Investigation of strongly enhanced methane
Part II: Slow climate feedbacks

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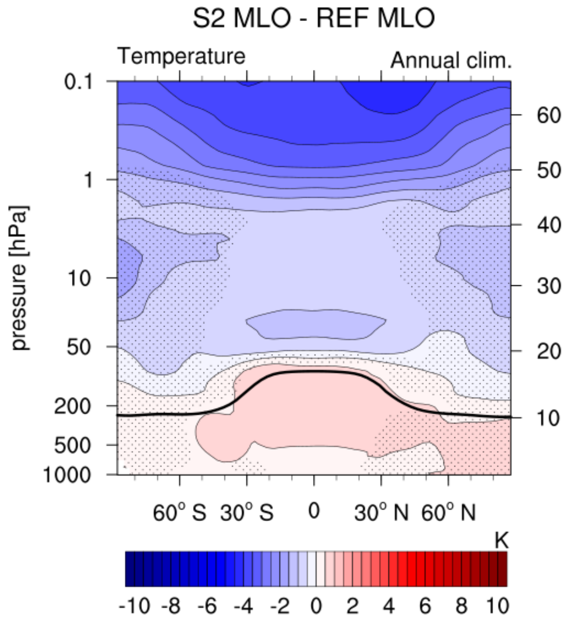
EGU General Assembly 2020
Middle atmosphere composition and feedbacks
in a changing climate
7 May 2020

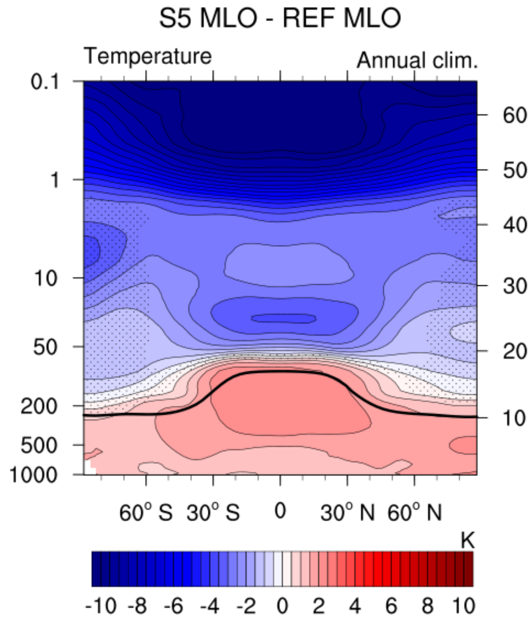
Objective: Quantifying the effects of slow SST-driven climate feedbacks in CH_4-driven climate change simulations

Simulation	Lower boundary of CH_4	SST and SIC		MESSy Version
REF fSST	1.8 ppm (reference 2010)	prescribed (Rayner et al., 2003)	*Rapid adjustments*	2.52
S2 fSST	2×REF fSST → 3.6 ppm[1]			
S5 fSST	5×REF fSST → 9.0 ppm			
REF MLO	1.8 ppm (reference 2010)	Mixed Layer Ocean (MLO) MESSy submodel MLOCEAN[2]	*Slow climate feedbacks*	2.54.0
S2 MLO	2×REF MLO → 3.6 ppm[1]			
S5 MLO	5×REF MLO → 9.0 ppm			

- Chemistry-climate model **EMAC** (Jöckel et al. 2016) in **T42L90MA** resolution
- **CH_4 lower boundary mixing ratios nudged by Newtonian relaxation**[3]
- Compare results including **MLO** with respective experiments with prescribed sea surface temperatures and sea ice concentrations (**fSST**; Winterstein et al. 2019) to **separate the effects of rapid adjustments and slow climate feedbacks**
- Look out for ***Investigation of strongly enhanced methane Part I: Chemical feedbacks and rapid adjustments*** in the fSST simulations in this session

CH_4-induced temperature response in MLO experiments





	ΔT_{2m} [K]
S2 MLO	0.42 ± 0.03
S5 MLO	1.28 ± 0.02

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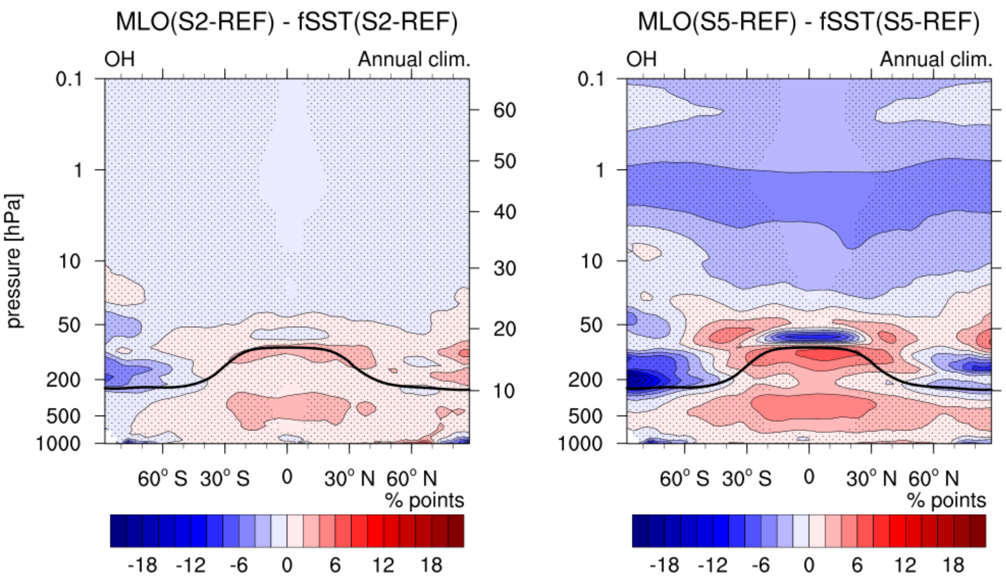
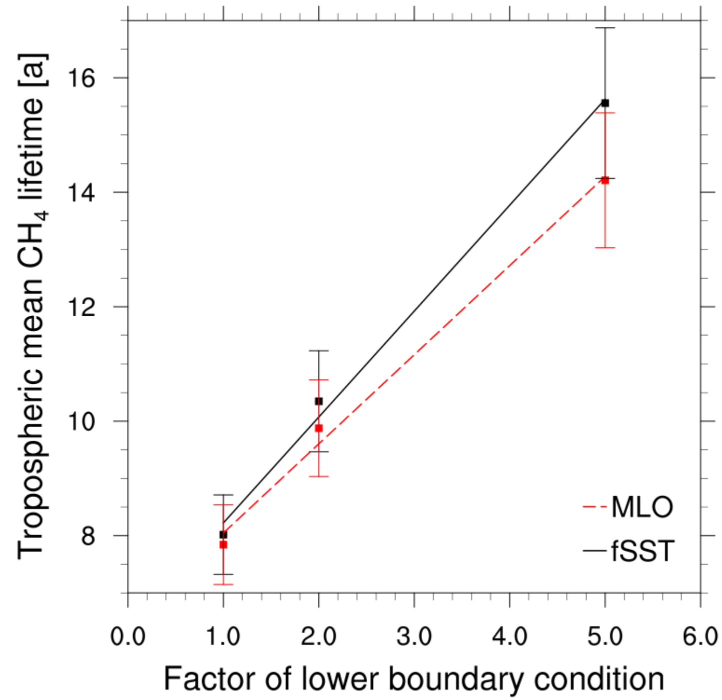
Tropospheric oxidation capacity

