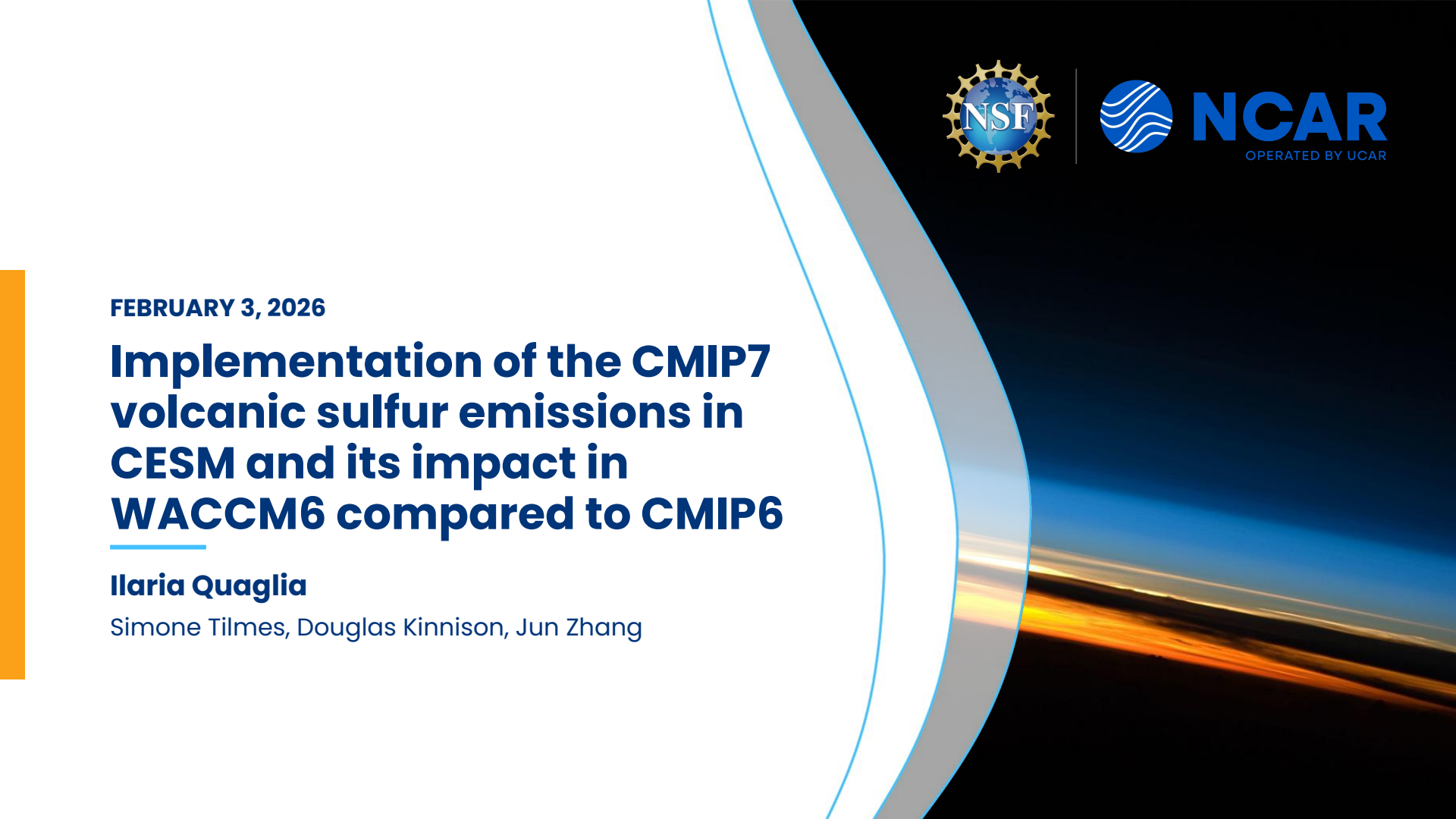


FEBRUARY 3, 2026

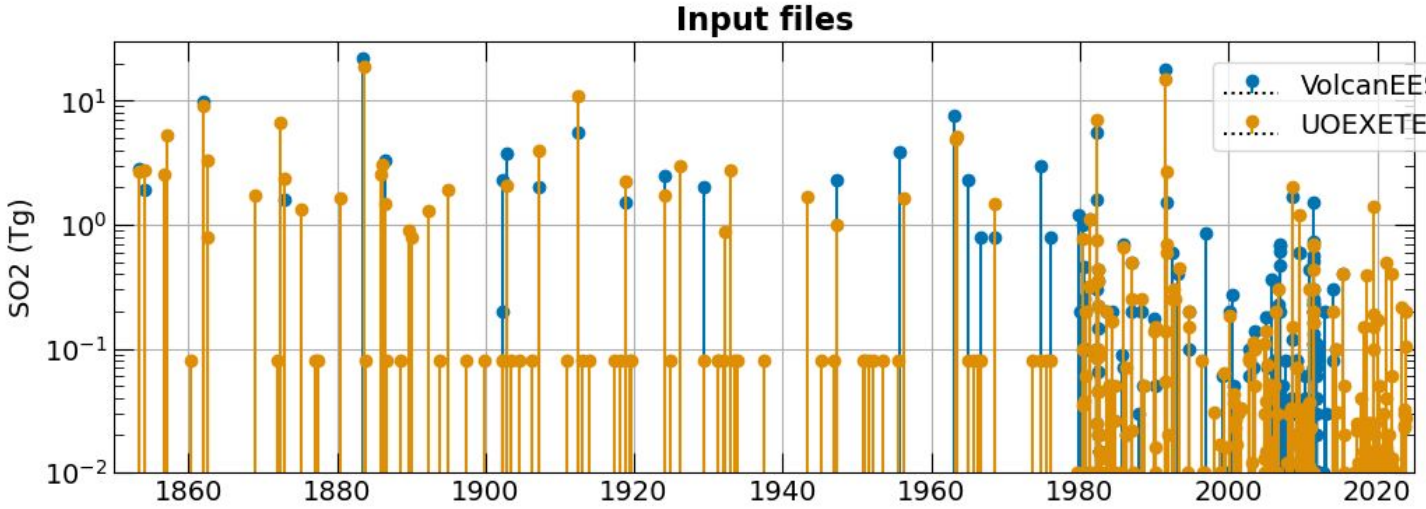
Implementation of the CMIP7 volcanic sulfur emissions in CESM and its impact in WACCM6 compared to CMIP6

Ilaria Quaglia

Simone Tilmes, Douglas Kinnison, Jun Zhang

CMIP6 and CMIP7 Volcanic emission input file: Differences

Sulfur emission dataset of explosive upper tropospheric and stratospheric volcanic eruptions over 1750-2023



