Exercises #3

- Sustainability, climate and energy

Today's goals

- Some important notions:
  - Radiative forcing
  - Water vapor and Clausius-Clapeyron equation
- Key feedbacks
- Average feedback
- Discussion around an article. Interview of Bjorn Stevens in « Die Zeit », October 2022

Radiative forcing of GHG

- Important work of Myhre et al. (1998). Use of the HITRAN spectral absorption bands.
- Use of a line-by-line radiative transfer model.
- Horizontal homogeneity.
- Corresponds to a Radiative Forcing RF, only considering stratospheric adjustment.
- RF calculated at the tropopause.
- Adjustment for overlaps of CO2, CH4 and N2O spectral bands.

GEOPHYSICAL RESEARCH LETTERS, VOL. 25, NO.14, PAGES 2715-2718, JULY 15, 1998

New estimates of radiative forcing due to well mixed greenhouse gases

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Trace gas	Preindustrial mixing ratio, x_0, ppb	2016 mixing ratio, x, ppb	Expression for forcing, $W{\cdot}m^{-2}$
CO_2	278×10^3	403×10^3	$5.35(\ln x - \ln x_0)$
CH_4	700	1843	$0.036(\sqrt{x} - \sqrt{x_0})$
N_2O	270	329	$0.12(\sqrt{x} - \sqrt{x_0})$
CCl_2F_2	0	0.512	$0.33\,(x - x_0)$

Source: Schwartz, 2018 ; based on Myhre et al., GRL 1998

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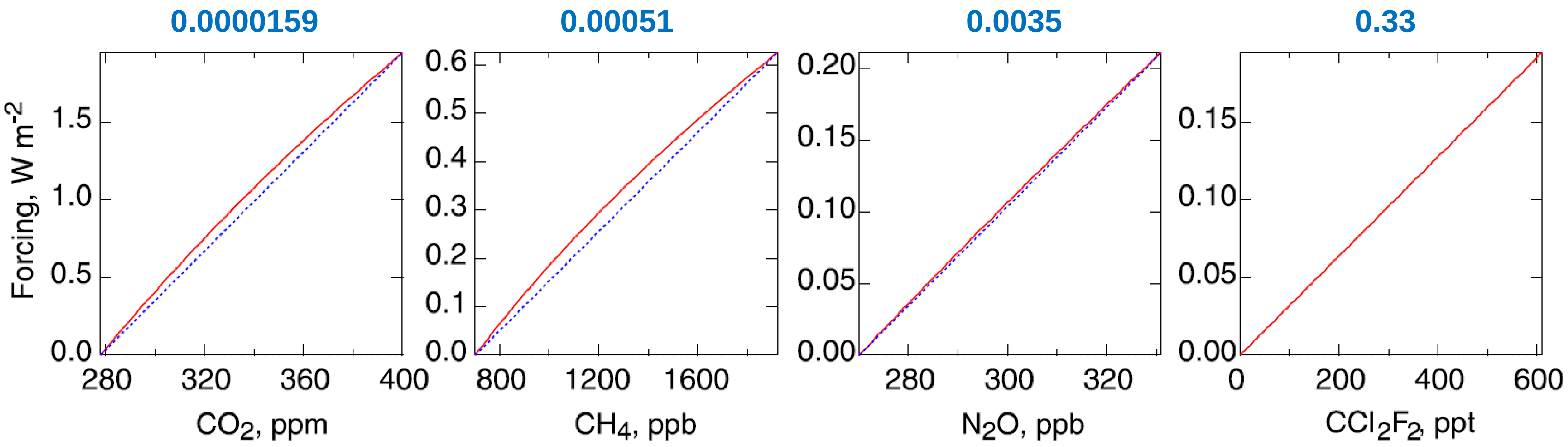
Calculate the relative forcing in 2016 compared to pre-industrial, for all the four GHG on the slide.

sublinear
sublinear
sublinear
linear

The results appear as red lines in the graphs below.

Slopes of linear fits (blue dotted): units in $W\ m^{-2}\ ppb^{-1}$



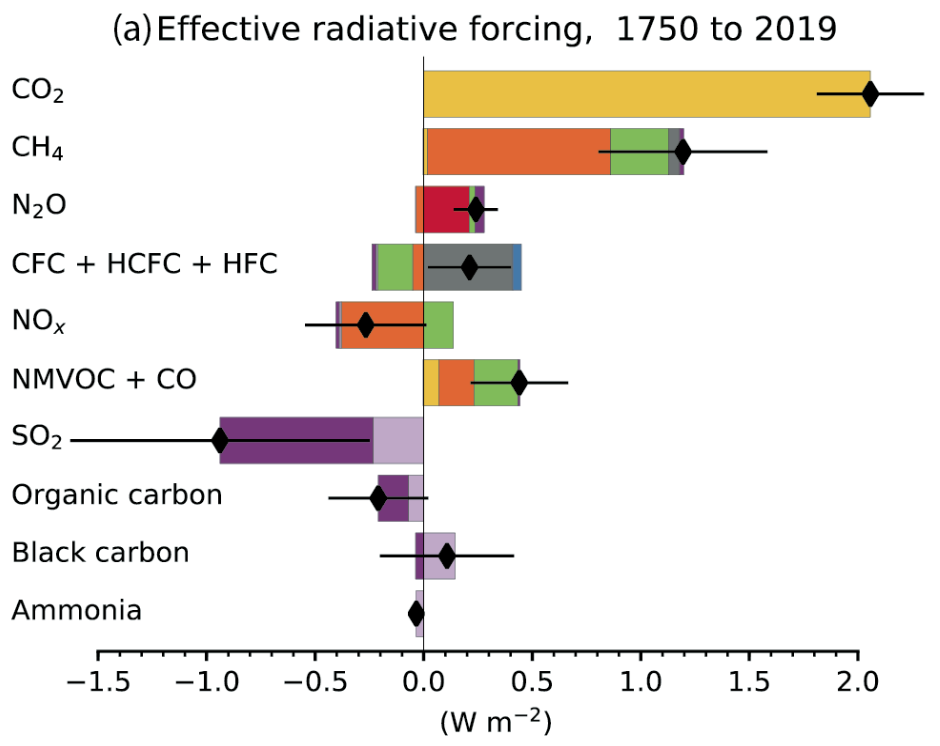
Source: Schwartz, 2018 ; based on Myhre et al., GRL 1998

