2 Background: climate physics

The simplest climate model can be conceptualized as:

$$\text{change in heat content} = +\,\text{absorbed solar radiation (energy from the Sun's rays)} \tag{1}$$

$$-\,\text{outgoing thermal radiation (i.e. blackbody cooling to space)} \tag{2}$$

$$+\,\text{human-caused greenhouse effect (trapped outgoing radiation)} \tag{3}$$

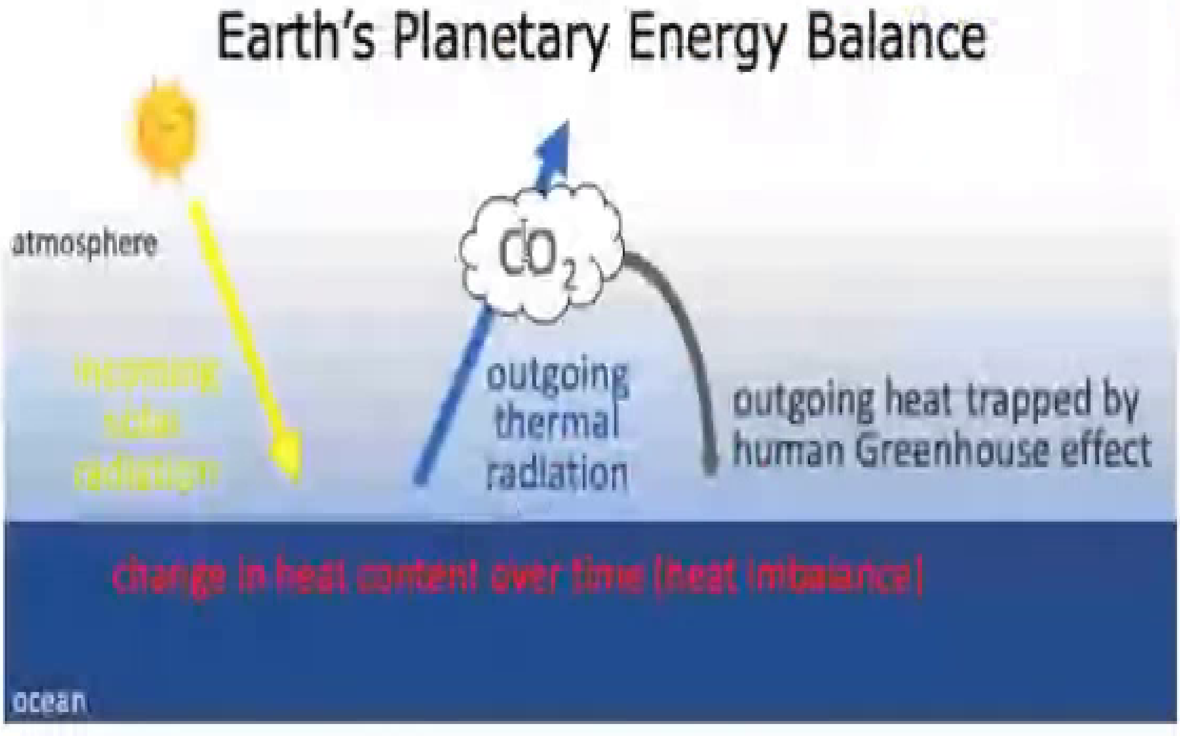


Figure 4: Earth's Planetary Energy Balance

2.1 Absorted solar radiation

In the physical world there are physical variables to identify.
In our baking the earth example, we will identify the following quantities:

- Industrial Revolution Start: 1850

− outgoing thermal radiation (i.e. blackbody cooling to space) (2)

\+ human-caused greenhouse effect (trapped outgoing radiation) (3)