Total SO2 burden 1850-2014

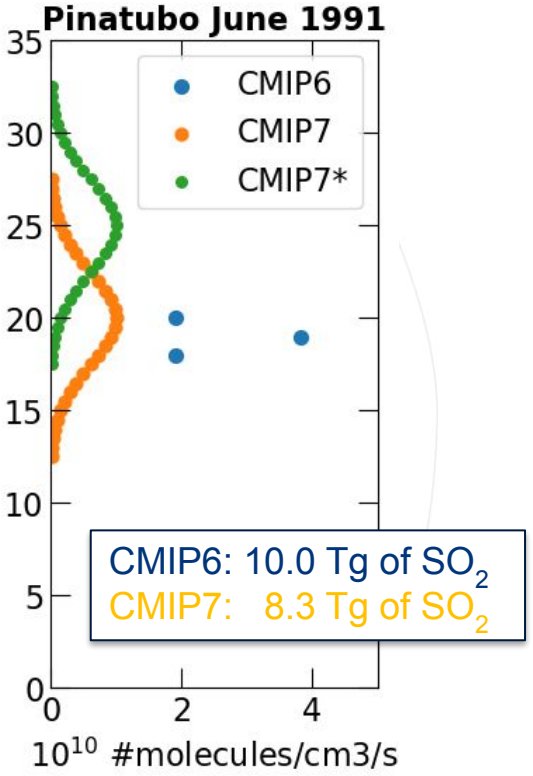
CMIP6: 138.5

CMIP7: 163.6

Aubry et. al (2025): Stratospheric aerosol forcing for CMIP7 (part 1): Optical properties for pre-industrial, historical, and scenario simulations (version 2.2.1)

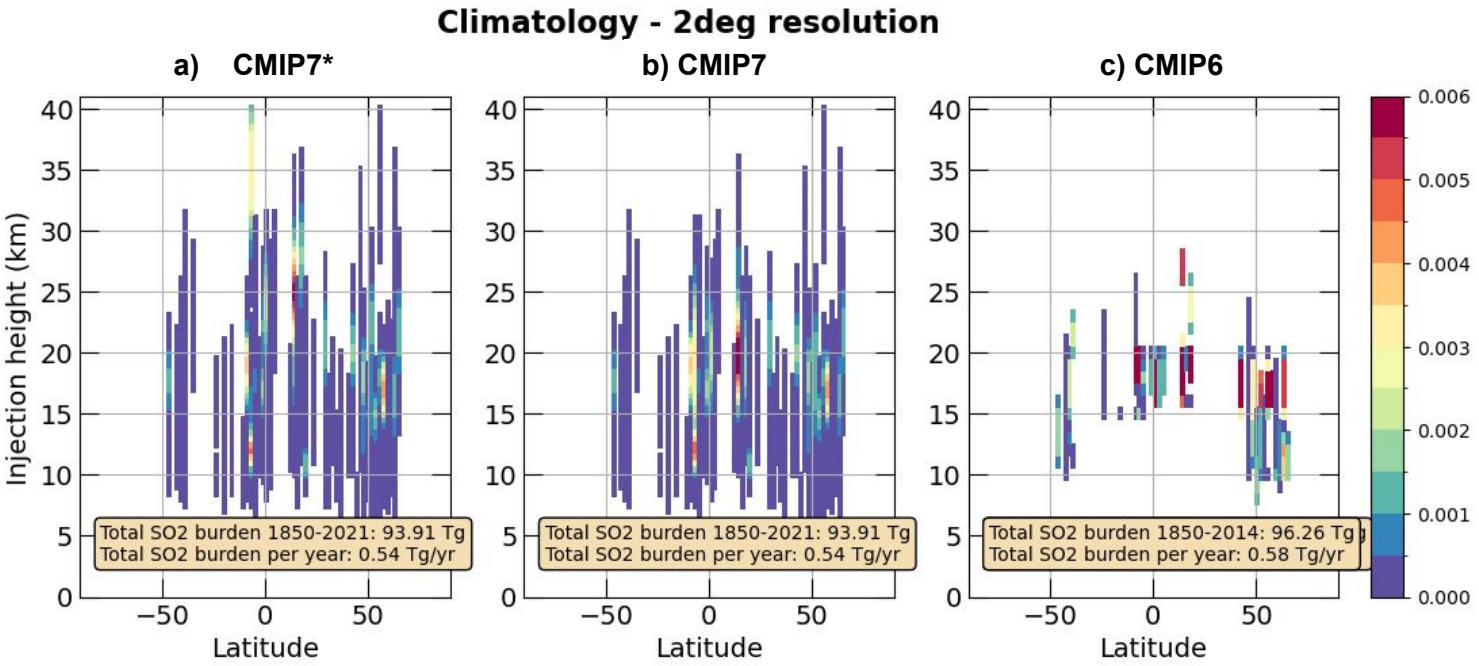
CMIP6 and CMIP7 Volcanic emission input file: Differences – Transient

