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Ozone radiative feedback in global warming simulations with CO_2 and non-CO_2 forcing

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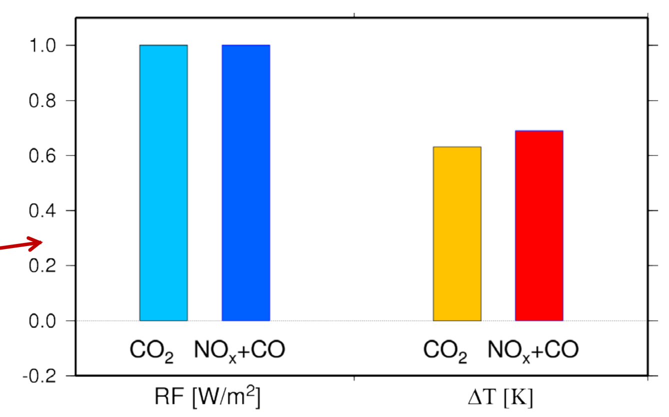
Climate sensitivity, efficacy, and radiative feedbacks

The climate sensitivity parameter λ describes the global mean surface temperature response to a radiative forcing RF:

With a certain CO_2 increase chosen as some kind of reference forcing, other (especially non-CO_2) radiative forcings are said to have reduced or enhanced efficacy, if the surface temperature response per unit radiative forcing (i.e., the climate sensitivity parameter) is smaller or larger than the reference parameter (λ_{CO_2}).

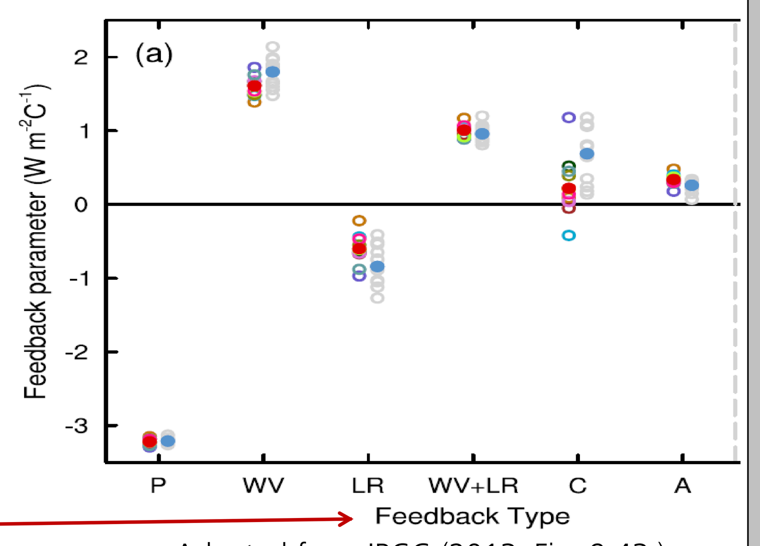
$$\Delta T_S = \lambda \cdot RF = r \cdot \lambda_{CO_2} \cdot RF$$



Variations of the climate sensitivity (among different models, among different forcings etc.) may be related to distinctive radiative feedbacks.