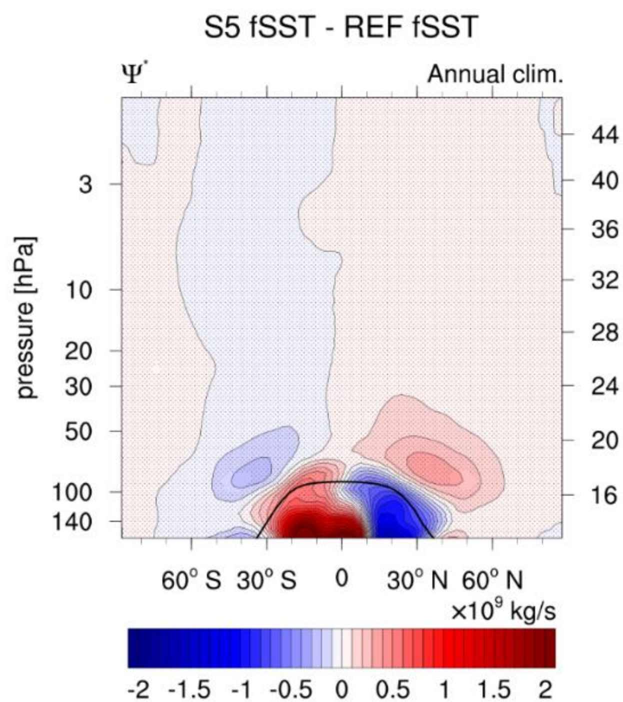
Difference of OH response in MLO w.r.t. fSST

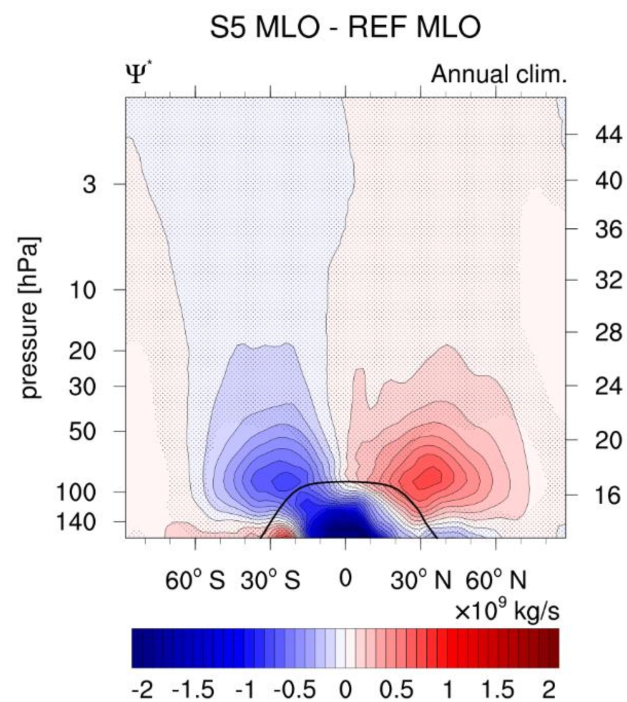




Weaker reduction of OH in the troposphere in the MLO simulations leads to an offset of the prolongation of tropospheric mean CH_4 lifetime.

Strengthening of Brewer-Dobson Circulation in simulations with tropospheric warming



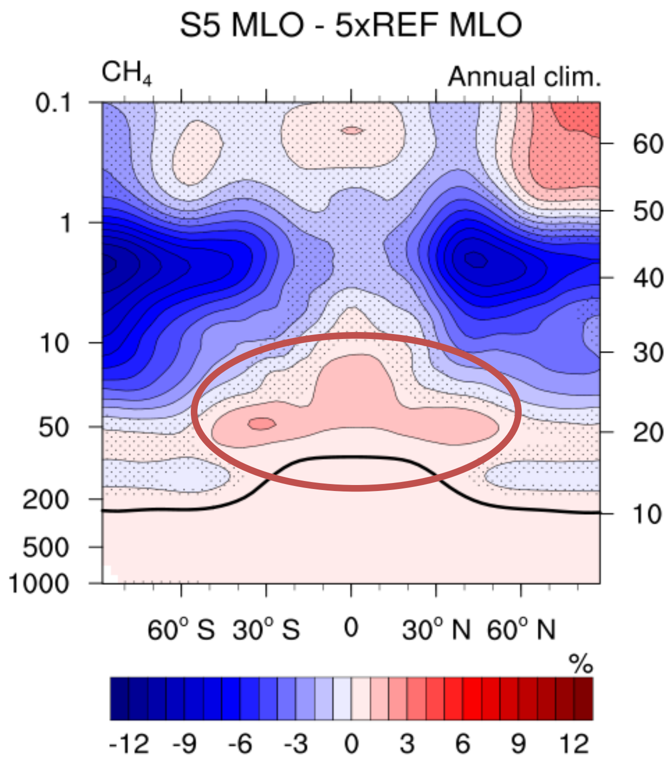


Residual mean streamfunction
→ **More pronounced strengthening in S5 MLO compared to S5 fSST**

The respective Plots for 2× CH_4 are shown in the Supplementary Information at the end of the presentation.

