

- 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 CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O 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 <sub>2</sub>	$278 \times 10^3$	$403 \times 10^3$	$5.35(\ln x - \ln x_0)$
CH <sub>4</sub>	700	1843	$0.036(\sqrt{x} - \sqrt{x_0})$
N <sub>2</sub> O	270	329	$0.12(\sqrt{x} - \sqrt{x_0})$
CCl <sub>2</sub> F <sub>2</sub>	0	0.512	$0.33 (x - x_0)$

# Radiative forcing of GHG

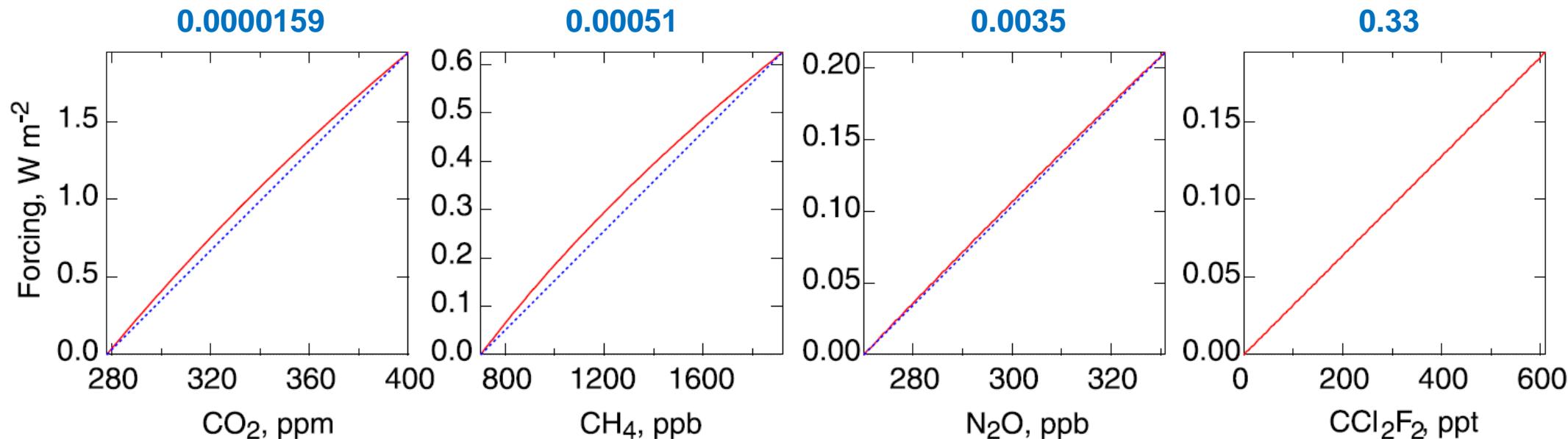
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Calculate the relative forcing in 2016 compared to pre-industrial, for all the four GHG on the slide.

sublinear  
sublinear  
sublinear  
linear

The results appear as red lines in the graphs below.

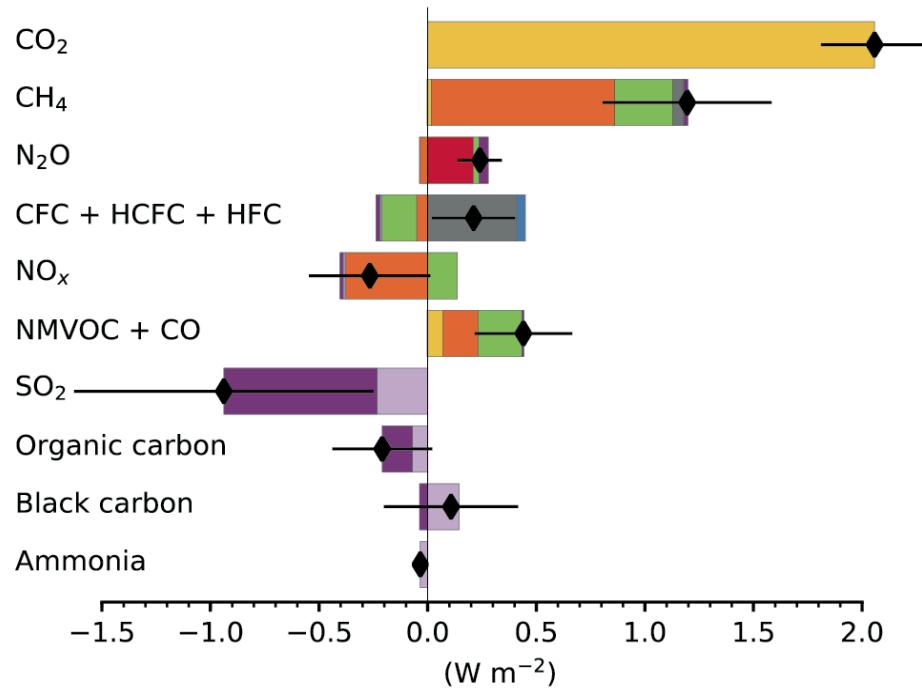
Slopes of linear fits (blue dotted): units in  $\text{W m}^{-2} \text{ ppb}^{-1}$



