{ppm}\right) + 221.962 \qquad \textbf{\textit{(1.06 AU)}}$$

3.1 Weird Output at 1.03AU

As seen above, the linear regressions have a clear pattern, except for at $1.03AU$. The models output vs vs the linear regression at this distance is shown below. I have no idea why but all the outputs at this distance seem strange. The model has two different polynomial parameterizations for $190K - 280K$ and $280K - 370K$, but I don't think we are near the edges of any of those ranges. Example output for 10 billion people is shown below. Also fractional ice coverage in the program goes to zero once temperatures rise above $273K$.

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



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

- $N_{max} = 13$ billion people
- $\alpha_{birth,0} = 0.019$
- $\alpha_{death,0} = 0.015$
- $\Delta T = 1.73K$
- $\Delta P = 6.3 * 10^{-5}\ Bar$
- $\epsilon = 0.00019$
- $\Lambda = 3.94$

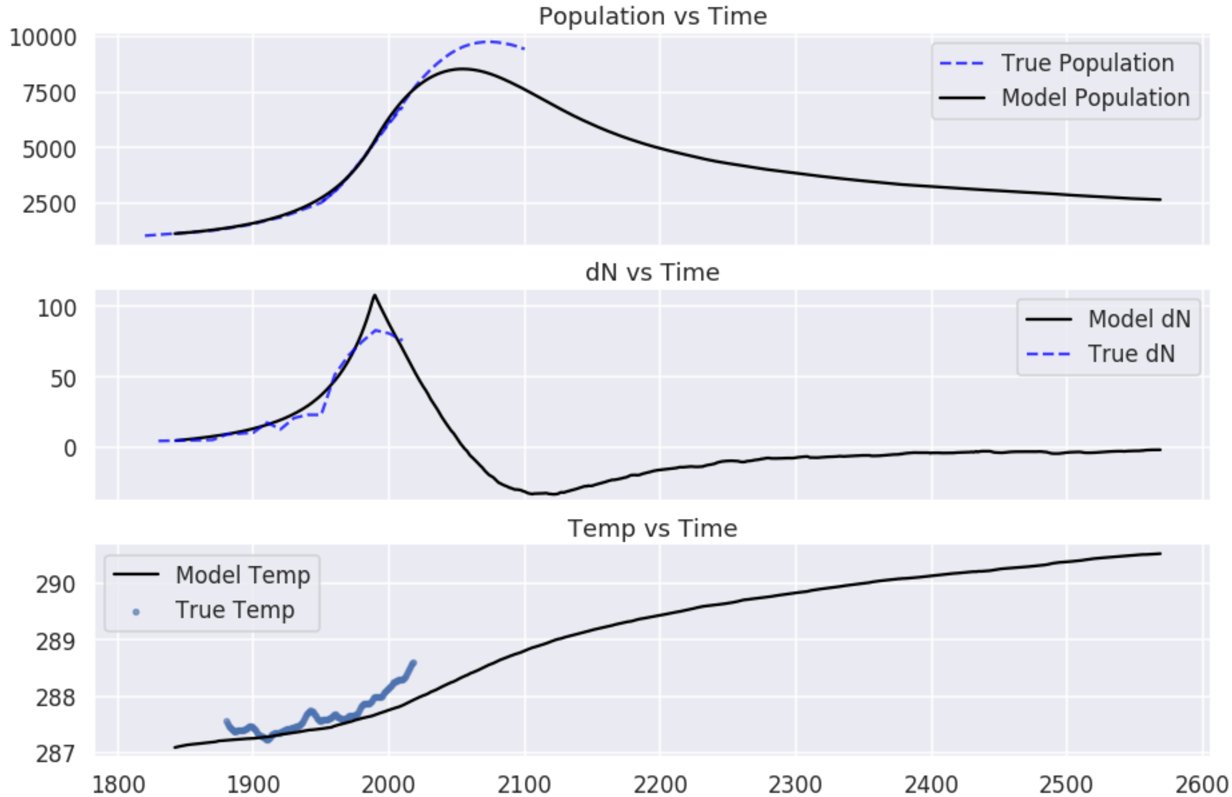


Figure 1: Model Output (solid black line) vs Real Global Data (dotted blue line) for 750 Years

