Investigation of strongly enhanced methane Part I: Chemical feedbacks and rapid adjustments

EGU General Assembly,

Middle atmosphere composition and feedbacks in a changing climate,

07.05.2020

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

DLR

Chemical feedbacks and rapid adjustments in scenarios with strongly enhanced methane

Motivation:

- CH_4 mixing ratios are on a sharp rise.
- Secondary chemical effects of CH_4 are crucial to understand the total climate effects of CH_4.
- Strongly enhanced mixing ratios sharpen the knowledge on potential climate impacts.

DLR

Experimental set-up

Simulations:

Simulation ID	Lower boundary condition of CH_4
REF	1.8 ppmv (reference 2010)
S2	2x REF fSST $\Rightarrow$ 3.6 ppmv*
S5	5x REF fSST $\Rightarrow$ 9.0 ppmv

* according to RCP 8.5 this value will be reached about 2080

- State of the art chemistry-climate model EMAC (Jöckel et al. 2016)
- Lower boundary condition of CH_4 nudged by Newtonian relaxation
- Time-slice equilibrium simulation of 20 years
- Prescribed oceanic conditions (sea surface temperature and sea ice conc.)

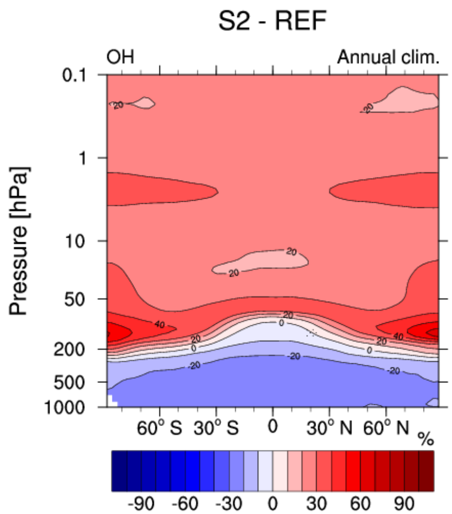
$\Rightarrow$ mimicking present day (2010) tropospheric temperatures, changes are largely suppressed

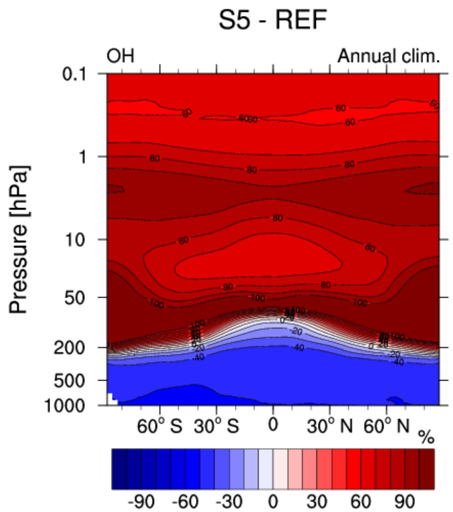
$\Rightarrow$ focus on rapid (chemical driven) adjustments

For the complete picture including the slow climate feedback please consider also the follow up study presented in this session:
Investigation of strongly enhanced methane Part II: Slow climate feedbacks

Impact on tropospheric oxidation capacity

OH

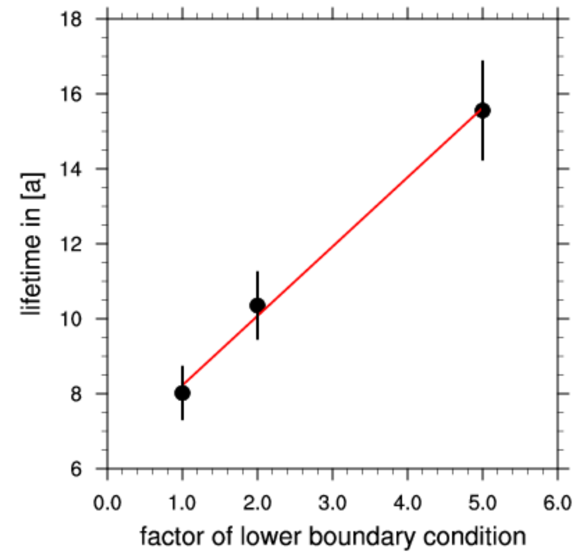




Left:
Difference in OH mixing ratio in percent [%] between REF and sensitivity simulations S2 (upper) and S5 (lower).

Right:
Tropospheric CH_4 lifetime with respect to the applied scaling factor of the lower boundary condition: 1.0 (REF), 2.0 (S2) and 5.0 (S5). The lifetime is calculated with respect to the tropospheric OH sink (see supplementary material).

tropospheric CH_4 lifetime

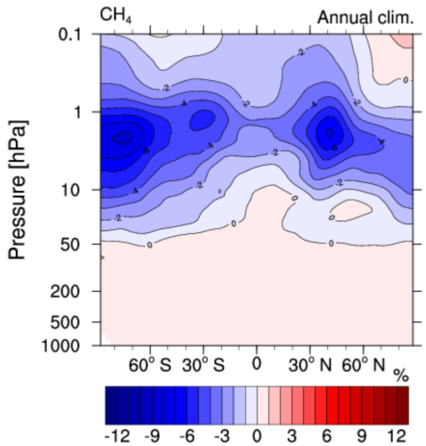


Enhanced CH_4 mixing ratios lead to a reduction in tropospheric OH and a prolongation of CH_4 lifetime.