Solution

Calculate the relative forcing in 2016 compared to pre-industrial, for all the four GHG on the slide.

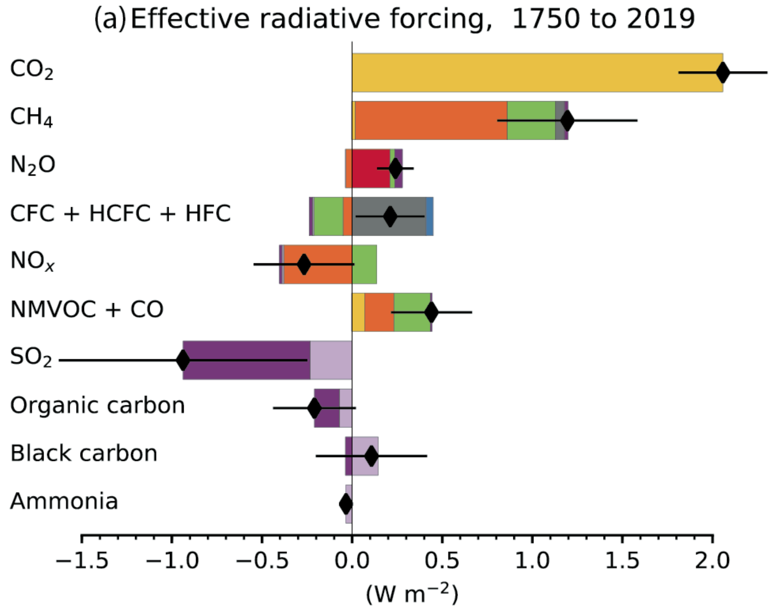
- Solution:
  - CO_2 = 1.99 $W.m^{-2}$
  - CH_4 = 0.59 $W.m^{-2}$
  - N_2O = 0.20 $W.m^{-2}$
  - CCl_2F_2 = 0.17 $W.m^{-2}$

- Total = 2.95 $W.m^{-2}$.
- To be compared to an ERF of 3.84 $W.m^{-2}$ since 1750 according to IPCC AR6.



Why such difference ?

- Total = **2.95 W.m^{-2}**.
- To be compared to an ERF of **3.84 W.m^{-2}** since 1750 according to IPCC AR6.



- Why such difference ?
  - Other GHG contributors.
  - Updated concentrations.
  - Refined radiative transfer models.
  - Refined overlap between CH_4 and N_2O.
  - IPCC AR6 focuses on ERF (rapid feedbacks) instead of RF.

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Water vapor and Clausius-Clapeyron

- The Clausius-Clapeyron equation give the temperature dependence of vapor pressure.
- When applied to gases considered as following the ideal gas law, it can be applied to the vaporization of liquids.
- For water vapor, the equation is:

$$\frac{\Delta e_s}{\Delta T} = \frac{e_s L_v}{T^2 R_v}$$

- Where:
  - e_s = equilibrium vapor pressure ($kg.m^{-1}.s^{-2}$)
  - T = temperature (K)
  - L_v = latent heat of vaporization (2500 $kJ.kg^{-1}$)
  - R_v = specific gas constant for water vapor (461.5 $J.kg^{-1}.K^{-1}$)

Calculate how much more water vapor the atmosphere can hold for a warming of 1°C, starting from a temperature of 14°C.

