

- 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, $\text{W} \cdot \text{m}^{-2}$
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 ₂ O	270	329	$0.12(\sqrt{x} - \sqrt{x_0})$
CCl ₂ F ₂	0	0.512	$0.33(x - x_0)$

Radiative forcing of GHG

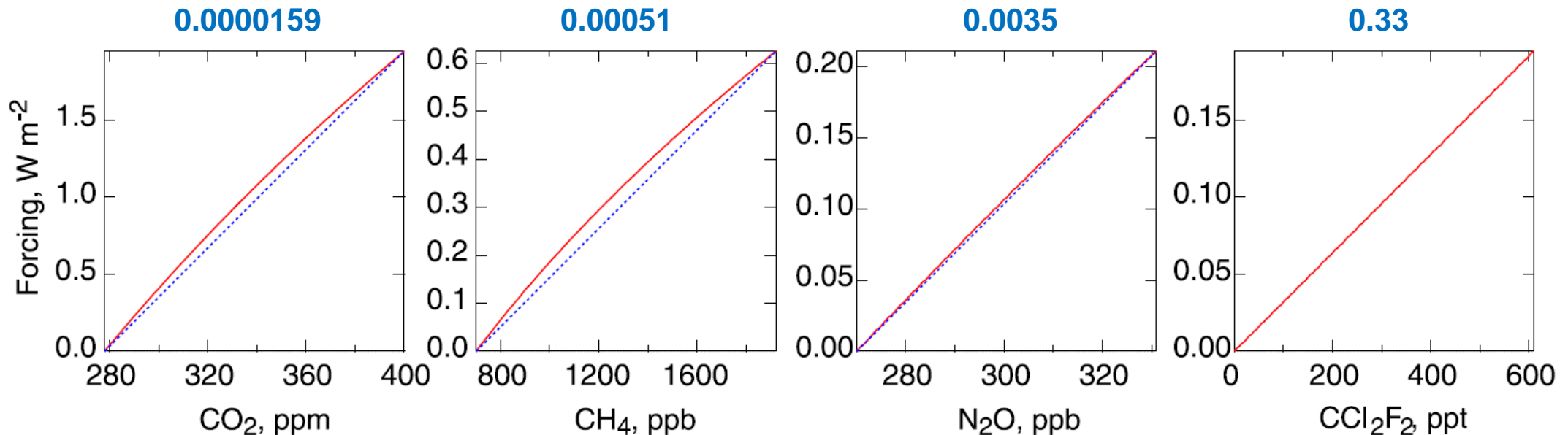
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Calculate the relative forcing in 2016 compared to pre-industrial, for all the four GHG on the slide.

sublinear
sublinear
sublinear
linear

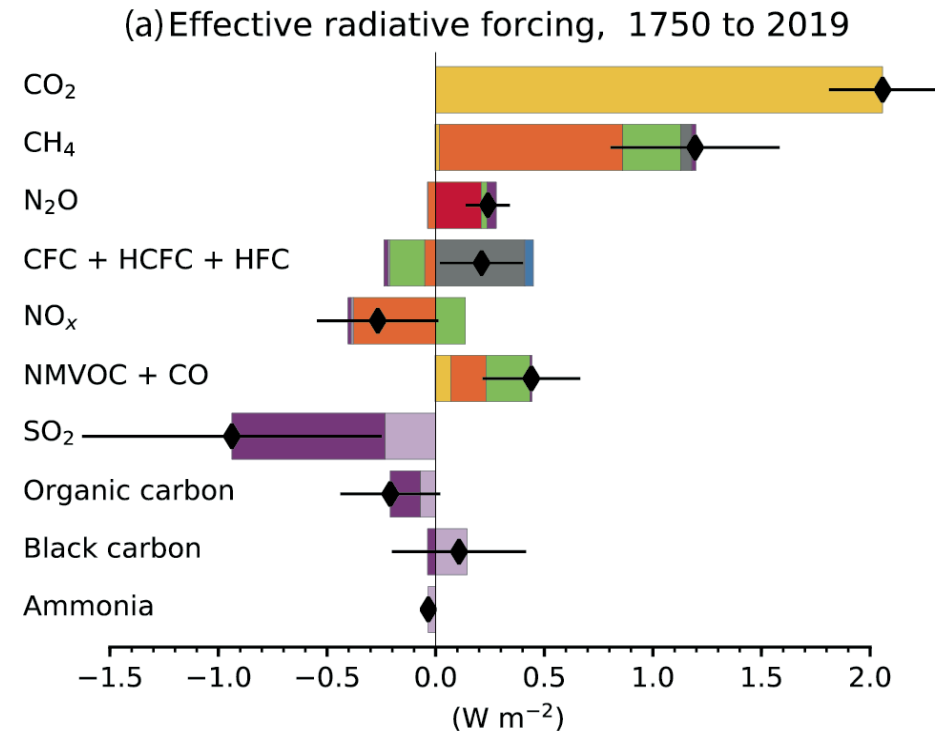
The results appear as red lines in the graphs below.

