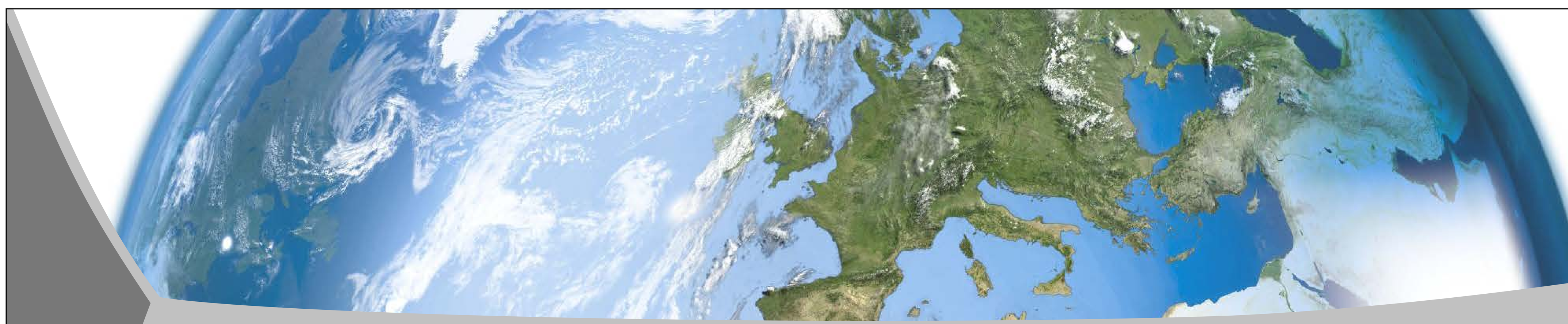


Ozone Radiative Feedback and Climate Sensitivity

Michael Ponater, Simone Dietmüller, and Vanessa Rieger

Conceptual Framework

Radiative forcing, radiative feedback, climate sensitivity

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

Non-CO_2 radiative forcings are said to have reduced or enhanced efficacy r, if the surface temperature response per unit radiative forcing (i.e, λ) is smaller or larger than the reference climate sensitivity 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 α_x.

$$\alpha_{phys} = \sum_x \alpha_x = -\frac{1}{\lambda}$$

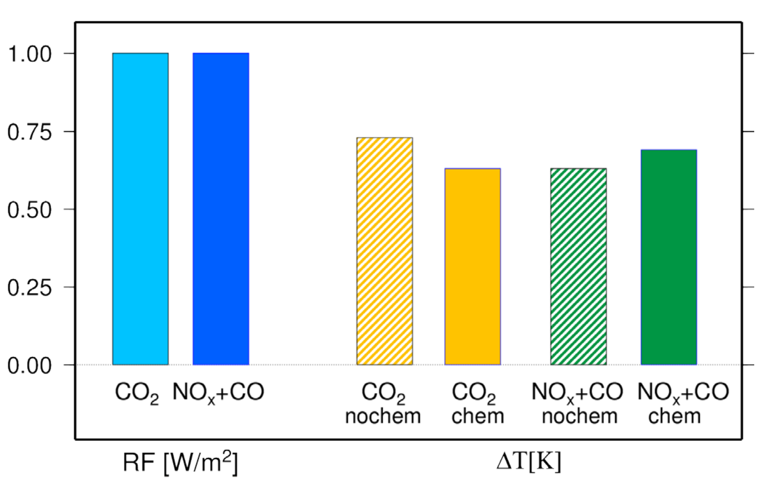
Classical climate models (AOGCMs) include a well defined set of physical feedback processes (x): Planck, water vapor, lapse rate, cloud, and surface albedo feedbacks).

Additional chemical feedback

Chemistry climate models (CCMs) include more feedbacks (y) than AOGCMs due to the presence of additional radiatively active tracers:

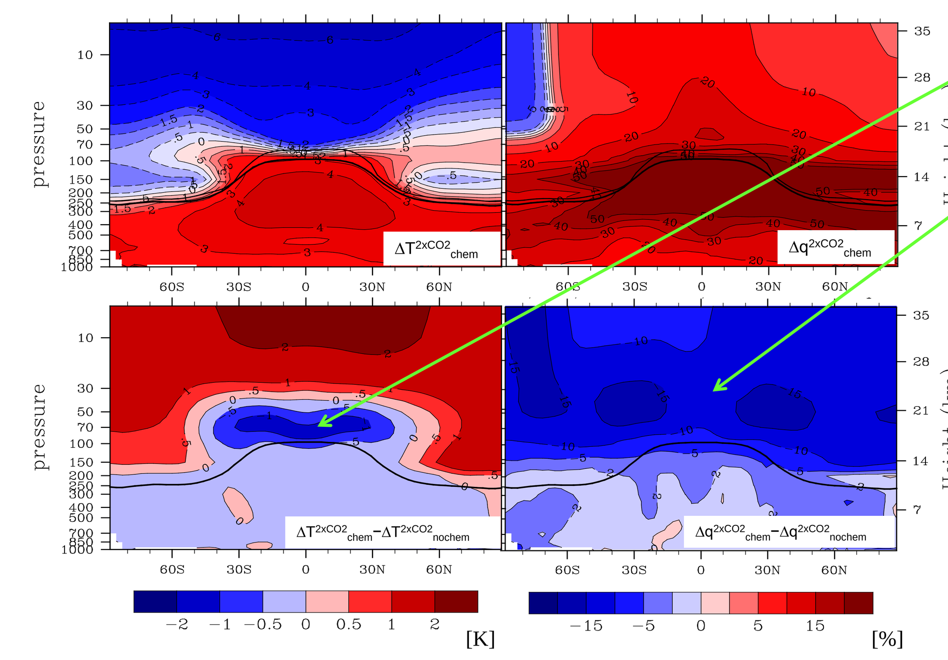
$$\alpha = \sum_y \alpha_y = \alpha_{phys} + \alpha_{chem}$$

Hence, CCMs can be expected to simulate a different climate sensitivity than a equivalent counterpart model with the chemical feedback α_{chem}.



The modifying impact of chemical feedbacks on the climate sensitivity may be as important as the efficacy of different radiative forcings.

Synergy of Ozone and Stratospheric Water Vapour Feedbacks



Reduced ozone related heating at tropical cold point

Stratospheric water vapour uptake and the respective radiative feedback decrease, compared to model "nochem" model setup

2xCO2

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

4xCO2

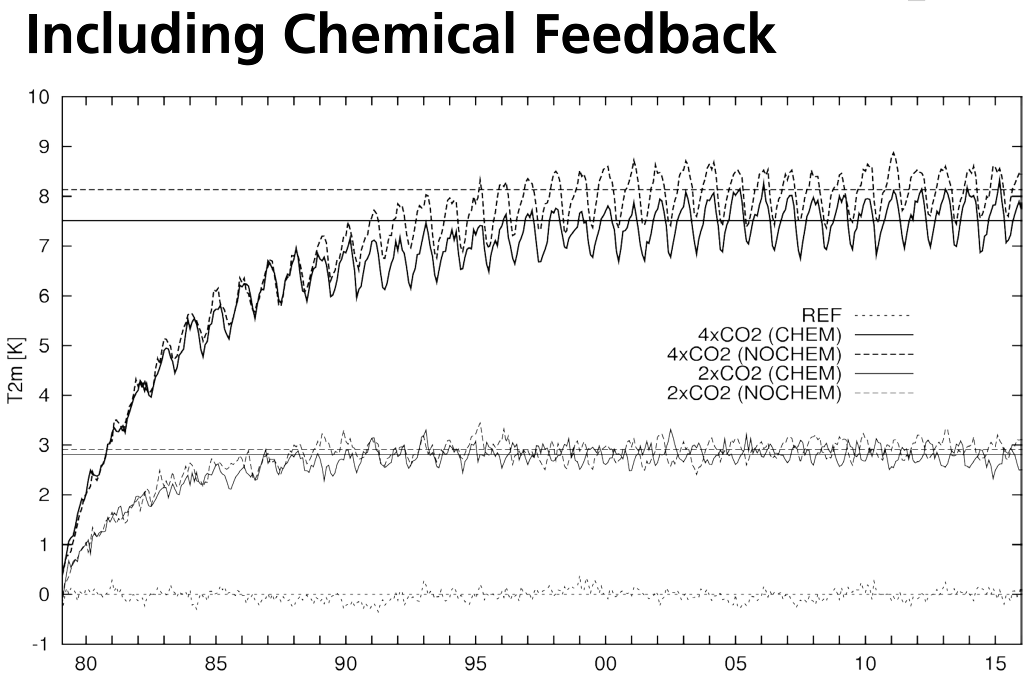
$\Delta\alpha_q = -0.047\ Wm^{-2}K^{-1}$

EMAC Dietmüller et al. (2014)

Interactive chemistry in CO_2-driven climate change simulations

- introduces an additional negative feedback from stratospheric ozone.
- may lead to a substantial reduction of the stratospheric water vapor feedback (with considerable inter-model dependency)
- may significantly reduce the climate sensitivity, with considerable inter-model dependency (in **EMAC** by 3.4%: 2xCO2, or by 8.4%: 4xCO2 in comparison to a model setup with prescribed ozone).