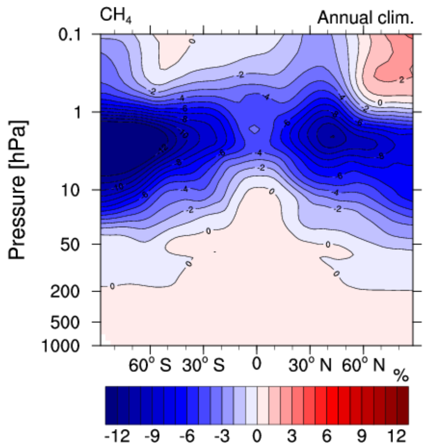
Non-linear stratospheric CH_4 depletion

CH_4

CH_4^{S2} - $2xCH_4^{REF}$



CH_4^{S5} - $5xCH_4^{REF}$

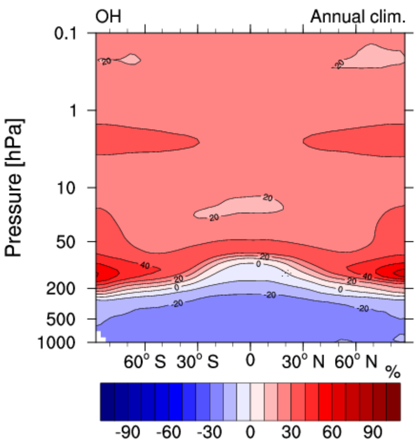


Left:
Non-linear stratospheric CH_4 depletion. We substracted from the CH4 mixing ratio in the sensitivity simulations the mixing ratio of the reference multiplied with the respective factor (2 for S2 and 5 for S5). The blue areas show where relatively more CH_4 is oxidized in the sensitivity simulation than in the reference simulation.

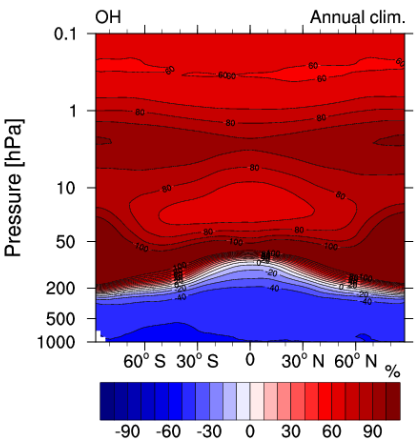
Right:
Difference in OH mixing ratio in percent [%] between REF and sensitivity simulations S2 (upper) and S5 (lower).