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



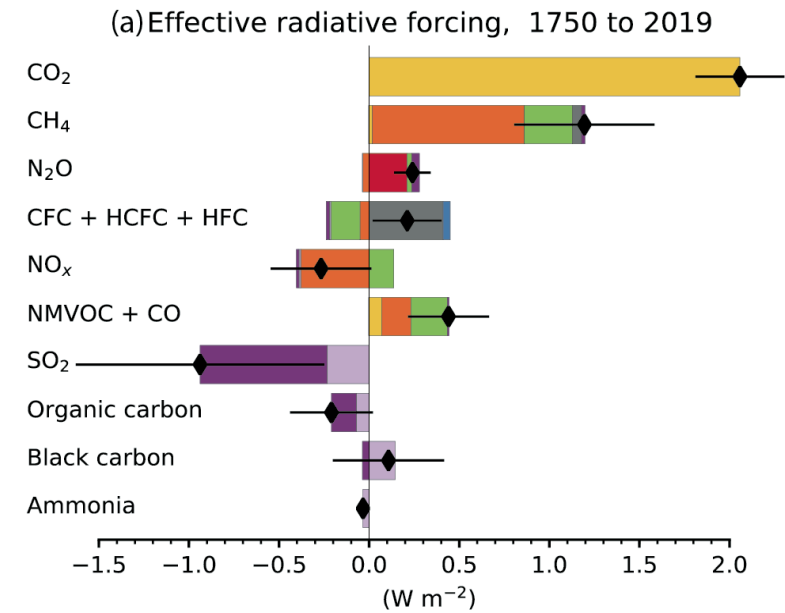
Calculate the relative forcing in 2016 compared to pre-industrial, for all the four GHG on the slide.

- 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.



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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:

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

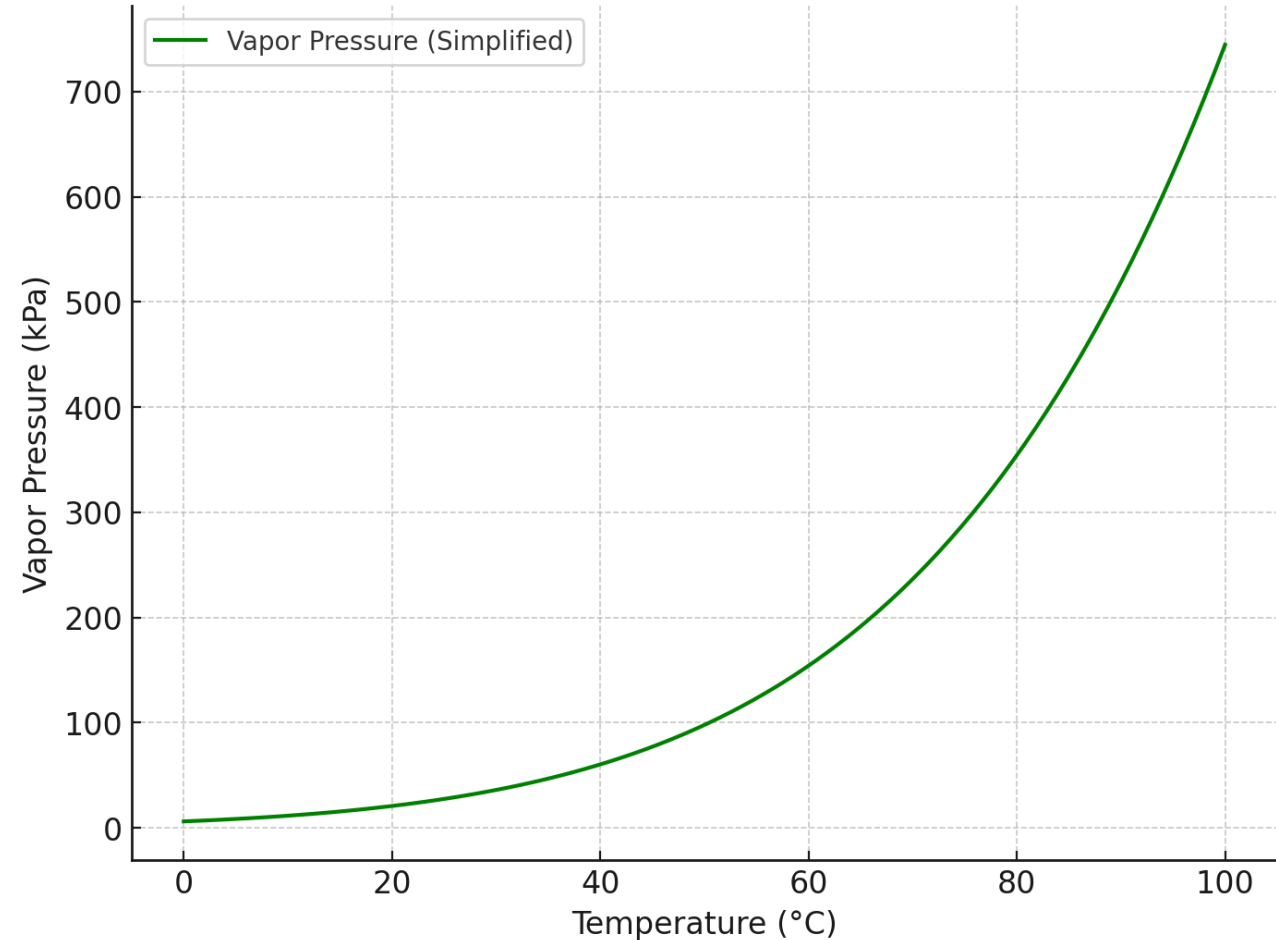
- Where:
 - e_s = equilibrium vapor pressure ($\text{kg.m}^{-1}.\text{s}^{-2}$)
 - T = temperature (K)
 - L_v = latent heat of vaporization (2500 kJ.kg^{-1})
 - R_v = specific gas constant for water vapor ($461.5 \text{ J.kg}^{-1}.\text{K}^{-1}$)

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

- 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).