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$$\frac{\Delta e_s}{\Delta T} = \frac{e_s L_v}{T^2 R_v} \Rightarrow \frac{\Delta e_s}{e_s} = \frac{L_v}{T\, R_v} * \frac{\Delta T}{T}$$

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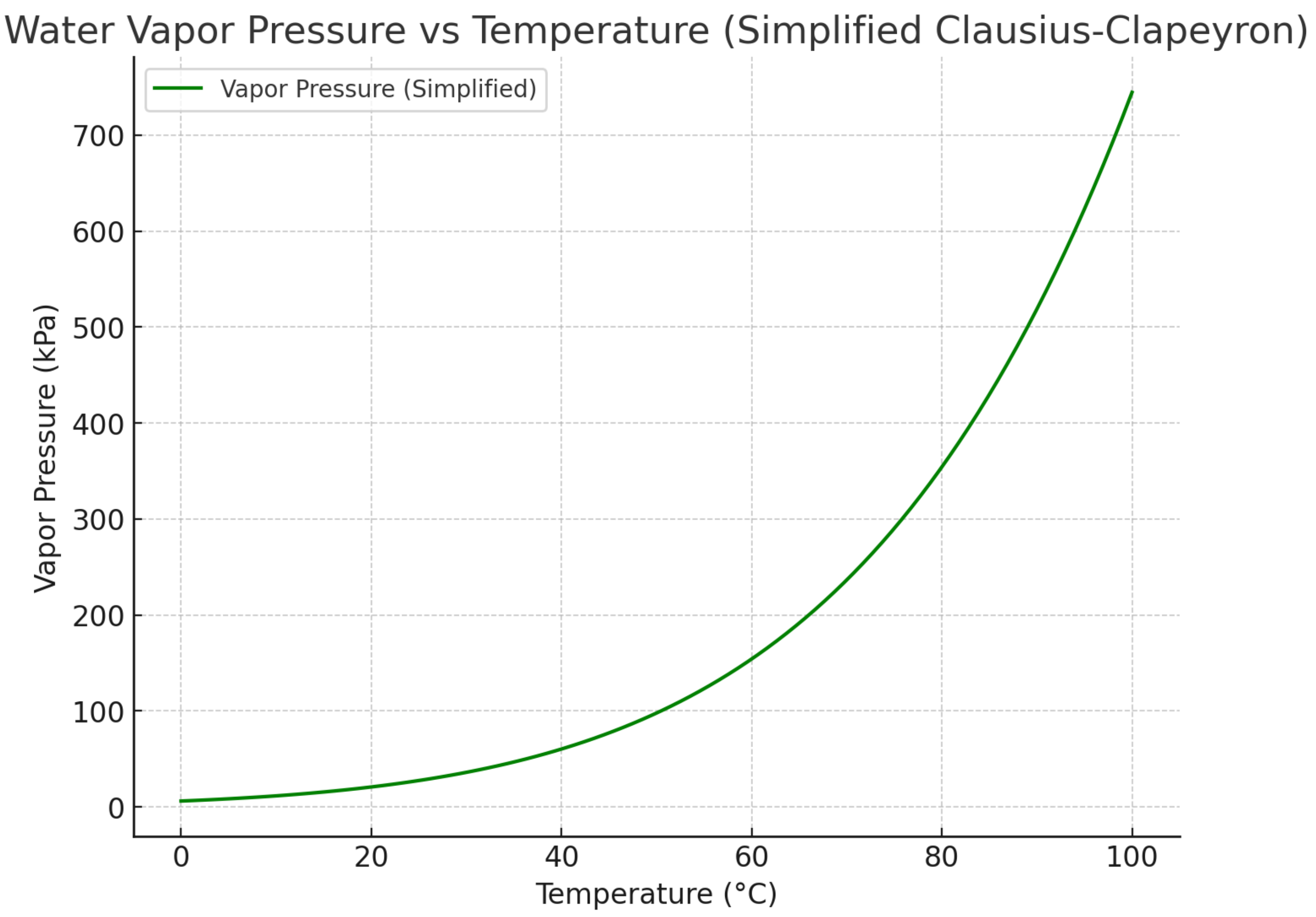
$$\frac{\Delta e_s}{e_s} = \frac{2500.10^3}{287 \times 461.5} \times \frac{1}{287} = 6.6\ \%$$

Calculate how much more water vapor the atmosphere can hold for a warming of 1°C, starting from a temperature of 14°C.

Solution

- Water vapor pressure roughly increase exponentially with temperature.
- This explains why the water vapor feedback is important in climate science.
- It strongly amplifies the radiative forcing from greenhouse gases.
- It’s a **feedback response** to temperature change, **not a forcing factor** (anthropogenic emissions of H_2O are negligible compared with natural fluxes due to evaporation / condensation).

