

Creation of the next generation CMIP7 ozone forcing database

Olaf Stein¹, Xiaodan Ma², Michaela Hegglin², Matthias Rißé², Lars Hoffmann¹, Patrick Jöckel³, Douglas Kinnison⁴, David A. Plummer⁵

¹Research Centre Jülich, Jülich Supercomputing Centre, Jülich, Germany

²Research Centre Jülich, ICE-4, Jülich, Germany

³DLR-IPA, Oberpfaffenhofen, Germany

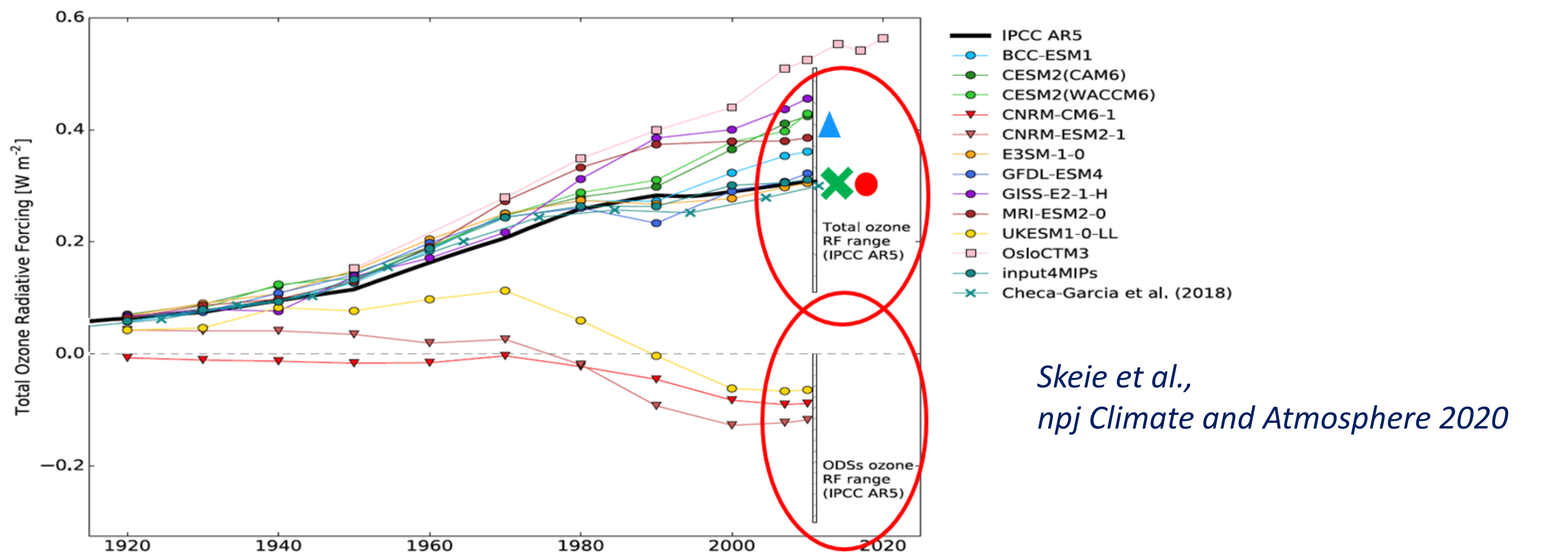
⁴ACOM, NSF NCAR, Boulder, CO, USA

⁵Environment and Climate Change Canada, Montréal, Canada

Why do we need an Ozone Forcing?

- Global warming in IPCC is generally attributed to well-mixed greenhouse gases and short-lived pollutants (NO_x, VOCs, SO₂). In this framing Ozone is an important intermediary.
- These forcings are used in CMIP models which do not include interactive chemistry
- Well-mixed greenhouse gases led to a positive climate forcing.
- Short-lived pollutants can exert both a negative (via aerosol) or a positive (via e.g. ozone) climate forcing.

The total ozone forcing (mainly due to tropospheric air pollutant emissions) is positive. Ozone forcing due to ODSs is negative (stratospheric ozone depletion).