$$\lambda = 1.8 \text{ W.m}^{-2}.\text{°C}^{-1}$$

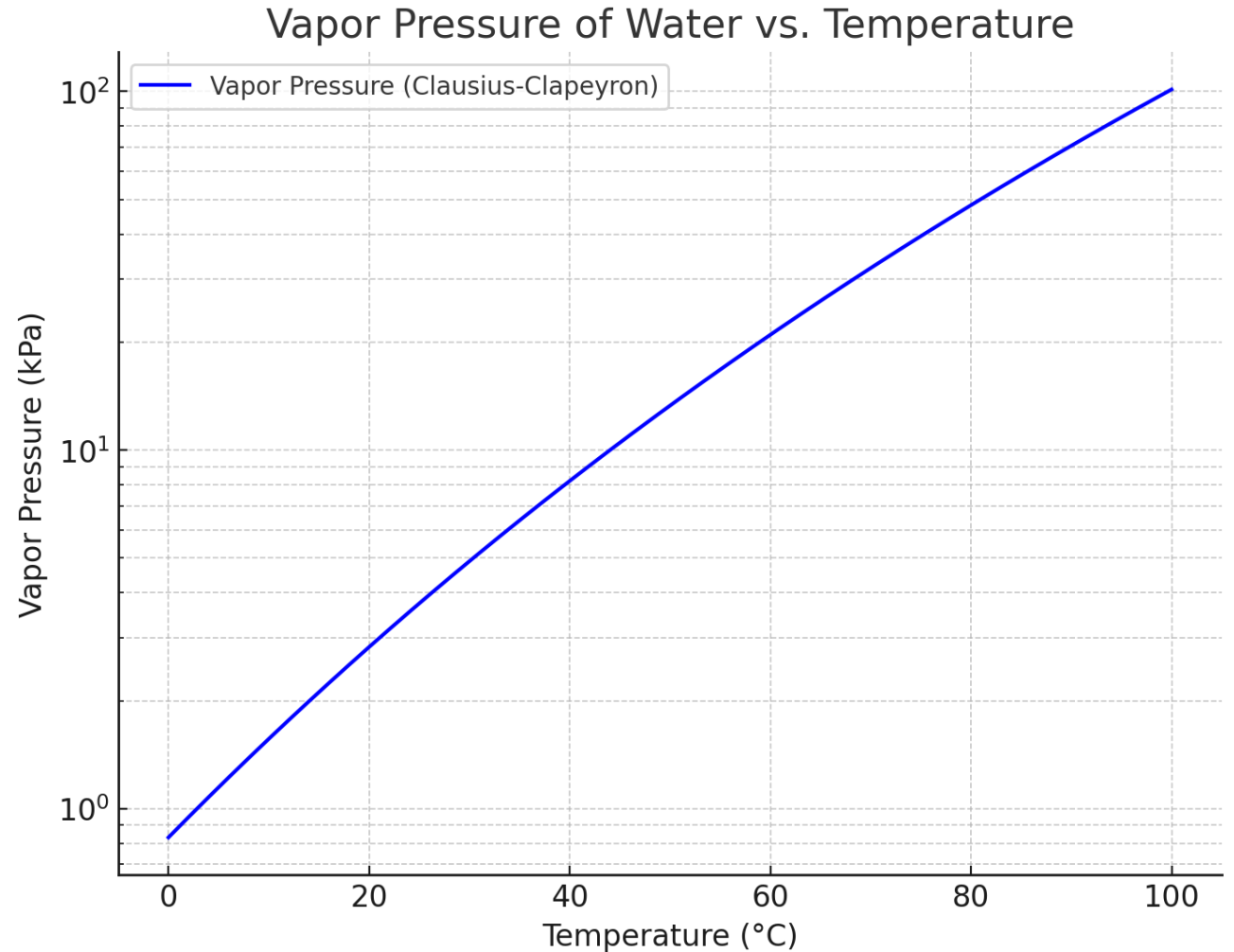
Water Vapor Pressure vs Temperature (Simplified Clausius-Clapeyron)



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$$\lambda = 1.8 \text{ W.m}^{-2}.\text{°C}^{-1}$$

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

0%

0%

0%

0%

0%

0%

0%

0%

0%

0%

Positive

Negative

Positive

Negative

Positive

Negative

Positive

Negative

Positive

Negative

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Climate feedback

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

N : Top of atmosphere radiative imbalance.

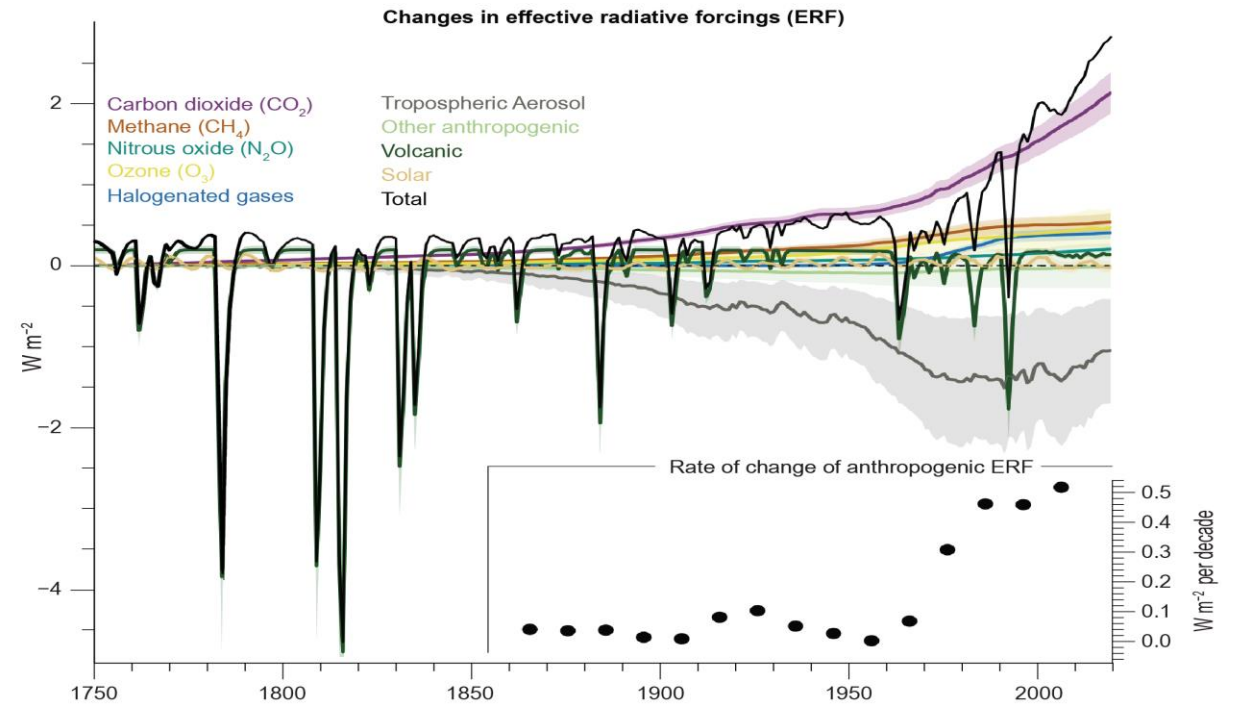
RF : radiative forcing.