OH

S2 - REF



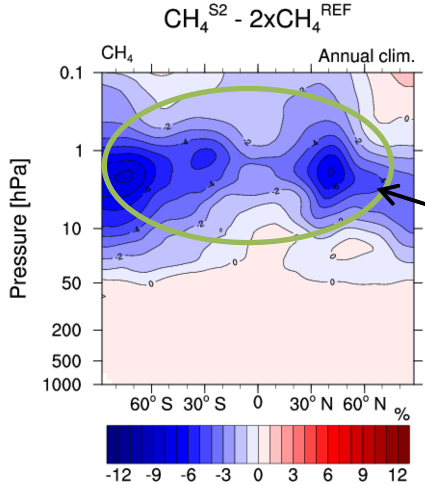
S5 - REF

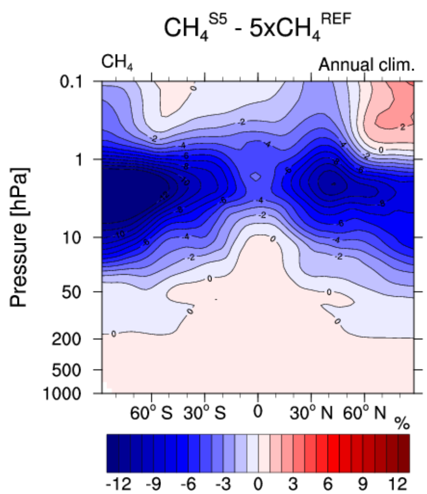


DLR

Non-linear stratospheric CH_4 depletion

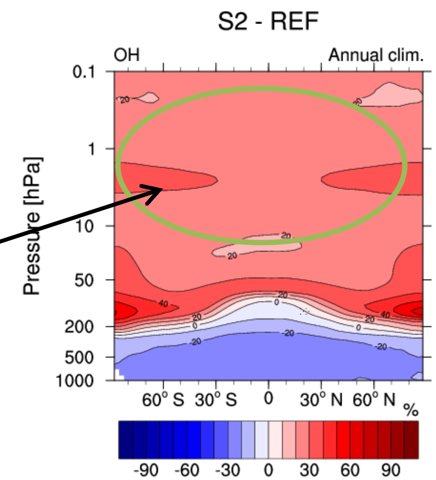
CH_4

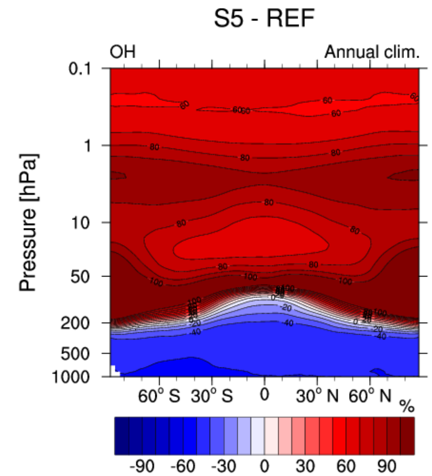




Areas where more CH_4 is oxidized than linearily expected, correspond to areas with increased OH mixing ratios

OH



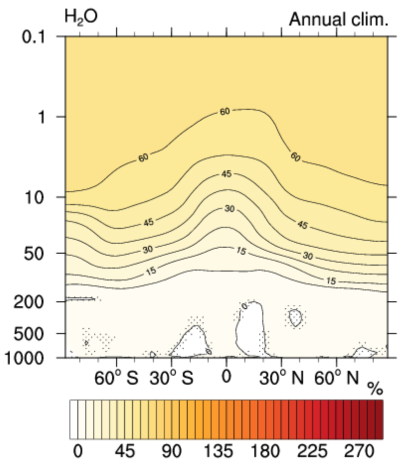


Impact on stratospheric chemistry

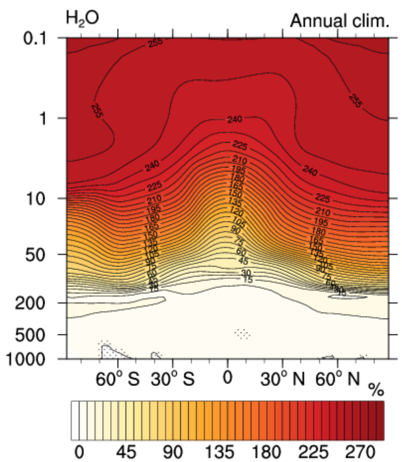
Left: Difference in H_2O mixing ratio in percent.
Middle: Difference in temperature in K.
Right: Difference in O_3 mixing ratio in percent.