$\lambda = 1.8\ W.m^{-2}.°C^{-1}$



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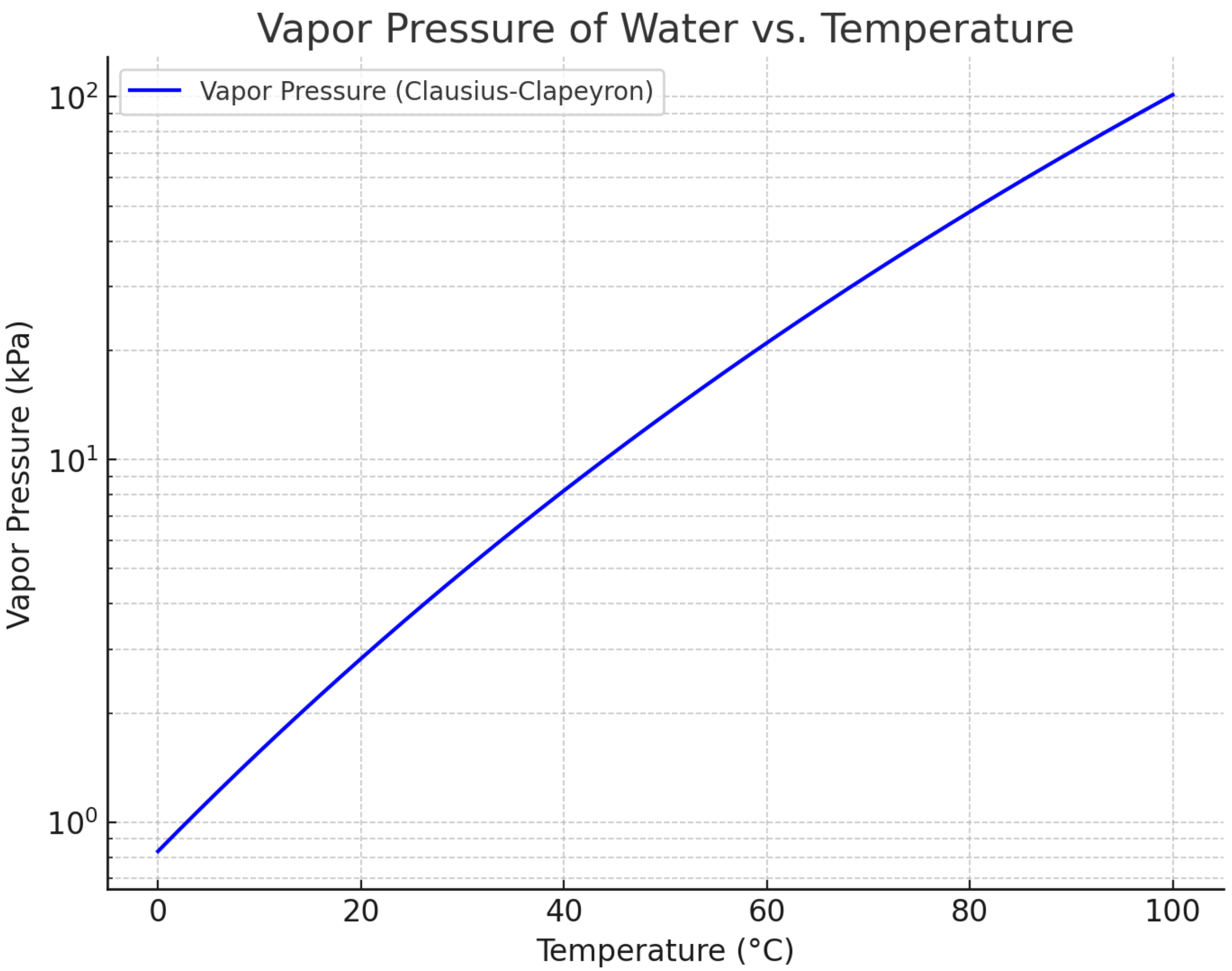

λ = 1.8 W.m^{-2}.°C^{-1}

What happens at 100°C ?

The water vapor pressure reaches 100 hPa. Liquid water boils !

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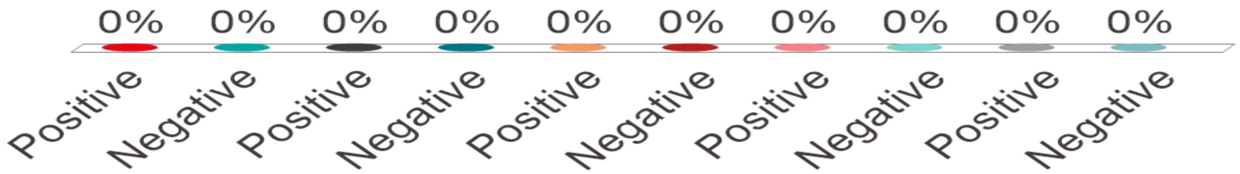
What is the sign of these feedbacks ?

Feedback	Positive or Negative ?
Planck	A. Positive ✓ B. Negative
Water vapor	✓ C. Positive D. Negative
Surface albedo (snow)	✓ E. Positive F. Negative
Lapse rate	G. Positive ✓ H. Negative
Clouds	✓ I. Positive ✓ J. Negative



