Laura Stecher, Franziska Winterstein, Martin Dameris, Patrick Jöckel, and Michael Ponater

Deutsches Zentrum für Luft- und Raumfahrt – Institut für Physik der Atmosphäre, Oberpfaffenhofen (Germany)

Estimating the impact of the radiative feedback from atmospheric methane on climate sensitivity

Motivation & Research Questions

Methane (CH_4) is removed from the atmosphere via chemical degradation. Here, we assess the radiative feedback of atmospheric CH_4 resulting from changes in its chemical sink, which is mainly the oxidation with the hydroxyl radical (OH), and which is influenced by temperature and the chemical composition of the atmosphere.

We explore the feedback of CH_4 in sensitivity simulations perturbed by either CO_2 or CH_4 increase to assess the following questions:

- How large are the **rapid radiative adjustments** and the **slow climate feedbacks** for CO_2 and for CH_4 perturbations? Which role does the interactive chemistry play?
- What is the **feedback from interactive CH_4** on the climate sensitivity in CO_2- and in CH_4- driven equilibrium climate change simulations?
- How does the climate feedback of CH_4 affect the **climate feedback of tropospheric ozone (O_3)**?

Simulation set-up

<u>CO_2 (concentration) and CH_4 (emission) perturbation experiments:</u>

ERF: Effective Radiative Forcing
SSTfix: prescribed SSTs and SIC (HadISST; Rayner et al., 2003)
chem: interactive chemistry
→ **ERF & rapid radiative adjustments**

ECC: Equilibrium Climate Change
SSTvar: Mixed Layer Ocean
chem: interactive chemistry
→ **Slow climate feedbacks & climate sensitivity**

SSTvar: Mixed Layer Ocean
nochem: prescribed chemical tracer distributions of O_3 and CH_4 from $ERFCO_2{}^{SSTfix}{}_{chem}$ / $ERFCH_4{}^{SSTfix}{}_{chem}$
→ **Influence of interactive chemistry on climate sensitivity**

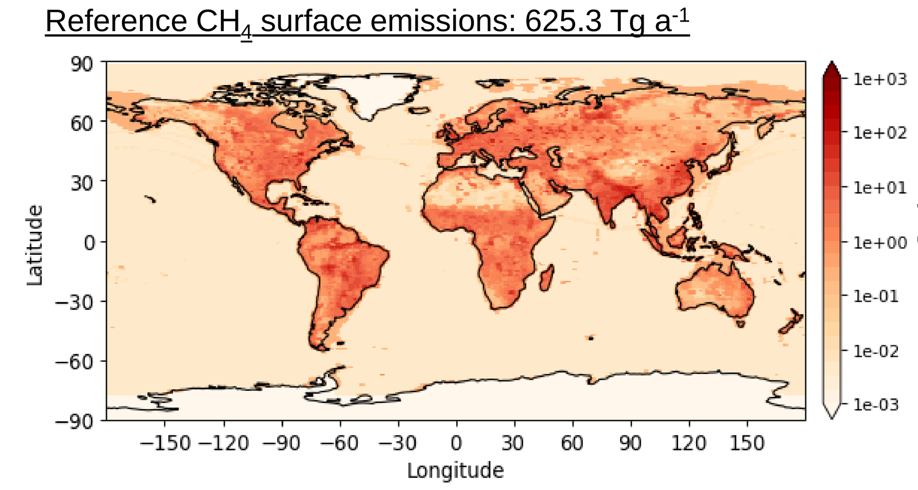
$REF^{SSTfix}{}_{chem}$
$REF^{SSTvar}{}_{chem}$
$REF^{SSTvar}{}_{nochem}$

CO_2x1.35	CH_4x2.75
$ERFCO_2{}^{SSTfix}{}_{chem}$ ERF = 1.61 ± 0.24 Wm^{-2}	$ERFCH_4{}^{SSTfix}{}_{chem}$ ERF = 1.72 ± 0.22 Wm^{-2}
$ECCCO_2{}^{SSTvar}{}_{chem}$ ΔT = 1.09 ± 0.09 K	$ECCCH_4{}^{SSTvar}{}_{chem}$ ΔT = 1.17 ± 0.09 K
$ECCCO_2{}^{SSTvar}{}_{nochem}$	$ECCCH_4{}^{SSTvar}{}_{nochem}$

