Analysis of radiative feedbacks in model simulations including interactive chemistry

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Radiative forcing, climate response, climate sensitivity and radiative feedbacks

The climate sensitivity parameter λ links the global mean surface temperature response (ΔT_S) and the radiative forcing RF:

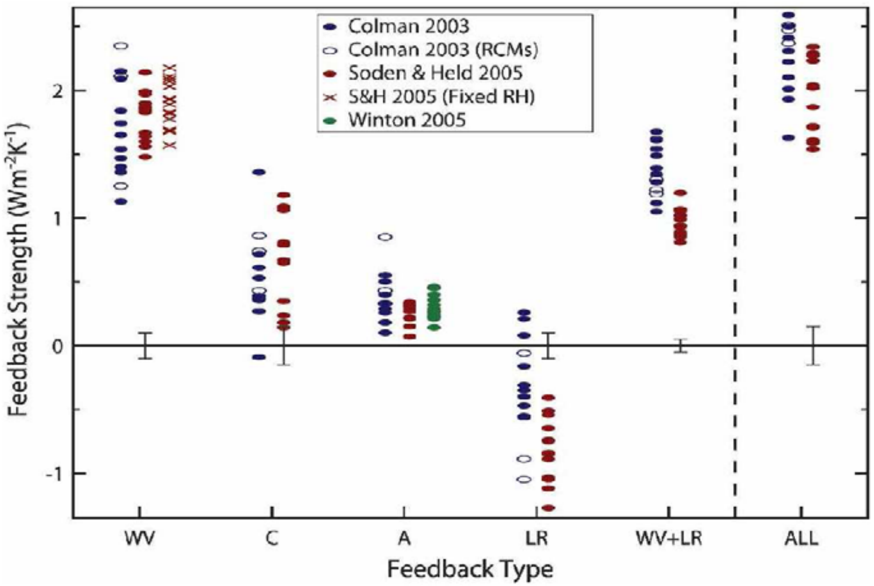
$$\Delta T_S = \lambda \cdot RF$$

λ crucially depends on the strengths of a number of the radiative feedbacks (α_x) acting in a given model and for a given forcing perturbation:

$$-\frac{1}{\lambda} = \alpha = \Sigma \alpha_x$$

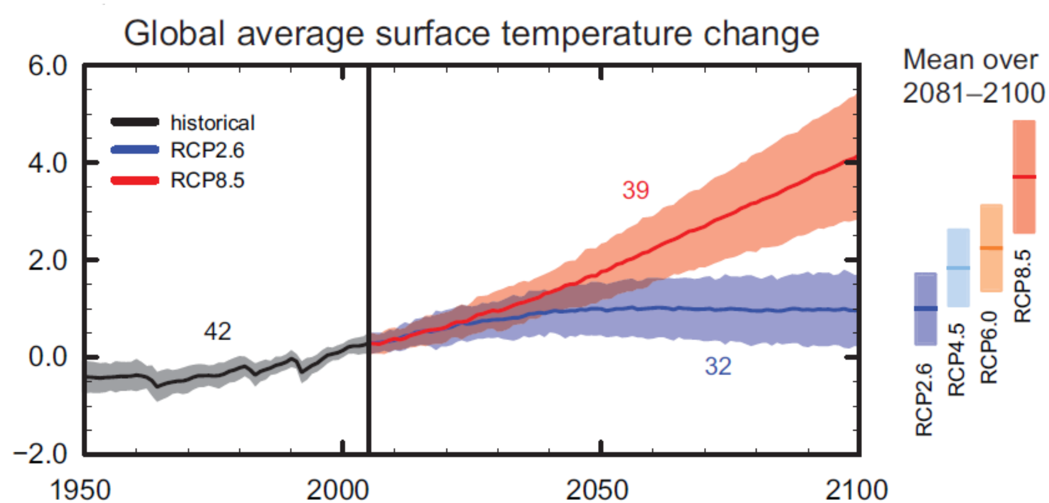
As the feedbacks may be both model and perturbation dependent, so is the climate sensitivity parameter.