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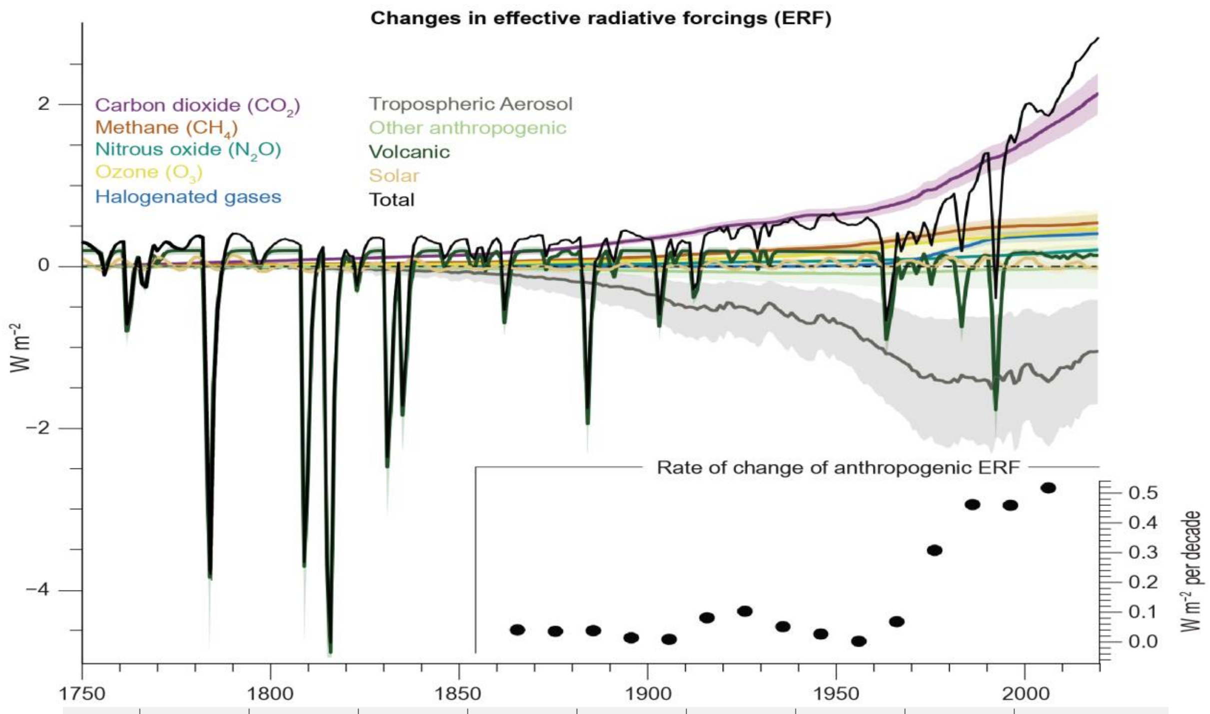
Climate feedback

$$N = RF + \lambda \Delta T$$

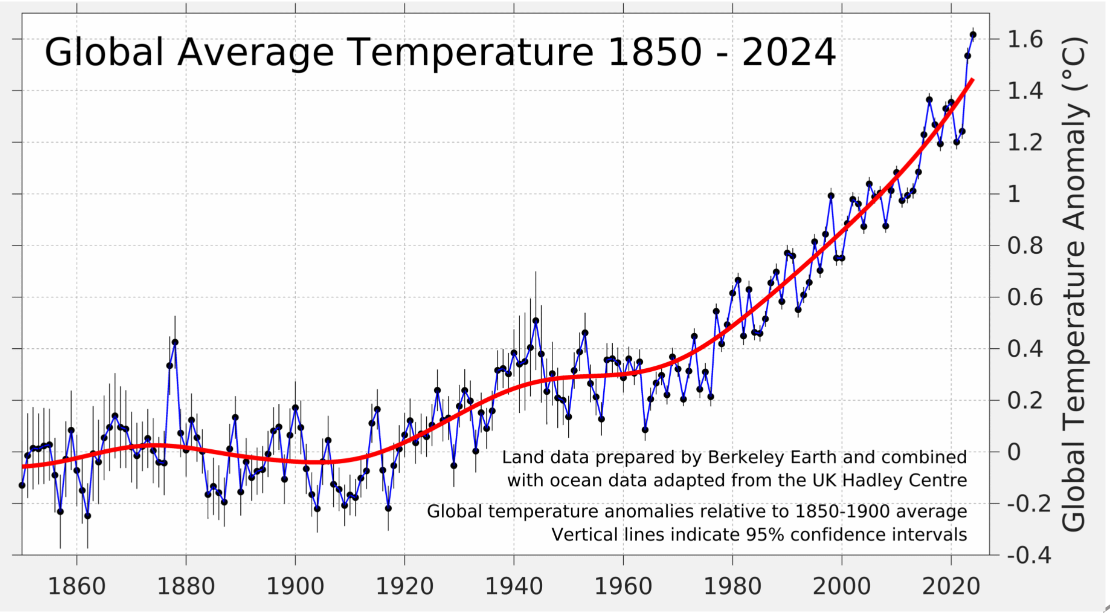
N: Top of atmosphere radiative imbalance.
RF: radiative forcing.
ΔT: global surface temperature response.
λ : feedback factor.

Can you estimate an average feedback factor from the two graphs ?