H_2O

S2 - REF

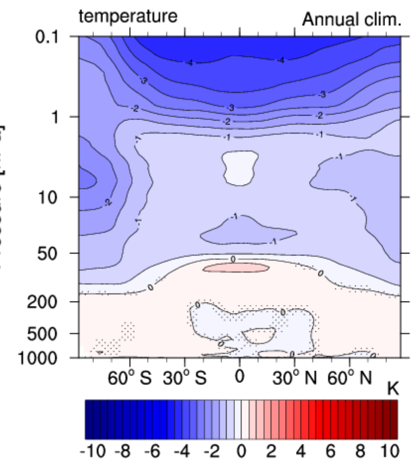


S5 - REF

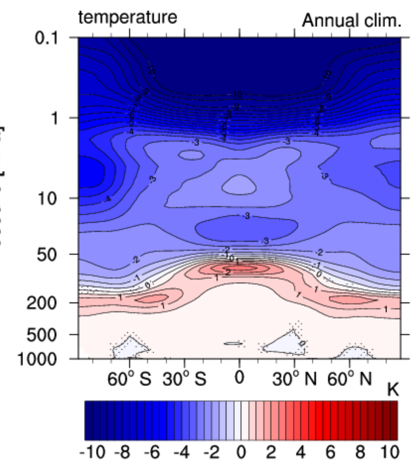


Temperature

S2 - REF

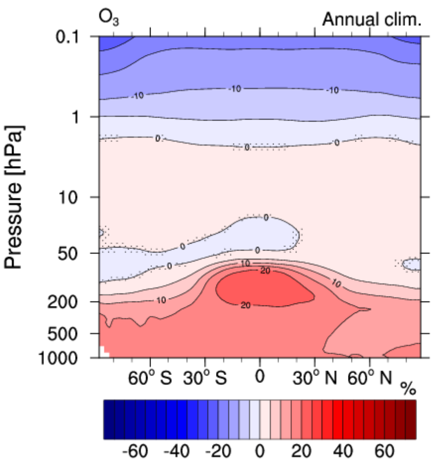


S5 - REF

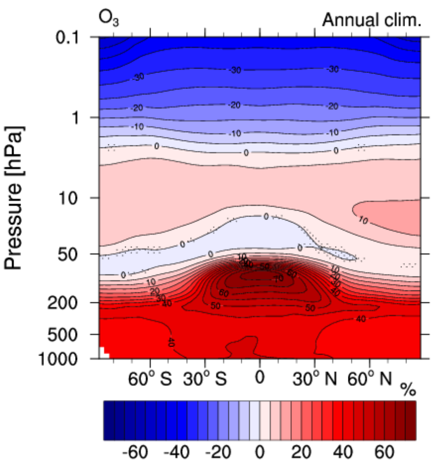


O_3

S2 - REF



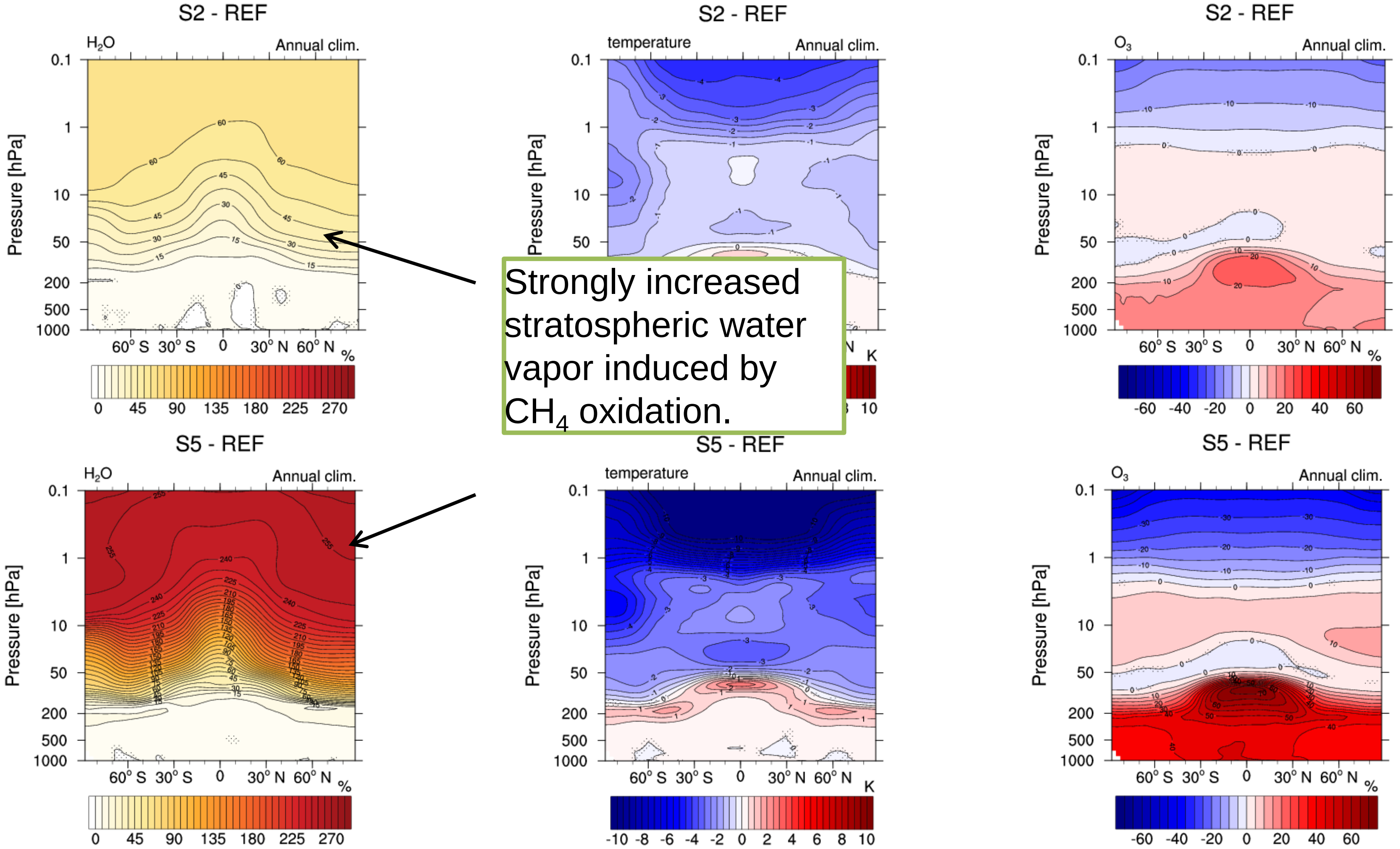
S5 - REF



Impact on stratospheric chemistry

Left: Difference in H_2O mixing ratio in percent.
Middle: Difference in temperature in K.
Right: Difference in O_3 mixing ratio in percent.