Physical feedbacks in climate models



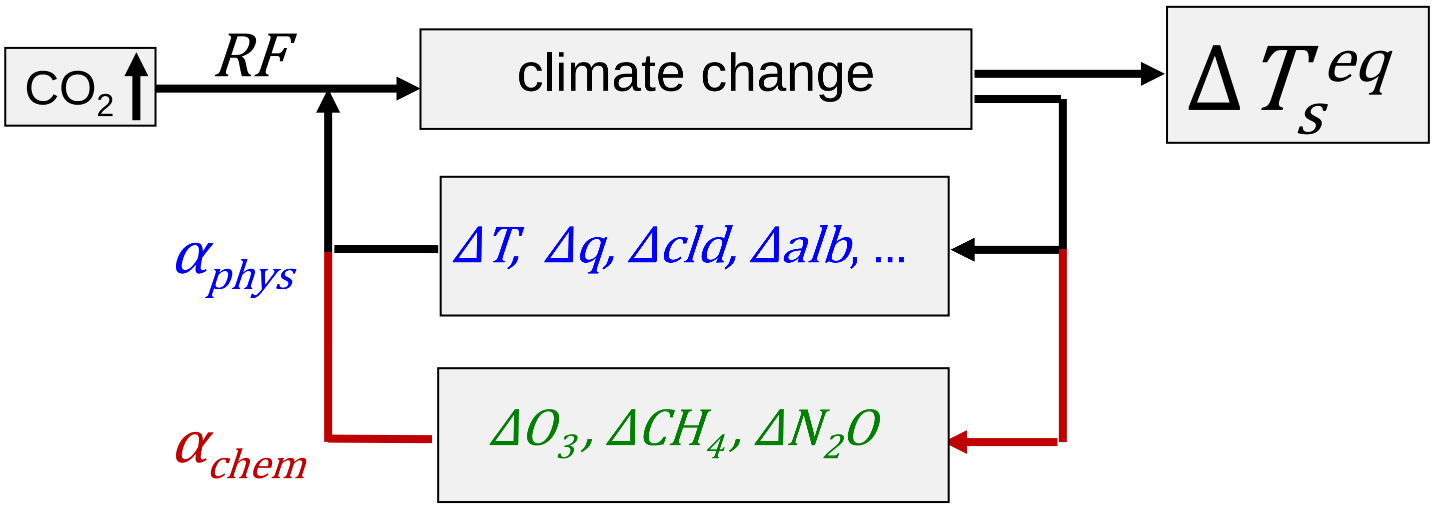
The strength of global radiative feedbacks (particularly via clouds) is known to differ between different climate models (here: example from Bony et al., 2006), resulting in a model dependent climate sensitivity parameter (λ).

Hence, different climate models simulate a different temperature response development, even if the (radiative) forcing is the same (here: IPCC, 2013).



Introducing interactive chemistry to equilibrium climate change simulations adds new feedbacks

CO_2 perturbation simulations:



$$\alpha = \sum_x \alpha_x = \alpha_{pla} + \alpha_q + \alpha_{LR} + \alpha_{alb} + \alpha_{cld} + \ldots$$

$$\ldots + \alpha_{O3} + \alpha_{CH4} + \alpha_{N2O} + \alpha_{FCKW} + \alpha_{Aero} \ldots$$

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ECHAM5/MESSy Atmospheric Chemistry (EMAC)