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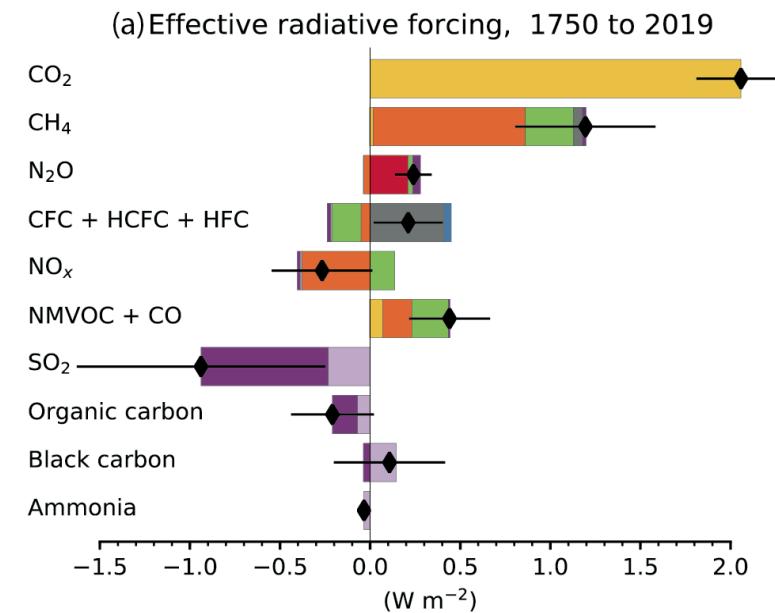
- Total =  $2.95 \text{ W.m}^{-2}$ .
- To be compared to an ERF of  $3.84 \text{ W.m}^{-2}$  since 1750 according to IPCC AR6.

(a) Effective radiative forcing, 1750 to 2019



# Why such difference ?

- Total = **2.95 W.m<sup>-2</sup>**.
- To be compared to an ERF of **3.84 W.m<sup>-2</sup>** 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:

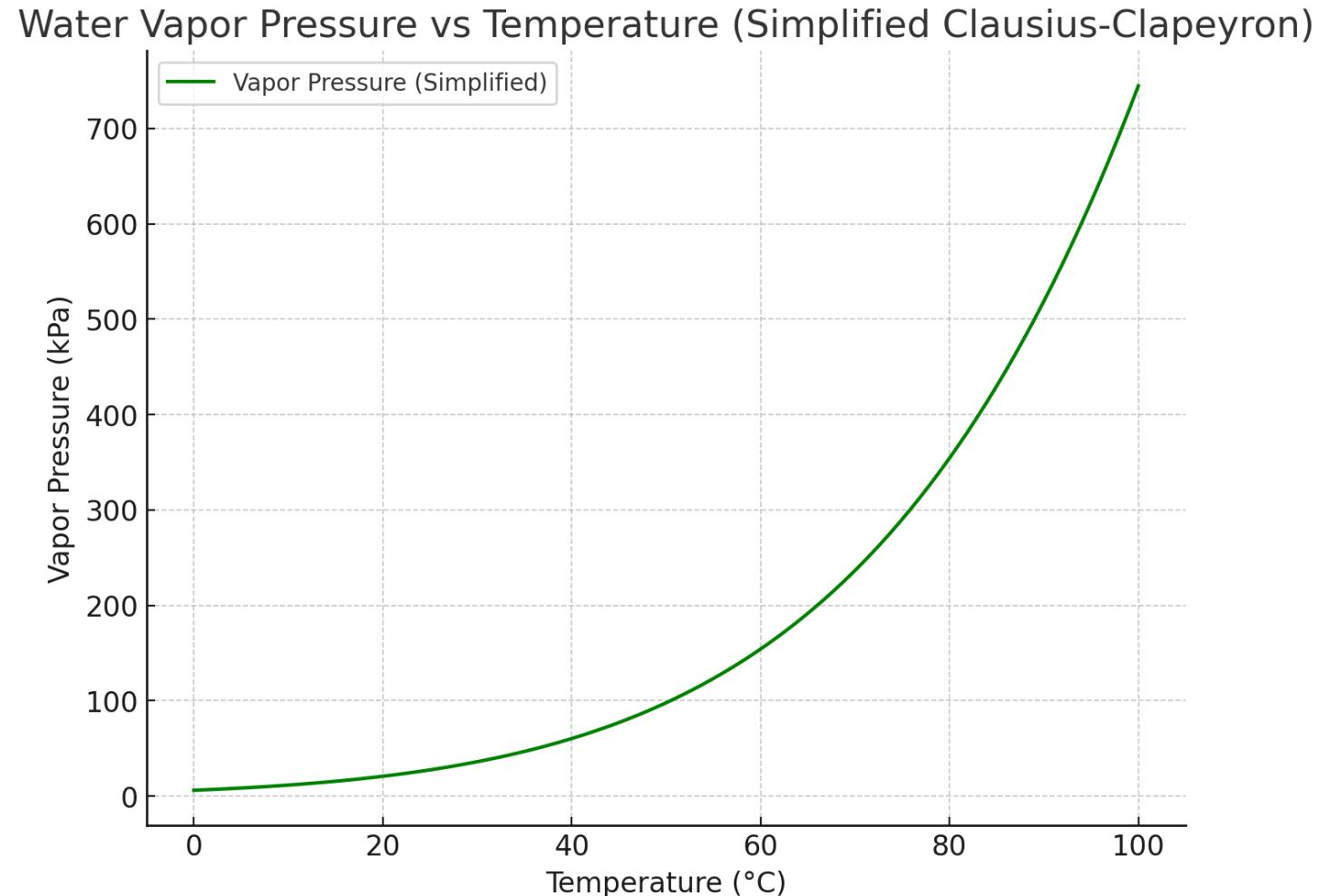
$$\frac{\Delta e_s}{\Delta T} = \frac{e_s L_v}{T^2 R_v}$$

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

**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  $\text{H}_2\text{O}$  are negligible compared with natural fluxes due to evaporation / condensation).