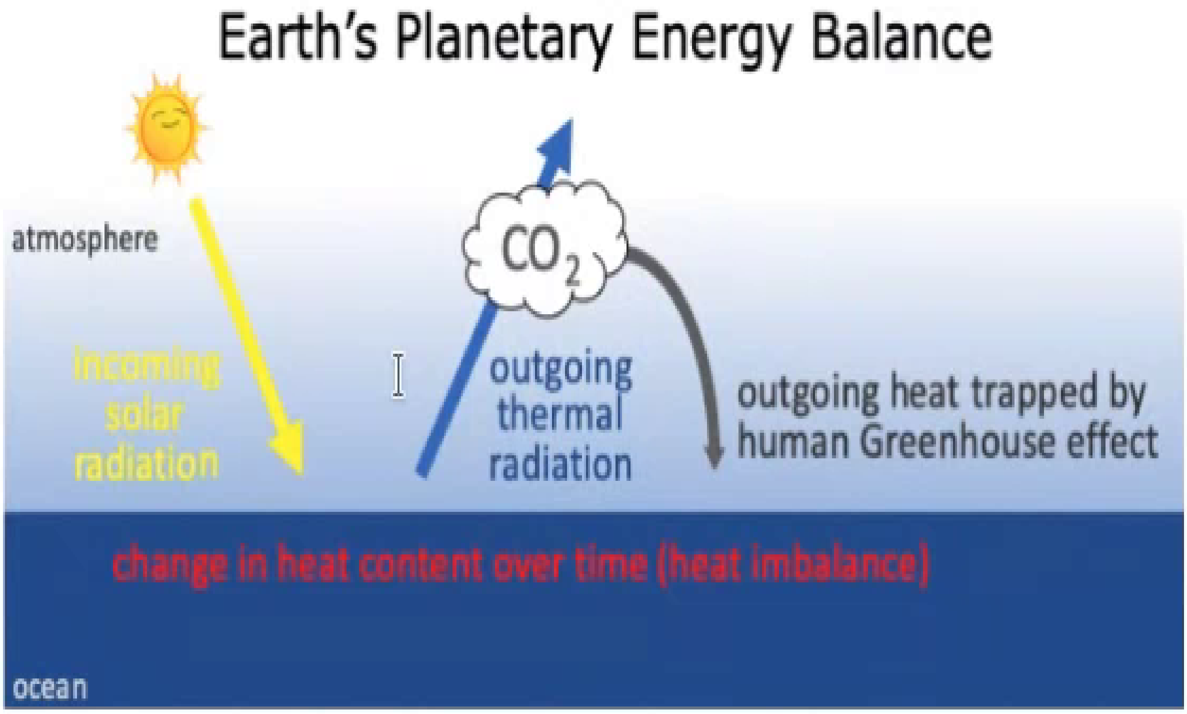


Figure 4: Earth's Planetary Energy Balance

2.1 Absorted solar radiation

In the physical world there are physical variables to identify.
In our baking the earth example, we will identify the following quantities:

- Industrial Revolution Start: 1850

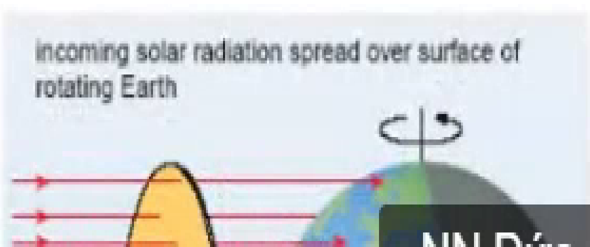
In our baking the earth example, we will identify the following quantities:

- Industrial Revolution Start: 1850
- Avg Temperature in 1850: 14.0 ℃
- Solar Insolation $S = 1368W/m^2$: energy from the sun
- Albedo or plentary reflectivity:$\alpha = 0.3$
- atmosphere and upper-ocean heat capacity: $C = 51J/m^2/C$

Earth Baking Formula: $C\ \text{temp}'(t) = S(1-\alpha)/4$.

At Earth's orbital distance from the Sun, the power of the Sun's rays that intercept the Earth is equal to $S = 1368$. A small fraction $\alpha = 0.3$ of this incoming solar radiation is reflected back out to space (by reflective surfaces like white clouds, snow, and ice), with the remaining fraction $(1-\alpha)$ being absorbed.

Since the incoming solar rays are all approximately parallel this far from the Sun, the cross-sectional area of the Earth that intercepts them is just a disc of area πR^2. Since all of the other terms we will consider act on the entire surface area $4\pi R^2$ of the spherical Earth, the absorbed solar radiation *per unit surface area* (averaged over the entire globe) is reduced by a factor of 4..



tion is reflected back out to space (by reflective surfaces like white clouds, snow, and ice), with the remaining fraction $(1-a)$ being absorted.