ΔT : global surface temperature response.

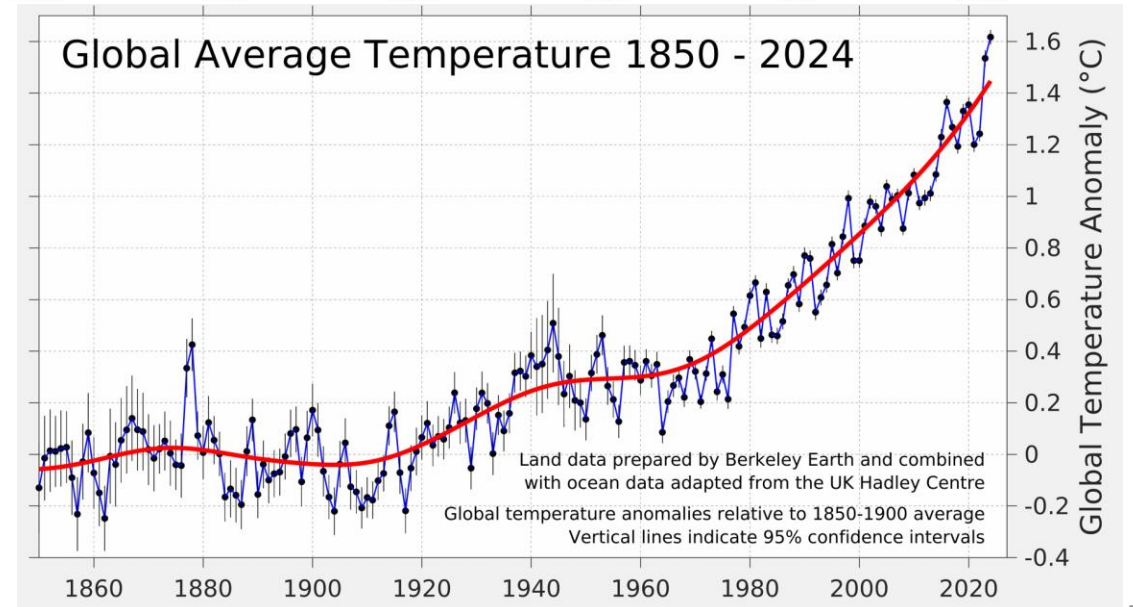
λ : feedback factor.