Skeie et al.,
npj Climate and Atmosphere 2020

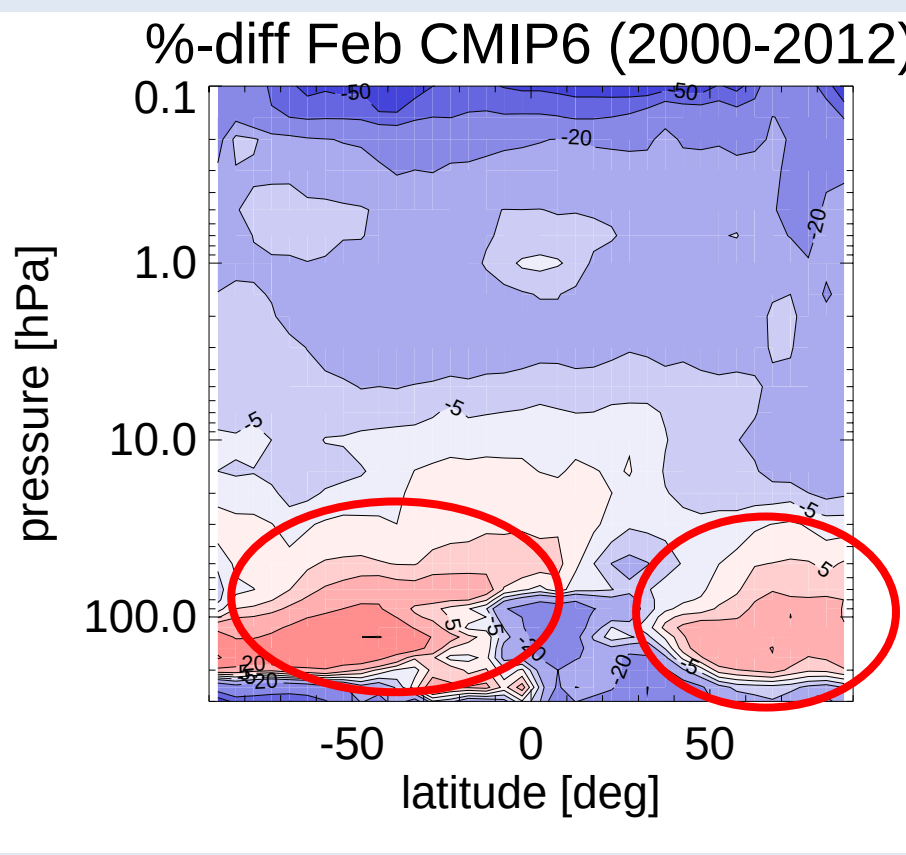


CMIP6 ozone forcing agrees with CMIP5 multi-model mean (due to emissions used being the same!)

The CMIP6 multi-model mean ozone RF is larger w/o outliers (i.e. UKESM and two stratosphere-only models).