ECHAM5 = ECMWF-model, version 5 HAMburg

General circulation model

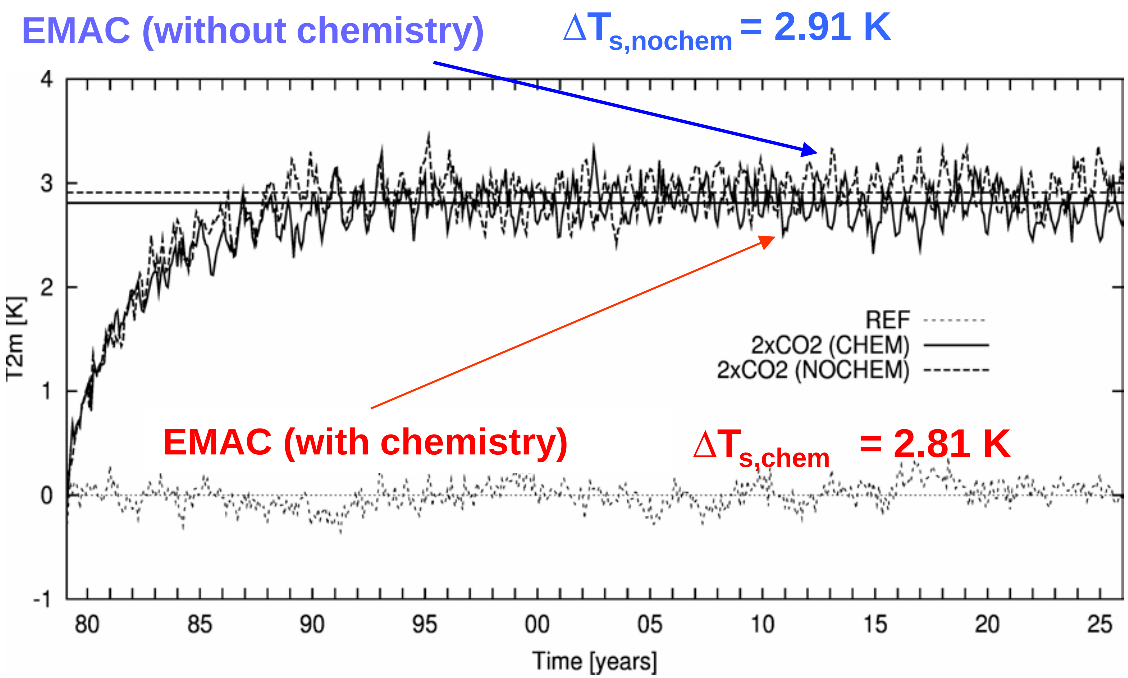
Reference: Roeckner et al. , MPI-Report No.349

MESSy = Modular Earth Submodel System

Reference: Jöckel et al., 2005 (*Atmos. Chem. Phys.*)

- an interface with infrastructure to couple 'processes' (submodels) to a GCM (base model)
- a set of processes coded as switchable submodels
- an appropriate coding standard