- CCM EMAC (Jöckel et al., 2016)
- T42L90MA resolution
- Time slice simulations representing year 2010
- Chemical mechanism consisting of 265 gas-phase, 82 photolysis and 12 heterogeneous reactions for 160 species

- CH_4 emissions instead of prescribed CH_4 mixing ratios at the lower boundary
  - Inverse optimized emission inventory representing the year 2010 (Frank, 2018)
  - No feedback of emissions: either reference emissions or increased by global mean factor

<u>Reference CH_4 surface emissions: 625.3 Tg a^{-1}</u>



Partial radiative perturbation method

(following e.g., Rieger et al., 2017)

$$\alpha_{phys} = \alpha_{Planck} + \alpha_{Lapse\ Rate} + \alpha_{H_2O} + \alpha_{Cloud} + \alpha_{Albedo}$$
$$\alpha = \alpha_{phys} + \alpha_{chem} = \alpha_{phys} + \alpha_{O_3} + \alpha_{CH_4} + \ ...$$

$$\Delta R^{FW}_{H_2O} = R(T, p, H_2O, CH_4, ...) - R(T, p, H_2O, CH_4, ...)$$
$$\Delta R^{BW}_{H_2O} = -(R(T, p, H_2O, CH_4, ...) - R(T, p, H_2O, CH_4, ...))$$
$$\Delta R_{H_2O} = \frac{1}{2}(\Delta R^{FW}_{H_2O} + \Delta R^{BW}_{H_2O})$$

Reference

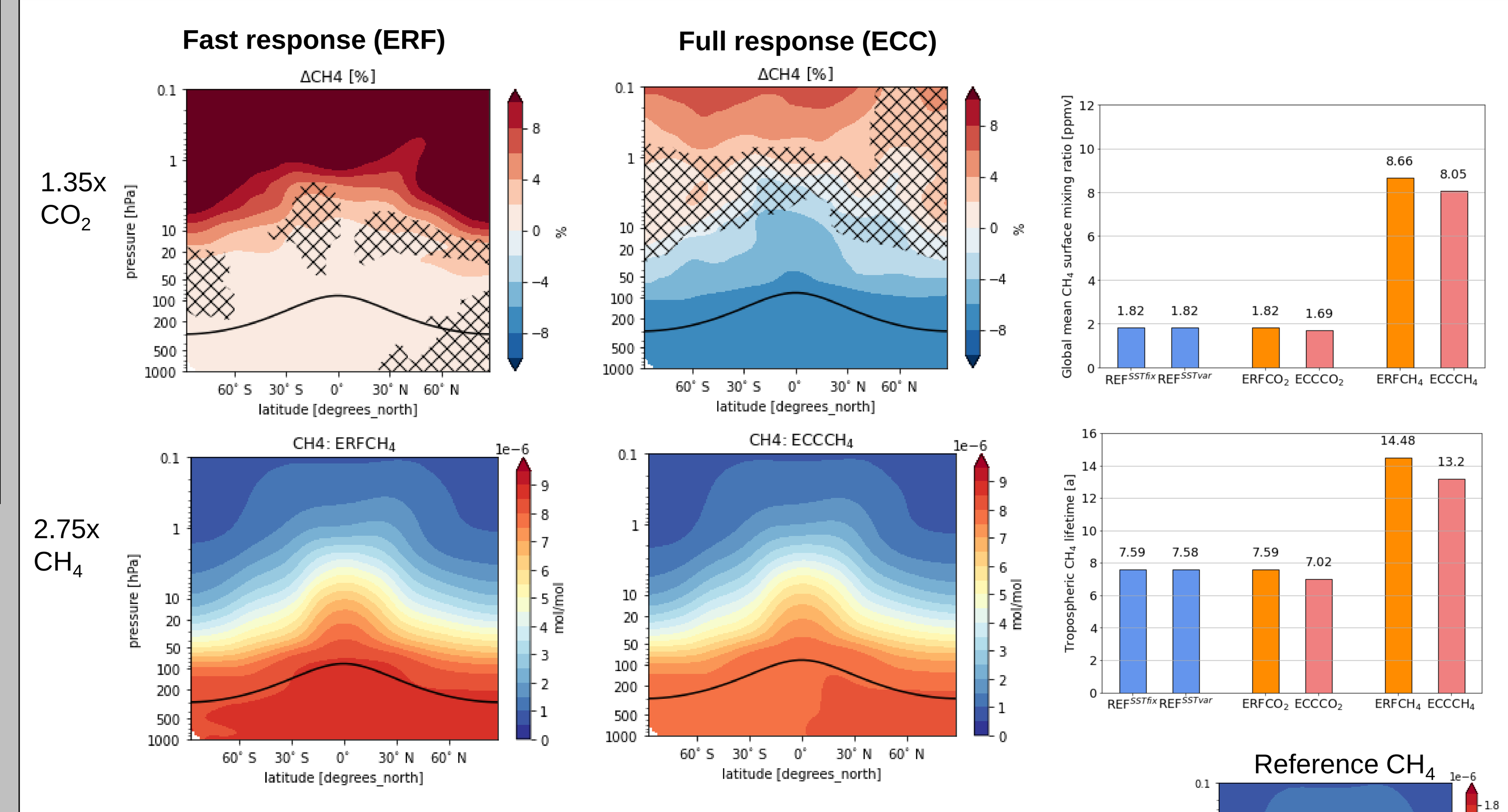
Experiment (e.g. $ERFCO_2{}^{SSTfix}{}_{chem}$)