Reduced Climate Sensitivity in CO_2-driven Simulations Including Chemical Feedback



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)

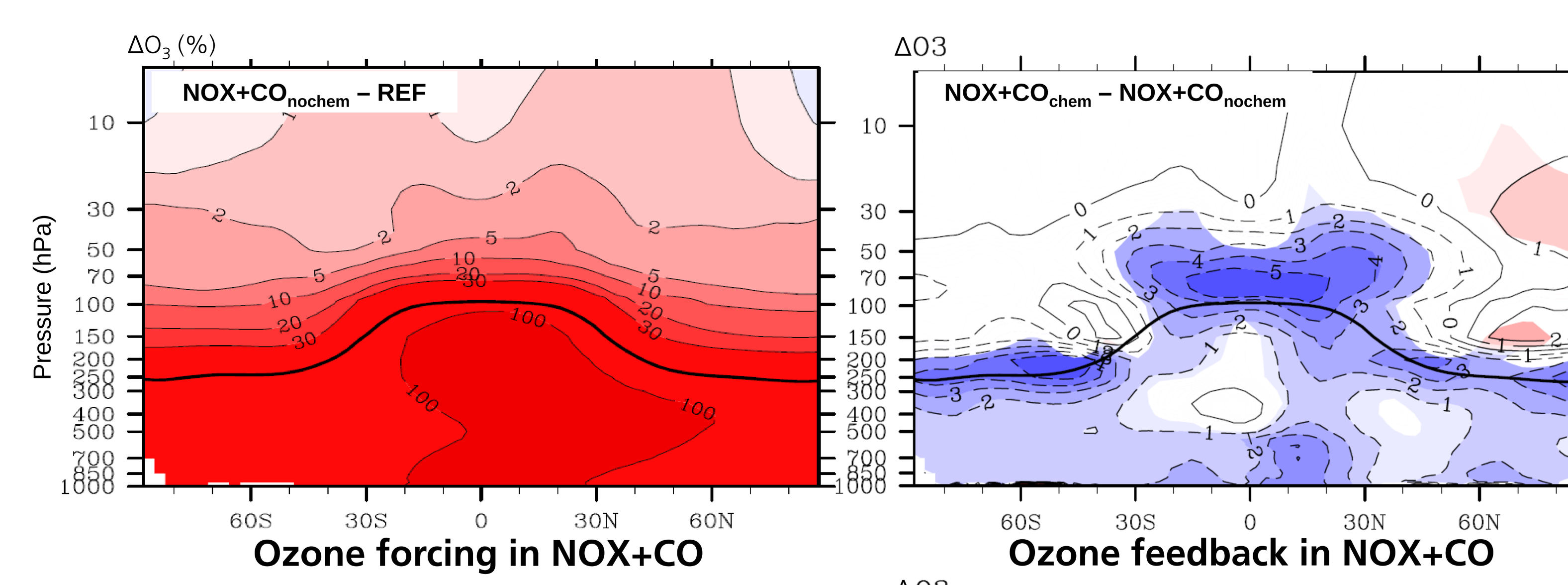
Simulation		RF Wm^{-2}	chemistry	Climate sensitivity λ $K/(Wm^{-2})$ mean	[95% confi.]
Increase of CO_2 by 75 ppmv	+75CO2	1.06	no	0.73	[0.67; 0.79]
			yes	**0.63**	**[0.57; 0.68]**
Doubling of CO_2	2xCO2	4.13	no	0.70	[0.69; 0.72]
			yes	**0.68**	**[0.66; 0.69]**
Quadrupling of CO_2	4xCO2	8.93	no	0.91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

Simulations:

Dietmüller (2011)
Dietmüller et al. (2014)