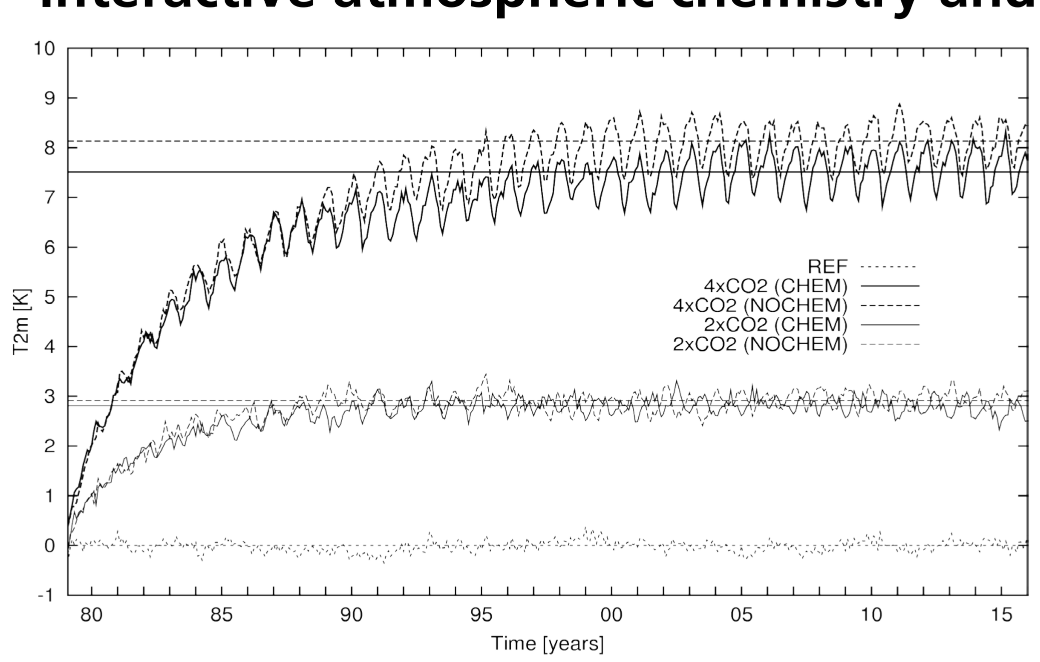
$$\alpha = \sum_x \alpha_x = -\frac{RF}{\Delta T_S} = -\frac{1}{\lambda}$$

There is large experience with inter-model variations of the common set of physical feedbacks (Planck, water vapor, lapse rate, cloud, and surface albedo feedbacks).



Adapted from IPCC (2013, Fig. 9.43)

Interactive atmospheric chemistry and climate sensitivity



Model: EMAC

ECHAM5/MESSy atmospheric chemistry model

ECHAM5 : ECMWF/MPI-HAMburg model, version 5 (Roeckner et al., 2005)

MESSy: Modular Earth Submodel System (Jöckel et al., 2005)

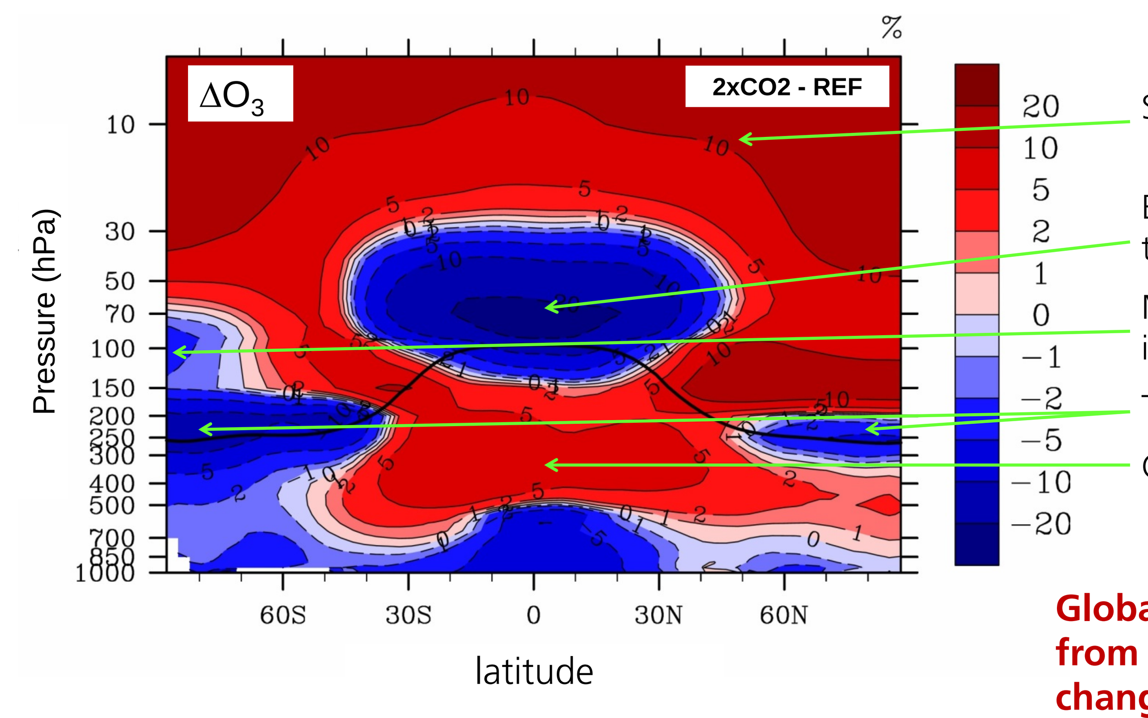
Feedback changes associated with interactive chemistry reduce the climate sensitivity in CO_2 driven equilibrium climate change simulations!