0.39 W^{m-2} [0.27-0.51] W^{m-2}

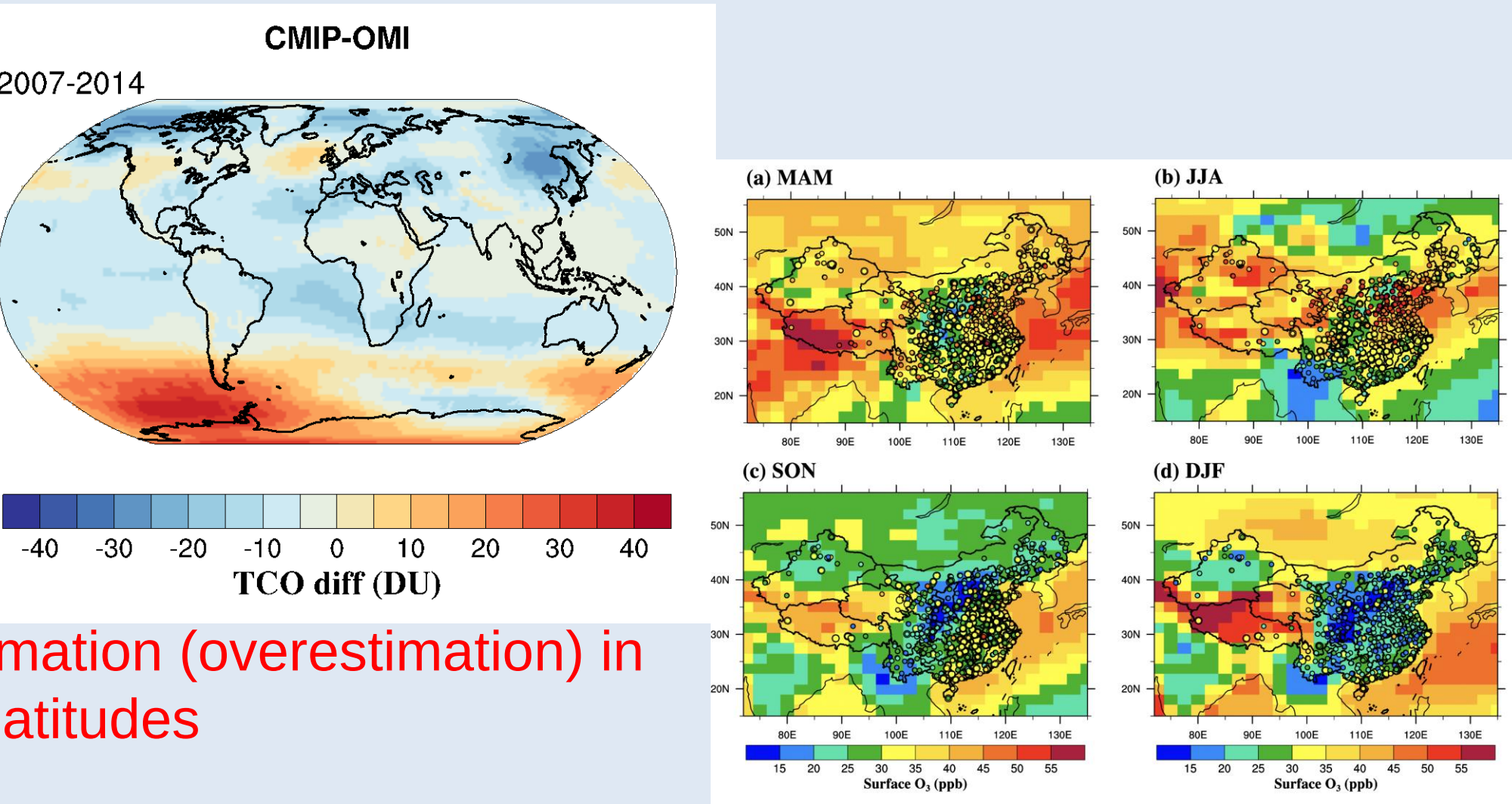
Known deficiencies



against SPARC Data Initiative satellite observations

LMS positive bias
- a long-standing problem in CCMs!

Tegtmeier et al., JGR 2013; Hegglin et al., ESSD 2021



against OMI

General underestimation (overestimation) in the NH (SH) high latitudes

The CMIP6-plus database (extended from CMIP6 based on the CMIP6 SSP370 scenario) against ground-based observations
Underestimation in MAM and JJA over China

CMIP7 approach

Ozone forcing is treated with increasing sophistication:

CMIP5:

- Merger between stratospheric and tropospheric chemistry-climate models
- Historical stratospheric fields before 1960 were generated using an observation-based MLR approach

CMIP6:

- ozone database consistent in time, interactive ozone chemistry
- Merged ozone fields from two CCMs (CESM1-WACCM and CMAM)
- Produced with full stratosphere-troposphere chemistry.

CMIP7:

- fully consistent with other forcings (solar, volcanoes, GHG/ODS, emissions)
- Nudged to updated QBO signal
- Use now three CCMs to ameliorate known issues in CMIP6:

ECAM5/MESSy Atmospheric Chemistry (EMAC) v2.5.5

Jöckel et al. 2016

- Model resolution: 2.8°x2.8°, 90 levels up to 0.01 hPa
- standard gas and aqueous-phase chemistry (similar to CCM1-2022)
- 158 species and 353 reactions

Whole Atmosphere Chemistry Climate Model (CESM1 WACCM4)

Gettelman et al. 2019

- Model resolution: 1.9°x2.5°, Model top ~ 5 x 10⁻⁴ Pa
- detailed chemistry up to the lower thermosphere, 183 species

Canadian Middle Atmosphere Model (CMAM)