CO_2 simulations: interactive chemistry reduces climate sensitivity



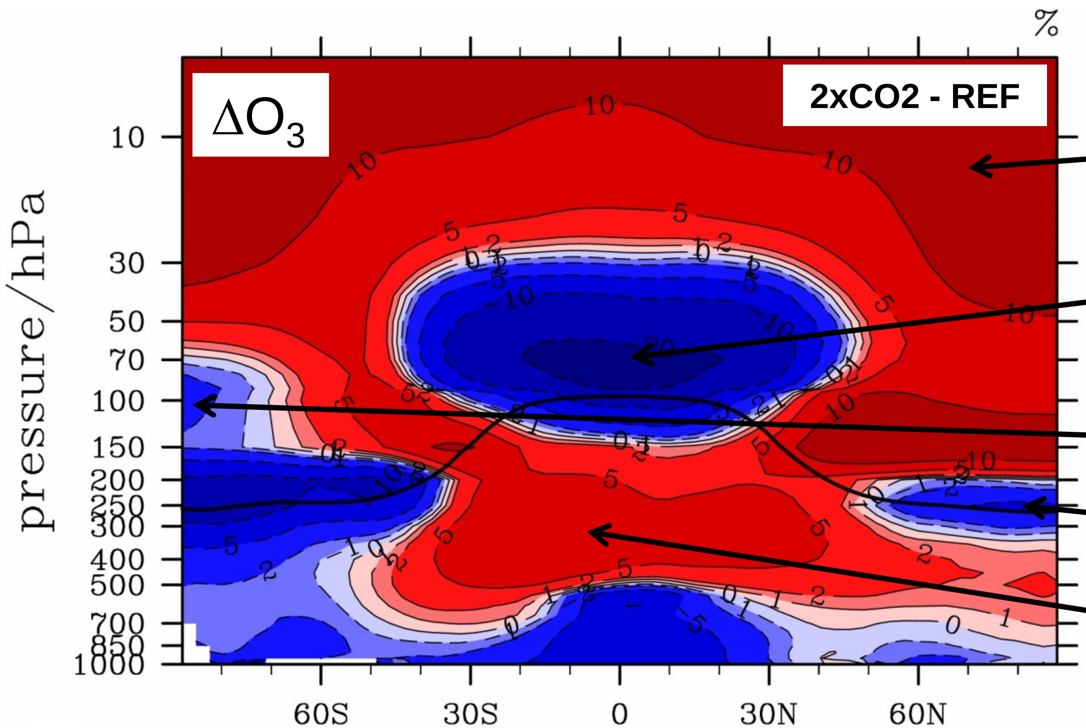
Significant reduction of climate sensitivity through chemical feedbacks
by 3.4 % (2xCO2)
or 8.4 % (4xCO2), respectively.

(Statistical) uncertainties increase as the forcing decreases

(Dietmüller et al.. 2014)

Simulation		RF Wm^{-2}	chemistry	Climate sensitivity λ (K/Wm^{-2}) mean	[95% confi.]
75 ppmv CO_2 increase	+75CO2	1.06	no	0.73	[0.67; 0.79]
			yes	**0.63**	**[0.57; 0.68]**
Doubling of CO_2	2xCO2	4.13	no	0.70	[0.69; 0.72]
			yes	**0.68**	**[0.66; 0.69]**
Quadrupling of CO_2	4xCO2	8.93	no	0.91	[0.90; 0.92]
			yes	**0.84**	**[0.83; 0.85]**