RF



ΔT



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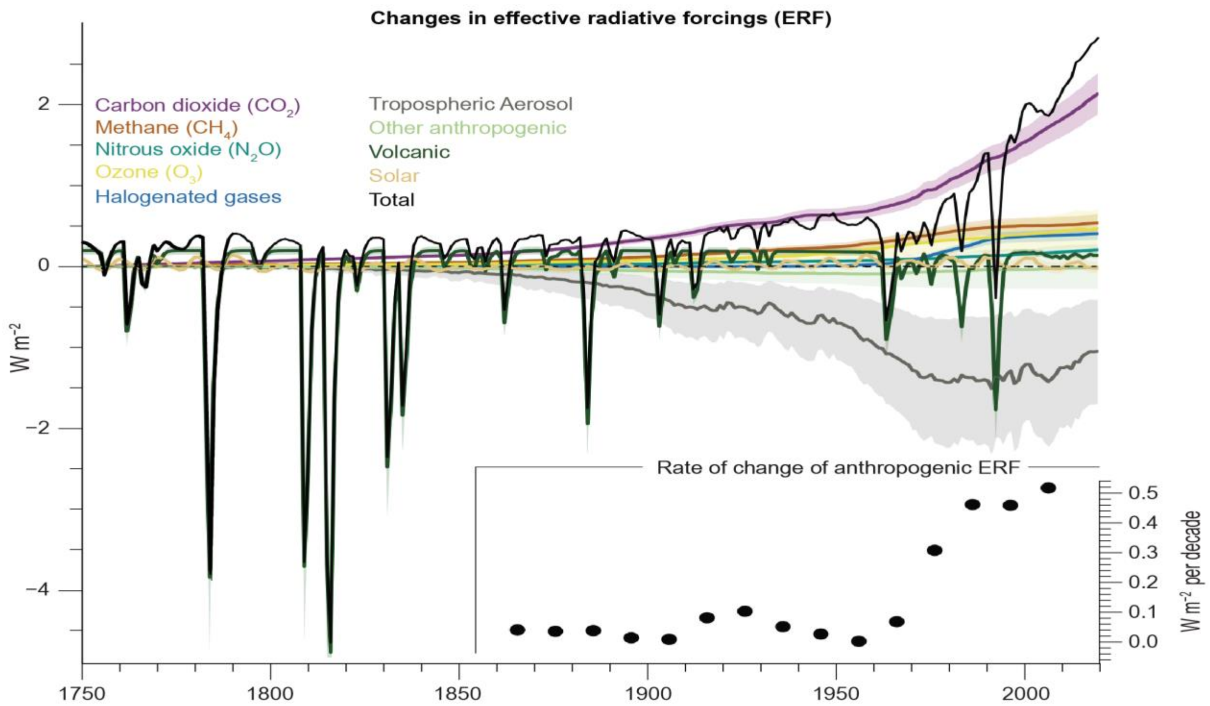
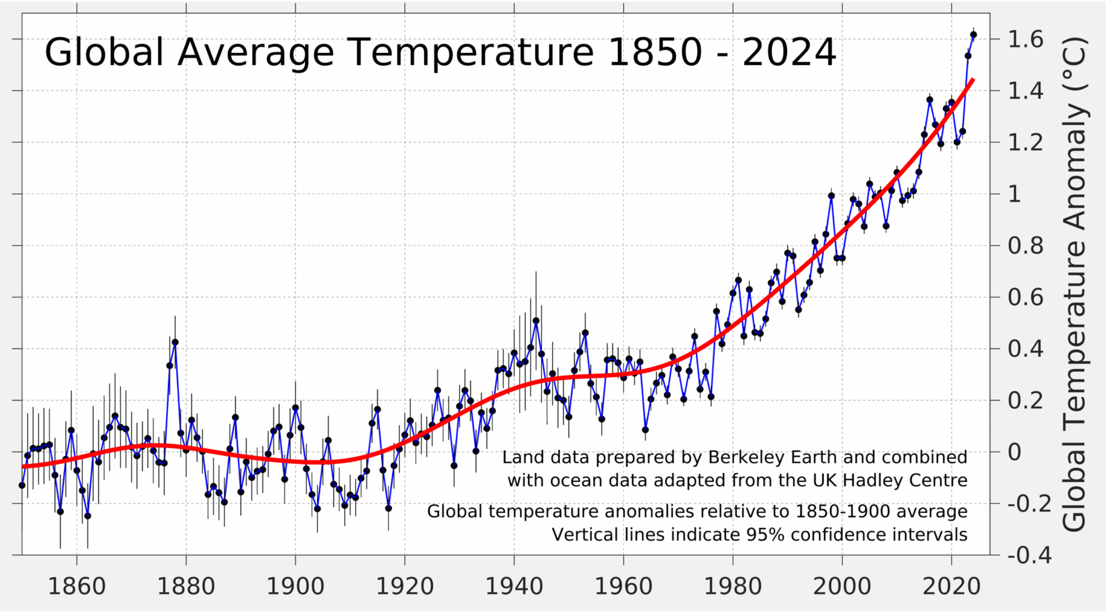


