Can feedback analysis be used to understand efficacy differences between radiative forcings?

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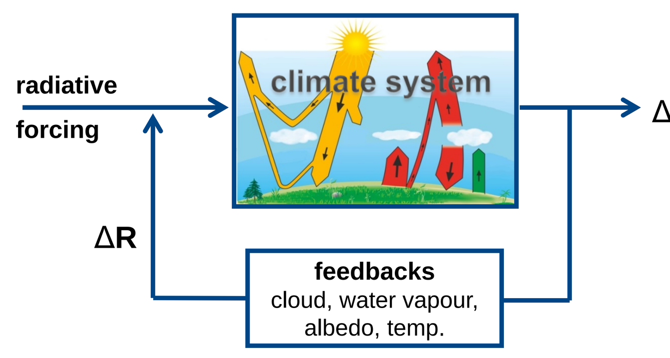
Motivation

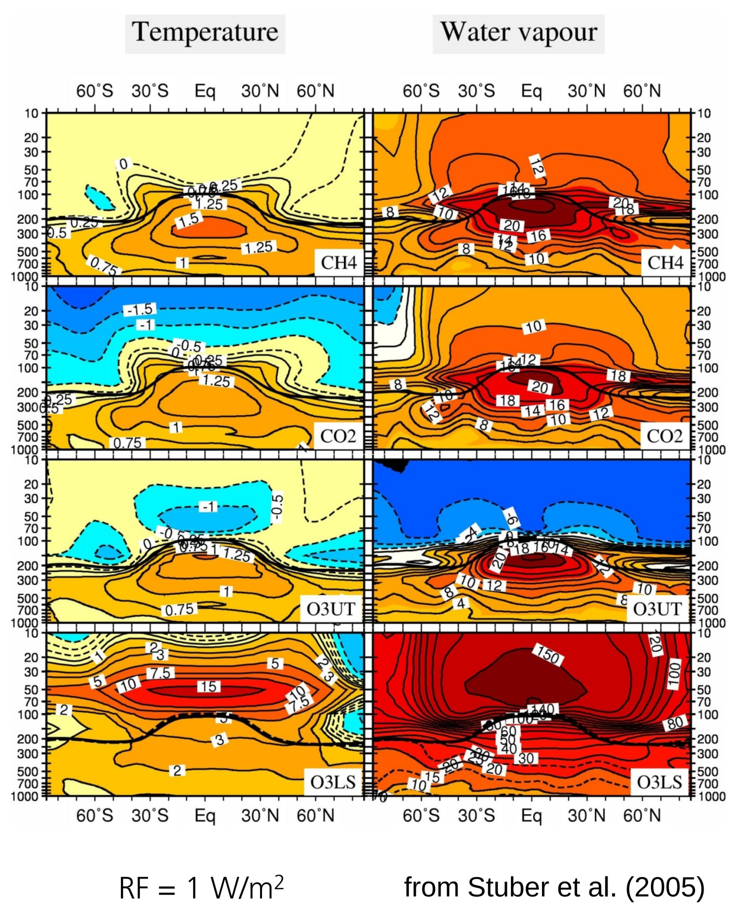
Climate sensitivity λ and efficacy r describe the global mean surface temperature response to a radiative forcing RF:

$$\Delta T_S = \lambda \cdot RF = r \cdot \lambda_{CO_2} \cdot RF$$

Radiative forcings from perturbations of different kind or structure may cause distinctive radiative feedbacks (e.g. water vapour feedback, right), in turn leading to distinctive efficacies.

Feedback analysis could be useful to identify those climate feedbacks that are responsible for different temperature responses and efficacies.