- 6 hours emissions from 12:00 to 18:00 UT.
- Injection depth defined the **1-sigma** width of a **Gaussian** vertical profile centered on the emission height, instead of a uniform injection.
- Following the CMIP6 approach, two mass scaling factor are applied:
  - A mass scaling factor of **1/1.8**, instead of those with SO_2 > 10 Tg, to eruptions to all eruptions
  - SO_2 > 3.5 Tg and h ≥ 20 km → **h= 20 km**



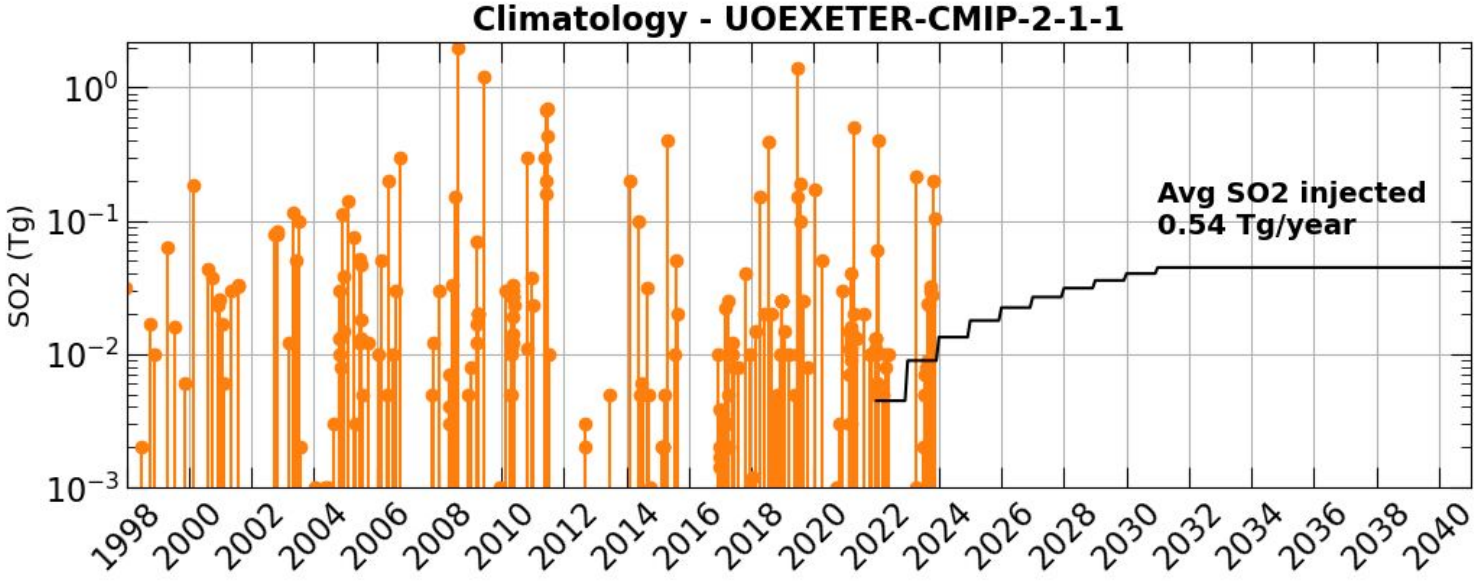
CMIP6 and CMIP7 Volcanic emission input file: Differences - Climatology

Climatology constructed using the 1850–2021 instead of 1850-2014



CMIP6 and CMIP7 Volcanic emission input file: Differences – Future scenarios

Climatology constructed using the 1850–2021 average is applied to both pre-industrial and future simulation (2022–2100), but with a 9-year ramp over 2022-2030 for future simulations