Since the incoming solar rays are all approximately parallel this far from the Sun, the cross-sectional area of the Earth that intercepts them is just a disc of area πR^2. Since all of the other terms we will consider act on the entire surface area $4\pi R^2$ of the spherical Earth, the absorbed solar radiation *per unit surface area* (averaged over the entire globe) is reduced by a factor of 4..

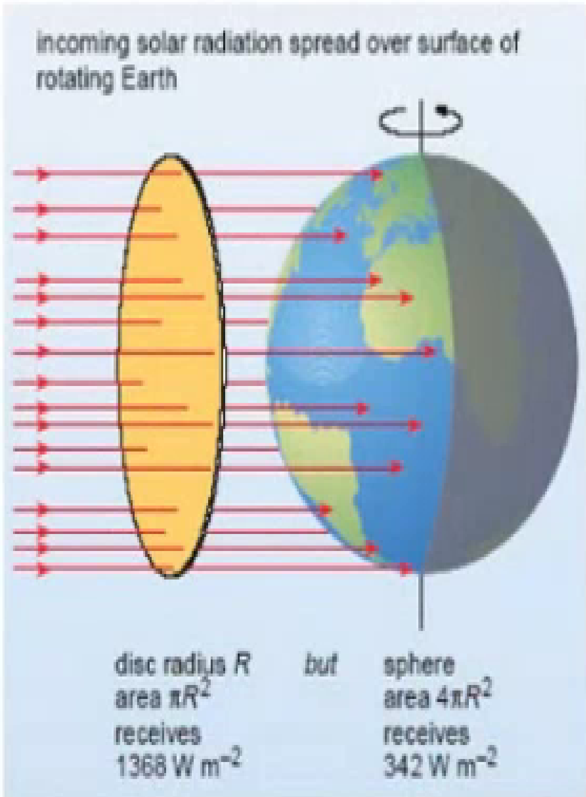


Figure 5: Incoming solar radiation

The absorbed solar radiation per unit area is thus absorbed solar radiation $\equiv \frac{S(1-a)}{4}$ The heat content $Ctemp$ is determined by the temperature $temp$ (in Kelvin) and the heat capacity of the climate system. While we are interested in the temperature of the atmosphere, which has a very small heat capacity, its heat is closely coupled with that of the upper ocean, which has a much larger heat capacity of.

The *change in heat content over time* is thus simply given by $\frac{d(CT)}{dt}$. Since the heat capacity of sea water hardly changes with temperature, we can rewrite this in terms of the change in temperature with time as:

$$\text{change in heat content} = C\frac{dtemp}{dt}$$

Your work here is modeling ODE with only absorted solar radiation to predict the change in temperature for 200 years from 1850 and visualizing your model

2.2 Outgoing: thermal radiation

The outgoing thermal radiation term $\mathcal{G}(T)$ (or "blackbody cooling to space") represents the combined effects of *negative feedbacks that dampen warming*, such as **blackbody radiation**, and *positive feedbacks that amplify warming*, such as the **water vapor feedback**.

Since these physics are too complicated to deal with here, we *linearize* the model combining the incoming and the outgoing.

We assume that the preindustrial world was in energy balance, and thus the equilibrium temperature is the preindustrial temperature.

Thus we assume temp'(t) = B(temp(0)-temp(t)) for some value of B. The minus sign in front of temp(t) indicating it restores equilibrium. The climate feedback parameter has been chosen is $B = 1.3 W/m^2/°C$.

Extending your model with thermal radiation and visualizing it

2.3 Greenhouse: Human-caused greenhouse effect

Empirically, the greenhouse effect is known to be a logarithmic function of gaseous carbon dioxide (CO_2) concentrations

$$\text{human-caused greenhouse effect } = (\text{forcing\_coef}) \ln\left(\frac{[\mathrm{CO}_2]}{[\mathrm{CO}_2]_{\text{PreIndust}}}\right),$$

where

- CO_2 forcing coefficient is $5.0 W/m^2$
- preindustrial CO_2 concentration is 280.

combining the incoming and the outgoing.

We assume that the preindustrial world was in energy balance, and thus the equilibrium temperature is the preindustrial temperature.

Thus we assume temp'(t) = B(temp(0)-temp(t)) for some value of B. The minus sign in front of temp(t) indicating it restores equilibrium. The climate feedback parameter has been chosen is $B = 1.3W/m^2/°C$.