Negative global mean ozone feedback



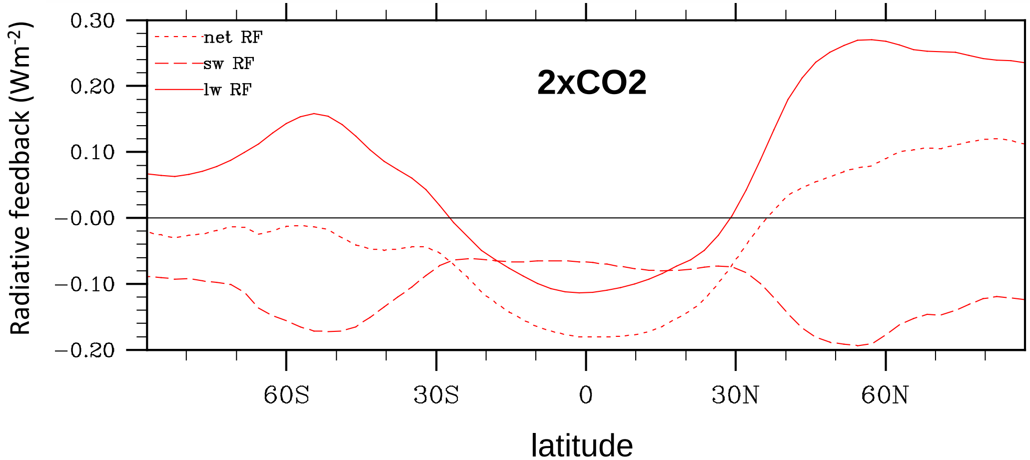
slower ozone destruction

enhanced tropical upwelling as troposphere warms

more PSCs in cooler stratosphere

tropopause lifting

changed NO_y response



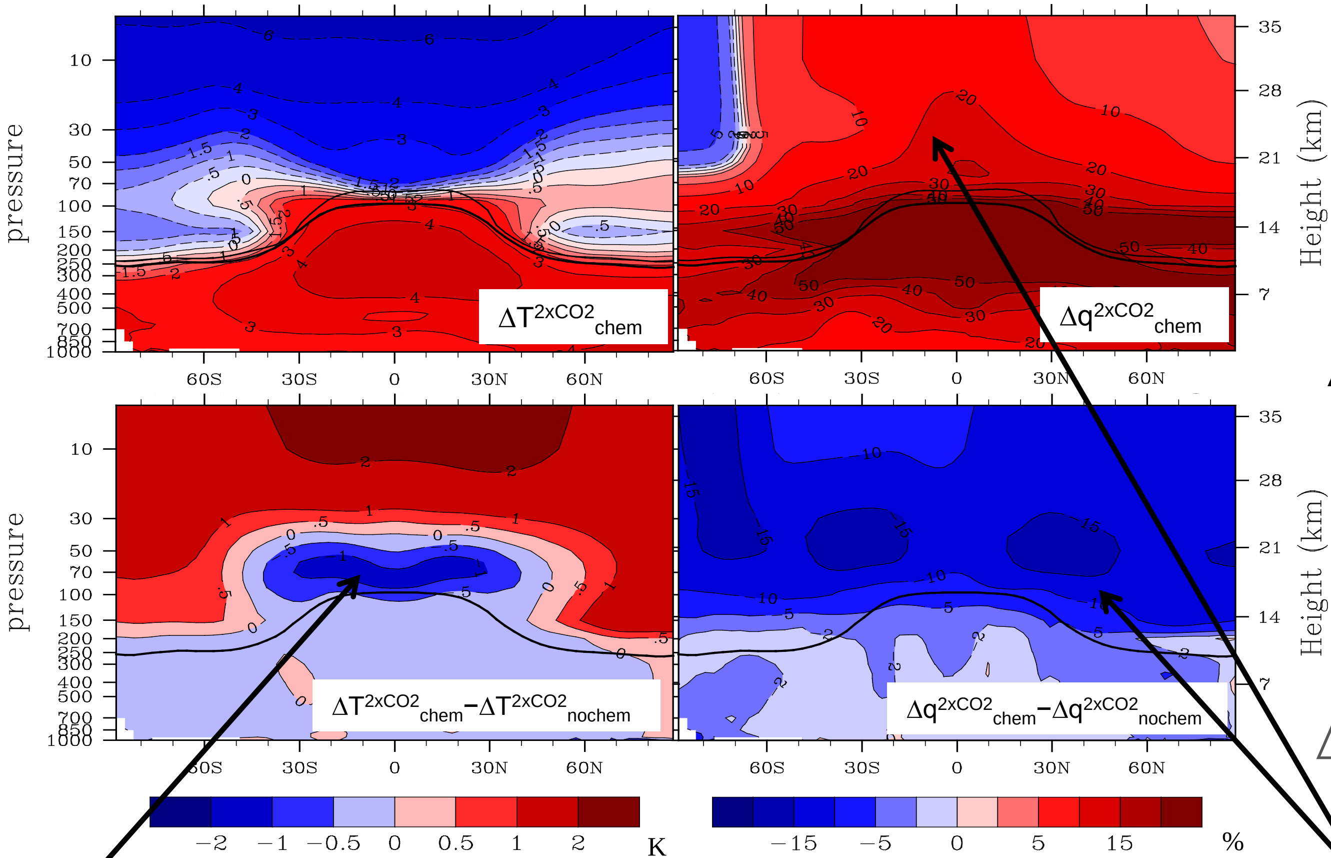
$\alpha_{O3} = -0.022\ Wm^{-2}K^{-1}$

↓ 4xCO2

$\alpha_{O3} = -0.015\ Wm^{-2}K^{-1}$

(Dietmüller et al.. 2014)