CMIP6 and CMIP7 Volcanic emission impact: Simulations

Models

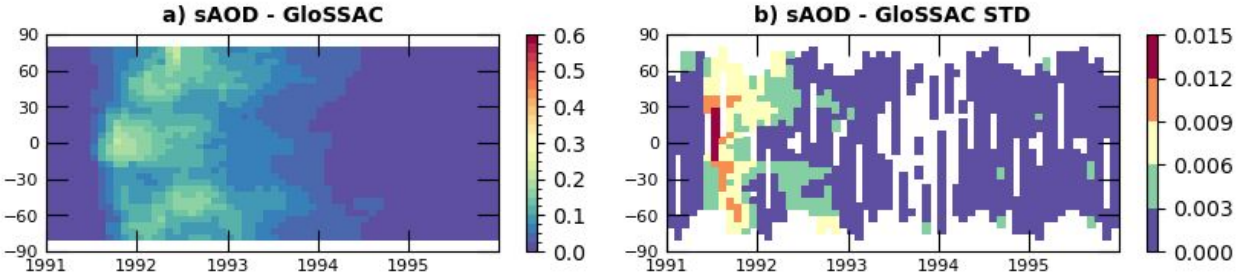
- CESM2-WACCM6, 2 deg resolution and 70 levs (140 km), fully-coupled
- CESM3-CAM6, cubed-sphere grid (approximately 1-degree resolution) and 93 levs (up to 80 km, mid-top), fixed-SST and T4S

Simulations

- Historical simulations:
  - CMIP6 : mass scaling + altitude reduction,1 ensemble member
  - CMIP7*: mass scaling, 1 ensemble member
  - CMIP7 : mass scaling + altitude reduction, 3 ensemble members
  - CMIP7_ne30 : mass scaling + altitude reduction, 2 ensemble members
- Pre-industrial control simulations:
  - CMIP6: mass scaling + altitude reduction
  - CMIP7: mass scaling + altitude reduction

CMIP6 and CMIP7 Volcanic emission impact: Evaluation w/r to Observations

- Quantify model performance by comparing outputs to observations, accounting for measurement uncertainties

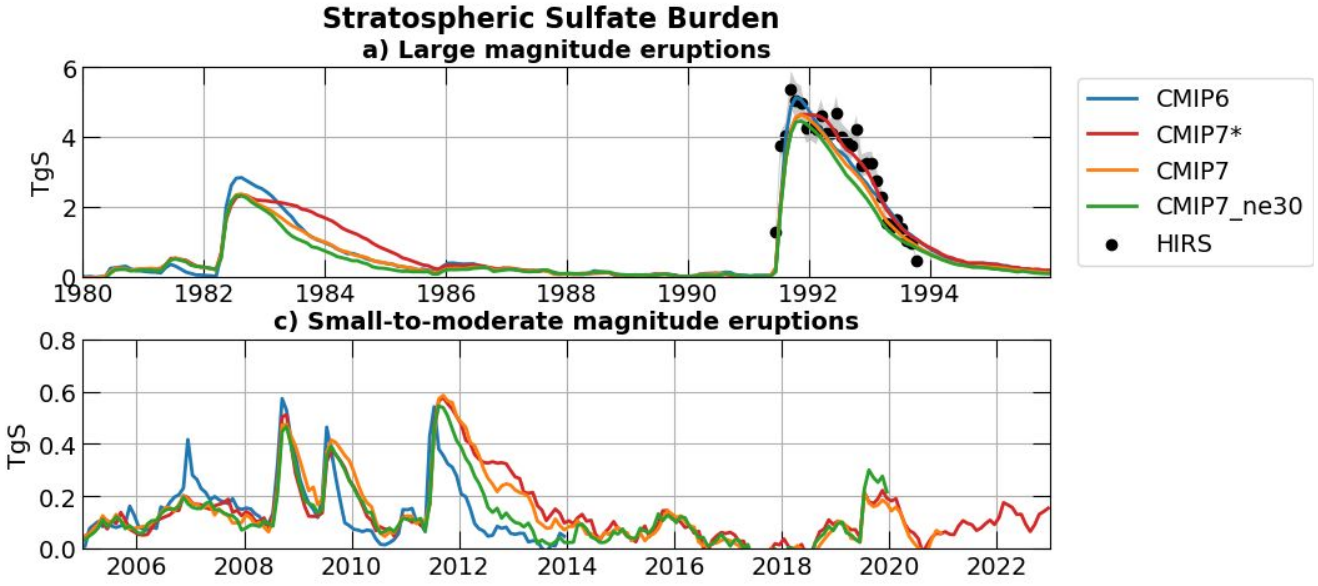


$$WRMSE = \sqrt{\frac{\sum_{i=time,lev,lat} \left(X_{model,i} - X_{observation,i}\right)^2 \cdot \omega_i^2 \cdot cos\vartheta_i}{N_{time} \cdot N_{lev} \cdot \sum_{lat} cos\vartheta_{lat}}}$$

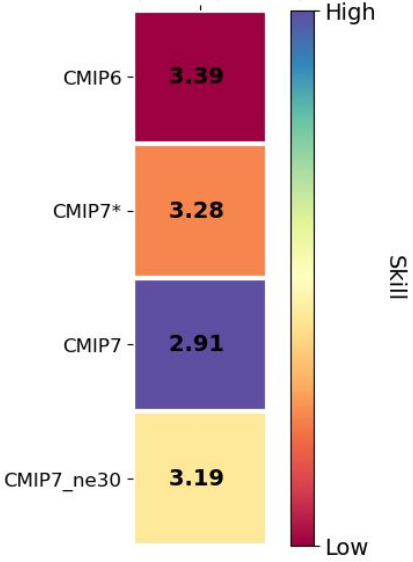
$$\omega_i = \frac{1}{\sigma_{observation,i}}$$

- **WRMSE <1:** Modeled variables fall within the observational range, on average for the considered period

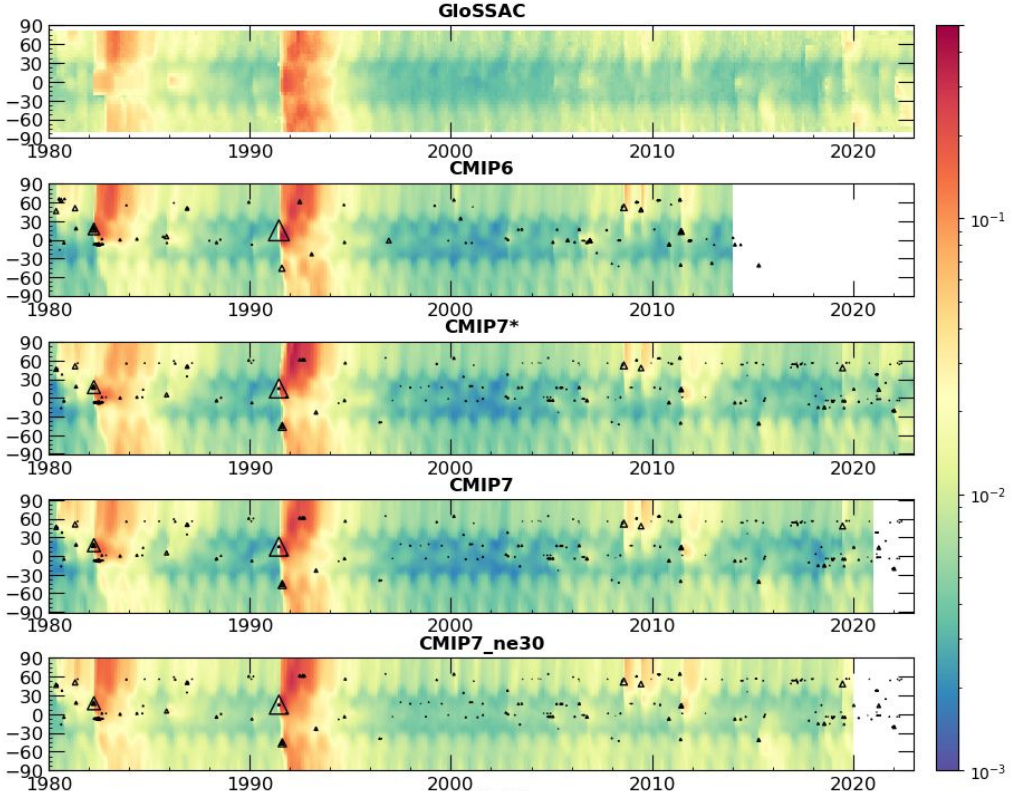
CMIP6 and CMIP7 Volcanic emission impact: Results: Stratospheric Sulfate Burden



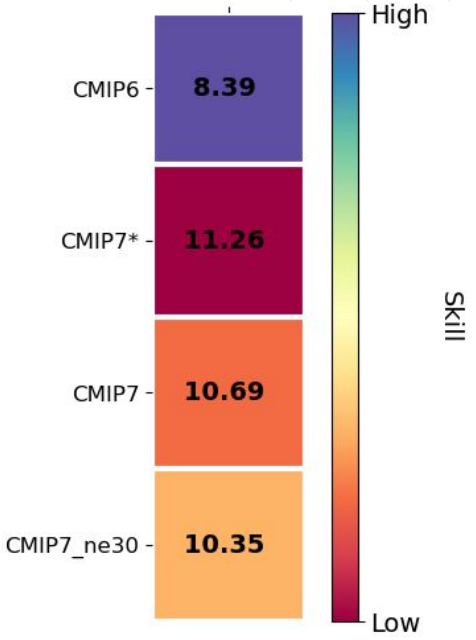
Weighted Root Mean Square Error over 1991-1993