H_2O | Temperature | O_3

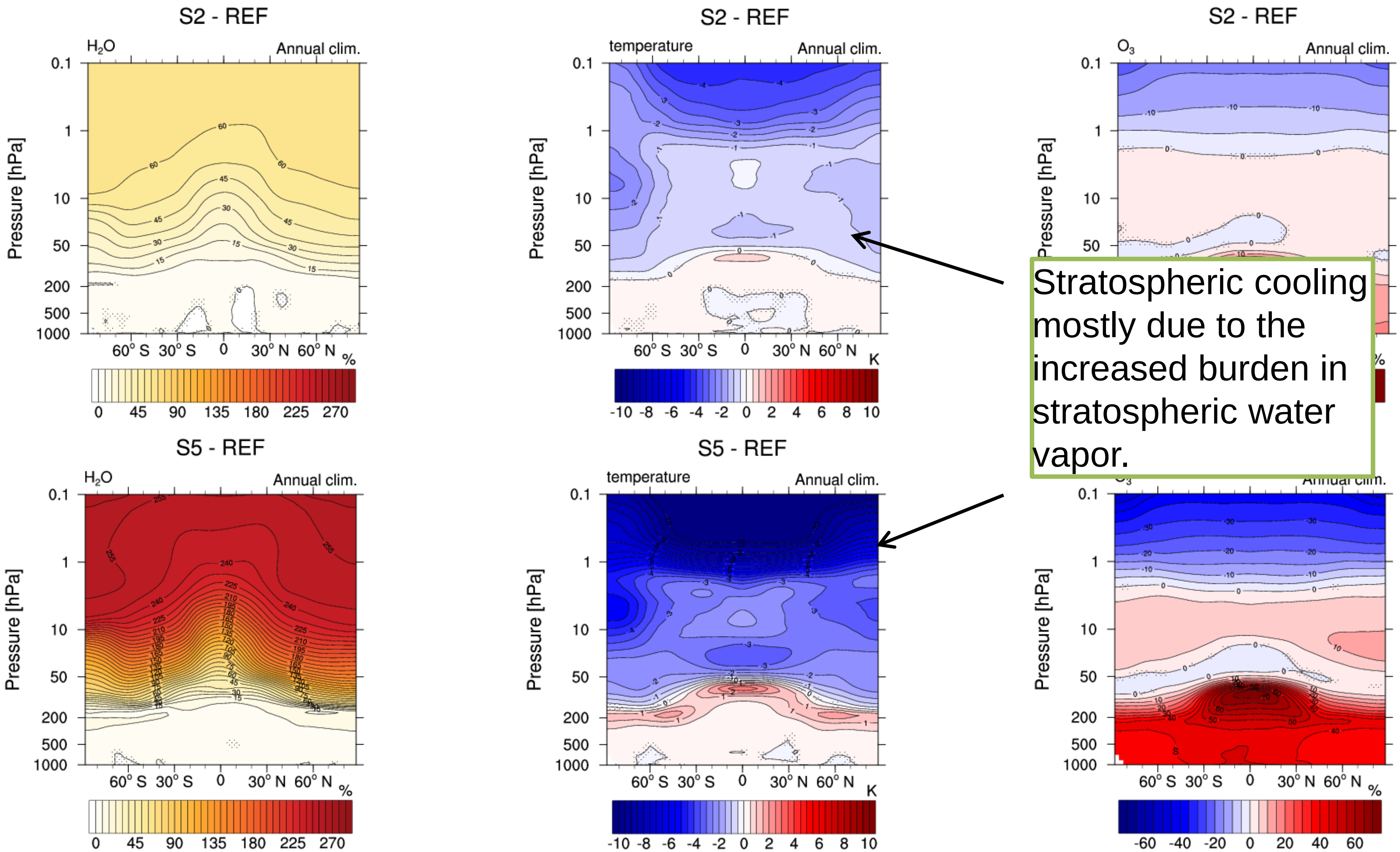


Strongly increased stratospheric water vapor induced by CH_4 oxidation.

Impact on stratospheric chemistry

Left: Difference in H_2O mixing ratio in percent.
Middle: Difference in temperature in K.
Right: Difference in O_3 mixing ratio in percent.