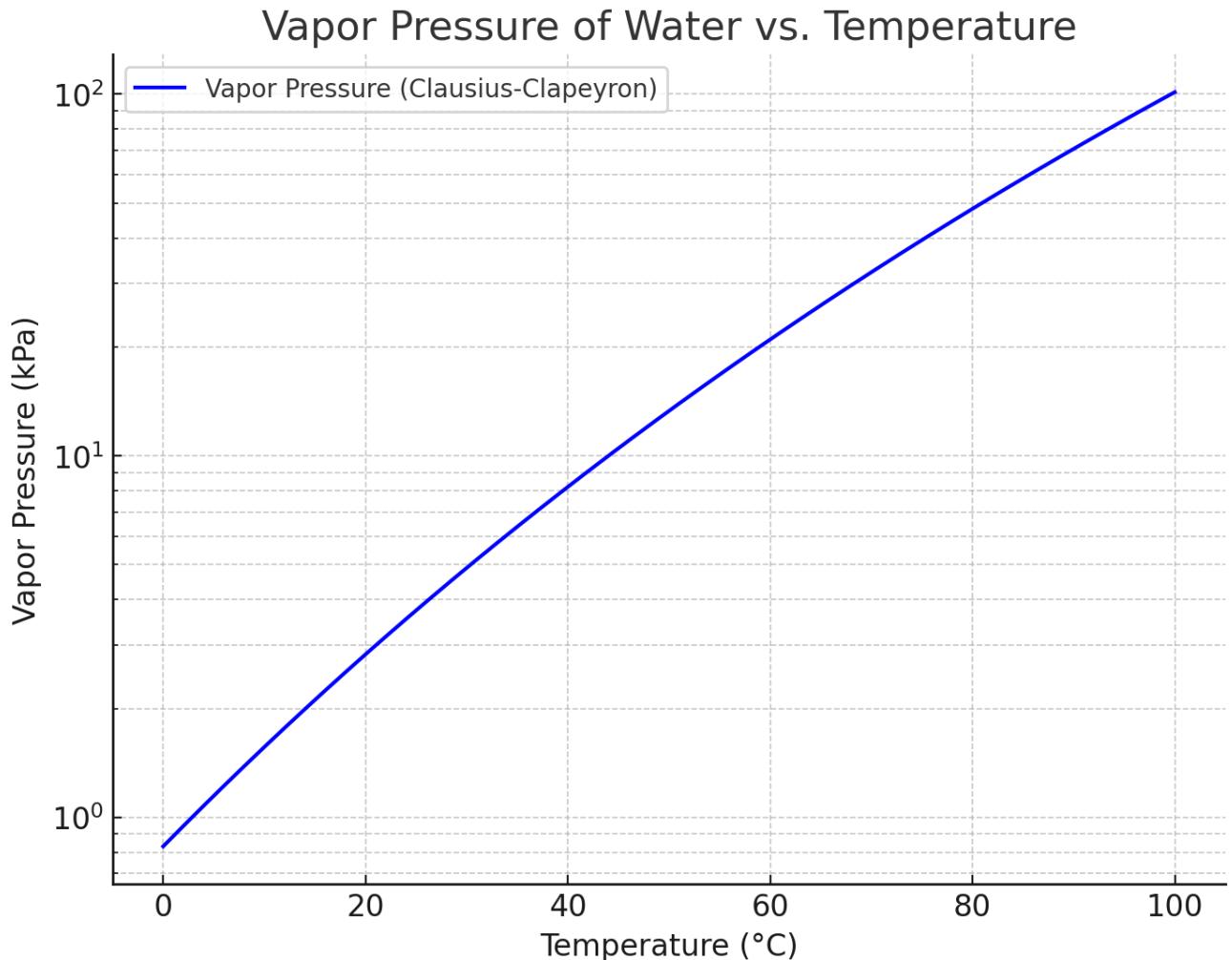
$$\lambda = 1.8 \text{ W.m}^{-2} \cdot \text{°C}^{-1}$$



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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	0% 0% 0% 5% 0% 0% 0% 0% 0% 0% 0% 0% Positive Negative Positive Negative Positive Negative Positive Negative Positive Negative Positive Negative G. Positive H. Negative I. Positive J. Negative
Clouds	

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# Climate feedback

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

N: Top of atmosphere radiative imbalance.

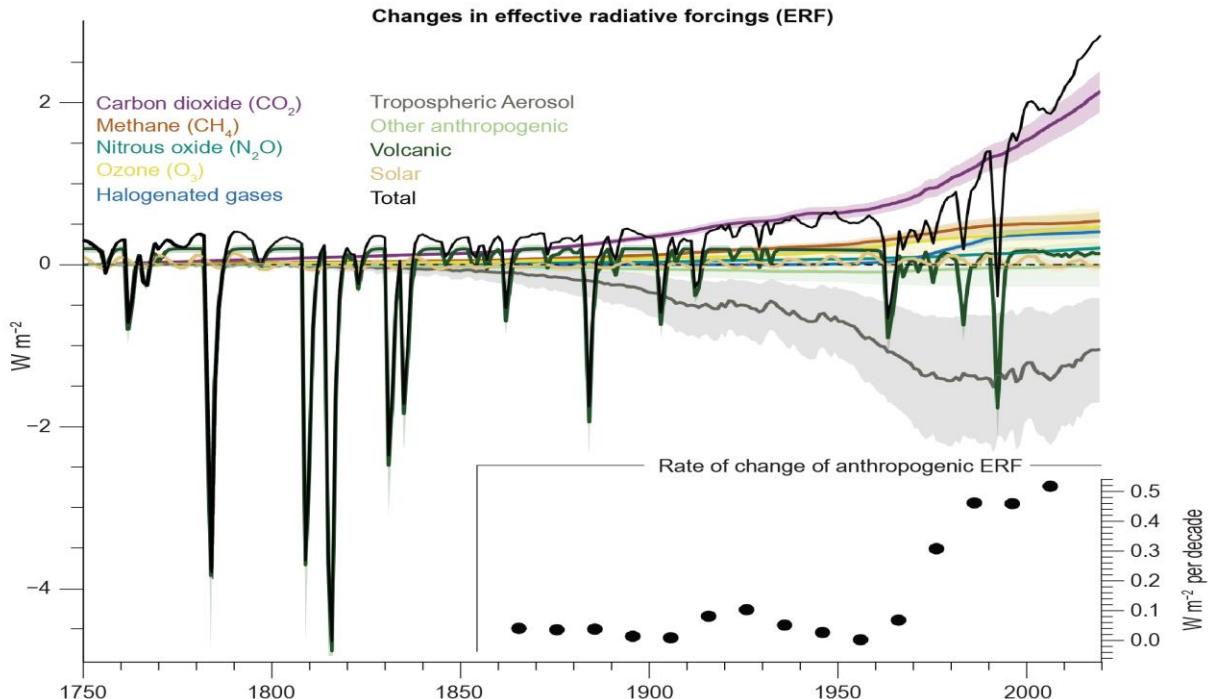
RF: radiative forcing.