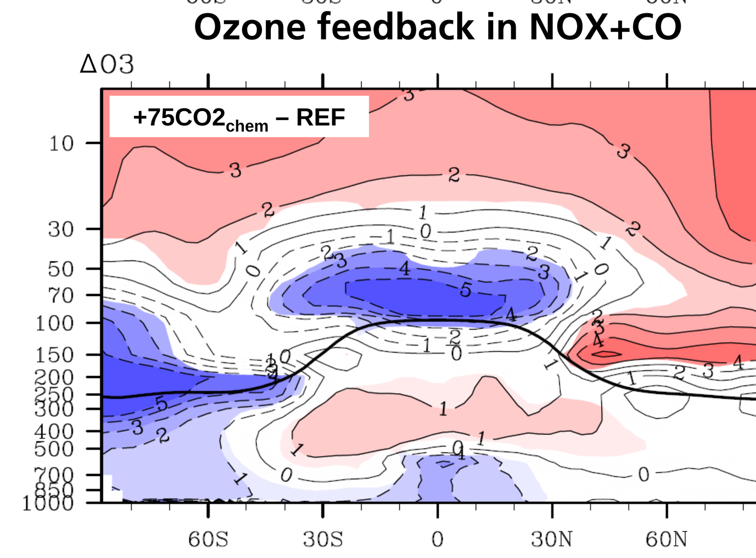
Climate sensitivity changes are initiated by the feedback induced by interactive ozone.

Non-CO_2 forcing: Ozone Forcing and Ozone Feedback from Enhanced NO_x/CO Surface Emissions



Ozone forcing in NOX+CO

Ozone feedback in NOX+CO



Ozone feedback in +75CO2

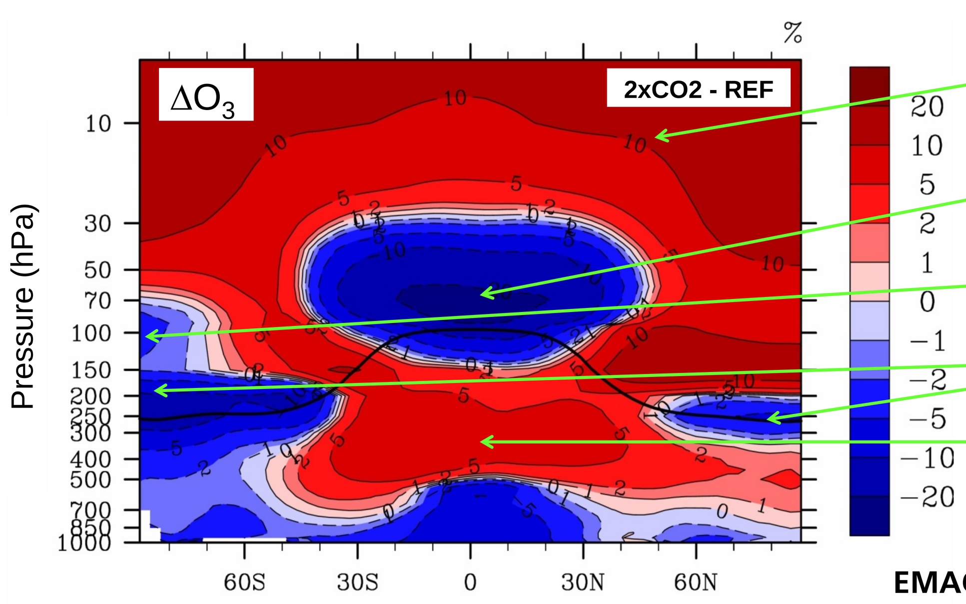
Ozone radiative feedback gets even more negative in NOX+CO ($-0.17\ Wm^{-2}K^{-1}$) compared to CO_2 increase simulations, but efficacy is enhanced with respect to +75CO2.

Need of complete feedback analysis is indicated for consistent interpretation!