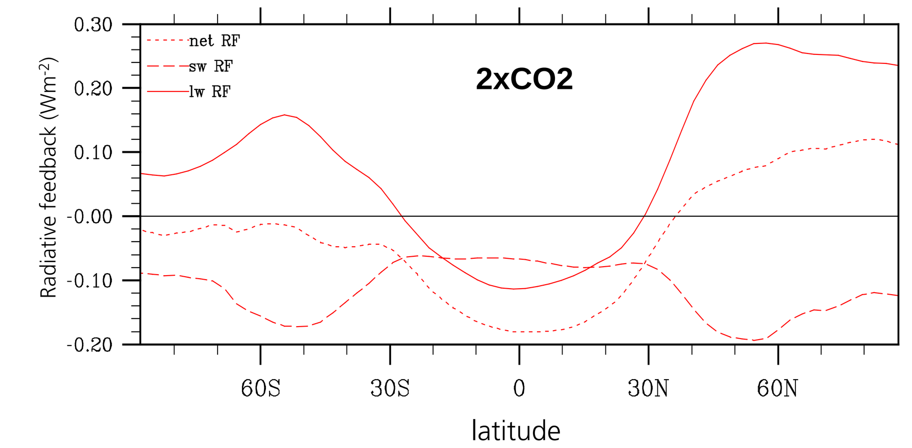
Simulation		RF Wm^{-2}	chemistry	Climate sensitivity λ K/(Wm⁻²) mean	[95% confi.]
Increase of CO_2 by 75 ppmv	+75CO2	1.06	no **yes**	0.73 **0.63**	[0.67; 0.79] **[0.57; 0.68]**
Doubling of CO_2	2xCO2	4.13	no **yes**	0.70 **0.68**	[0.69; 0.72] **[0.66; 0.69]**
Quadrupling of CO_2	4xCO2	8.93	no **yes**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

Simulations:

Dietmüller (2011)
Dietmüller et al. (2014)

2xCO2: Ozone radiative feedback





Global mean radiative feedback from ozone concentration change is negative CO_2 increase simulations