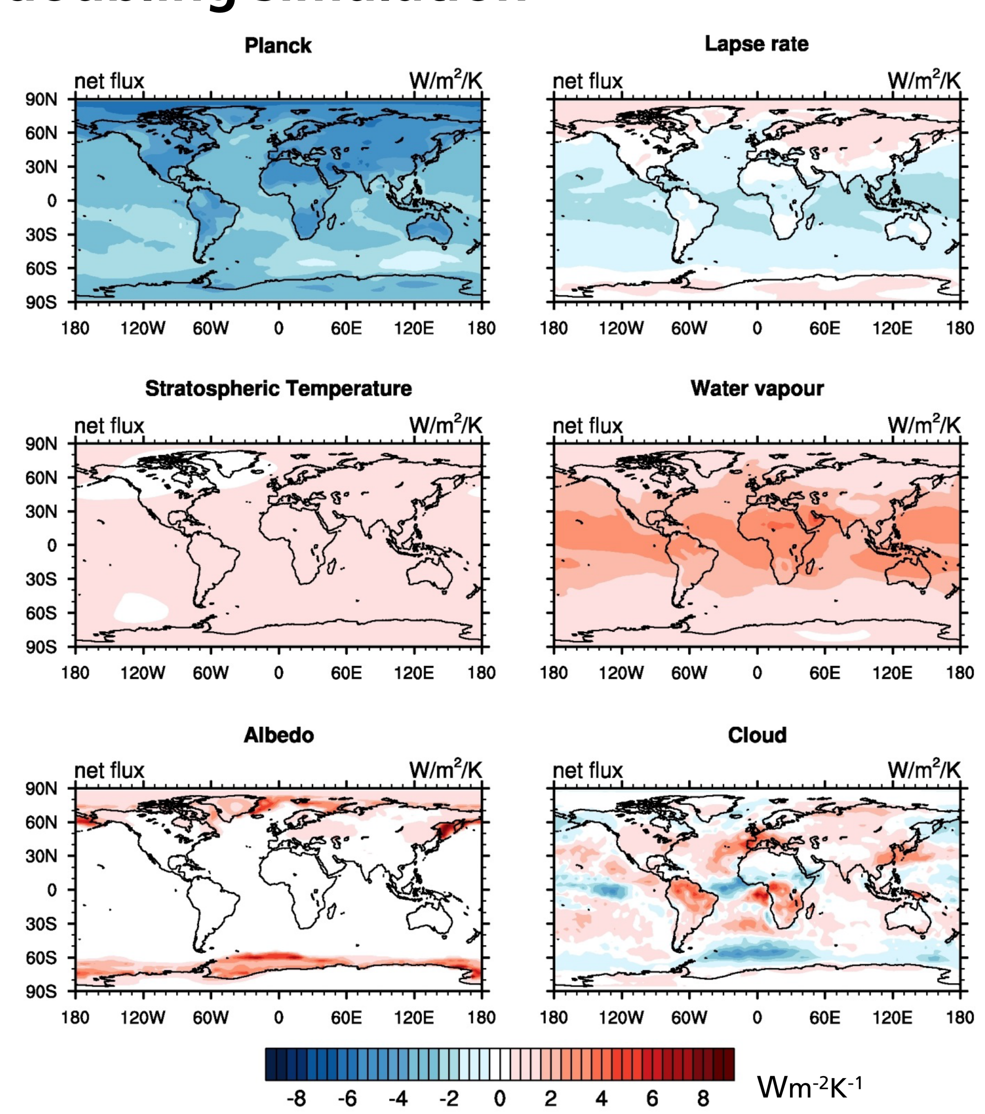




RF = 1 W/m² from Stuber et al. (2005)

ΔT_S = 0.86 K (CH4); 0.73 K (CO2); 0.55 K (O3UT); 1.31 K (O3LS)

Global distribution of climate feedbacks for a CO_2 doubling simulation



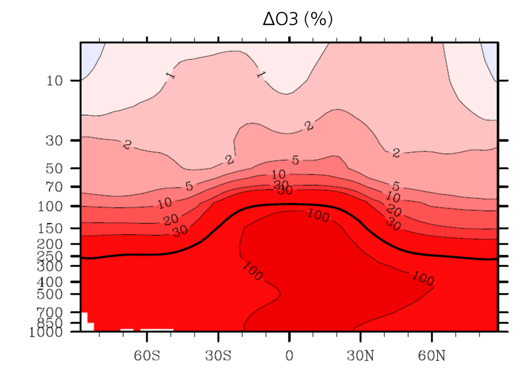
Global mean feedbacks:

- Temperature feedback split up:
  - Planck feedback α_{pla}: - 3.10 Wm^{-2}K^{-1}
  - Lapse rate feedback α_{LR}: - 0.86 Wm^{-2}K^{-1}
  - Stratospheric temperature feedback α_{str}: + 0.56 Wm^{-2}K^{-1}
- Water vapour feedback α_q: + 2.01 Wm^{-2}K^{-1}
- Surface albedo feedback α_A: + 0.23 Wm^{-2}K^{-1}
- Cloud feedback α_C: : + 0.29 Wm^{-2}K^{-1}