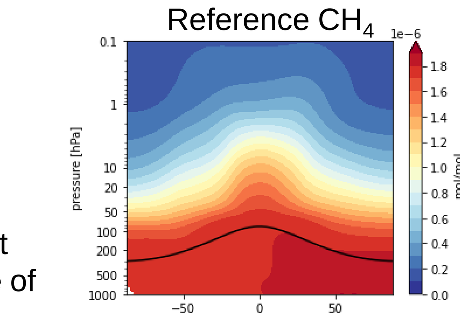
→ Radiative perturbation $[\frac{W}{m^2}]$

R: net radiative flux at TOA
FW: Forward
BW: Backward
T: temperature
p: pressure

Offline radiative transport with the Modular Earth Submodel System (MESSy) basemodel RAD (MBM RAD), which is fully consistent with EMAC radiation (default radiation scheme of ECHAM5 or Psrad (Pincus and Stevens, 2013) available).

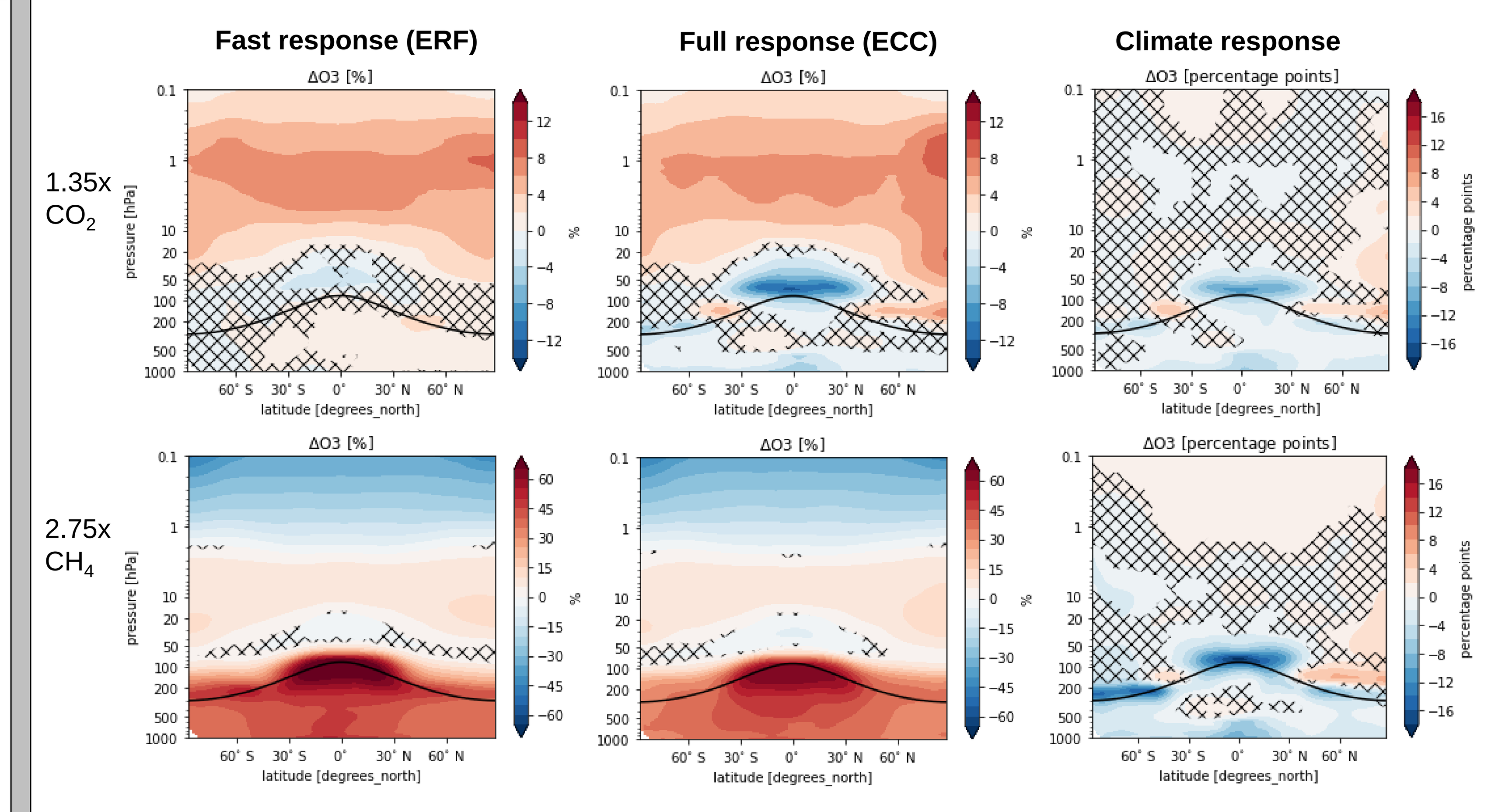
CH_4 response