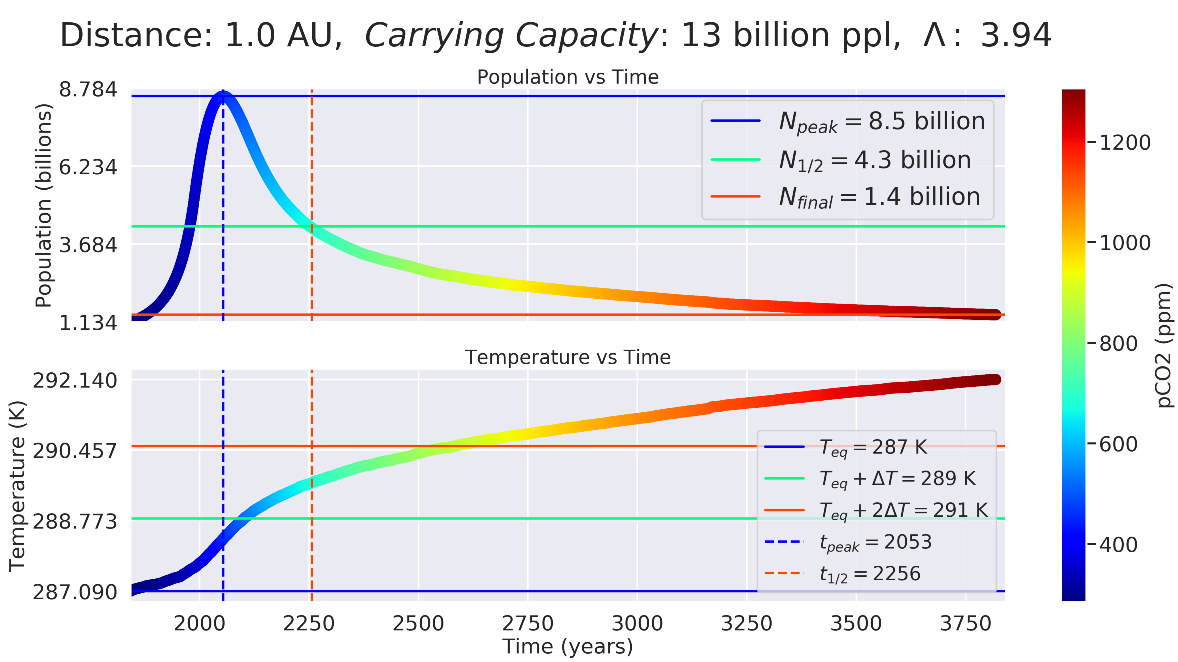


Figure 2: Model Output for 2000 Years

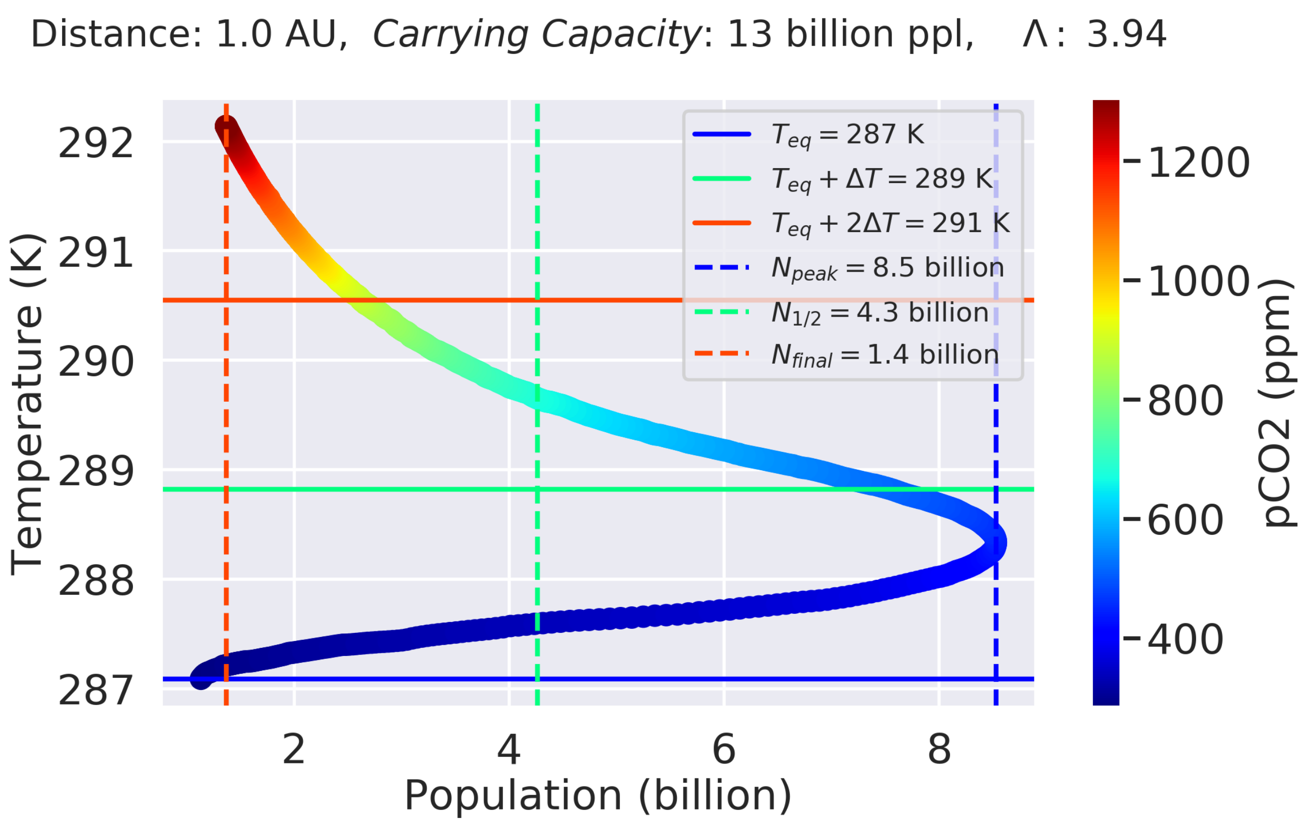


Figure 3: Phase Diagram of Model Output (2000 years)