Ozone feedback reduces stratospheric water vapour feedback



$\Delta\alpha_q = -0.027\ \mathrm{Wm^{-2}K^{-1}}$

↓ 4xCO2

$\Delta\alpha_q = -0.047\ \mathrm{Wm^{-2}K^{-1}}$

(Dietmüller et al.. 2014)

Ozone feedback leads to reduced heating at the tropical cold point tropopause.

Stratospheric water vapor increase and its radiative feedback is smaller than without interactive chemistry.

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Radiative feedback analysis explains reduced climate sensitivity

Taking into account interactive chemistry in CO_2-driven climate change simulations (Dietmüller et al.. 2014)

- introduces an additional negative feedback from stratospheric ozone.
- leads to a reduction of the stratospheric water vapour feedback by between 15% and 20%.
- reduces the climate sensitivity by <u>3.4%</u> (2xCO2) and <u>8.4%</u> (4xCO2) in comparison to an equivalent model setup with prescribed ozone.

Robustness

EMAC/MLO results qualitatively confirmed by 2 similar model setups in 4xCO2 simulations (Muthers et al., 2014, Nowack et al., 2015), but the latter paper finds <u>20%</u> climate sensitivity reduction in HADGEM3/AO.

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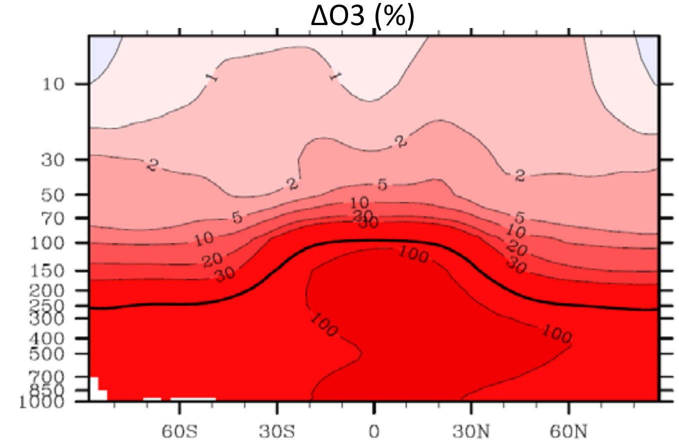
Non-CO_2 simulations: ozone forcing (ΔO_3) from enhanced NO_x+CO surface emissions

Even larger (negative) ozone feedback ($\alpha_{O3} = -0.166\ Wm^{-2}K^{-1}$) compared to a CO_2-driven simulation with similar RF, yet the climate sensitivity *increases* in the setup including interactive ozone chemistry!

(Dietmüller , 2011)