ΔT



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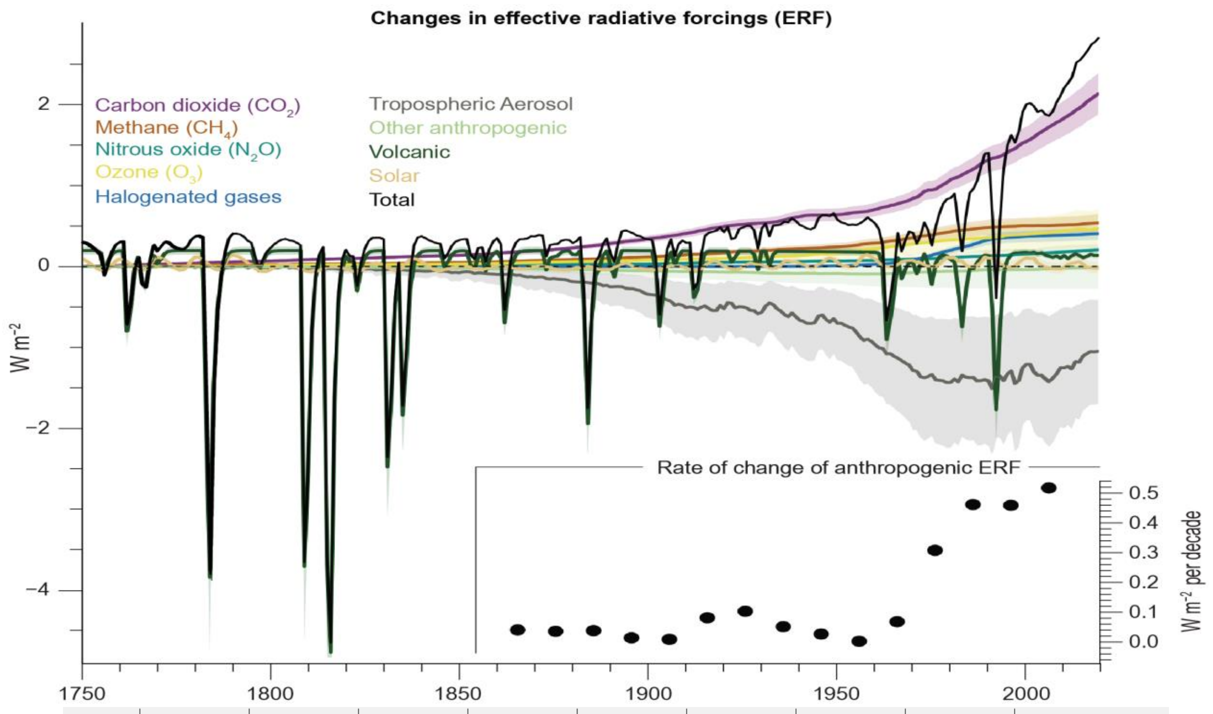
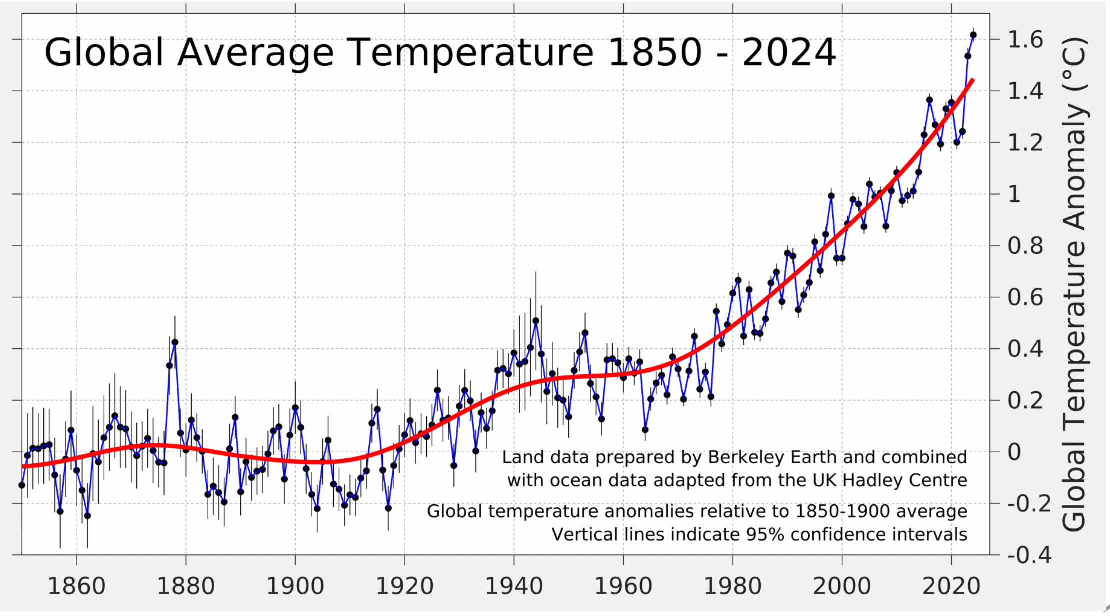
Can you estimate an average feedback factor from the two graphs ?

- We assume equilibrium. $N = 0$
- Then: $\lambda = -\frac{RF}{\Delta T}$
- Total ERF in 2020: **2.72 W.m^{-2}** since 1750.
- **Best estimate of** ΔT between 1850-1900 and 2010-2019 = **+1.07°C**.
- **λ = -2.5 W.m^{-2}.°C^{-1}.**

RF



ΔT



Does it make sense ?

