Can feedback analysis be used to understand efficacy differences between radiative forcings?
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Motivation
Climate sensitivity \( \Delta T_S \) and efficacy \( r \) describe the global mean surface temperature response to a radiative forcing \( RF \):
\[
\Delta T_S = \Delta R F - r \Delta T \Delta R F
\]
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:

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

Simulations experiment


\[
\Delta R F = 1 \text{ W/m}^2
\]

\[
\Delta T_S = 0.86 \text{ K (CH}_4 \); 0.73 \text{ K (CO}_2 \); 0.55 \text{ K (O}_3\text{UT)}; 1.31 \text{ K (O}_3\text{LS)}
\]

1. Varying strength of forcings

- 2xCO\(_2\) and 4xCO\(_2\) can be significantly distinguished
- Scenario of stratospheric temperature, water vapour and cloud feedback is responsible for variation in climate sensitivity
- No significant distinction of the feedback sum for +75CO\(_2\) 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

- NO\(_x\)+CO and +75CO\(_2\) show a significant distinction
- Interplay of stratospheric temperature, water vapour and cloud feedback is responsible for high interannual variability caused by small forcings
- Restricted possibility to identify feedback processes responsible for climate sensitivity variation

“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 \( \Delta \text{RF} \), are calculated:

\[
\text{feedback parameter } a = \sum a_i \Delta R F_i / \Delta T_S
\]

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

\[
\Delta T_S = \sum a_i \Delta R F_i / \Delta T_S
\]

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 reproducibility 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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