Extending your model with thermal radiation and visualizing it

2.3 Greenhouse: Human-caused greenhouse effect

Empirically, the greenhouse effect is known to be a logarithmic function of gaseous carbon dioxide (CO_2) concentrations

$$\text{human-caused greenhouse effect} = (\text{forcing\_coef}) \ln\left(\frac{[\mathrm{CO}_2]}{[\mathrm{CO}_2]_{\mathrm{PreIndust}}}\right),$$

where

- CO_2 forcing coefficient is $5.0W/m^2$
- preindustrial CO_2 concentration is 280.

How this depends on time into the future depends on human behavior! Time is not modelled in the above equation. Through observations to 2020 (figure 6), we can assume that the CO_2 concentration (ppm) increase each t year from 1850 by $1+\left(\frac{t}{220}\right)^3$ times.

Extending your model with Greenhouse Effects and visualizing it

3 Experiments

1. Building a model for temparature prediction using **Python** programming language.
2. Predicting the temperature change in 2030.
3. Comparing your model predictions with NASA observations.

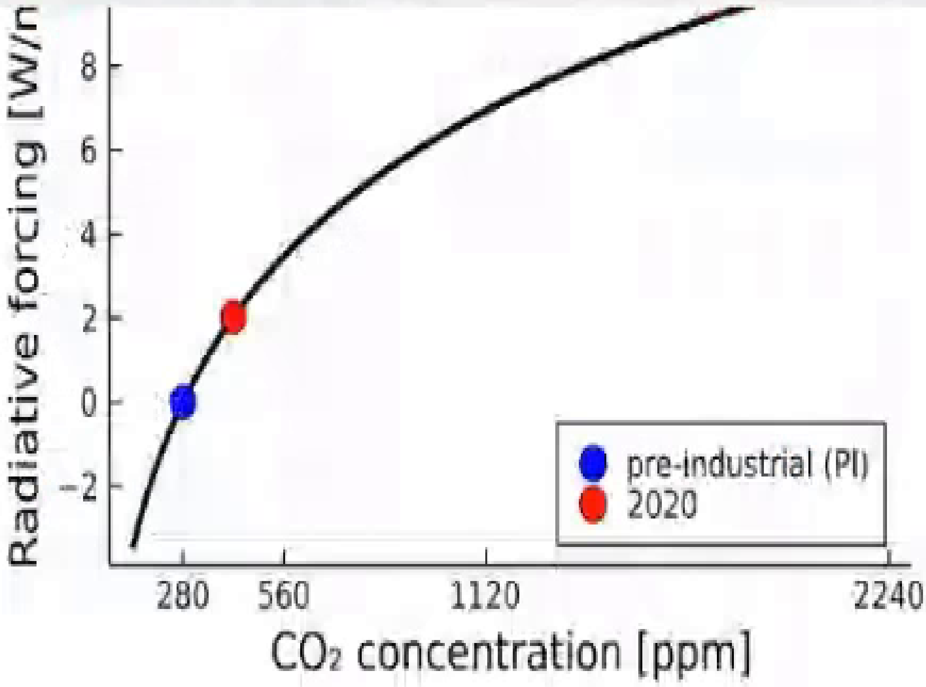


Figure 6: The change of CO_2 concentration from PI to 2020

4 Submission

Each group (2-3 members) submits a compressed file (GroupID.zip), including:

- An ipython notebook (GroupID.ipynb) containing the analysis. Be sure the results are reproducible, meaning they remain unchanged after rerunning all cells. You can use any tool you know to conduct the analysis.

- A Data directory containing all relevant data files. If any file in the data set is too large, you may replace it with a text file containing the link to the file (be sure it is publicly accessible).

Improving your model for additional points.

References

Alan Edelman, D. P. Sanders, and C. E. Leiserson. Introduction to Computational Thinking. URL `https://computationalthinking.mit.edu/Spring21`. pages

F. Li. Ordinary Differential Equation in Python. URL `https://towardsdatascience.com/ordinal-differential-equation-ode-in-python-8dc1de2132` pages

J. J. Tyson, K. C. Chen, and B. Novak. Sniffers, buzzers, toggles and blinkers: dynamics of regulatory and signaling pathways in the cell. Current Opinion in Cell Biology, 15(2):221–231, 2003. ISSN 0955-0674.