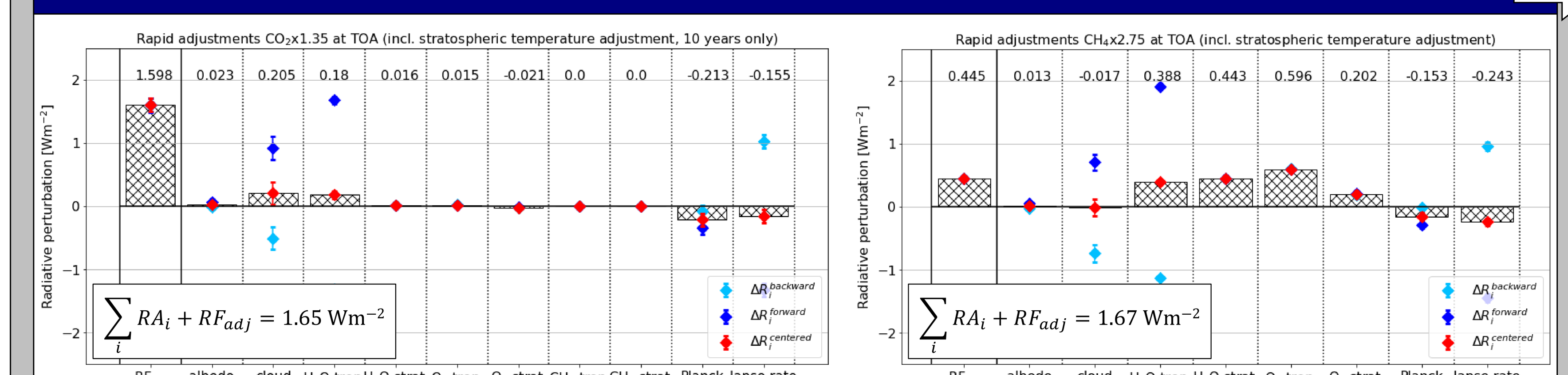
- Increase of CH_4 emissions by factor 2.75 results in an increase of CH_4 surface mixing ratios by factor 4.76.
- The increasing abundance of OH due to warming and associated moistening of the troposphere, and the temperature dependence of the reaction rate coefficient lead to the shortening of the atmospheric CH_4 lifetime. This results in a decrease of the CH_4 mixing ratios, a negative CH_4 climate feedback.