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

RF



ΔT



Climate feedback

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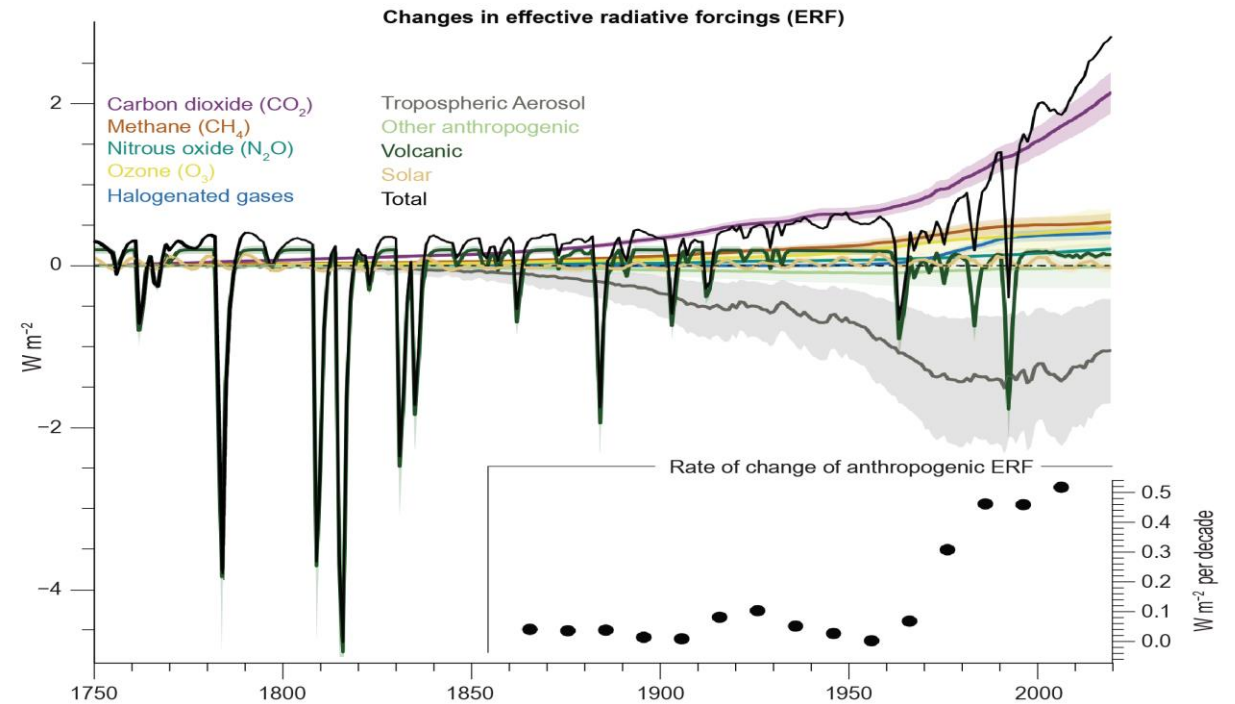
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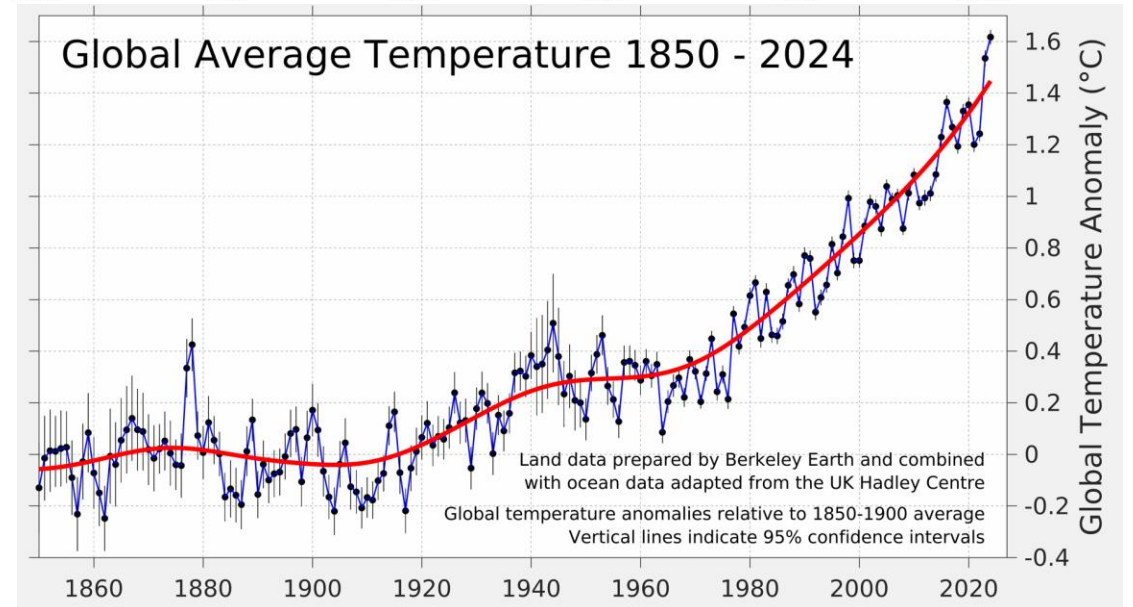
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Discussion around an interview

- 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