$\Delta T$ : global surface temperature response.

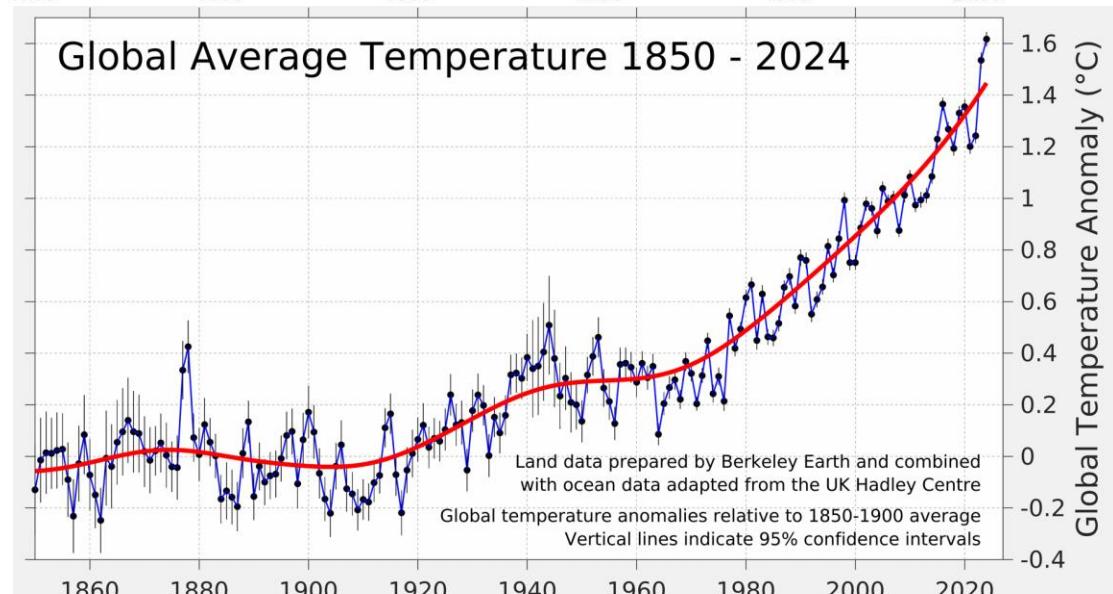
$\lambda$  : feedback factor.