Beagley et al. 1997; Scinocca et al. 2008

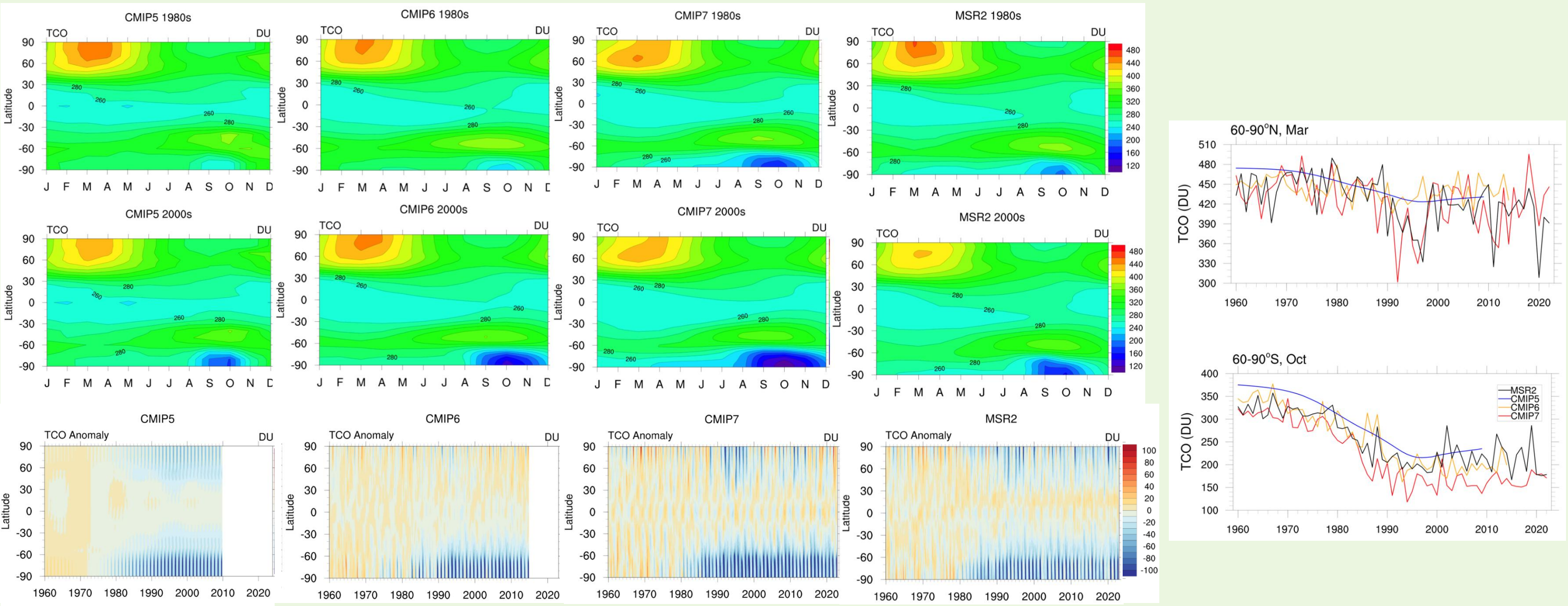
- Model resolution: 3.75°x3.75°, 71 levels up to 0.001 hPa
- detailed stratospheric chemistry
- tropospheric chemistry based on methane chemistry with bulk VOCs

Simulations

- PreIndustrial Control: 1850 - 1871 with constant forcing except solar and QBO
- Historical Simulation: 1850 - 2022 free running with CMIP7 forcings
- 7 Future Scenarios: 2023 - 2100 (van Vuuren et al., GMD 2026)

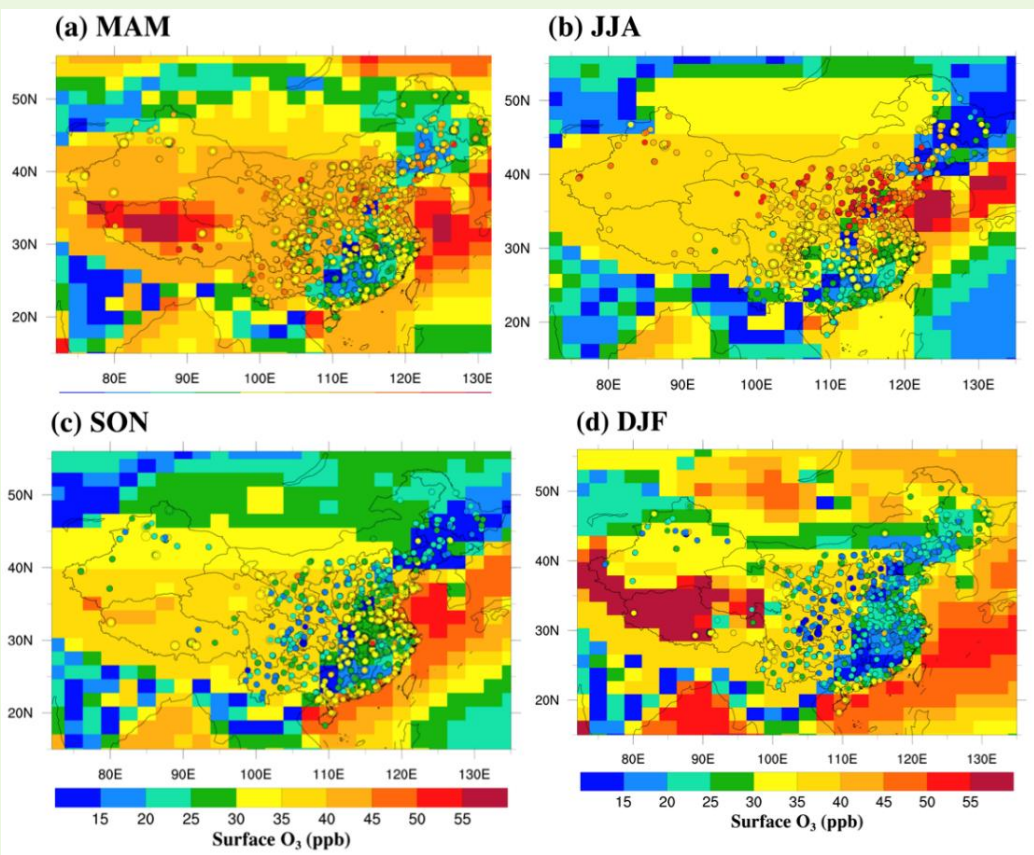
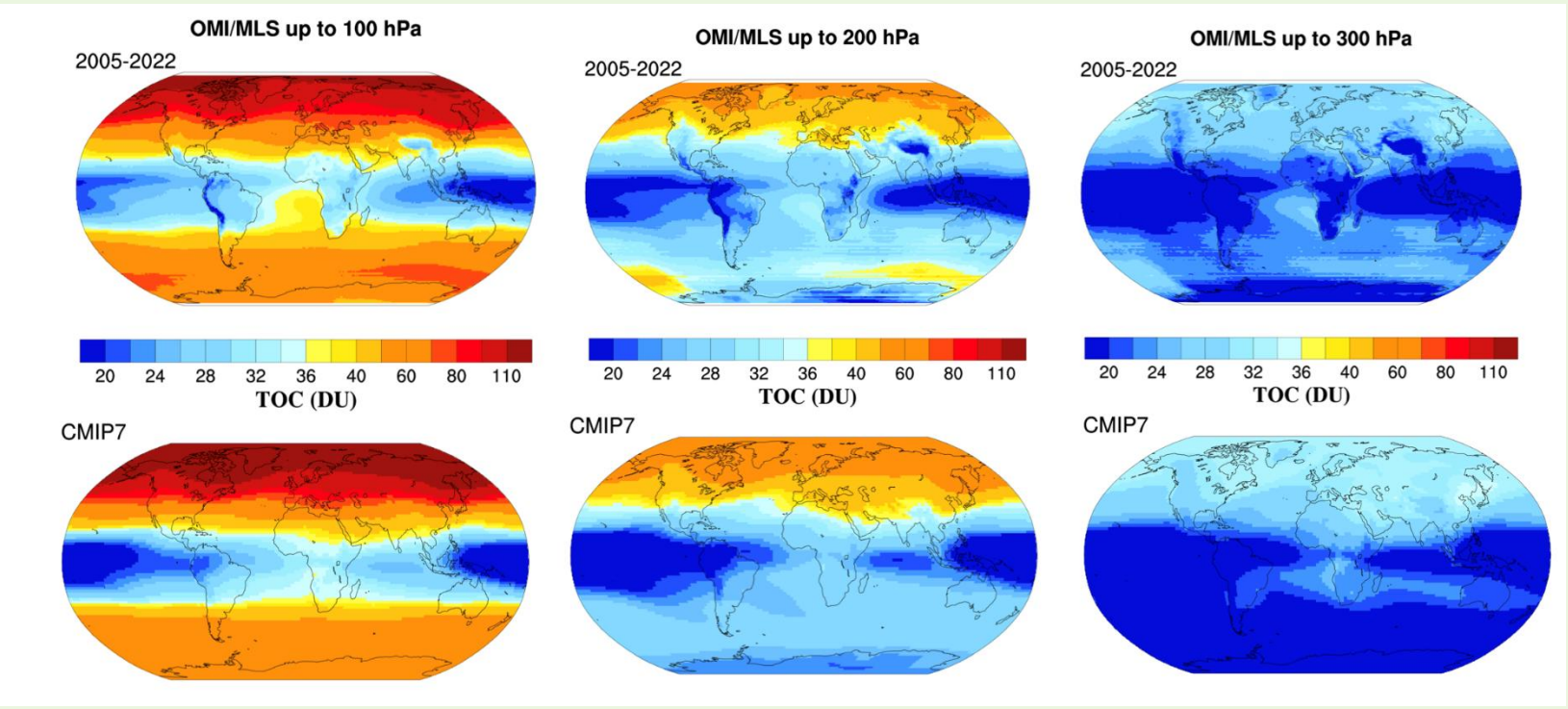
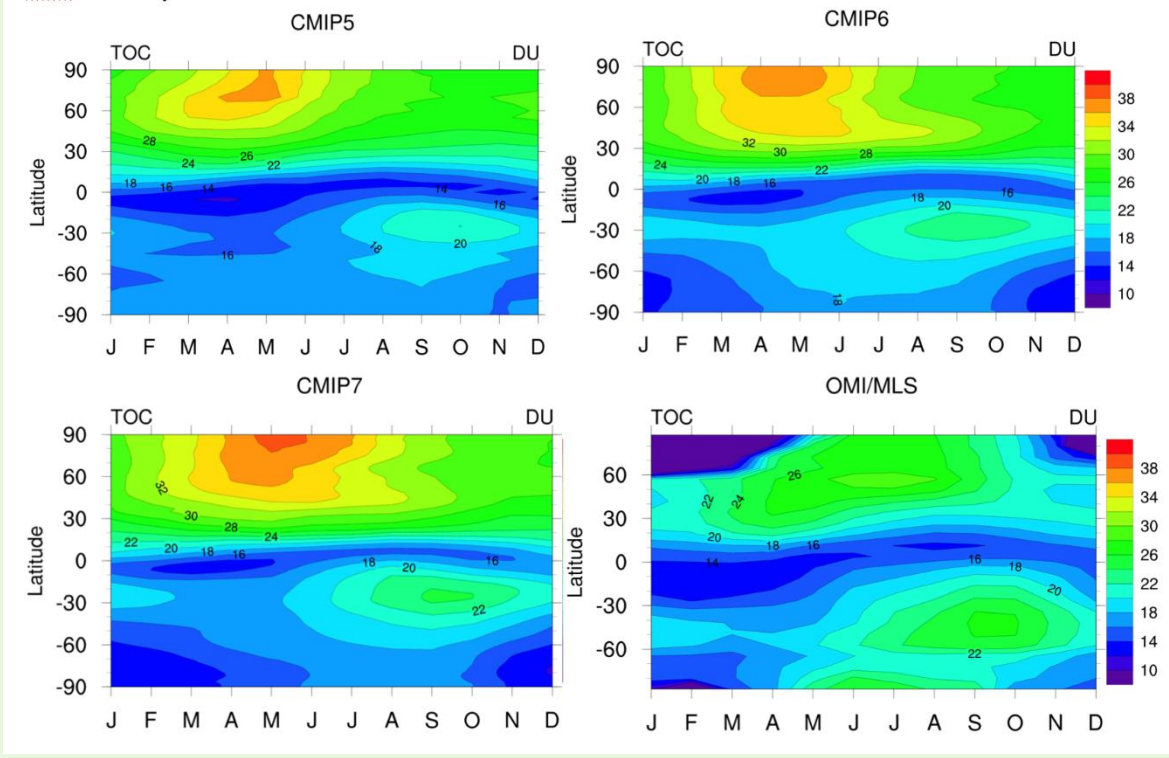
First evaluation results – Merged CMIP7 Ozone Forcing

Total Column Ozone (TCO)
against Multi-Sensor Reanalysis (MSR2)



- pronounced Antarctic springtime ozone minimum in the 2000s, broadly consistent with MSR2
- CMIP7 maintains the observed large-scale seasonal structure of NH ozone
- more detailed representation of observed temporal and latitudinal variability
- realistic simulation of year-to-year variability and long-term Antarctic ozone decline, with tendency toward stronger Antarctic ozone depletion

Tropospheric Ozone (TOC)
against OMI/MLS



against surface observations

- CMIP datasets generally show higher TOC at NH high latitudes than OMI/MLS, particularly during boreal spring
- CMIP7 reproduces the dominant large-scale geographical patterns observed by OMI/MLS
- definition of TOC and tropopause treatment are still issues
- CMIP7 captures major seasonal and regional patterns of near-surface ozone over China but does not reproduce the full magnitude of the local-scale variability

CMIP products delivered to ESGF

CMIP6Plus Ozone Forcing: Extension of CMIP6 ozone forcing to 2022

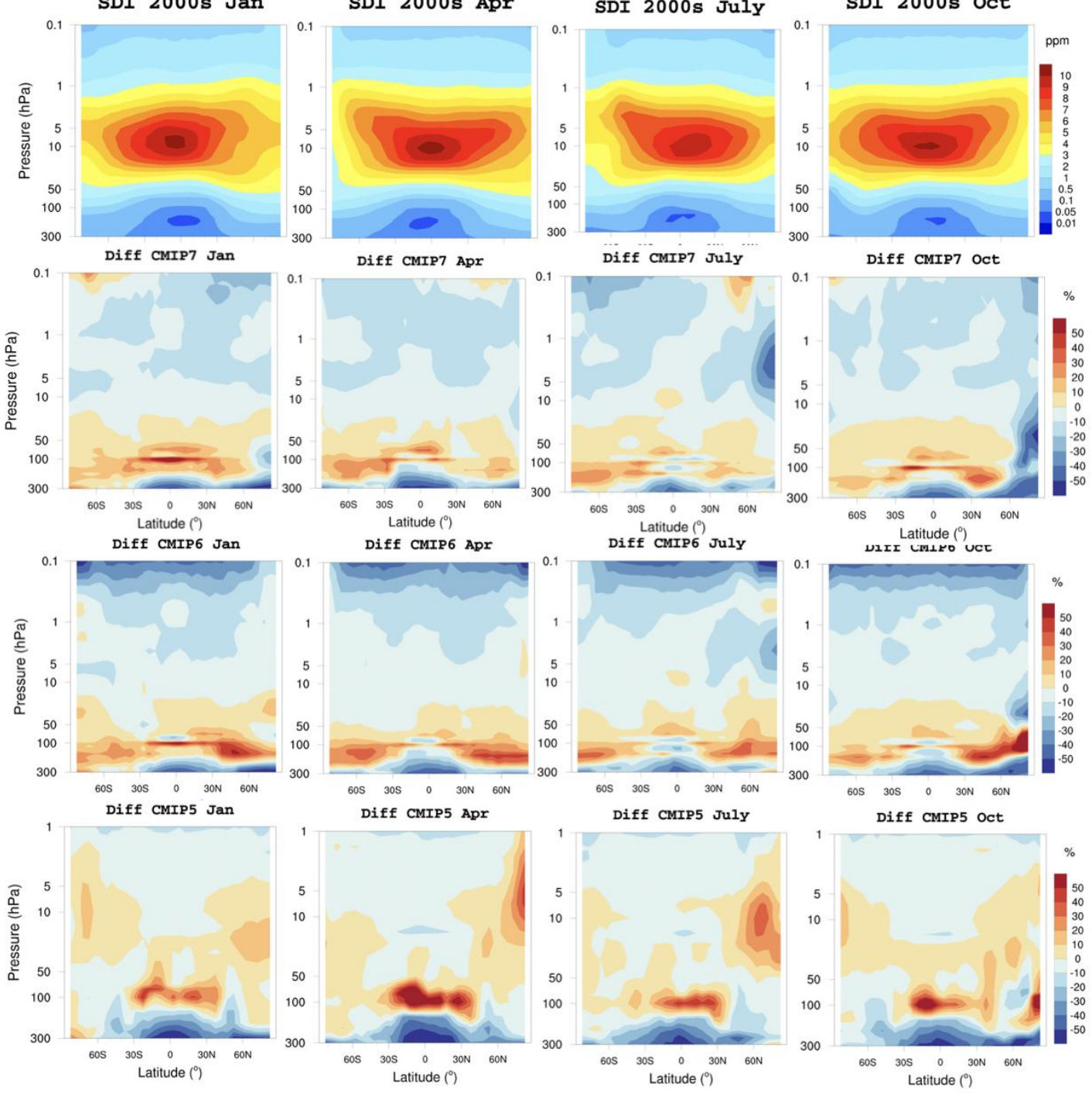
CMIP7 historical Ozone Forcing (merged: EMAC, WACCM, CMAM)

- FZJ-CMIP-ozone-1-2: PICtrl, historical simulation (some issues)
- FZJ-CMIP-ozone-2-0: historical simulation with updates and corrections
- Nitrogen deposition forcing datasets