Ozone response

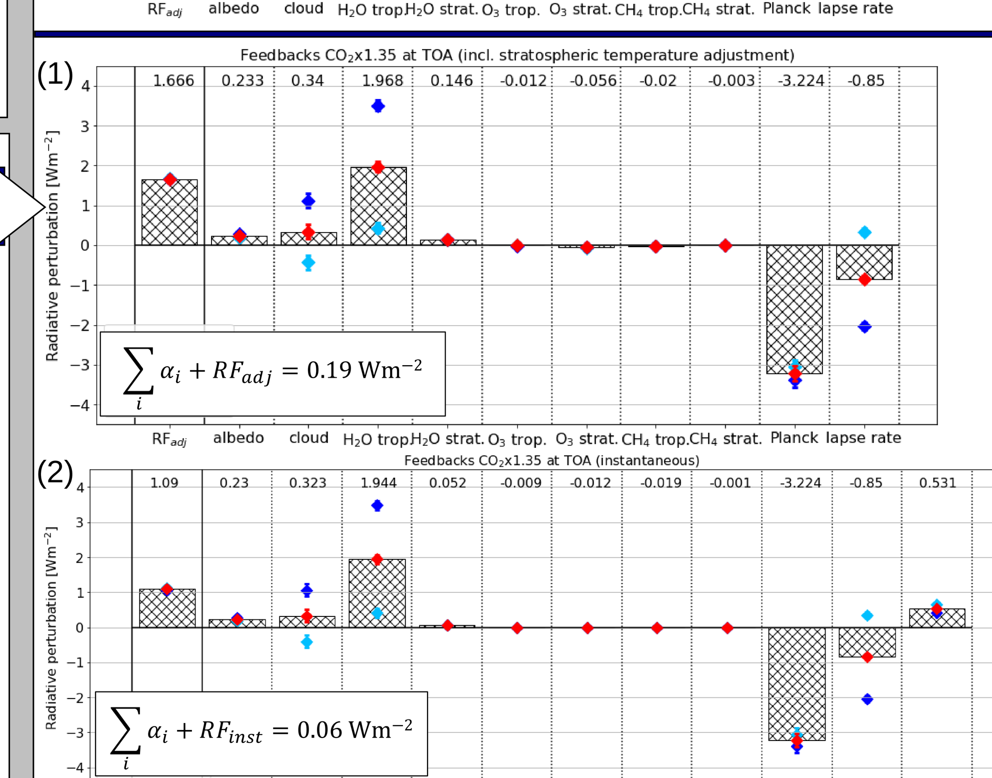


Climate response of tropospheric O_3 reduced by negative CH_4 feedback
- Less O_3 is formed from CH_4 degradation
- Counteracted by enhanced O_3 formation from increased biogenic and lightning NO_x emissions
- Climate response of O_3 (Full response – Fast response) consistent for CO_2 and CH_4 perturbation

Individual radiative contributions



(1)
(2)



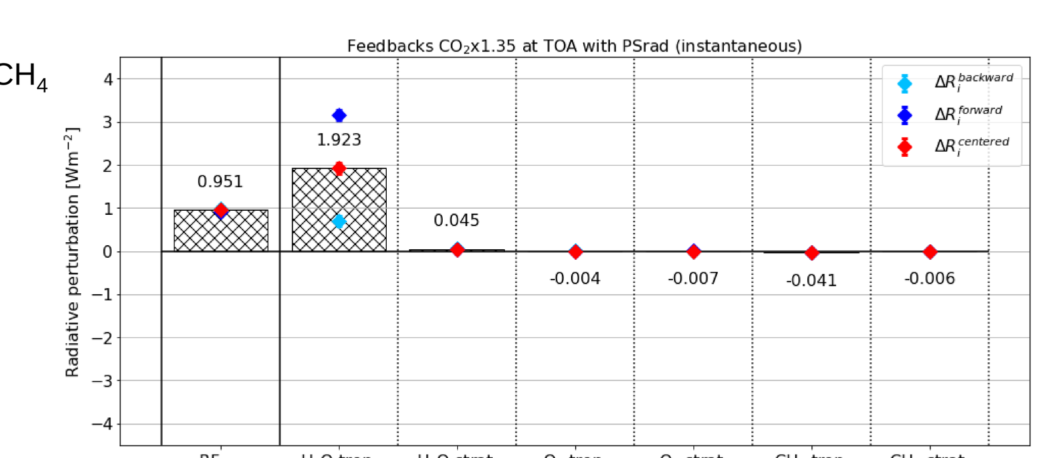
<u>Rapid adjustments:</u>
- CO_2: dominated by stratospheric temperature adjustment (strat. temp. adj.); chemical contributions small
- CH_4: important chemical contributions from H_2O and O_3