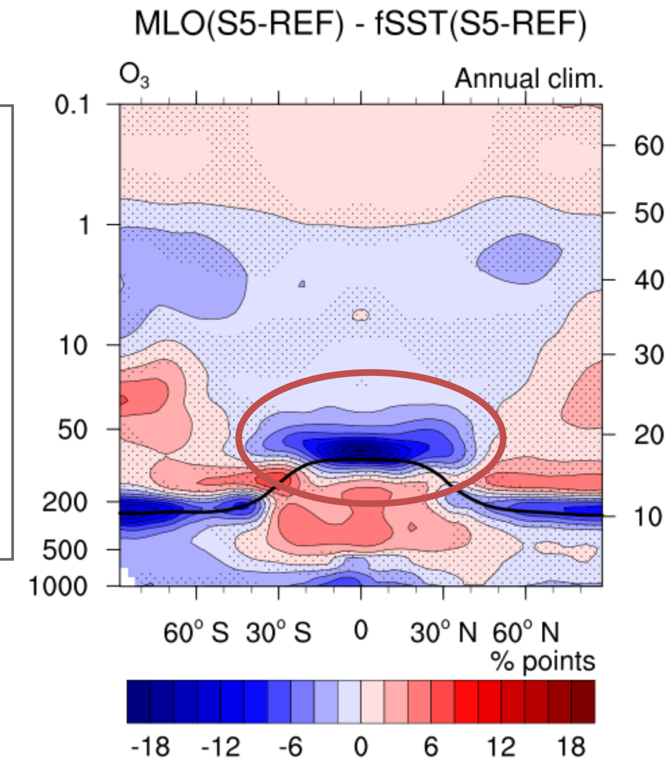
CH_4 and O_3: additional indicators of strengthened tropical upwelling

Difference between
S5 MLO and 5 × REF MLO
→ hightlights where S5 MLO deviates from 5 × increase



Increase of CH_4 and **decrease of O_3** indicate enhanced transport of tropospheric airmasses into the stratosphere

Difference of O_3 response in S5 MLO w.r.t. S5 fSST



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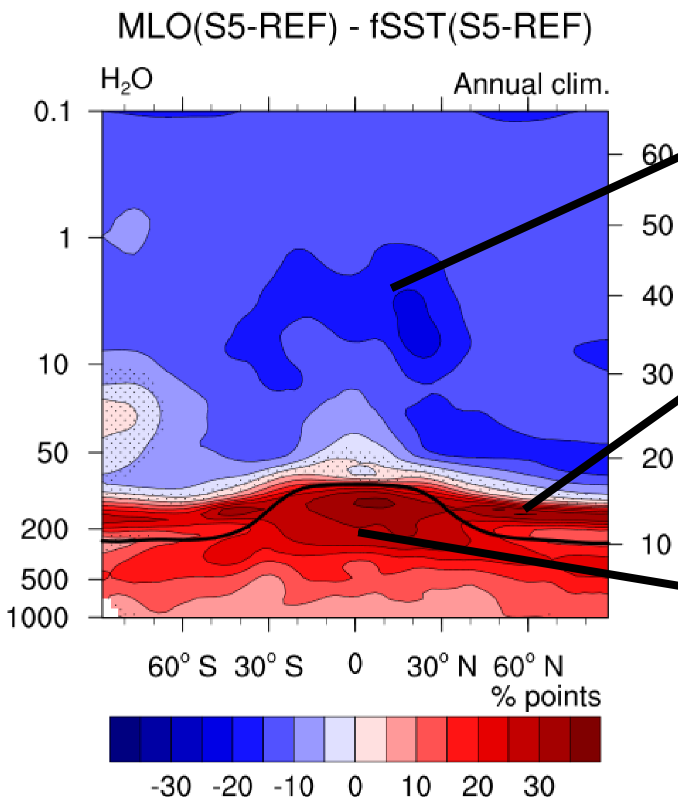
Water vapor response in S5 MLO w.r.t. S5 fSST



Weaker increase of SWV in MLO:
→ weaker increase of in-situ source for SWV from CH_4 oxidation

Stronger increase of SWV in lowermost stratosphere
→ entry of tropospheric H_2O

Stronger increase of tropospheric H_2O with tropospheric warming

Corresponding Radiative Impact of H_2O in W m^{-2} :

	Trop. H_2O MLO	Trop. H_2O fSST	Strat. H_20 MLO	Strat. H_2O fSST
S2	0.72 ± 0.06	0.08 ± 0.08	0.19 ± 0.01	0.15 ± 0.00
S5	2.23 ± 0.10	0.30 ± 0.09	0.65 ± 0.01	0.55 ± 0.01

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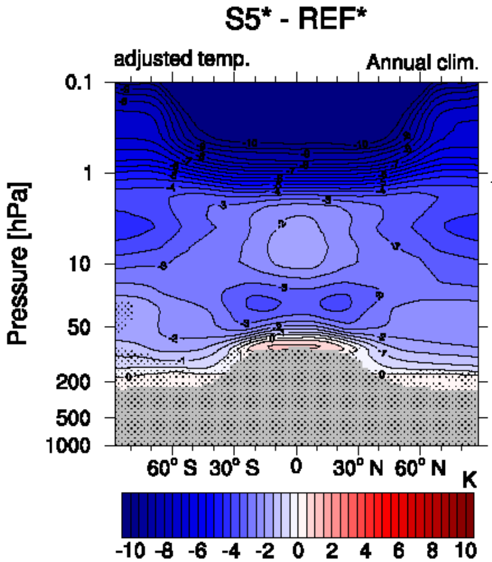
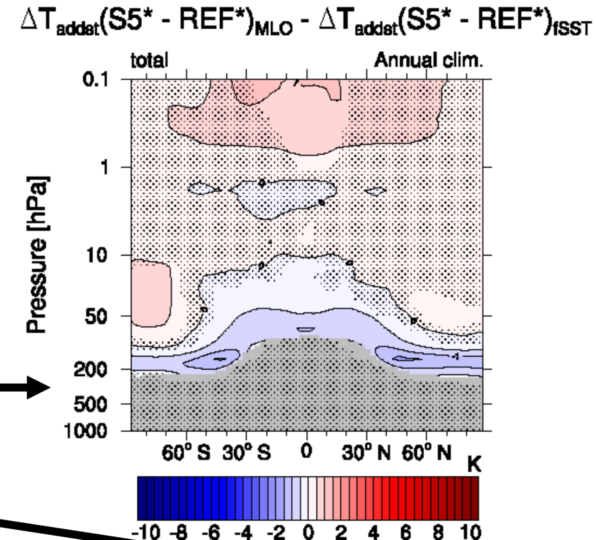
Stratospheric adjusted temperatures:

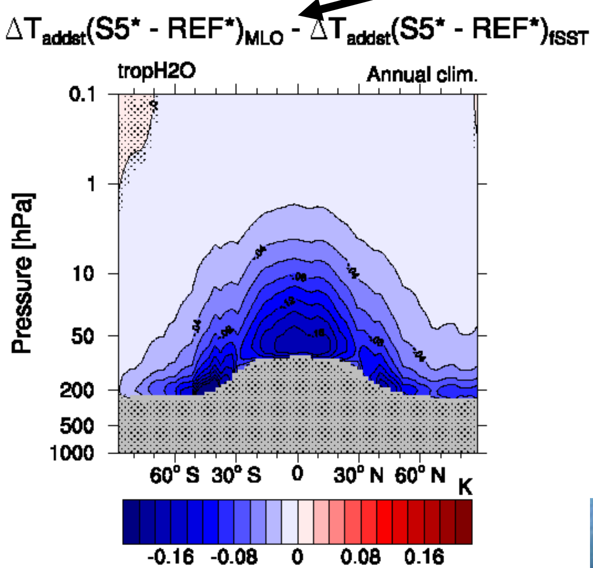
induced by response of individual radiatively active gases

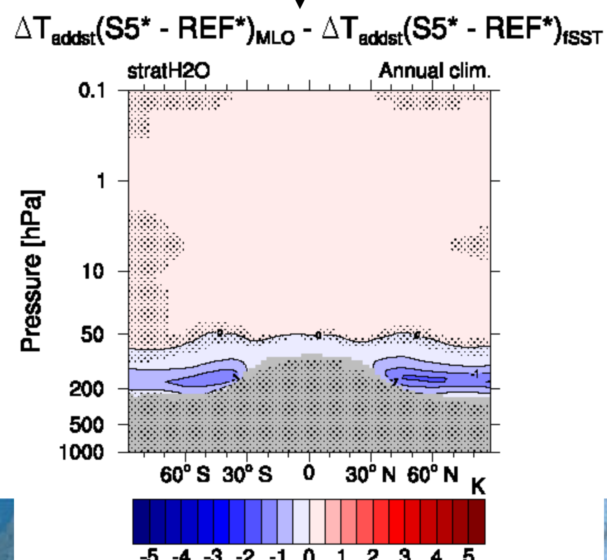


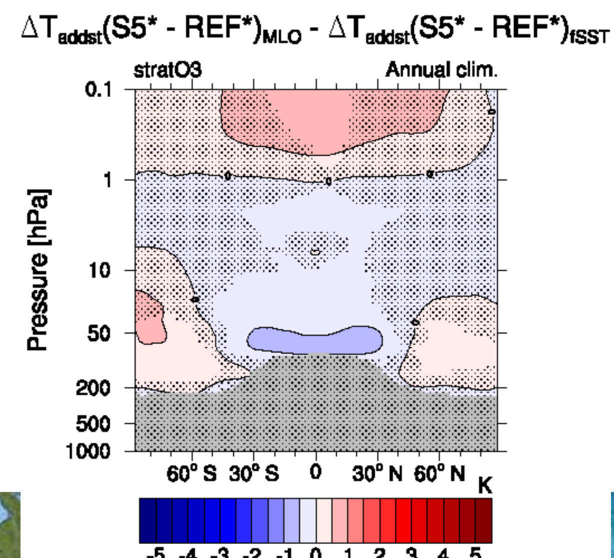
Response of stratospheric adjusted temperatures to changes of CH_4, H_2O and O_3

Difference between MLO and fSST dominated by changes induced by **trop.** $\mathbf{H_2O}$, **SWV** and **strat.** $\mathbf{O_3}$

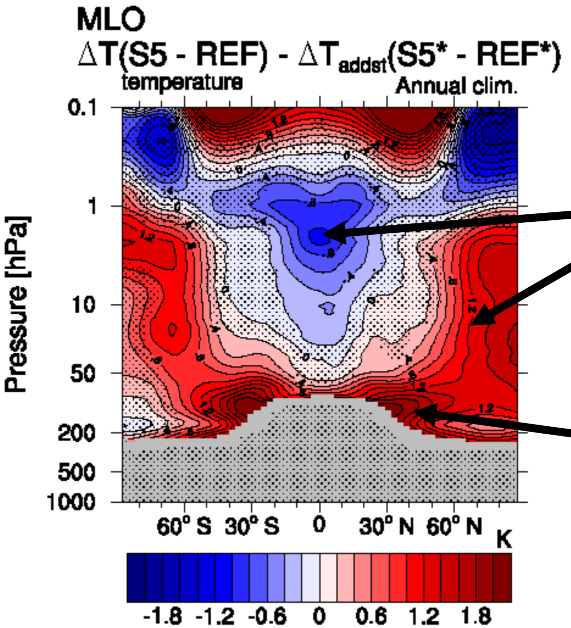








Dynamically induced temperature response



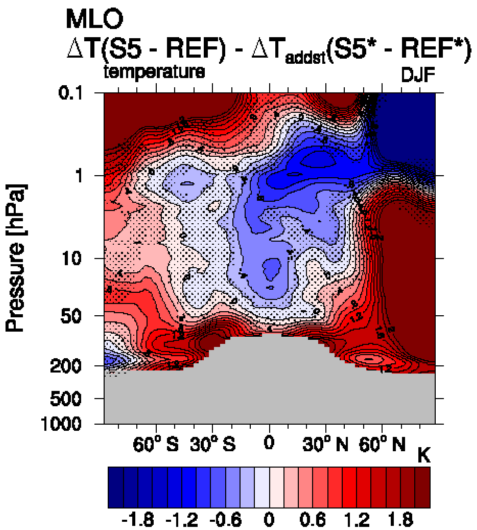
$$\Delta T_{\mathrm{dyn}} = \Delta T(S5\ MLO - REF\ MLO) - \Delta T_{addst}(S5\ MLO - REF\ MLO)$$

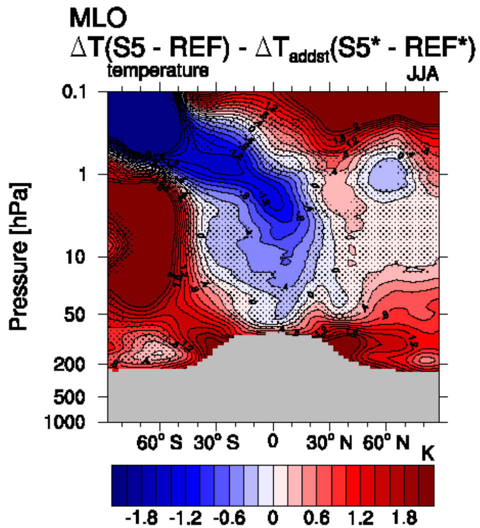
Cooling in tropical stratosphere and warming in extratropical stratosphere
→ Associate with strengthening of *deep branch* of BDC

Two warming patches in lower stratosphere
→ Associate with strengthened downwelling in subtropical lower stratosphere (*shallow branch*)

Pattern in middle and upper stratosphere is shifted to respective winter hemisphere

Warming patches in lower stratosphere present all year





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Summary and Conclusions

To quantify the effect of slow SST-driven climate feedbacks in CH_4-forced climate change scenario calculations we compare the response in experiments with MLO to the response in the respective fSST experiments.