H_2O | Temperature | O_3

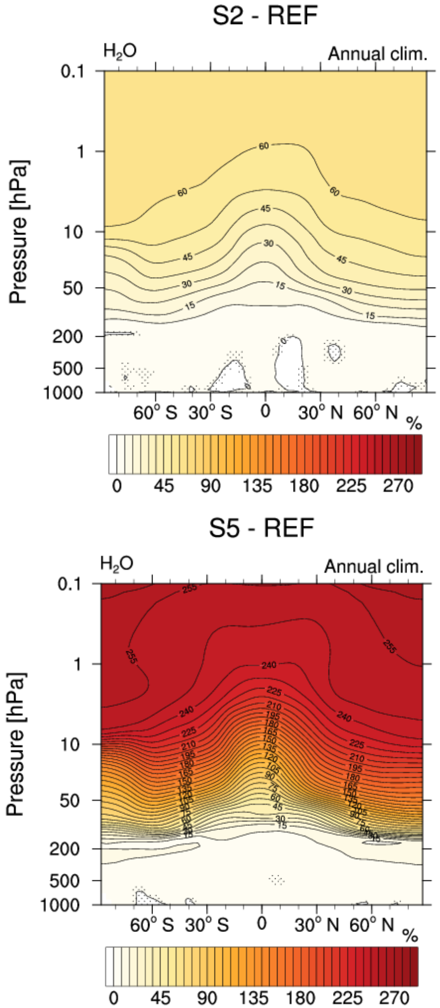


DLR

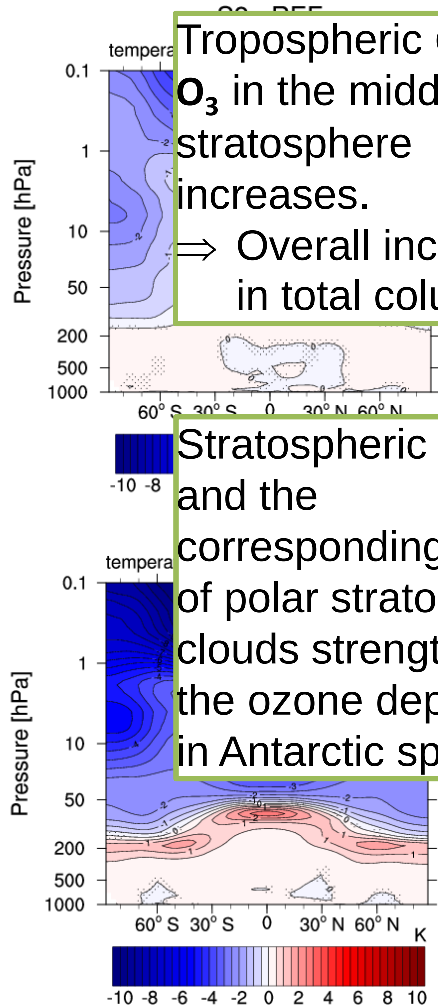
Impact on stratospheric chemistry

Left: Difference in H_2O mixing ratio in percent.
Middle: Difference in temperature in K.
Right: Difference in O_3 mixing ratio in percent.

H_2O



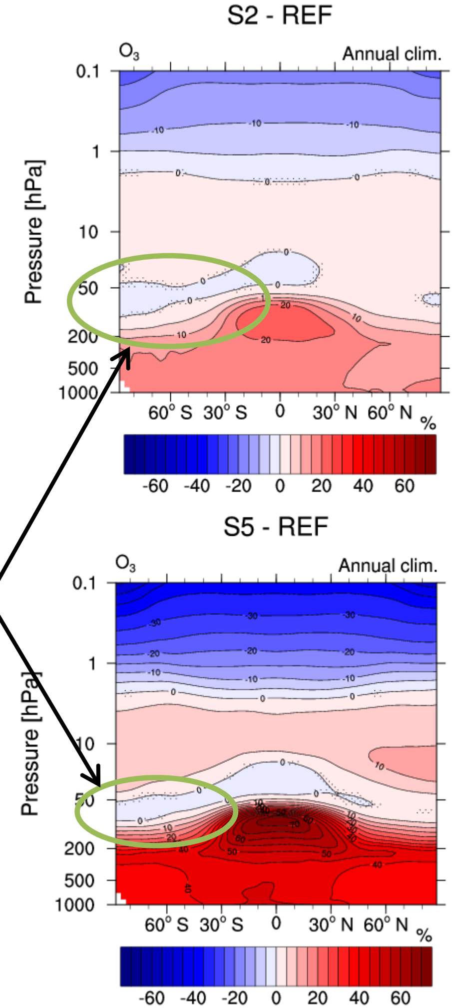
Temperature



Tropospheric **O_3** and **O_3** in the middle stratosphere increases.
⇒ Overall increase in total column **O_3**.

Stratospheric cooling and the corresponding favor of polar stratospheric clouds strengthens the ozone depletion in Antarctic spring.

O_3



DLR

Radiative impact

Solitary radiative impacts in W m^{-2}:

Simulation	CH_4	SWV	O_3	Chem. effect	Phys. effect	Total
S2* (+1800 ppbv)	0.23	0.15	0.27	0.66	0.03	0.69
S5* (+7200 ppbv)	0.51	0.55	0.76	1.82	-0.03	1.79

Estimates from other studies:

- 0.48±0.1 W m^{-2} [IPCC, 2013] (+1100 ppbv)
- 1 W m^{-2} [HadGEM2, Forster 2016, Smith et al. 2018] (+3534 ppbv)
- 1.4 W m^{-2} [CESM1, Forster 2016, Smith et al. 2018] (+3534 ppbv)

The solitary radiative impact of CH_4 is comparably small, which is found in other studies using ECHAM5 as well (Lohmann et al. 2010).

Conclusions

- First of its kind study investigating the **rapid adjustments** of CH_4 in a chemistry-climate-model
- Strong **impact on the oxidation capacity** of the troposphere (influences air quality and mitigation plans)
- Substantial **rise in stratospheric water vapor** (SWV)
- Overall increase in total **O_3** column but enhanced **O_3 depletion** in the Antarctic lower stratosphere
- Radiative impacts of 0.69 W m^{-2} ($2xCH_4$) and 1.79 W m^{-2} ($5xCH_4$), respectively, predominated by chemical induced radiative effects from SWV and O_3

The presented study is published in **Winterstein**, F., Tanalski, F., Jöckel, P., Dameris, M., and Ponater, M.: Implication of strongly increased atmospheric methane concentrations for chemistry-climate connections, Atmos. Chem. Phys., 19, 7151-7163, https://doi.org/10.5194/acp-19-7151-2019, 2019.