<u>Feedbacks:</u>

Either (1) strat. temp. adj. for each feedback individually included or (2) separate strat. temp. adj.
- Residual ($\sum_i \alpha_i + RF_{adj/inst}$) larger for (1): points to non-radiative driven feedback of stratospheric temperature
- Inclusion of strat. temp. adj. important for feedback of strat. H_2O, O_3 and potentially CH_4
- Radiative CH_4 feedback underestimated by ECHAM5 radiation scheme (see Outlook)

Conclusions & Outlook

<u>Conclusions:</u>
- Negative climate feedback of atmospheric CH_4 resulting from changes in its chemical sink explicitly simulated.
- CH_4 feedback reduces climate feedback of tropospheric O_3, which results in overall stronger negative feedback of O_3.
- Effect consistent for CO_2 and for CH_4 perturbation.
- Magnitude of radiative CH_4 feedback underestimated by used radiation scheme (ECHAM5 default).



<u>Outlook:</u>
- Additional radiation scheme, PSrad (Pincus and Stevens, 2013), implemented in EMAC.
- PSrad represents radiative effect of CH_4 better.
- Set-up with PSrad radiation online in chemistry-climate simulations in preparation.

	Winterstein et al., 2019 (EMAC-ECHAM5) [Wm^{-2}]	EMAC-PSrad [Wm^{-2}]	Myhre et al. 1998 [Wm^{-2}]	Etminan et al. 2016 [Wm^{-2}]
2xCH_4	0.23	0.56	0.53	0.62
5xCH_4	0.51	1.68	1.55	-

Reference CH_4: 1.8 ppm

References & Acknowledgments

- Frank, F.: Atmospheric methane and its isotopic composition in a changing climate: A modeling study, PhD thesis, Ludwig-Maximilians-Universität München, 2018
- Jöckel, P., et al.: Earth System Chemistry integrated Modelling (ESCiMo) with the Modular Earth Submodel System (MESSy) version 2.51, Geosci. Model Dev., 9, 1153-1200, https://doi.org/10.5194/gmd-9-1153-2016, 2016
- Pincus, R. and Stevens, B.: Paths to accuracy for radiation parameterizations in atmospheric models, Journal of Advances in Modeling Earth Systems, 5, 225–233, https://doi.org/https://doi.org/10.1002/jame.20027, 2013
- Rayner, N. A., et al.: Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century, J. Geophys. Res.-Atmos., 108, 4407, https://doi.org/10.1029/2002JD002670, 2003
- Rieger, V.S., et al.: Can feedback analysis be used to uncover the physical origin of climate sensitivity and efficacy differences?. Clim Dyn 49, 2831–2844, https://doi.org/10.1007/s00382-016-3476-x, 2017
- Winterstein, F., et al.: Implication of strongly increased atmospheric methane concentrations for chemistry-climate connections, Atmos. Chem. Phys., 19, 7151-7163, 2019

*This study has been conducted in the framework of the DFG project **IRFAM-ClimS** (grant no. WI 5369/1-1)
The model simulations have been performed at the German Climate Computing Centre (**DKRZ**) through support from the Bundesministerium für Bildung und Forschung (**BMBF**).*

Deutsches Zentrum für Luft- und Raumfahrt e.V.

Contact: laura.stecher@dlr.de

Scan for abstract:

Institut für Physik der Atmosphäre
http://www.dlr.de/ipa

18.04.2023