2xCO2

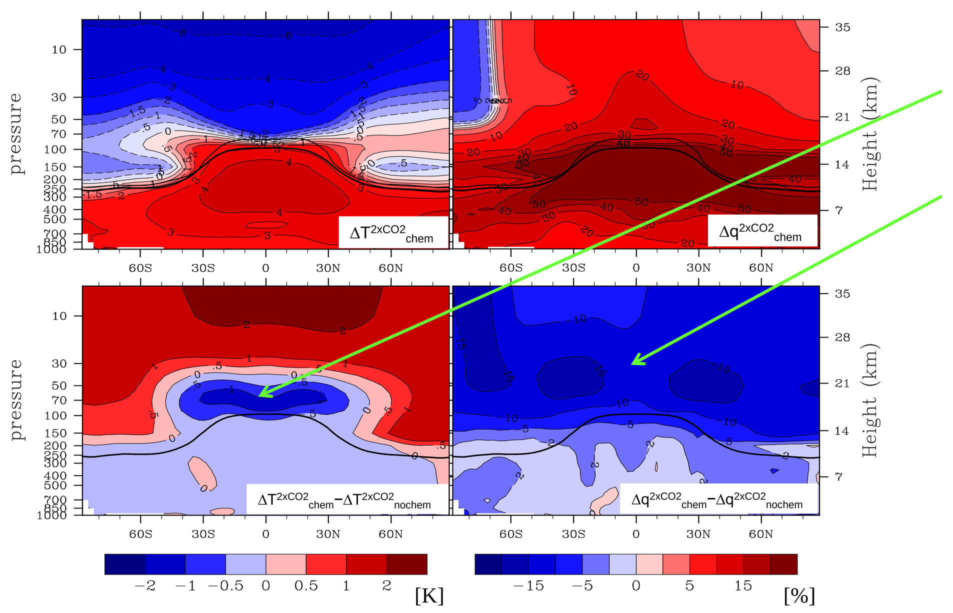
$\alpha_{O3} = -0.022$ Wm⁻²K⁻¹

↓ 4xCO2

$\alpha_{O3} = -0.015$ Wm⁻²K⁻¹

(Dietmüller et al., 2014)

2xCO2: Stratospheric water vapor radiative feedback



Reduced ozone related heating at tropical cold point

Stratospheric water vapor uptake and the respective radiative feedback decrease, compared to model setup without chemistry