- **Recuced prolongation of tropospheric mean CH_4 lifetime**
- **Circulation changes** in MLO experiments
- **Weakened increase of CH_4 depletion in stratosphere**
- **Increase of Radiative Impact induced by (tropospheric and stratospheric) H_2O** by SST-driven climate feedbacks
- Stratospheric adjusted temperature changes from SST-driven climate feedbacks dominated by changes of **trop. H_2O, SWV and strat. O_3**
  - → Enhanced radiative cooling in lowermost stratosphere

Look out for Stecher et al. (2020) in ACP coming soon!

Thank you!

References

Jöckel et al. 2016: *Earth System Chemistry integrated Modelling (ESCiMo) with the Modular Earth Submodel System (MESSy) version 2.51*, Geosci. Model. Dev.

Rayner et al. 2003: *Global analyses of sea surface temperatures, sea ice, and night marine air temperature since the late nineteenth century*, J. Geophys. Res. Atmos.

Winterstein et al. 2019: *Implication of strongly increased atmospheric methane concentrations for chemistry-climate connections*, Atmos. Chem. Phys.

Footnotes

[1]RCP8.5 scenario projects a doubling of CH_4 mixing ratios of the year 2010 by the end of the century.

[2]MLOCEAN submodel, M. Kunze, https://www.messy-interface.org; original code by Roeckner et al. 1995: *Climatic response to anthropogenic sulfate forcing simulated with a general circulation model*, Aerosol Forcing of Climate

[3]CH_4 lower boundary of reference simulations are nudged to observational zonal mean estimate by AGAGE, (https://agage.mit.edu) and NOAA/ESRL (https://www.esrl.noaa.gov/); CH_4 lower boundary of S2 and S5 are nudged to the double and the fivefold of this reference, respectively

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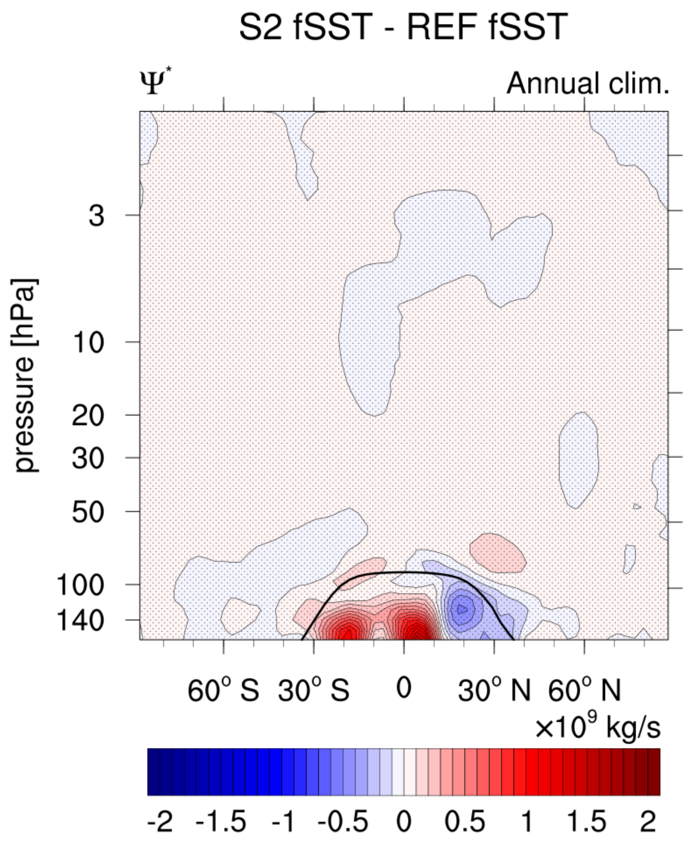
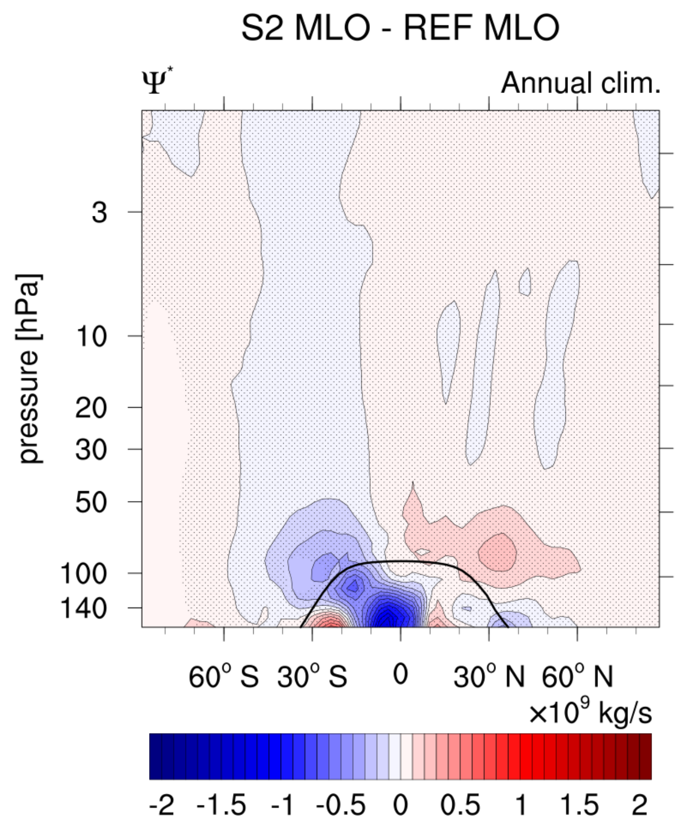
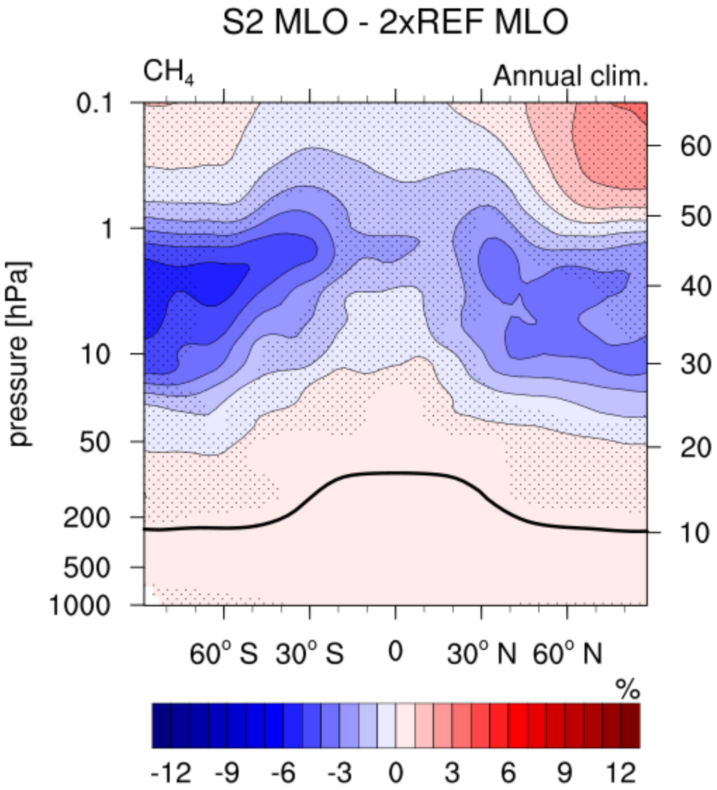
Supplementary Information