Literature references:

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.

Lohmann, U. et al.: Total aerosol effect: radiative forcing or radiativeflux perturbation?, Atmos. Chem. Phys., 10, 3235–3246,https://doi.org/10.5194/acp-10-3235-2010, 2010.

Winterstein, F., et al.: Implication of strongly increased atmospheric methane concentrations for chemistry–climate connections, Atmos. Chem. Phys., 19, 7151–7163, https://doi.org/10.5194/acp-19-7151-2019, 2019

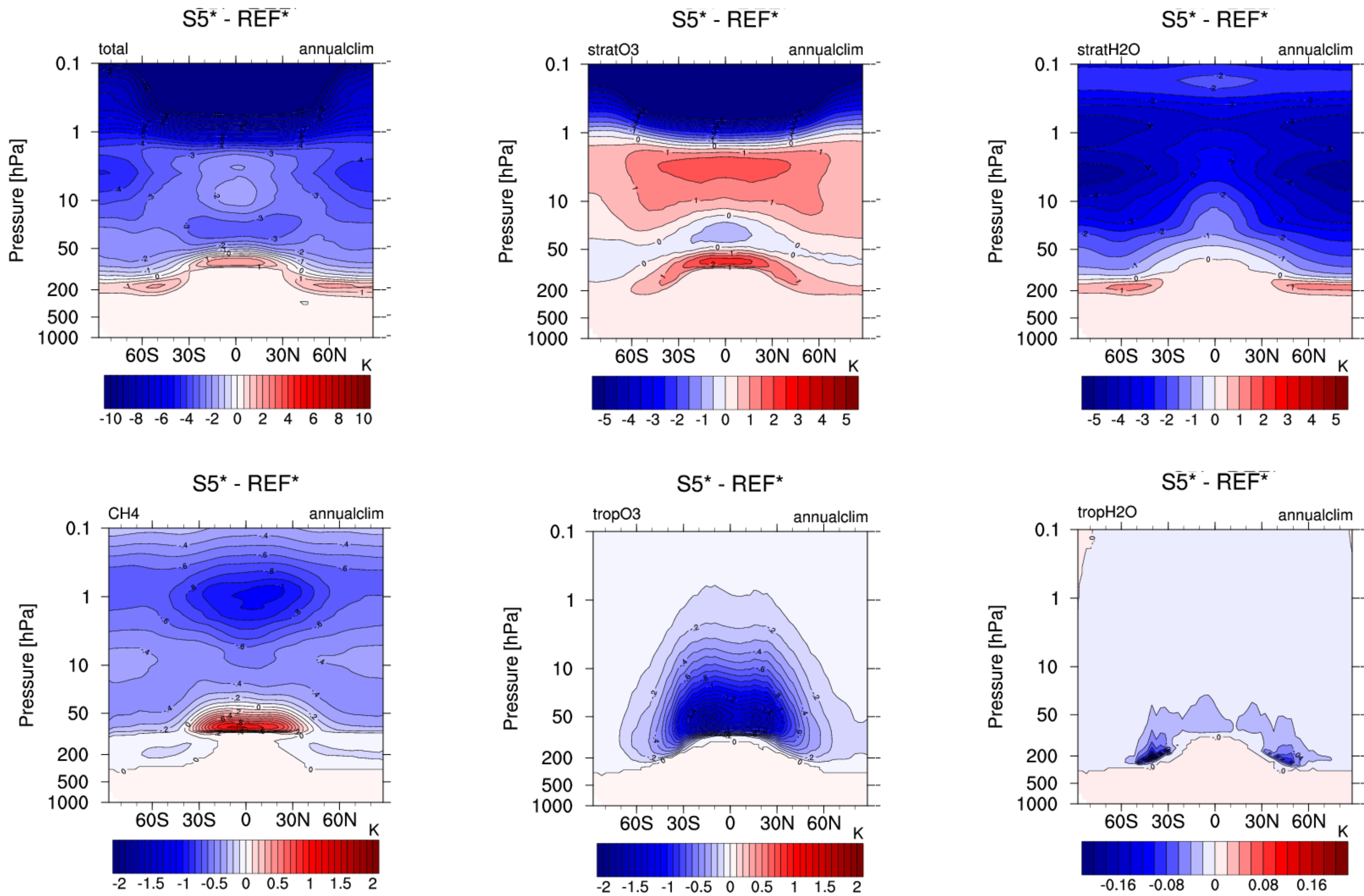
Forster, P. M. et al.: Recommendations for diagnosing effective radiative forcingfrom climate models for CMIP6, J. Geophys. Res.-Atmos., 121,12460–12475, https://doi.org/10.1002/2016JD025320, 2016

Smith, C. J. et al.: Understanding Rapid Adjustments to Diverse Forcing Agents, Geophys. Res. Lett., 45, 12023–12031,https://doi.org/10.1029/2018GL079826, 2018

