

Planet-Civ Update

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Model 0: Constant Growth Rates

$$C_v \frac{dT}{dt} = \psi(1 - A) - I + \nabla \cdot (\kappa \nabla T) \quad (1)$$

$$\frac{dP}{dt} = \epsilon N \quad (2)$$

$$\frac{dN}{dt} = \alpha_{net} N \quad (3)$$

- $P = pCO_2$ (ppm), ($P_0 = 284$)
 - $\epsilon = 4.5 * 10^{-5} = \text{carbon footprint per capita} = \text{amount of pCO}_2 \text{ added to the atmosphere by a million people in one year}$
- $N = \text{population} (*10^6)$
 - $\alpha_{net} = \alpha_{birth} - \alpha_{death} = .02 - .01 = .01 = \text{net/relative growth rate}$
- $T = \text{temperature} (K)$
- $t = \text{time} (yr)$, ($t_0 = 1880$)

Model 1: Non-constant Growth Rates with a Maximum Value acting as a Carrying Capacity

Goal: To try to replicate our planets growth rates by adding a maximum value that cannot be exceeded. Additions in pCO_2 would act as a proxy for technology, thus would increase the birth rates. Any deviations in global temperatures would make the planet less habitable, thus would increase the death rates.

- $E_n = \text{constant determining the relationship between changes in } pCO_2 \text{ and changes in birth rates ('technological abilities')}$
- $F_r = \text{constant determining the relationship between changes in temperature and changes in death rates ('fragility')}$
- $T_{eq} = \text{equilibrium temperature (ie: temperature at which the energy balance model finished balancing)}$
- $\alpha_{birth,0}/\alpha_{death,0} = \text{initial birth/death rates}$

Equation 1 is called.

$$\alpha_{birth} = \alpha_{birth,0} + E_n(pco2 - pco2_0)$$

$$\alpha_{death} = \alpha_{death,0} + F_r(T - T_{eq})^2$$

if($\alpha_{birth} \leq \alpha_{birth,max}$) then

- $\alpha_{net} = \alpha_{birth} - \alpha_{death}$
- Call: $\frac{dN}{dt} = \alpha_{net} N$

if($\alpha_{birth} > \alpha_{birth,max}$) then

- $\alpha_{net} = \alpha_{birth,max} - \alpha_{death}$
- Call: $\frac{dN}{dt} = \alpha_{net}$

Equation 2 is called.

Issues

- Although this helped to replicate our populations changes in growth rates, the sharp transition once the maximum growth rate is reached made for some very odd behavior.
- Could not use this model to replicate both the growth rates of our population as well as the amount of people.
- Makes ridiculously large numbers for the population.

Model 2: Non-Constant Growth Rates and Technological Abilities, with a Maximum Population as the Carrying Capacity

Goal: Instead of having a maximum growth rate, this model has a maximum population, which acts as a carrying capacity for the growth rates. So that as the population approaches its maximum, the growth rate approaches zero. Also, multiplied by the net growth rate and the per-capita carbon footprint by E_n , so that increases in technology both increase the growth rate as well as the per-capita carbon footprint. Finally, made E_n obey a differential equation which is proportional to the fractional increase in the population, with a proportionality factor representing the rate of the civilizations technological advancements.

- N_{max} = maximum population (carrying capacity)
- ΔN = annual change in population
- α_{tech} = rate of the civilizations technological advancements, has effect of increasing the amplitude of the model (higher population/growth rates).

Set the birth and death rates to their initial values, then start the main loop, where each loop represents one year.

- Call: $\frac{dT}{dt} = EBM(P)$
- $\alpha_{birth} = \alpha_{birth,0}$
- $\alpha_{net} = (\alpha_{birth} - \alpha_{death})(1 - \frac{N}{N_{max}})$
- Call: $\frac{dN}{dt} = E_n \alpha_{net} N$
- Call: $\frac{dE_n}{dt} = \alpha_{tech} (\frac{\Delta N}{N})$
- Call: $\frac{d\alpha_{death}}{dt} = F_r (T - T_{eq})^2$
- Call: $\frac{dP}{dt} = E_n \epsilon N$
- If time has reached then end program, if time hasn't reached the end then go back to the the first step.

Conclusion: This model did the best job of replicating our civilizations changing population and growth rates, as well as the temperature of our planet. Once downside is that population falls off faster in our model than is projected to in real life. The values for the relevant inputs are:

- $N_{max} = 7800 * 5$
- $\alpha_{birth,0} = 0.019$
- $\alpha_{death,0} = 0.015$

- $E_{n,0} = 1$
- $\alpha_{tech} = 7$
- $F_r = 2.25 * 10^{-10}$
- $\epsilon = 4.5 * 10^{-5}$

And the resulting output looks like:

