DACH MT 2022– Leonhard Hufnagl – 25 March 2022

The Influence of Ozone Changes on Stratospheric Dynamics in 4xCO_2 Climate Simulations

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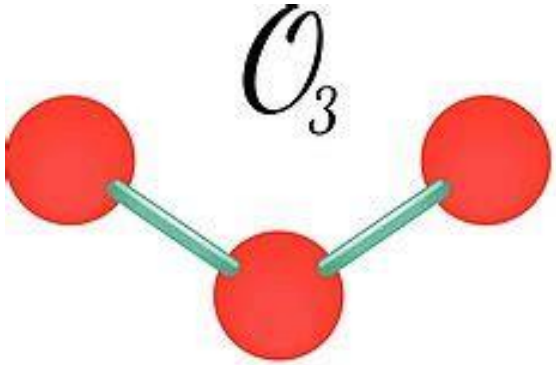
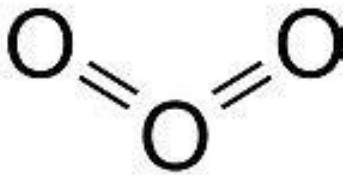
Ozone properties

- ozone formation and decomposition by Chapman cycle and catalytic reactions
- ozone = Absorber/emitter of shortwave/longwave radiation

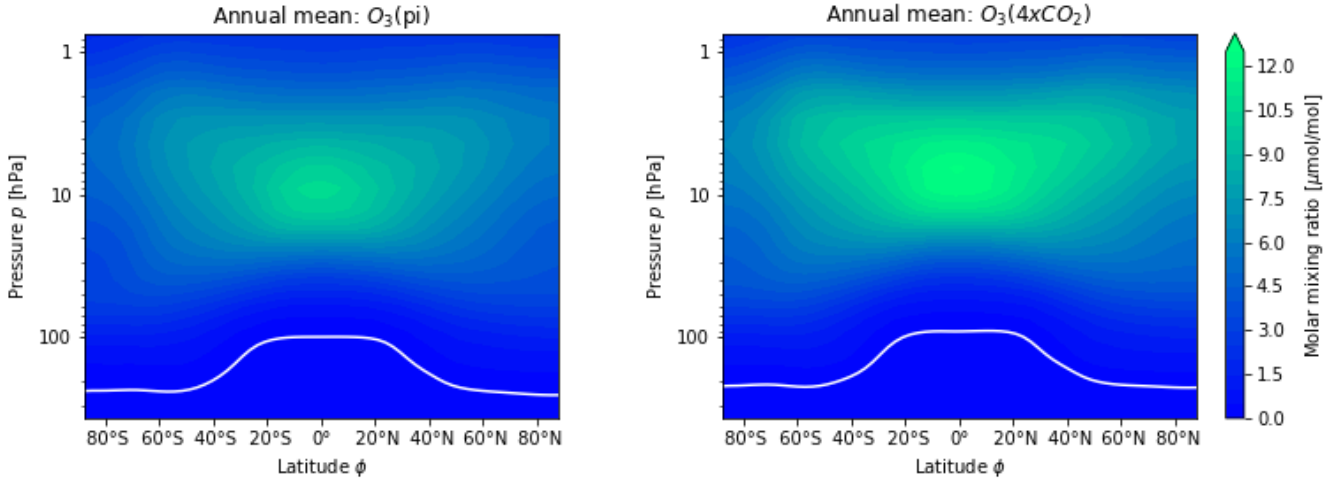
  →Protection of the biosphere from high energetic UV-radiation by stratospheric ozone (ozone layer)

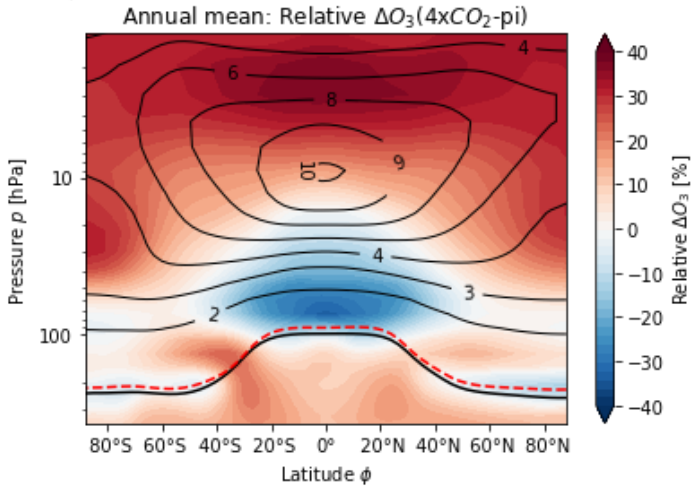
  →**Influence on temperature and wind structure**





Effect of 4xCO_2 on ozone





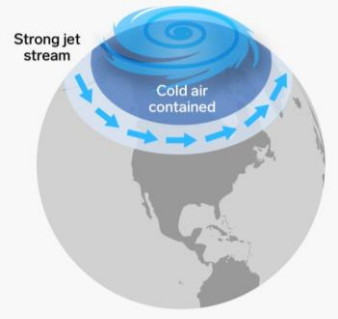
Contours:
Molar mixing ratio of pi-O_3 in µmol/mol

- Increase of ozone in the upper stratosphere because of CO_2-induced cooling and transport
- Decrease in tropical UTLS (upper troposphere and lower stratosphere) ozone by the acceleration of the tropical upwelling and lower photolysis rates

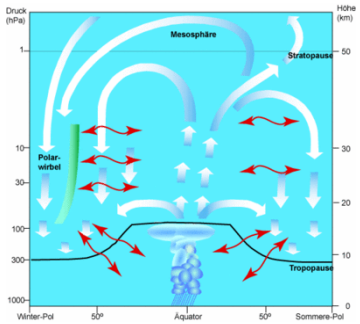
Science questions

How do CO_2-induced changes in ozone influence stratospheric dynamics?

- How are polar vorticies affected?



- How do Brewer-Dobson circulation (BDC) and stratospheric transport change?



Description of the simulations and analysis

Simulation setup:

Simulation name	CO_2	SST	O_3
piCtrl	pi	Prescribed from CMIP6-piCtrl	Prescribed from CMIP6-piCtrl
4xCO_2Ctrl	4xCO_2	Prescribed from CMIP6-4xCO_2	Prescribed from CMIP6-4xCO_2
4xCO_2piO_3	4xCO_2	Prescribed from CMIP6-4xCO_2	Prescribed from CMIP6-piCtrl

Description of the analysis

Change due to 4xCO_2 with changed ozone

Change due to 4xCO_2 with fixed ozone

4xCO_2Ctrl – piCtrl
shortened: **4xCO_2Ctrl**

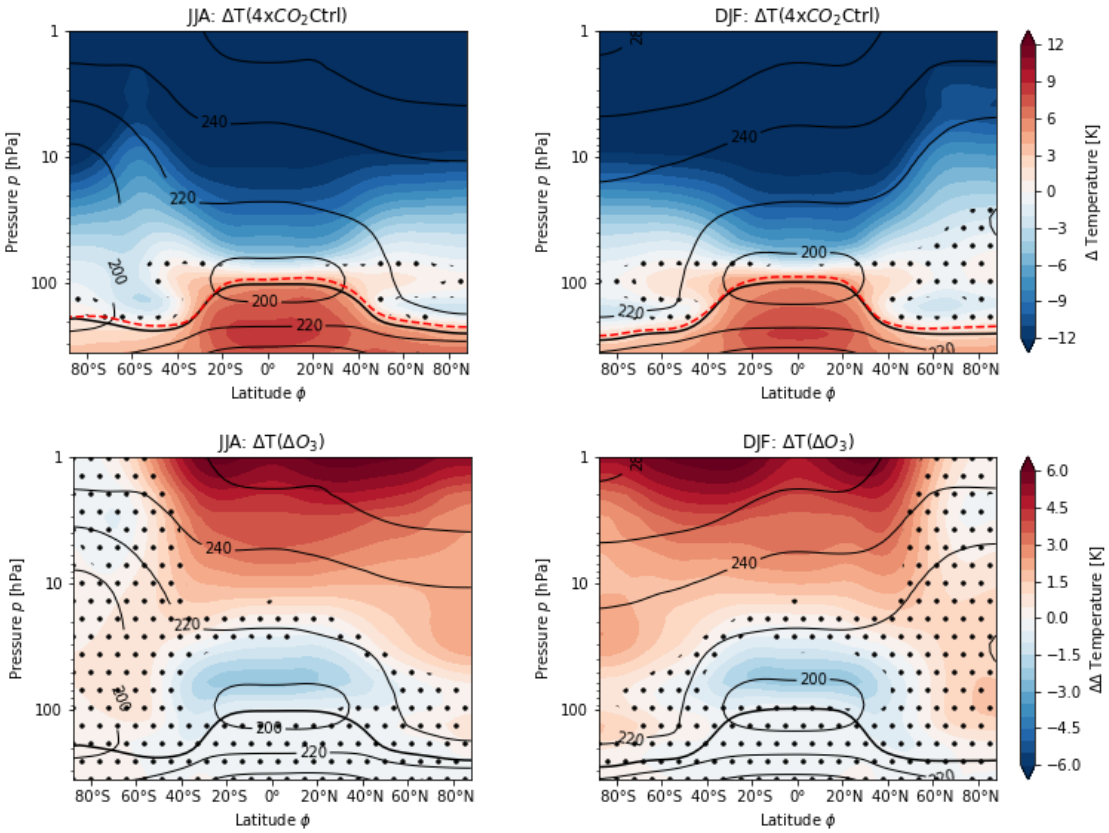
4xCO_2piO_3 - piCtrl
shortened: **4xCO_2piO_3**

–

(4xCO_2Ctrl – piCtrl) - (4xCO_2piO_3 - piCtrl)
shortened: **ΔO_3**

Ozone effect in 4xCO_2 simulation

Effect on temperature



CO_2 effect → Tropospheric warming and stratospheric cooling (Thompson et al., 2002, Marshall, 2003, Fomichev et al., 2007)

Contours:
Pi-climatology in K

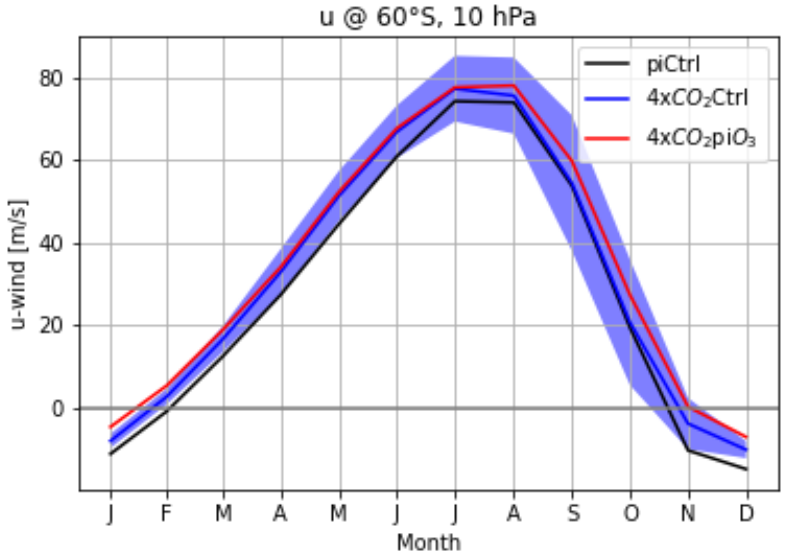
Ozone effect:

→ Cooling in the lower tropical stratosphere

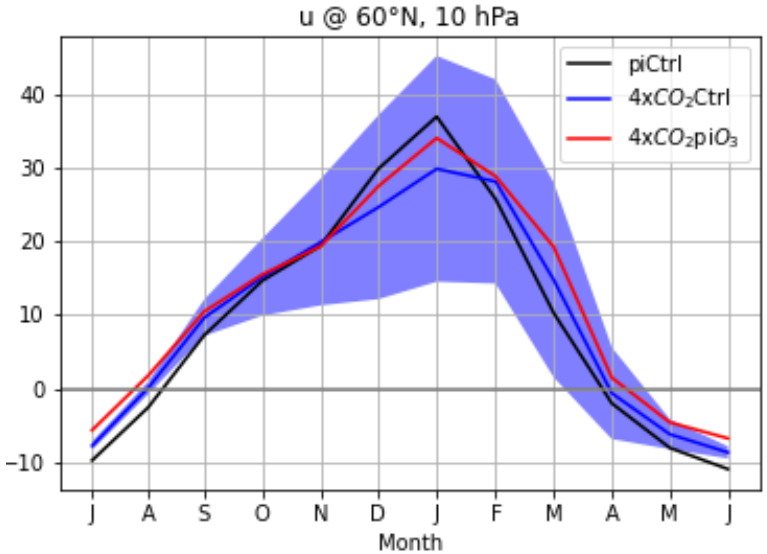
→ Warming in the upper tropical and extra-tropical summer stratosphere

Effect on the polar vorticies

Antarctic polar vortex



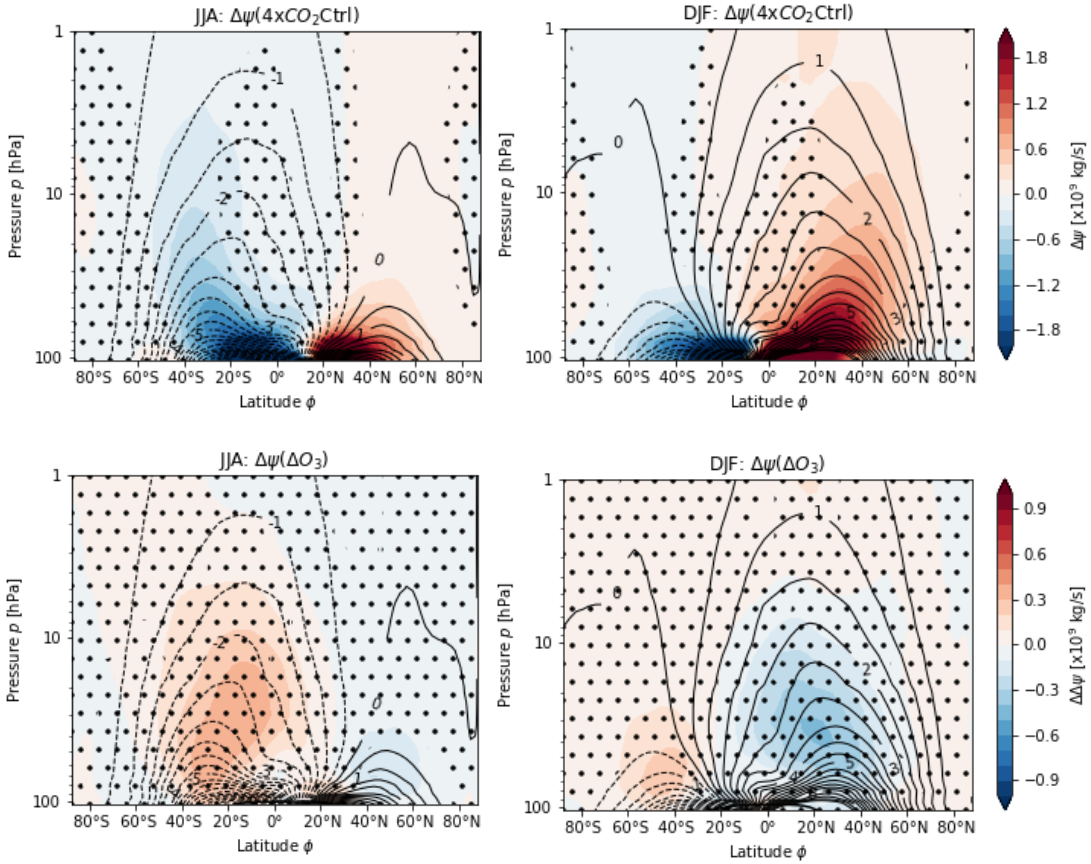
Arctic polar vortex



- CO_2 effect → Longer season (Ayarzagüena et al., 2020) and systematically stronger vortex (Garfinkel et al., 2017, Chiodo and Polvani, 2019) and weaker easterlies in summer
- Ozone effect:
  - → Stronger easterlies in summer ←→ strengthening of meridional temperature gradient in lower stratosphere in summer
  - → Later vortex build up and earlier breakdown: Shorter season and systematically weaker vortex

Effect on the mass streamfunction

Mass streamfunction as a diagnostic for the BDC



CO_2 effect → Acceleration of the whole BDC (Shepherd and McLandress, 2011)

Contours :
Pi-climatology of mass streamfunction in 10^{-5} kg/s

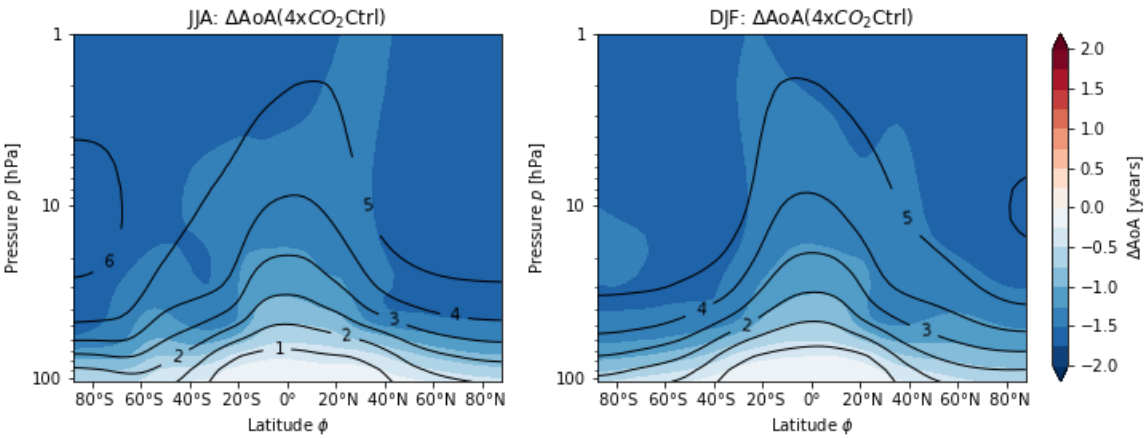
Ozone effect:

→ Systematic damping of the CO_2-induced BDC acceleration

→ But only significant in shallow summer branch

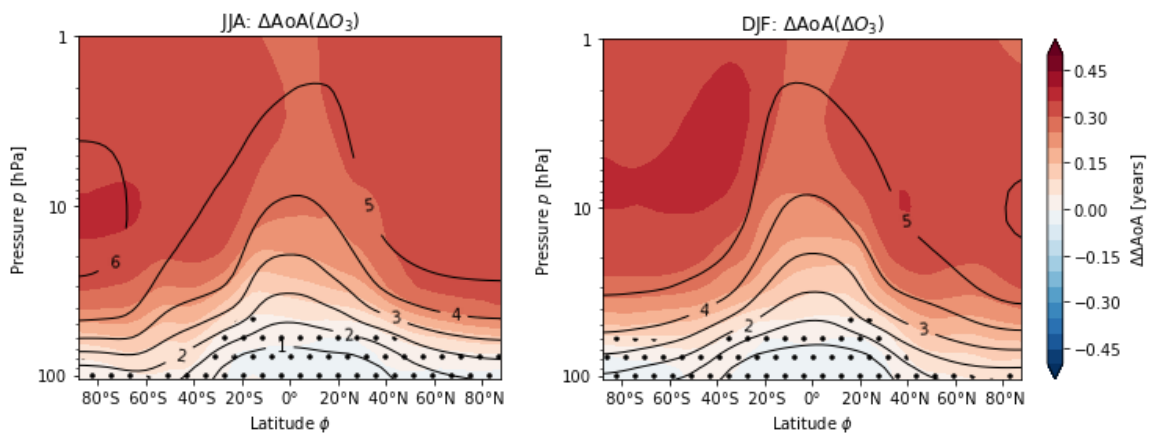
Effect on the age of air (AoA)

AoA = Time elapsed since the last contact of the air parcel with the tropical Earth's surface



CO_2 effect → Decrease of AoA (Eichinger et al., 2019)

Contours :
Pi-climatology of the AoA in years



Ozone effect→ Damping of the CO_2 effect by up to 23%

! despite no significant streamfunction changes, AoA changes significantly in the whole stratosphere !

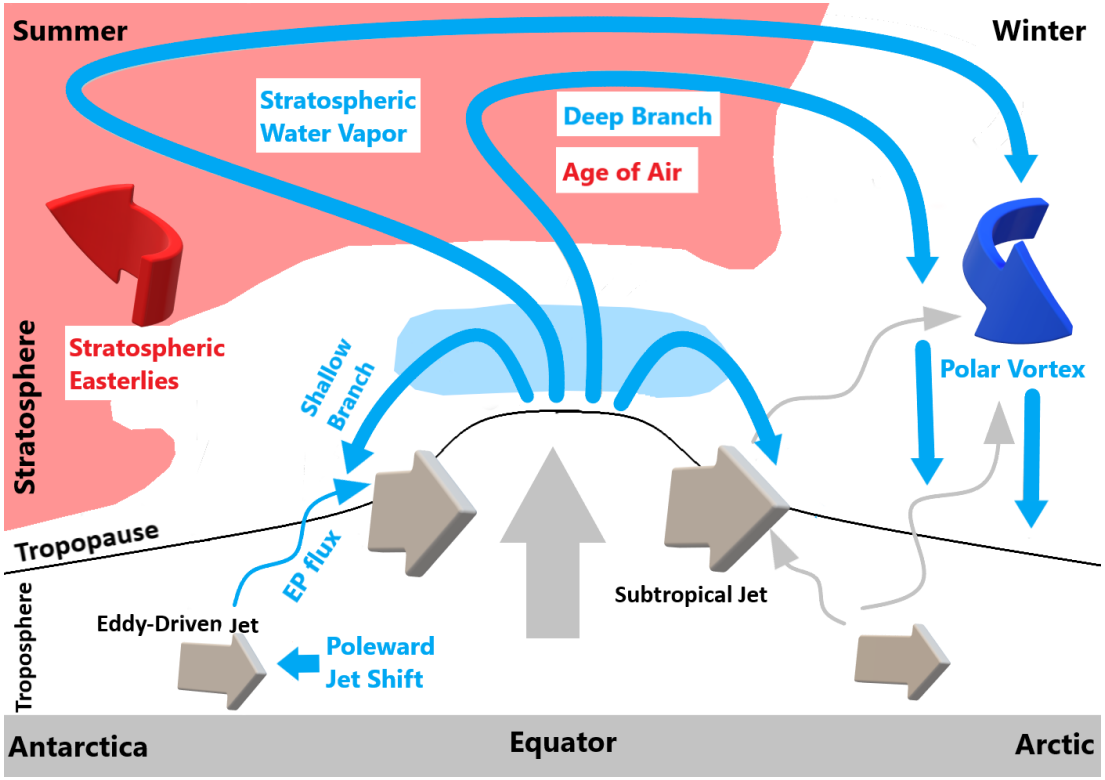
Summary and Conclusion

- How are polar vorticies affected?
  - **Shorter polar vortex season**
  - **Systematic weakening of the polar vorticies → effects on the troposphere!**
- How do Brewer-Dobson circulation (BDC) and stratospheric transport change?
  - **Mass streamfunction: Systematic damping of the CO_2-induced acceleration of all branches**
  - **AoA: Significant damping of the CO_2-induced decrease in the whole stratosphere**

The influence of CO_2-induced ozone changes on the dynamics underlines…

→…. the relevance of understanding the ozone effects for attribution of effects in climate (change) simulations

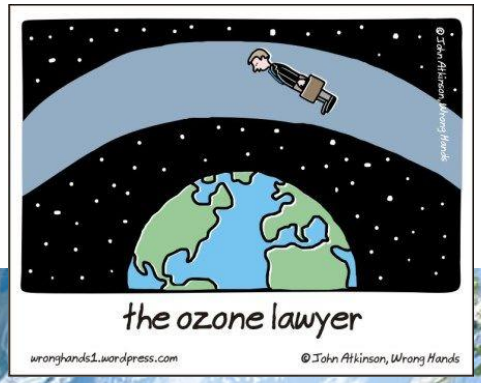
→…. the need of realistic representations of ozone fields in climate (change) simulations



Legend:

- Red shading: heating
- Red arrows: strengthening
- Blue shading: cooling
- Blue arrows: weakening
- Grey curved arrows: Brewer-Dobson circulation
- Grey wavy arrows: Planetary and synoptic-scale wave propagation

Thank you for your attention



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