2xCO2

$\Delta\alpha_q = -0.027$ Wm⁻²K⁻¹

↓ 4xCO2

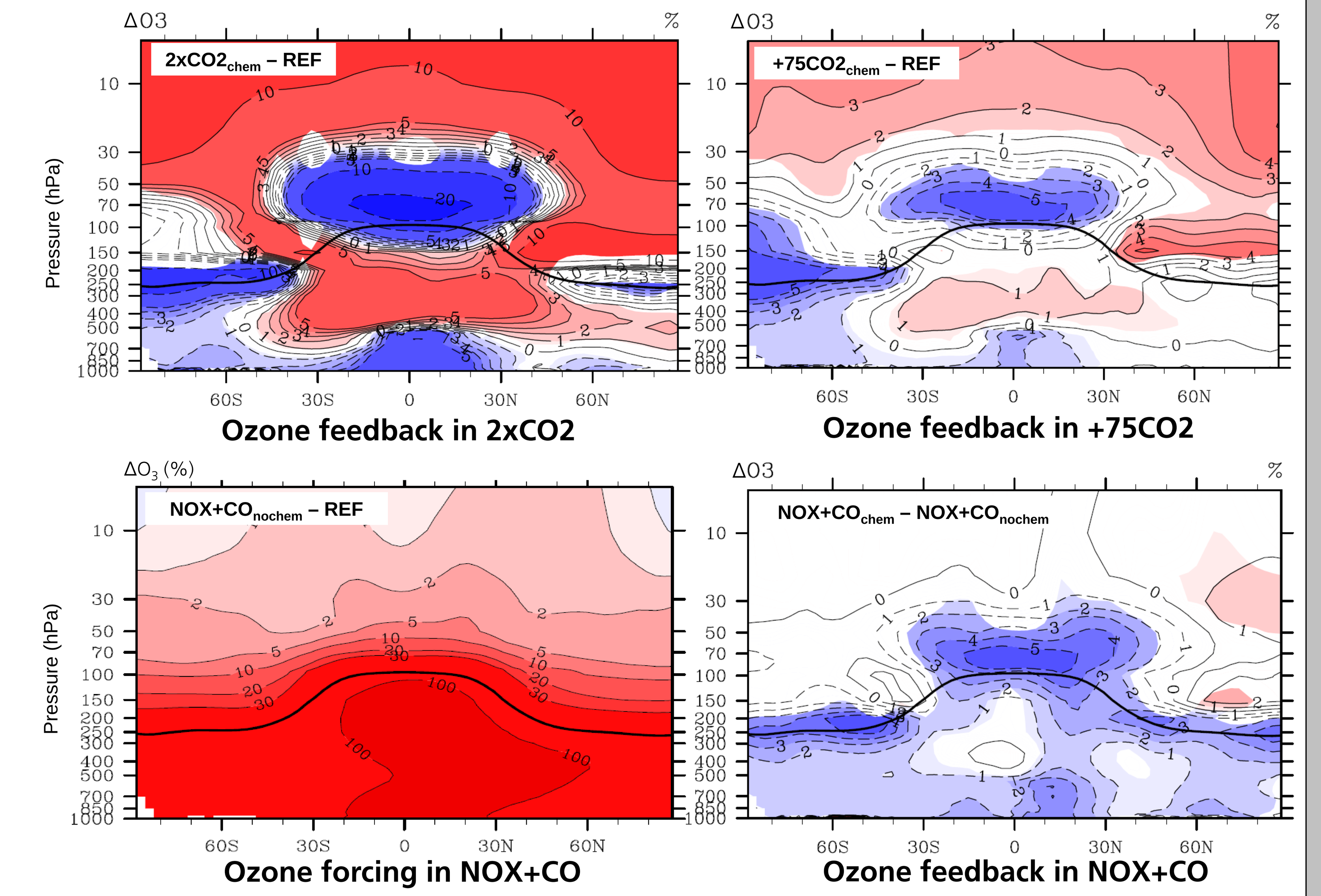
$\Delta\alpha_q = -0.047$ Wm⁻²K⁻¹

(Dietmüller et al., 2014)

Taking into account interactive chemistry in CO_2-driven climate change simulations

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

Non-CO_2 forcing: Ozone change from enhanced NO_x/CO surface emissions



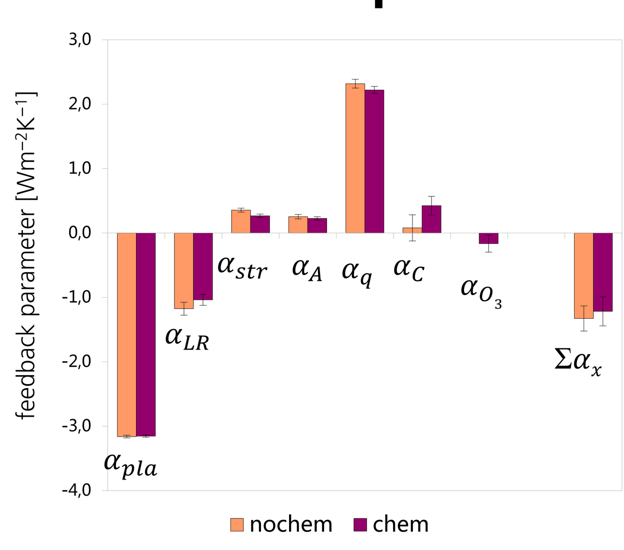
Simulation		RF Wm^{-2}	chemistry	Climate sensitivity λ K/(Wm⁻²) mean	[95% confi.]
Increase of CO_2 by 75 ppmv	+75CO2	1.06	no **yes**	0.73 **0.63**	[0.67; 0.79] **[0.57; 0.68]**
Ozone change from enhanced NO_x/CO surface emissions	NOX+CO	1.22	no **yes**	0.63 **0.69**	[0.57; 0.69] **[0.65; 0.73]**

Ozone radiative feedback is even more negative in NOX+CO (−0.17 Wm⁻²K⁻¹) compared to CO_2 increase simulations, but efficacy is enhanced with respect to +75CO2.

Complete analysis of feedbacks needed for a consistent interpretation!

(Dietmüller, 2011; Rieger et al., 2016)

Complete feedback analysis for NOX+CO



- Complete feedback analysis ensures consistency for NOX+CO: Direct effect of chemical feedbacks may be reversed by changes in physical feedbacks.
- Interpretation problems grow as the statistical uncertainty increases for (smaller) non-CO_2 forcings.
- Methodical advances are desirable as “adjusted” radiative forcings and “instantaneous” radiative feedbacks do not optimally fit.
- Analysis of climate sensitivity, efficacy, and feedbacks is most reasonable for forcings of similar magnitude.