

# Using feedback analysis to uncover the physical origin of efficacy differences

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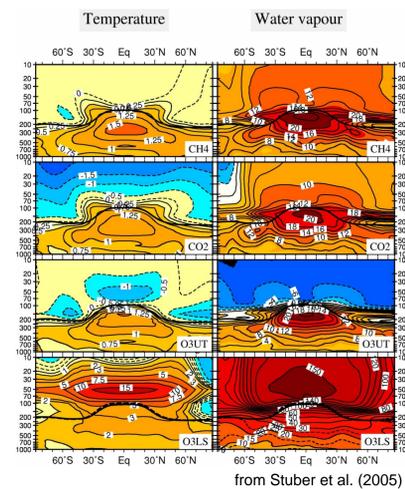
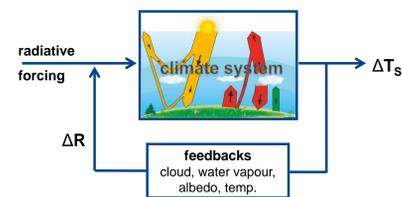
## Motivation

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

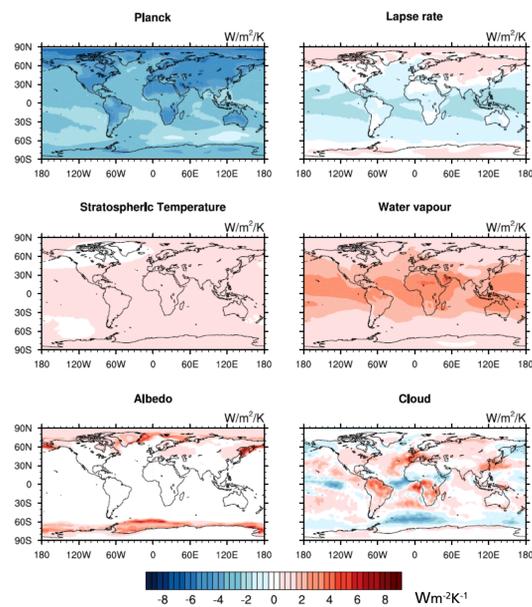
$$\Delta T_s = \lambda \cdot RF = r \cdot \lambda_{CO_2} \cdot RF$$

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.



## Global distribution of climate feedbacks for a CO<sub>2</sub> doubling simulation



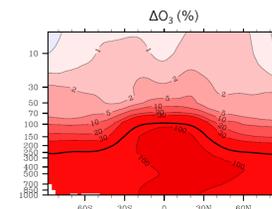
### Global mean feedbacks:

- Temperature feedback
  - Planck feedback  $\alpha_{pla}$ : -3.10 Wm<sup>-2</sup>K<sup>-1</sup>
  - Lapse rate feedback  $\alpha_{LR}$ : -0.86 Wm<sup>-2</sup>K<sup>-1</sup>
  - Stratospheric temperature feedback  $\alpha_{str}$ : +0.56 Wm<sup>-2</sup>K<sup>-1</sup>
- Water vapour feedback  $\alpha_q$ : +2.01 Wm<sup>-2</sup>K<sup>-1</sup>
- Surface albedo feedback  $\alpha_A$ : +0.23 Wm<sup>-2</sup>K<sup>-1</sup>
- Cloud feedback  $\alpha_C$ : +0.29 Wm<sup>-2</sup>K<sup>-1</sup>

## Feedbacks under a variety of forcings

Climate sensitivity and efficacy may vary under

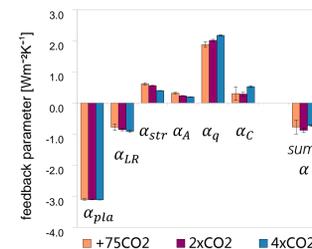
- different types of radiative forcings
- different strengths of radiative forcings
- spatial structure of the perturbation
- amongst models



