Climate Change Calculated 2

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Question: Does the CO_2 concentration influence the global temperature?

- **Physics:**
- Significant effect: Absorption spectra of CO_2 and water vapor:
- https://en.wikipedia.org/wiki/Radiative_forcing
- Water vapor is short lived and dependent on temperature, hence CO_2 is the primary gas.
- We see:
- CO_2 is **transparent** to the electromagnetic spectrum of **visible light**,
- but it **absorbs** in the **range of infrared**, ie the heat radiation
- The sun heats up the earth with the visible light,
- heat is radiated back into space as infrared radiation.

- This is how a balance is established.

The Radiative Forcing of CO_2

- More CO_2 in the atmosphere keeps more infrared radiation on Earth.
- This additional retained radiation is called "**radiative forcing**" (https://en.wikipedia.org/wiki/Radiative_forcing)
- Formula of radiative forcing of CO_2:

$$\Delta F = 5,35 \frac{\mathrm{W}}{\mathrm{m}^2} \cdot \ln \frac{C}{C_0}$$

- C_0 : CO_2 reference, 280ppm of the pre-industrial time,
- C: new CO_2 value, 410ppm (2019)
- The result is a power in watts per unit area m^2
- In Python:

```
import numpy as np

5.35 * np.log (410/280)
```

- Result: **2.04 W / m^2**
- CO_2 radiative forcing thus is approx. 2W / m^2 (+- ca. 10%)

- This is the **additional power** from the increase of CO_2 to 410ppm compared to the pre-industrial level of 280ppm.
- This is about the power of a bicycle lamp for every square meter of the earth.
- Variations of the solar radiation come to about 0.5W / m^2
- Other effects are even lower
- -> The radiative forcing of CO_2 is the dominating effect

Question: How long does it take for the radiative forcing to heat up earth by 1 degree C (1.8F)?

- The earth is **dominated by oceans**, accounting for 70% of the surface
- Therefore, we focus on the **oceans for our estimation**
- The **heat capacity** of water is the energy needed to warm up 1kg of water by 1 degree Celsius (or Kelvin).
- Unit: J / (kg * K) = (Ws) / (kg * K)
- Heat capacity of water: **$c = 4.2 * 10^3$ J / (kg * K)** (https://en.wikipedia.org/wiki/Table_of_specific_heat_capacities)
- Water also has a higher heat capacity than earth
- We can now transform the units of heat capacity to obtain the formula for the time for 1 degree warming:

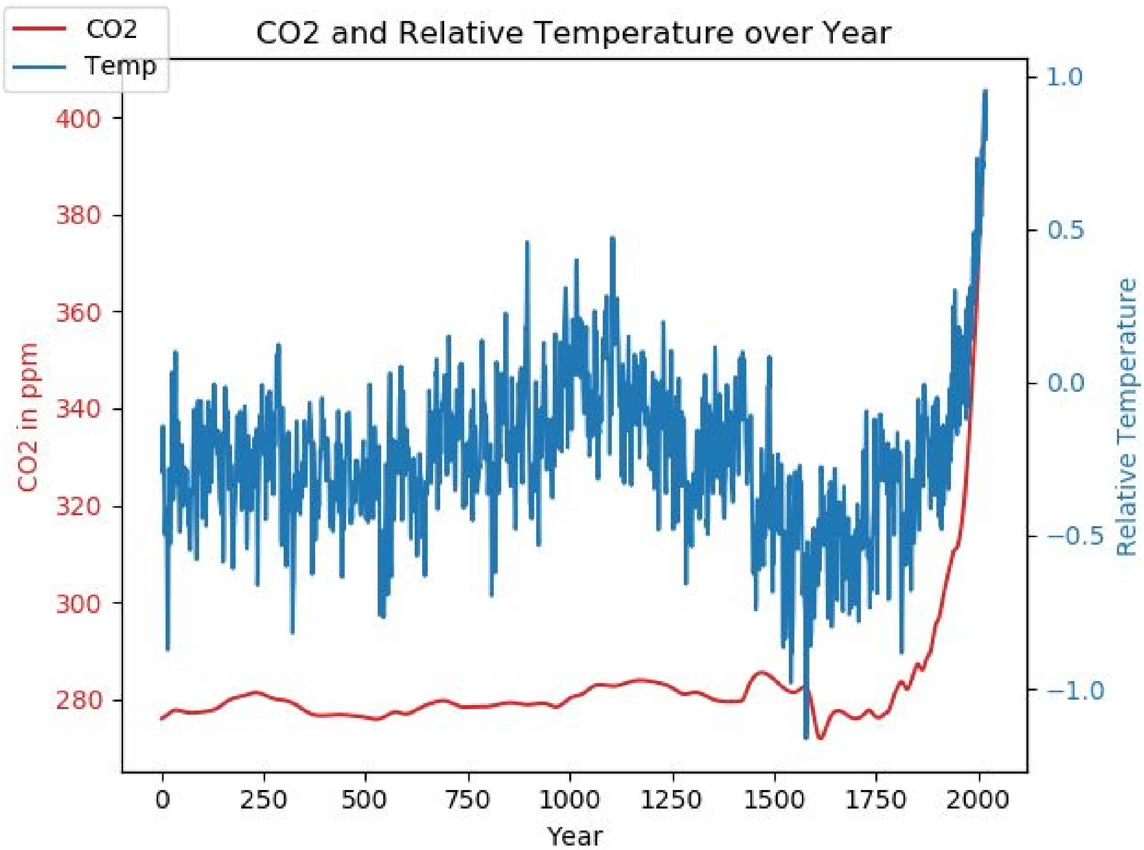
- $c = \frac{Ws}{kg \cdot K}$, hence:
- $\frac{c \cdot kg}{W} = \frac{s}{K}$
- Unit of right side: s / K, ie **seconds per Kelvin**
- This is the time in seconds needed for 1 degree temperature increase (Kelvin or Celsius).
- For every square meter of ocean we get the mentioned 2W radiative forcing
- But to what **depth** do we have to consider the oceans?
- The so-called "thermocline" is a kind of insulating boundary layer to the deep sea.
- https://de.wikipedia.org/wiki/Thermokline
- It extends roughly from 200-1000m depth in the oceans.
- Let's assume the middle of the layer at **600m** as the limit to which energy penetrates from the surface.
- Water has a mass of 1000 kg per cubic meter
- For each square meter and 600m water depth we have a water mass of 600m * 1000 kg / m^3 =**600000 kg / m^2**
- We insert this mass of 600000 kg / m^2 in our formula for the time per Kelvin and expand it with 1/m^2:
- $\frac{s}{k} = \frac{c \cdot kg}{W} = \frac{c \cdot kg/m^2}{W/m^2}$
- This leads to:
- s/ K = 4.2 * 10^3J / (kg * K) * 600000 kg / m^2 / (2 W / m^2) = (4.2e3 * 600e3 / 2) s/K
- = 1260000000.0 s/K = **1.26e9 s/K**
- This is now the time in seconds for 1 degree temperature increase. We can convert this to years by dividing by the number of seconds per year.

- 1 year = 60*60*24*365 s = 31536000 s = 31.536e6 s
- So: 1.26e9 s/K = 1.26e9 / 31.536e6 years/K
- = **39.95 years**
- **Over the last 40 years (1980-2019) we indeed had an increase of global temperature of about 1 degree Celsius (shown next), so this is a good fit.**