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

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	0.73	[0.67; 0.79]
			yes	**0.63**	**[0.57; 0.68]**
Ozone change from enhanced NO_x/CO surface emissions	NOX+CO	1.22	no	0.63	[0.57; 0.69]
			yes	**0.69**	**[0.65; 0.73]**

Ozone Feedback in CO_2-driven Simulations: Robustness



2xCO2

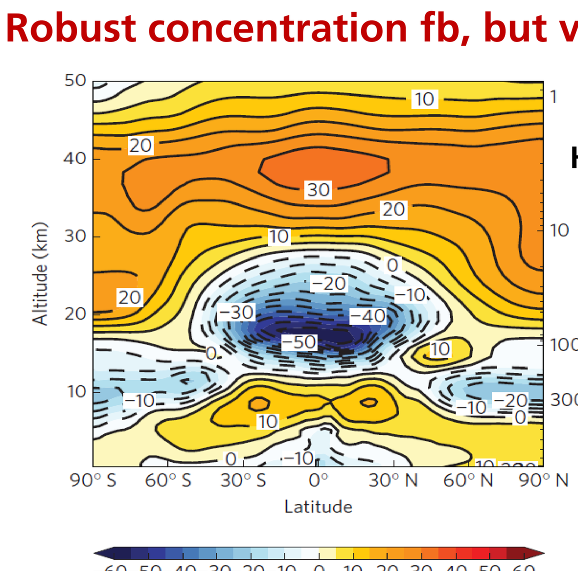
$\alpha_{O3} = -0.022\ Wm^{-2}K^{-1}$

4xCO2

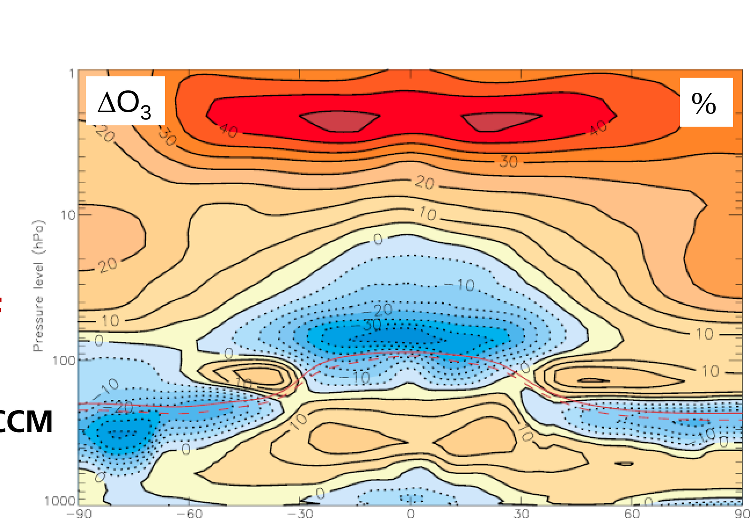
$\alpha_{O3} = -0.015\ Wm^{-2}K^{-1}$

EMAC Dietmüller et al. (2014)

Robust concentration fb, but variable radiative ozone fb!



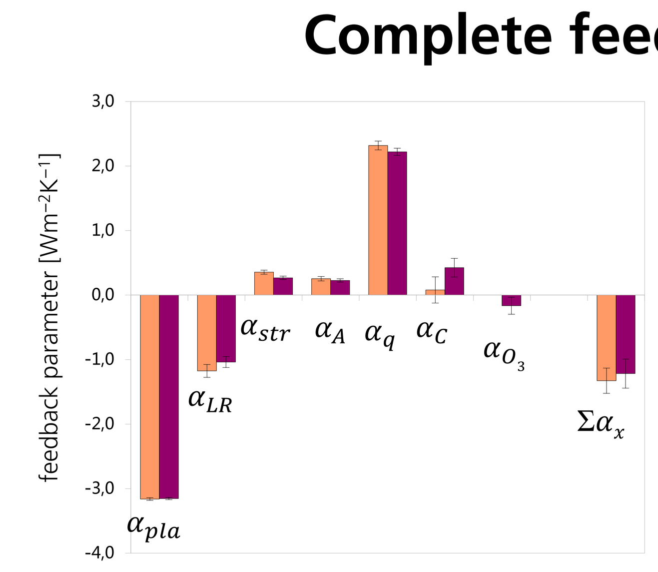
4xCO2 - REF



Nowack et al. (2015) $\alpha_{O3} \sim -0.13\ Wm^{-2}K^{-1}$

Marsh et al. (2016) $\alpha_{O3} \sim -0.011\ Wm^{-2}K^{-1}$

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. **but ...**
- 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.

$$\alpha = \sum_x \alpha_x = \sum_x \frac{\Delta R_x}{\Delta T_S}$$

Partial radiative perturbation (PRP) feedback analysis (e.g. Jonko et al., 2013)

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