CMIP7 scenarios

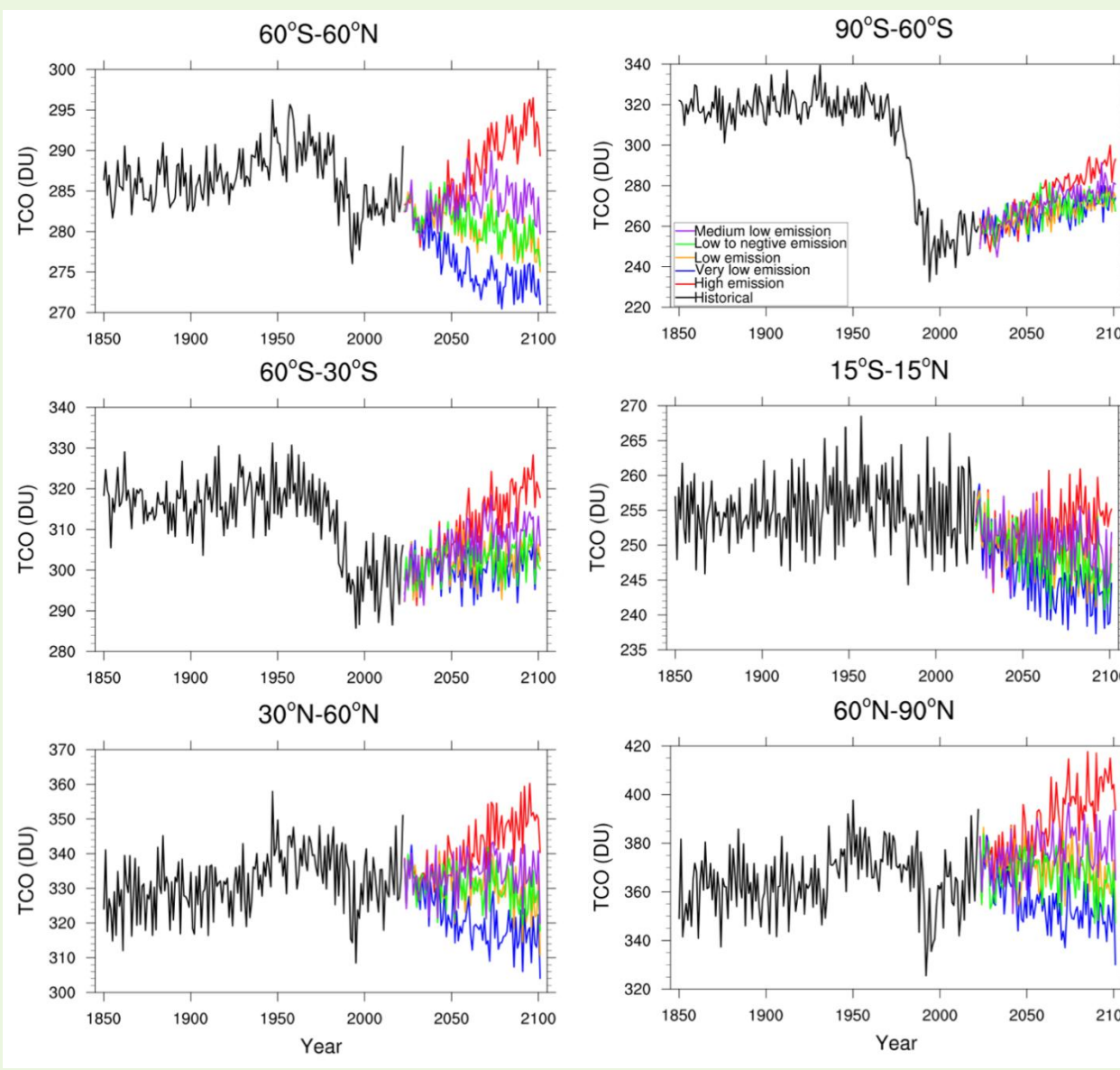
- FZJ-CMIP-ozone-v1-0
- FZJ-CMIP-ozone-h1-0
- FZJ-CMIP-ozone-m1-0
- FZJ-CMIP-ozone-l1-0
- FZJ-CMIP-ozone-l-1-0

Vertical Ozone cross-section
against SPARC Data Initiative (SDI)



- improved agreement with SDI through much of the middle and upper stratosphere
- lower stratosphere remains the region of largest biases despite some improvements over CMIP6

Ozone future database
annual mean TCO



- Scenario h produces the strongest TCO increase, while declining TCO is expected for scenario vl
- Antarctic ozone recovery is seen under all scenarios