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

*RF*



*$\Delta T$*



# Climate feedback

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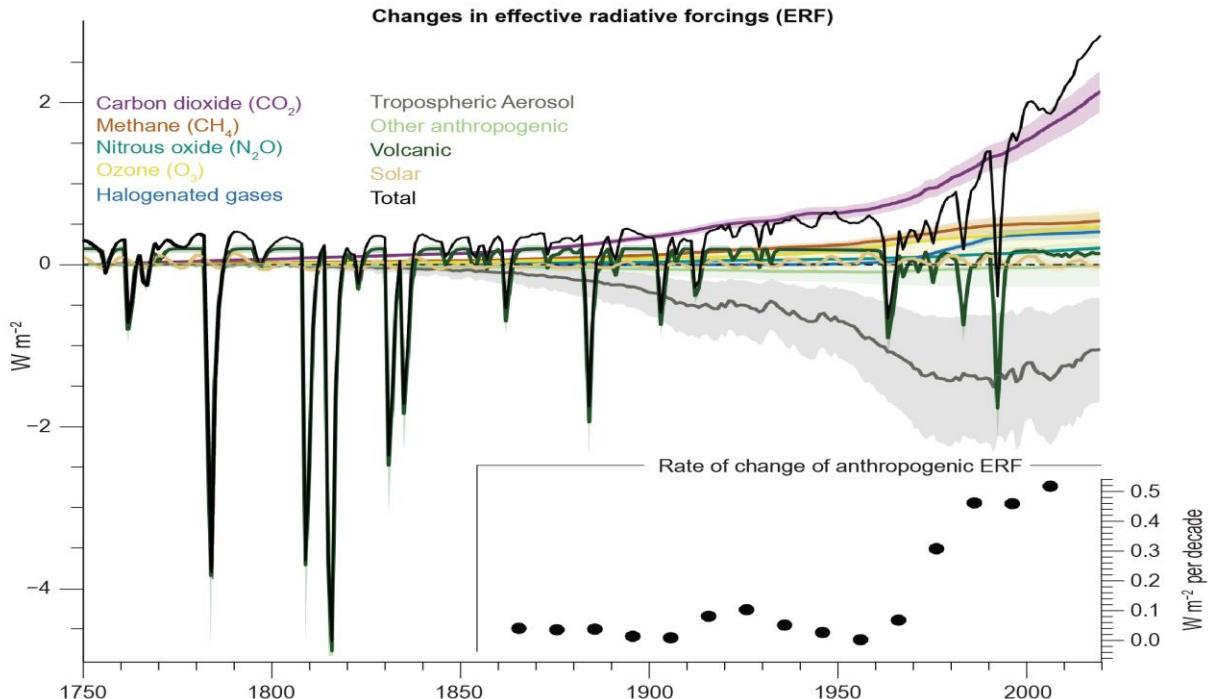
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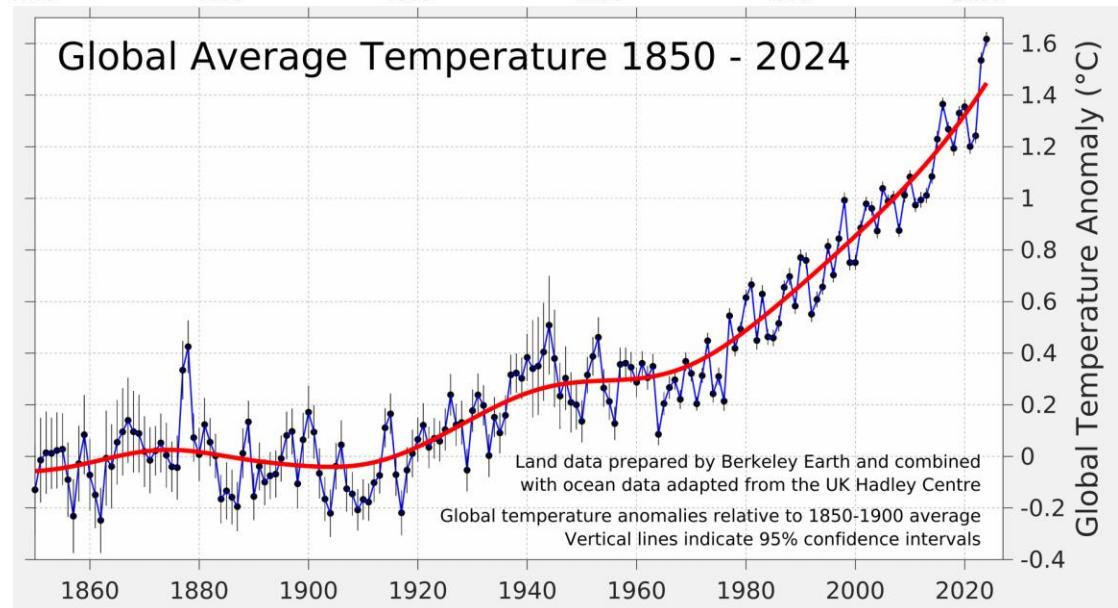
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$\Delta T$



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# Discussion around an interview

- Interview of Prof. Bjorn Stevens, published in «Die Zeit» on October 2022.
- Bjorn 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