Feedbacks under a variety of forcings

Climate sensitivity and efficacy may vary under

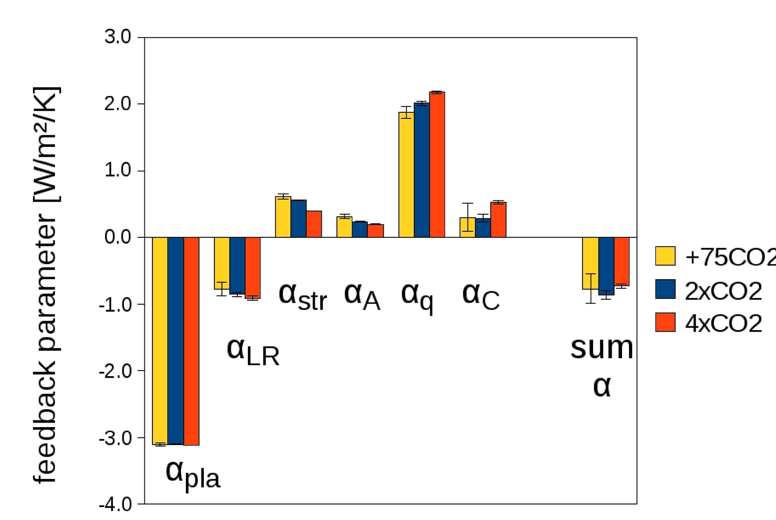
- different type of radiative forcings
- different strength of radiative forcings
- spatial structure of the perturbation
- amongst models



Simulation experiment		Radiative forcing Wm^{-2}	Climate sensitivity λ K/Wm^{-2}	[95% confi.]	Efficacy r
ΔO3 from enhanced NOX+CO (above)	NOX+CO	1.22	0.63	[0.55; 0.67]	0.86
Increase of CO_2 by 75 ppmv	+75CO2	1.06	0.73	[0.67; 0.79]	1
Doubling of CO_2	2xCO2	4.13	0.70	[0.69; 0.72]	0.96
Quadrupling of CO_2	4xCO2	8.93	0.91	[0.90; 0.92]	1.25

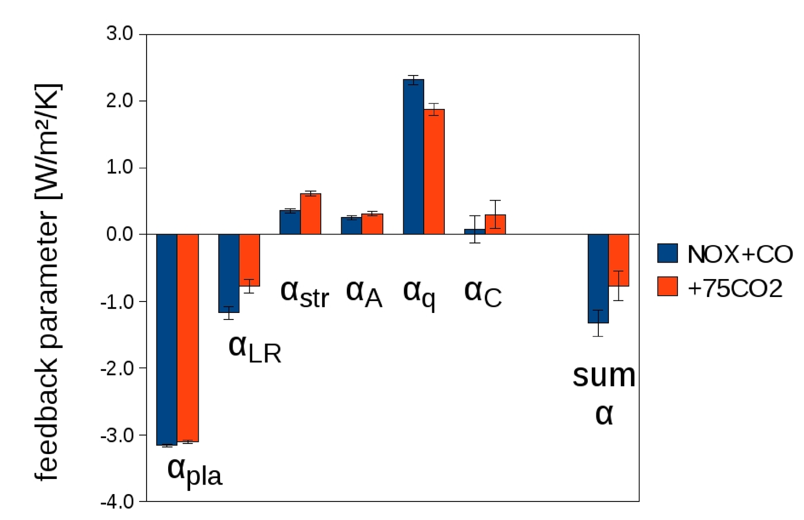
EMAC global model simulations by Dietmüller (2011)

1. Varying strength of forcings



- 2xCO2 and 4xCO2 can be significantly distinguished.
  ➔ Interplay of stratospheric temperature, water vapour and cloud feedback is responsible for variation in climate sensitivity.
- No significant distinction of the feedback sum for +75CO2 simulation is possible due to high interannual variability caused by small forcings.
  ➔ Restricted possibility to identify feedback processes responsible for climate sensitivity variation

2. Different type of forcings



- NOX+CO and +75CO2 show a significant difference of the feedback sum consistent with a reduced NOX+CO efficacy.
  ➔ Various feedback changes contribute to a distinctive NOX+CO efficacy; enhanced water vapour feedback is reversed by lapse rate, cloud and T_{strat} feedbacks.