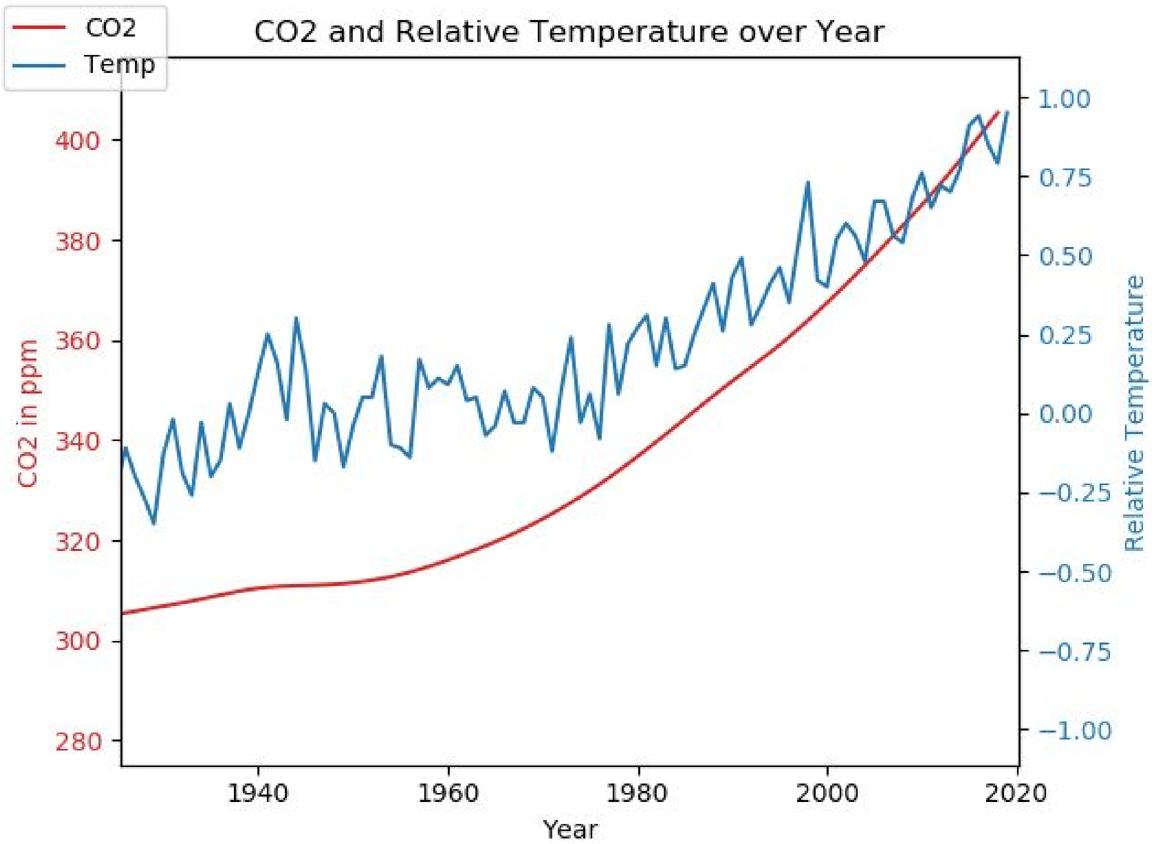
Historical temperature values

- We can obtain global temperature values, as relative temperatures (they are more accurate than absolute values), from1880 to present as a csv file:
- https://www.ncdc.noaa.gov/cag/global/time-series/globe/land_ocean/1/6/ 1880-2019.csv
- For the last 1000 years:
- https://www.temperaturerecord.org
- Below is a link for the last 2,000 years that we store and convert to csv:
- historical_temperature_dataset_0-1979_py.csv
- We combine both datasets using a Python Program, and plot it, along with the CO2 values.
- We start the program in the terminal with:
    - `python3 dataplot_twinplot2.py`
- The blue curve represents the combined temperature data

- The red curve is the CO_2 data for comparison
- We see: our **today's deviation of** the temperature from the annual mean is already **bigger than during the "small ice age"** in the Medieval Age, and **much warmer than at the time of the Roman empire!**



- We can zoom in on the modern times and see:
- From about 1980 we have a **temperature increase of about 1 degree, as we calculated!**



Conclusion

- Our estimation shows that the global **temperature rise is caused by the increased CO2 concentration.**
- With the further emissions of fossil CO2, the radiative forcing will continue to increase, and the **temperature rise will accelerate.**