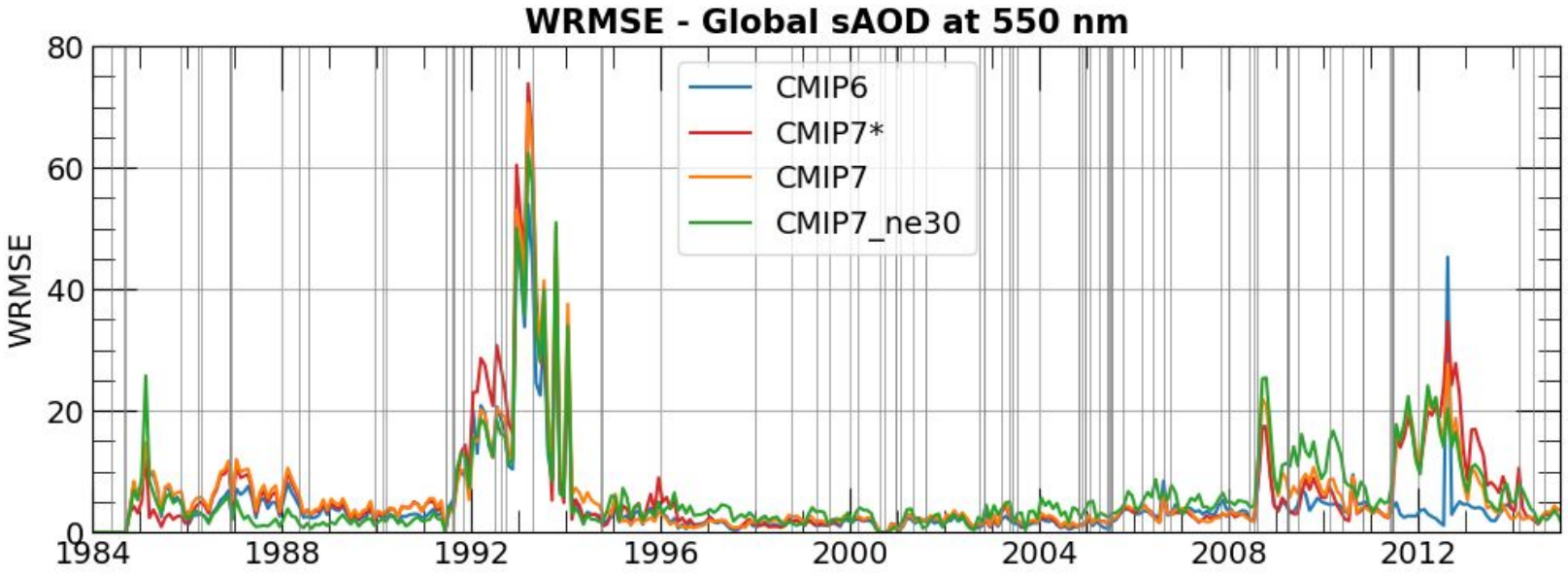
CMIP6 and CMIP7 Volcanic emission impact: Results: Stratospheric AOD at 550 nm



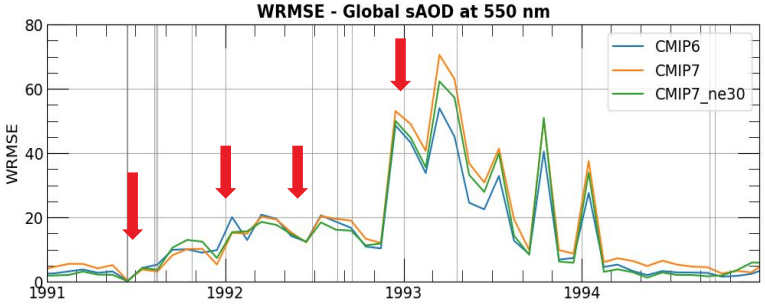
Weighted Root Mean Square Error over 1984-2013



CMIP6 and CMIP7 Volcanic emission impact: Results: Stratospheric AOD at 550 nm



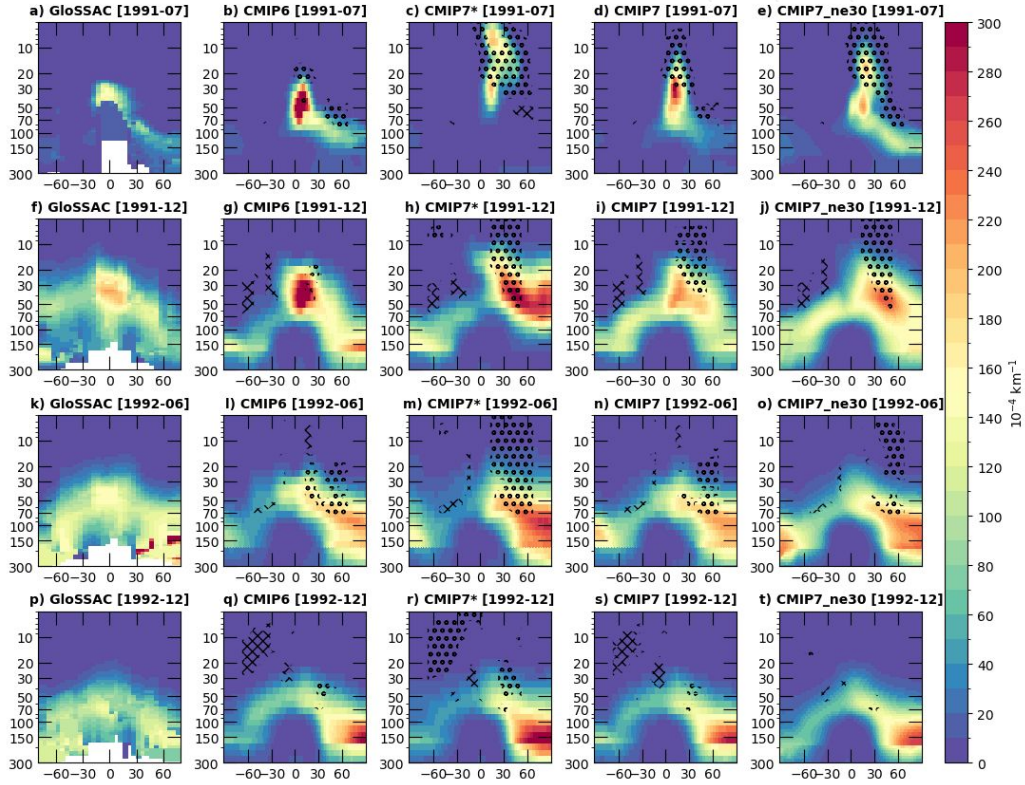
CMIP6 and CMIP7 Volcanic emission impact: Results: Extinction at 550 nm