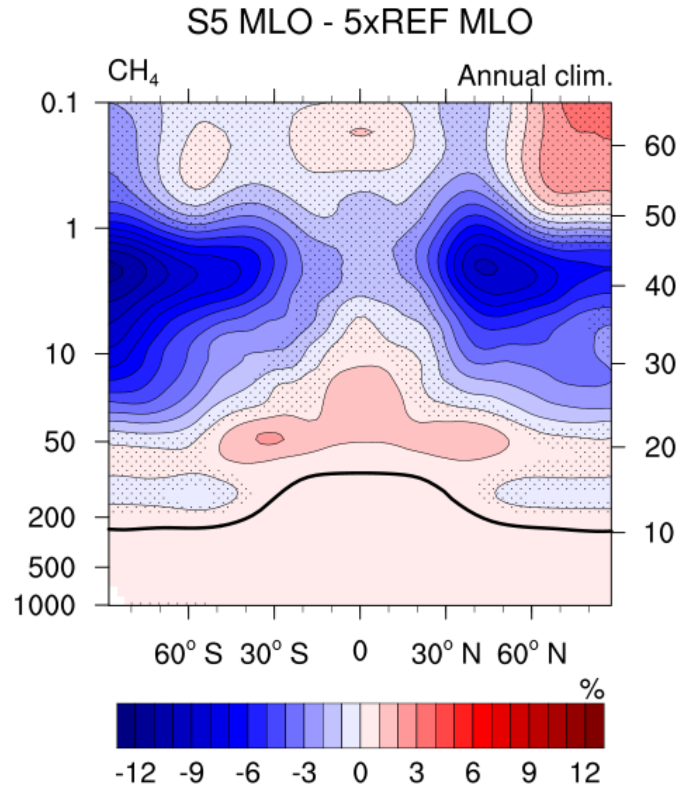
Residual mean streamfunction S2 fSST and S2 MLO





CH_4 response:
Difference between S2 MLO and 2 × REF / S5 MLO and 5 × REF MLO
→ hightlights where S2 MLO / S5 MLO deviate from 2 × / 5 × increase