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- Total ERF in 2020: **2.72 W.m^{-2}** since 1750.
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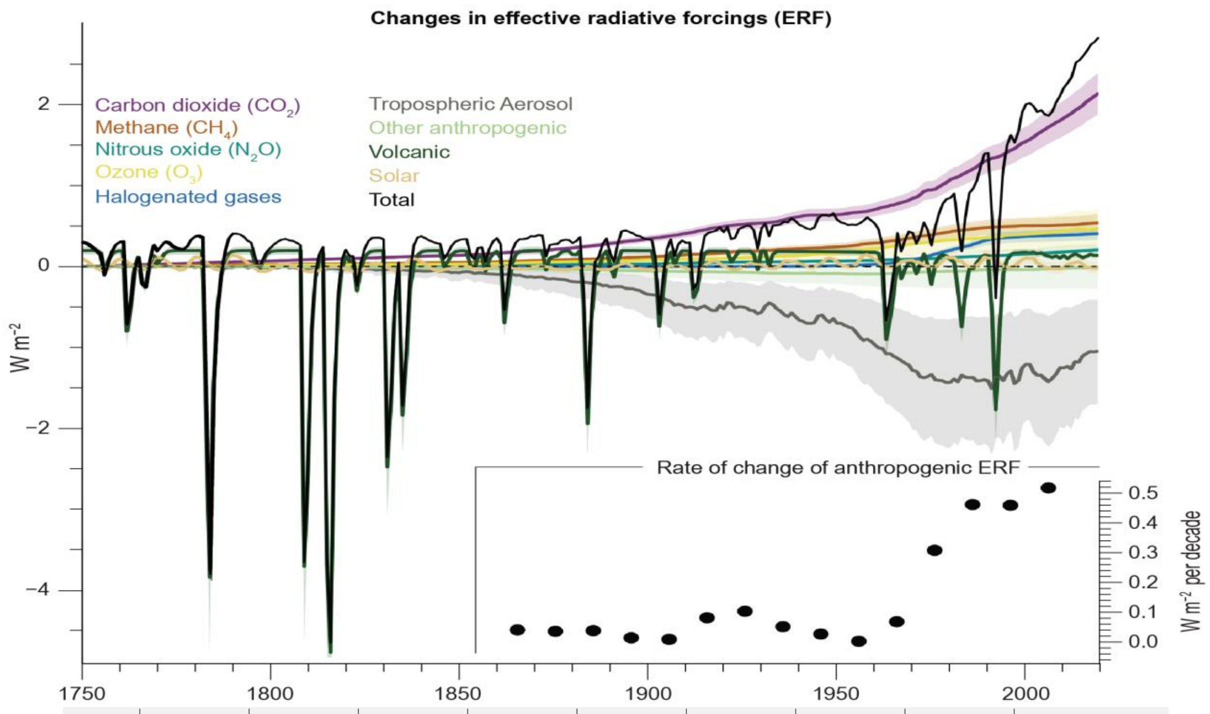

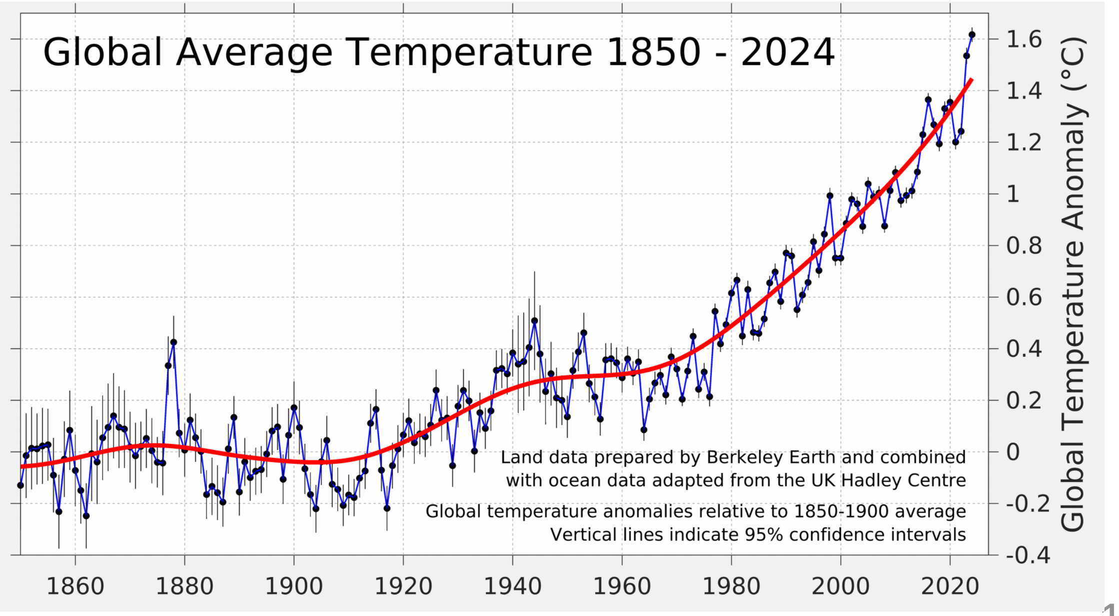

It's a first-order, «back of the envelope» calculation.
Clear over-simplification !

- We are not in equilibrium.
- There are expected time lags due to slow feedbacks.
- Some feedbacks are not necessarily linear.
- The radiative forcing of GHG and aerosols are not correlated, so the ERF changed through time.

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EPFL

Discussion around an interview

- Interview of Prof. Bjorn Stevens, published in «Die Zeit» on October 2022.
- Bjord Stevens is Director at the Max Planck Institute for Meteorology, the principal German climate science research and modeling centre.
- He is a specialist of climate sensitivity, aerosols and clouds.
- He was co-author of the chapter on clouds and aerosols for the IPCC AR5 report.

https://judithcurry.com/2022/10/22/an-interview-with-top-climate-scientist-bjorn-stevens/

Your reactions in a few words