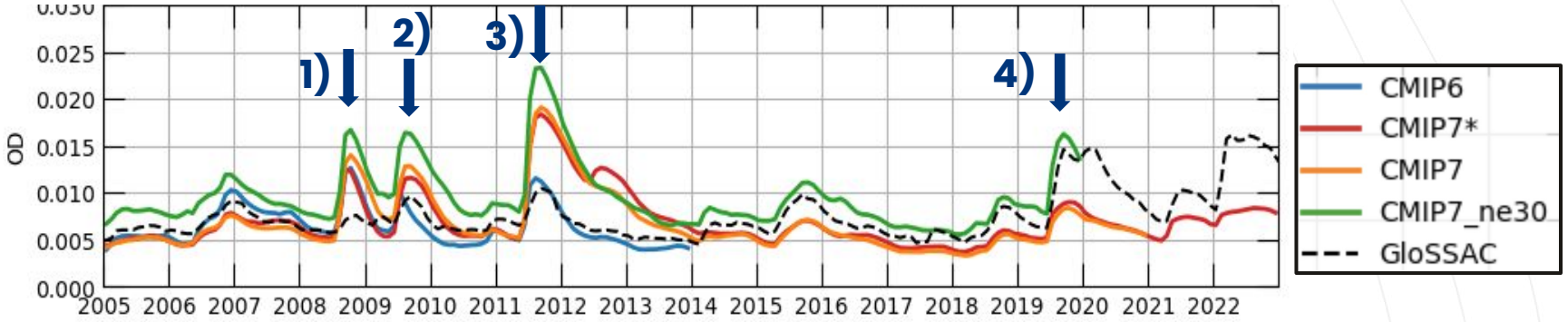
Hatches for WRMSE > 3 STD

X: underestimated

O: overestimated

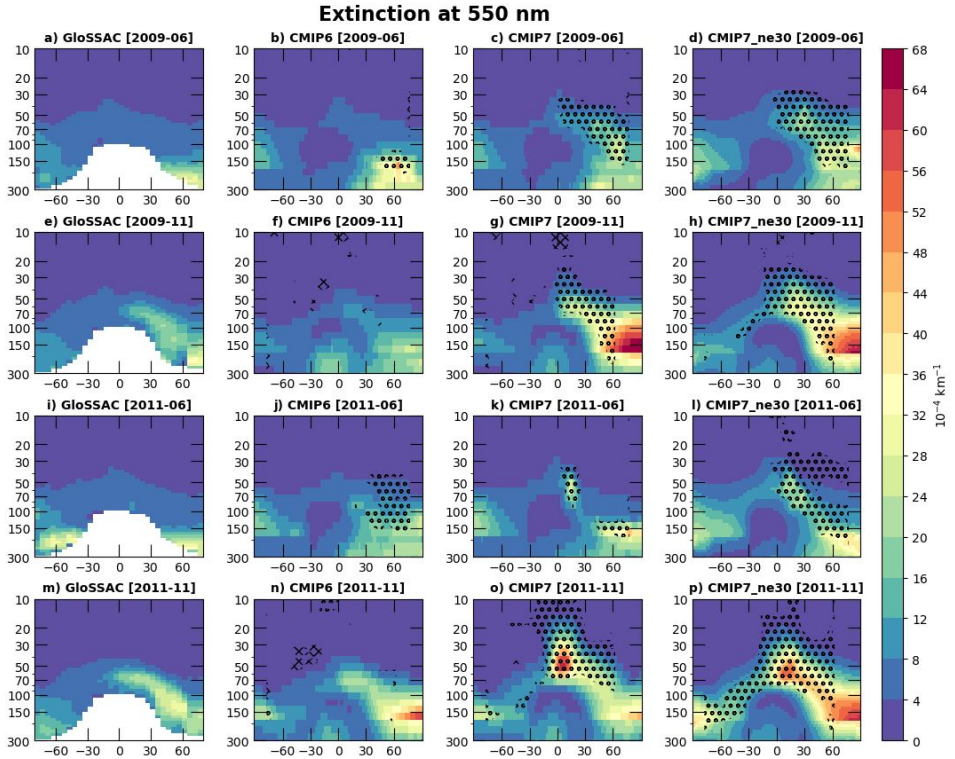


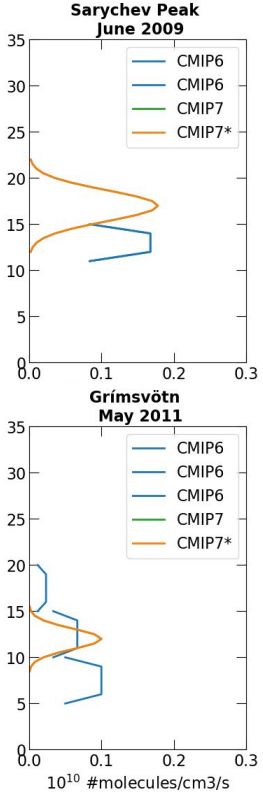
CMIP6 and CMIP7 Volcanic emission impact: Results: Extinction at 550 nm



1) **Kasatochi** (Alaska, August 2008)
2) **Sarychev Peak** (Russia, June 2009)
3) **Grímsvötn** (Iceland, May 2011)
4) **Raikoke** (Russia, June 2019)