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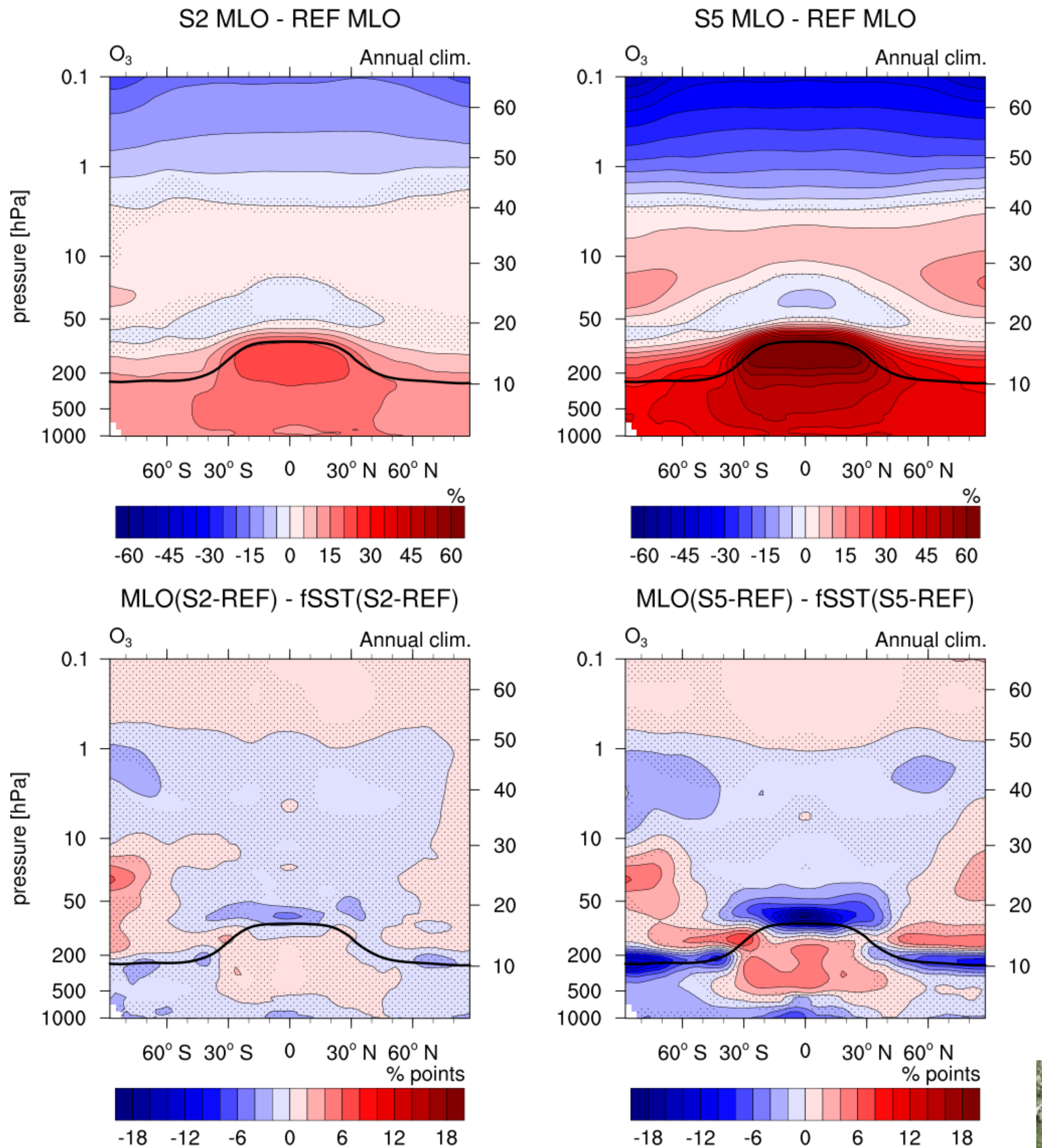
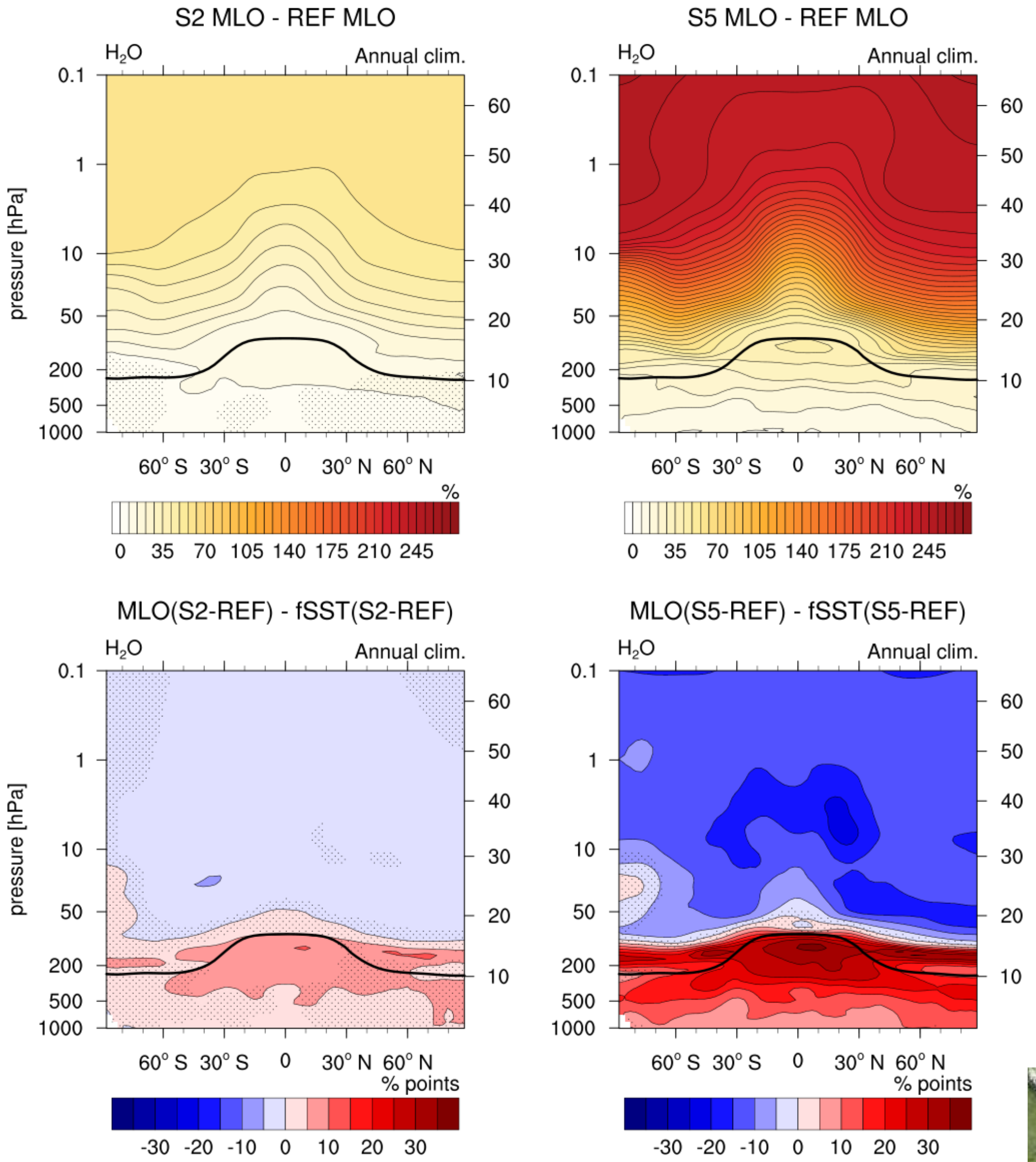
Upper: O_3 response in MLO
Lower: Difference of O_3 response in MLO w.r.t. fSST

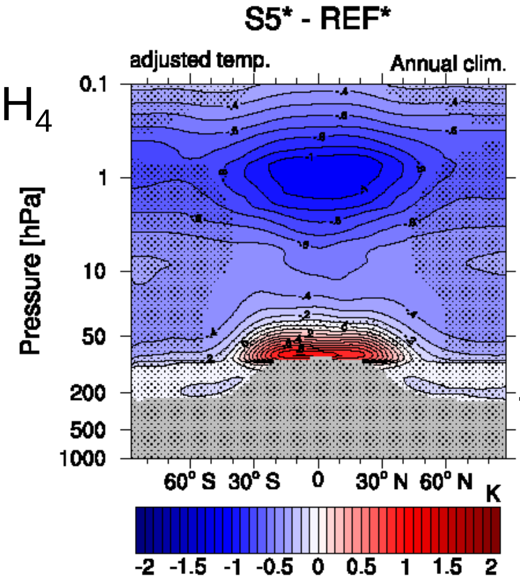


Upper: H_2O response in MLO
Lower: Difference of H_2O response in MLO w.r.t. fSST