Supplementary material

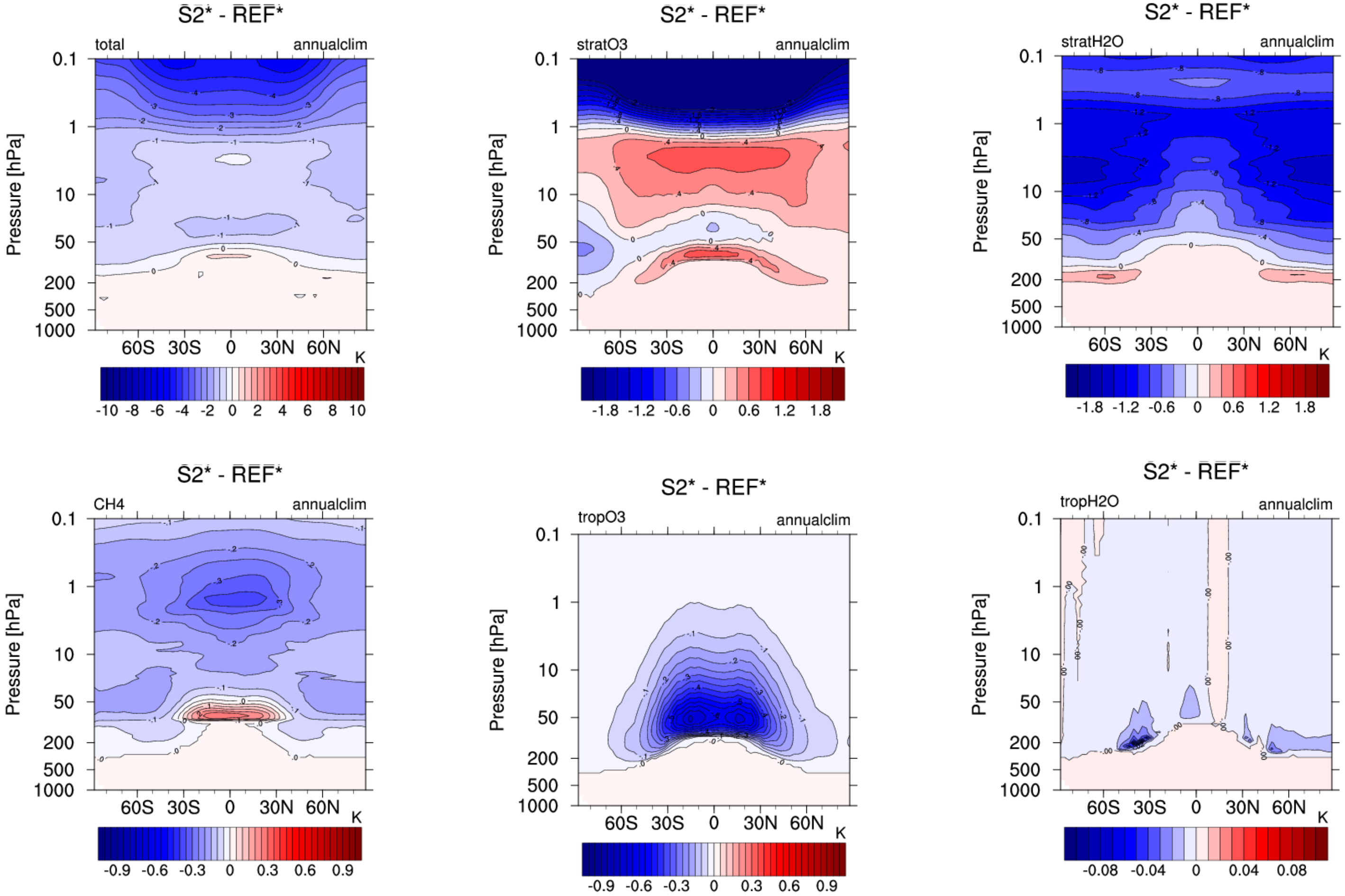
Adjusted stratospheric temperature

Stratospheric adjustments in temperature expected by the pertubation of the radiative active trace gas.



Adjusted stratospheric temperature

Stratospheric adjustments in temperature expected by the pertubation of the radiative active trace gas.



DLR

Tropospheric CH_4 lifetime:

$$\tau_{CH_4} = \frac{\sum_{b \in B} M_{CH_4}}{\sum_{b \in B} k_{CH_4+OH}(T) \cdot c_{air}(T, p, q) \cdot OH \cdot M_{CH_4}} \quad ,$$

M_{CH_4}: *mass of* CH_4 *in* $[kg]$

k_{CH_4+OH}: *reaction coefficient of reaction* $CH_4 + OH$ *in* $[cm^3\ s^{-1}]$

c_{air}: *concentration of air in* $[mol\ cm^{-3}]$

OH: *mixing ratio of* OH *in* $[mol\ mol^{-1}]$

Integration over all tropospheric gridboxes B