Simulation experiment with EMAC	Inter-active chemistry	Radiative forcing Wm <sup>-2</sup>	Climate sensitivity $\lambda$ K/Wm <sup>-2</sup> [95% confi.]	Efficacy $r$	
$\Delta O_3$ from enhanced NO <sub>x</sub> +CO (v.s.)	no	NOX+CO	1.22	0.63 [0.55; 0.67]	0.86
$\Delta O_3$ from enhanced NO <sub>x</sub> +CO (v.s.)	yes	NOX+CO_chem	1.22	0.69 [0.65; 0.73]	0.95
Increase of CO <sub>2</sub> by 75 ppmv	no	+75CO2	1.06	0.73 [0.67; 0.79]	1
Doubling of CO <sub>2</sub>	no	2xCO2	4.13	0.70 [0.69; 0.72]	0.96
Quadrupling of CO <sub>2</sub>	no	4xCO2	8.93	0.91 [0.90; 0.92]	1.25

EMAC global model simulations by Dietmüller (2011)

### 1. Different strengths of forcings

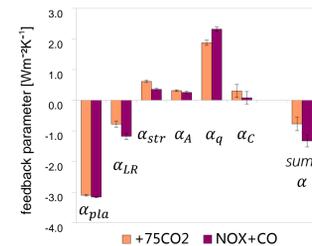


2xCO<sub>2</sub> and 4xCO<sub>2</sub> can be significantly distinguished. → Interplay of  $\alpha_{str}$ ,  $\alpha_q$ , and  $\alpha_C$  is responsible for the variation in climate sensitivity.

No significant distinction of the feedback sum for +75CO<sub>2</sub> simulation is possible due to high interannual variability caused by small forcings.

→ Restricted possibility to identify feedback processes which are responsible for climate sensitivity variation

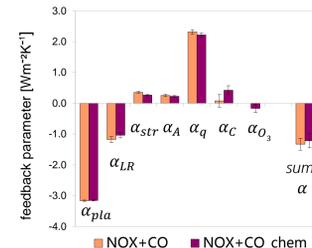
### 2. Different types of forcings



NOX+CO and +75CO<sub>2</sub> 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  $\alpha_q$  is reversed by  $\alpha_{LR}$ ,  $\alpha_C$ , and  $\alpha_{str}$ .

### 3. Additional feedbacks



Additional feedbacks occur in a model setup with interactive atmospheric chemistry. Despite a negative  $\alpha_{O_3}$ , the feedback sum including chemical feedbacks is less negative, enhancing the climate sensitivity.

→  $\alpha_C$  reacts markedly to the changes in  $\alpha_{str}$  and the negative  $\alpha_{O_3}$  and, hence, is found to be responsible for the impact reversion compared to the primary chemical feedback ( $\alpha_{O_3}$ ).

## “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  $\Delta R_x$  are calculated.

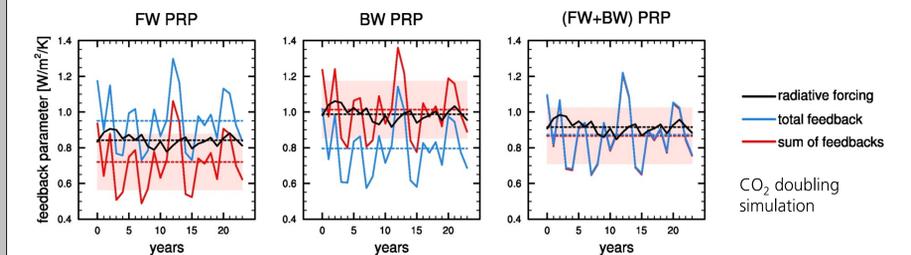
$$\rightarrow \text{feedback parameter } \alpha = \sum_x \alpha_x = \sum_x \frac{\Delta R_x}{\Delta T_s} \quad x = q, C, A, T, \dots$$

The feedback sum 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.