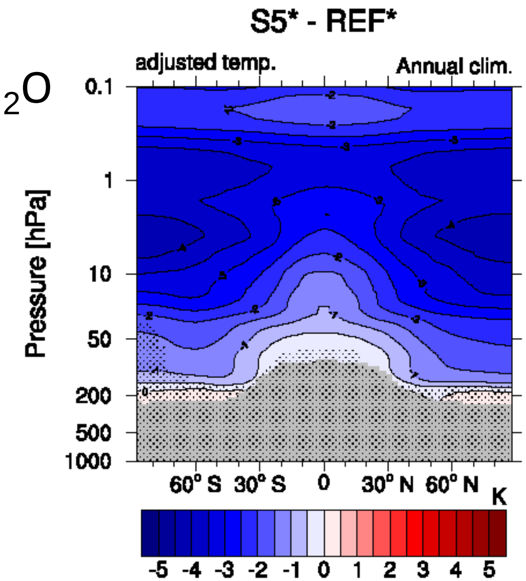


Stratospheric adjusted temperature response S5 MLO

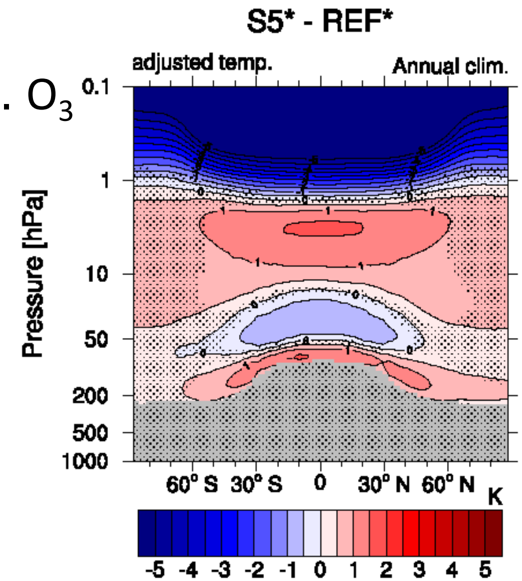
CH_4



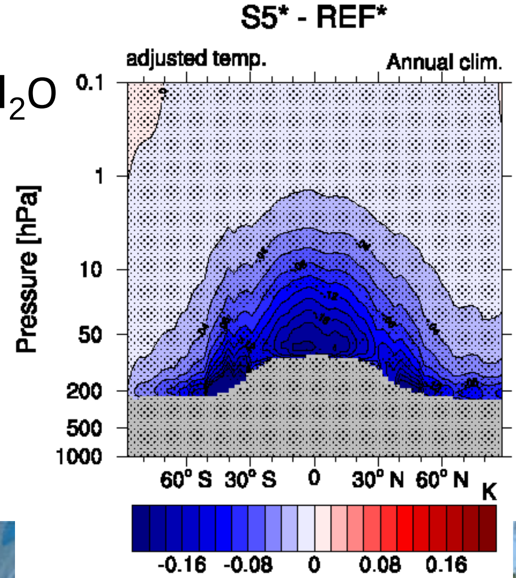
Strat. H_2O



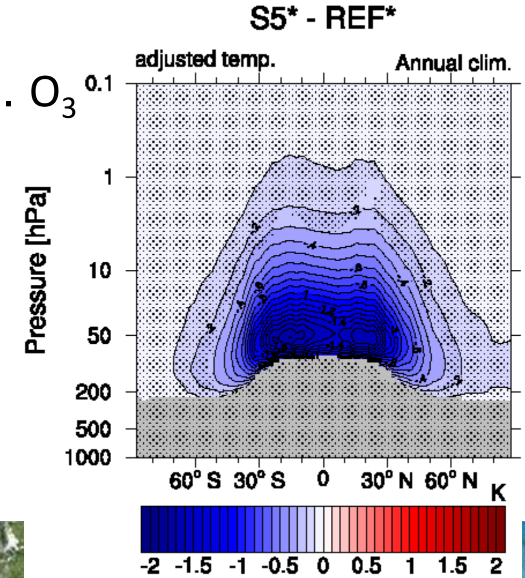
Strat. O_3



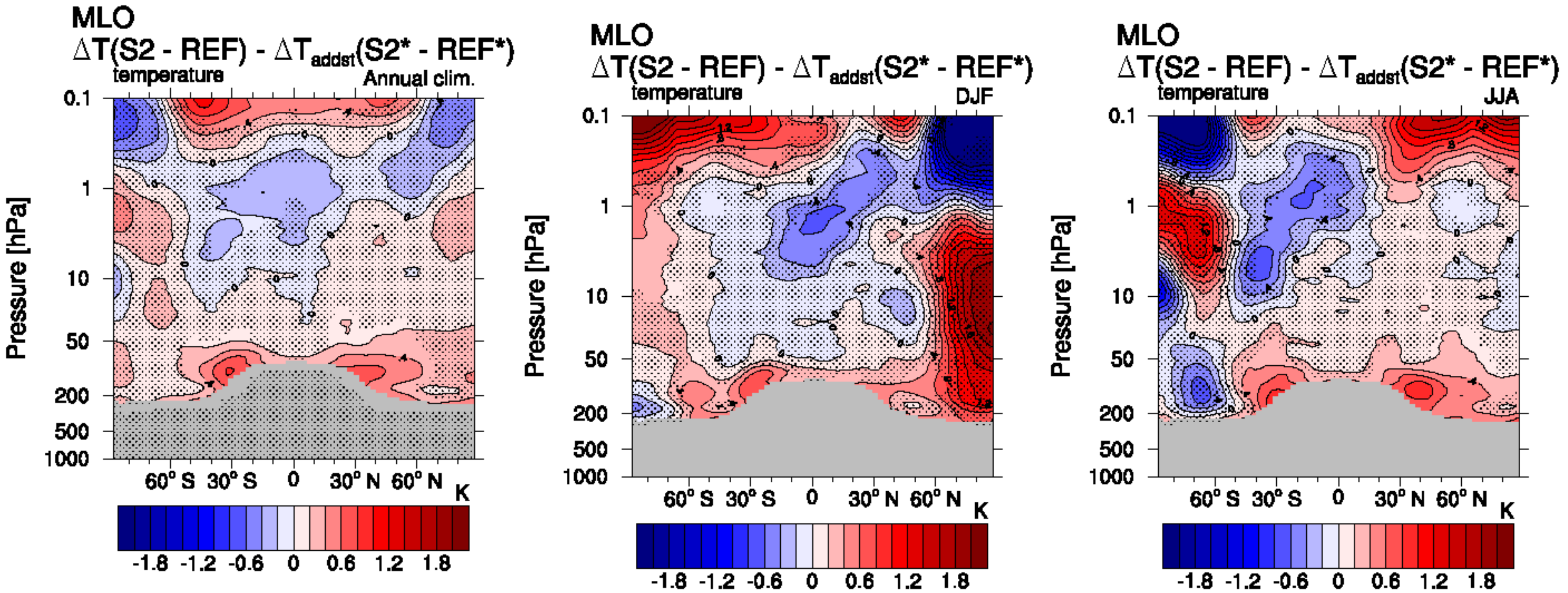
Trop. H_2O



Trop. O_3



Dynamically induced temperature response S2 MLO: Annual clim., DJF and JJA



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