Ozone change due to enhanced NO_X/CO emissions

Simulation		RF Wm^{-2}	chemistry	Climate sensitivity λ (K/Wm^{-2}) mean	[95% confi.]
Ozone change from higher NOX+CO surface emissions	NOX+CO	1.22	no	0.62	[0.55; 0.68]
			yes	**0.69**	**[0.65; 0.73]**
75 ppmv CO_2 increase	+75CO2	1.06	no	0.73	[0.67; 0.79]
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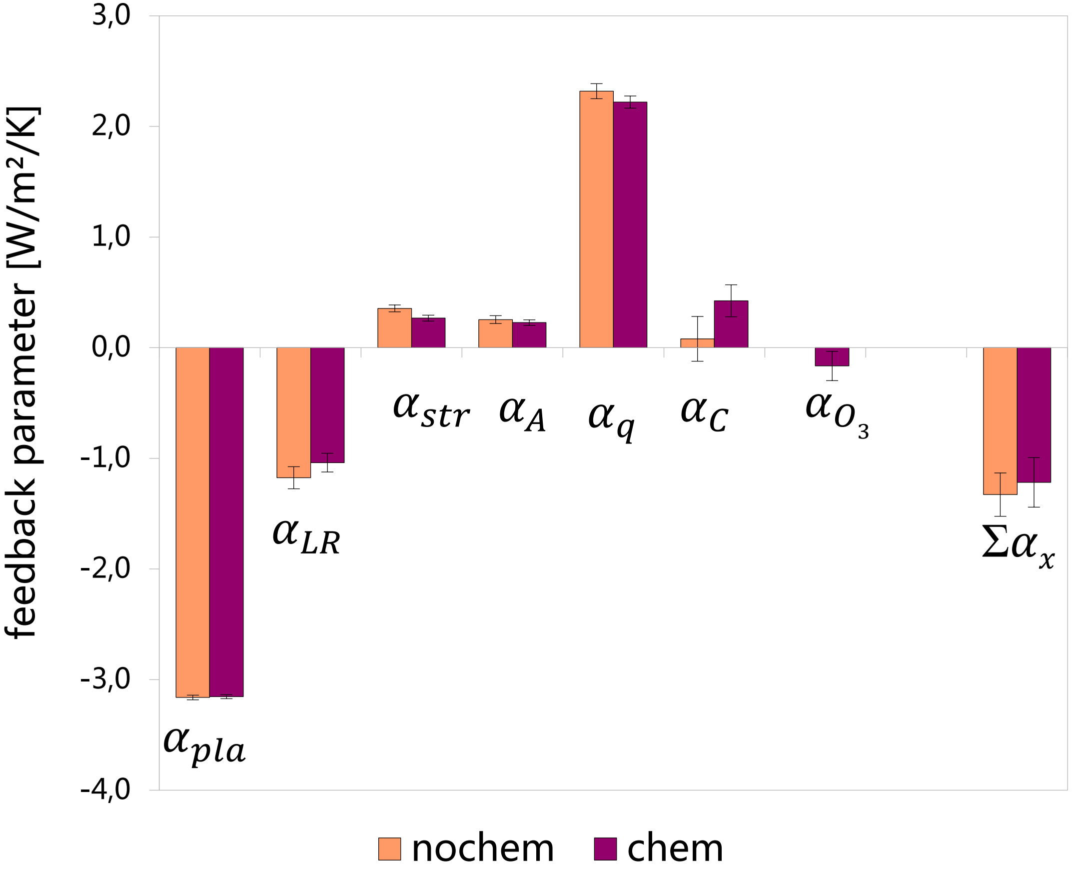
Non-CO_2 simulations: ozone forcing (ΔO_3) from enhanced NO_x+CO surface emissions

Complete feedback analysis of all contributing feedback components required!

Non-CO_2 simulations: ozone feedback overcompensated by changes in physical feedbacks



- Ozone feedback negative in NOX+CO (chem), contributions from both tropospheric and stratospheric ozone.
- Sum of feedbacks less negative in NOX+CO (chem) consistent with higher climate sensitivity compared to NOX+CO (nochem).
- Cloud feedback (α_C) increases significantly if chemical feedbacks are included (chem).

(Rieger , 2014)

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Conclusions

- Interactive ozone, moderately but significantly, reduces the climate sensitivity in CO_2-driven climate change simulations.
- The ozone radiative feedback is negative and dominated by stratospheric ozone changes.
- The negative ozone feedback is substantially amplified by a change in stratospheric water vapour feedback.
- If climate change is driven by ozone changes from enhanced NO_x/CO surface emissions, the climate sensitivity increases when using interactive chemistry.
- The ozone feedback is still negative but its effect is reversed by changes in the physical feedback.
- Conceptual advances of the mode setup are necessary to represent methane and nitrous oxide feedbacks, too.

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