"Partial Radiative Perturbation"-Method

Under the assumption of linearity and separability of radiative effects, each variable is substituted, one by one, from a climate change simulation, whereas all other variables are taken from a control simulation (forward calculation). By means of an offline radiation tool, the net radiation flux changes at top of the atmosphere ΔR_x are calculated.

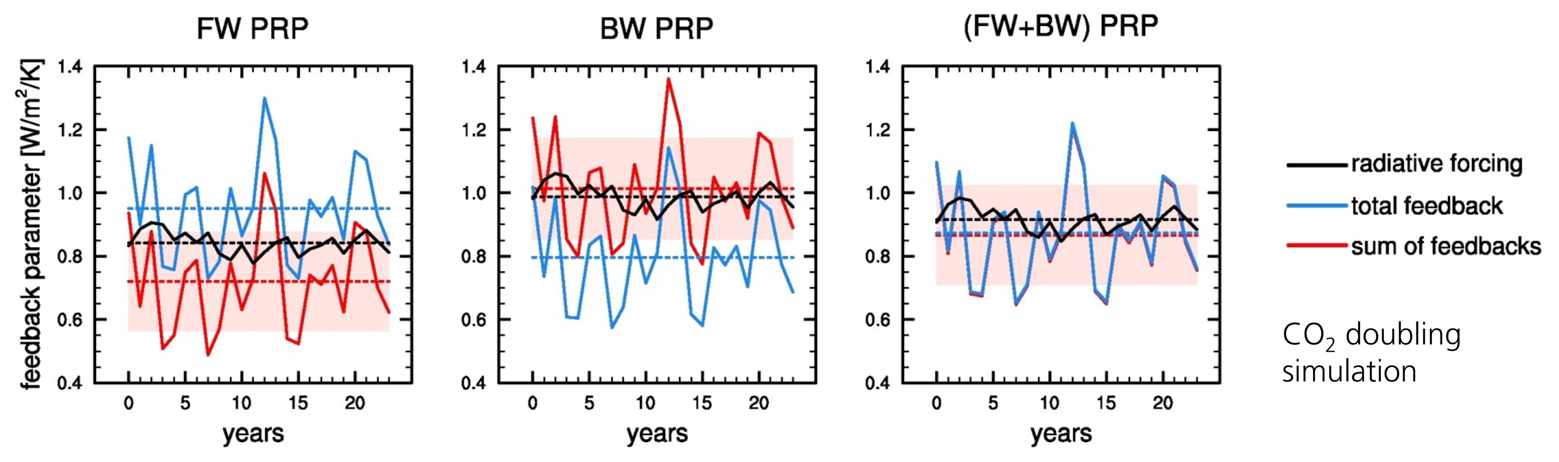
➔ feedback parameter $\alpha = \sum_x \alpha_x = \sum_x \frac{\Delta R_x}{\Delta T_S}$ $\quad x = q, C, A, T, \ldots$

The sum of feedbacks counteracts the radiative forcing to restore the radiative equilibrium at top of the atmosphere:

$$\alpha = \sum_x \alpha_x = -\frac{RF}{\Delta T_S} = -\frac{1}{\lambda}$$

Recommendations for successful feedback analysis

- Interannual variability is very high, especially for small forcings
  ➔ perturbation should be sufficiently large to extract the signal from high background noise
- Combination of forward (FW) and backward (BW) calculations guarantees
  ➔ reproduction of the near-zero radiation balance at top of the atmosphere
  ➔ separability of the feedbacks (no residuum)



Can feedback analysis be used to understand efficacy differences between radiative forcings?

- Significant feedback changes may be identified in a carefully chosen analysis framework.
  ➔ All feedbacks are potential candidates to significantly modify the feedback balance and to determine a distinctive efficacy of a given perturbation.
- Larger forcing gives a better signal to noise ratio and facilitates the analysis, but feedbacks and climate sensitivity can also change significantly with increasing forcing.
  ➔ Scaling forcings may be misleading when searching for physical reasons for efficacy differences.

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