CMIP6 and CMIP7 Volcanic emission impact: Results: Extinction at 550 nm





Sarychev Peak
(Russia, June 2009)

CMIP6: 1.2 Tg at h=13

CMIP7: 0.7 Tg at h=17

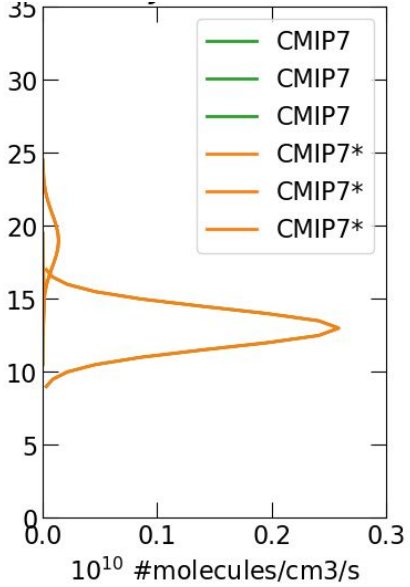
Grímsvötn
(Iceland, May 2011)

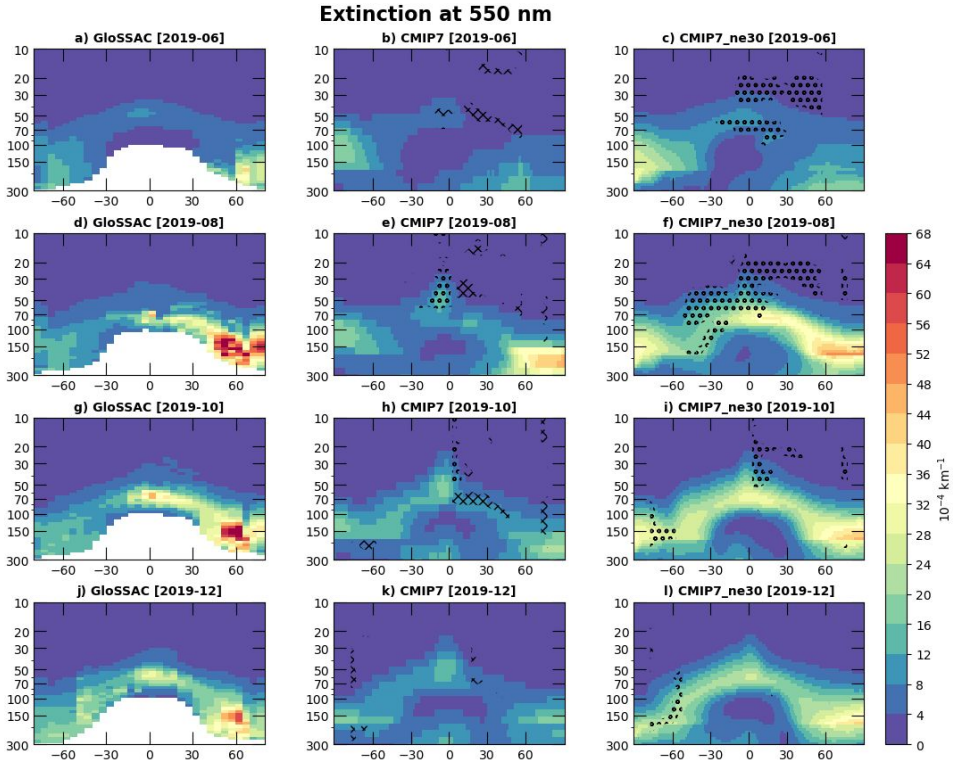
CMIP6: [0.07, 0.2 , 0.3] Tg at h=[17.5, 12.5, 7.5]

CMIP7: 0.2 Tg at h=12

CMIP6 and CMIP7 Volcanic emission impact: Results: Extinction at 550 nm

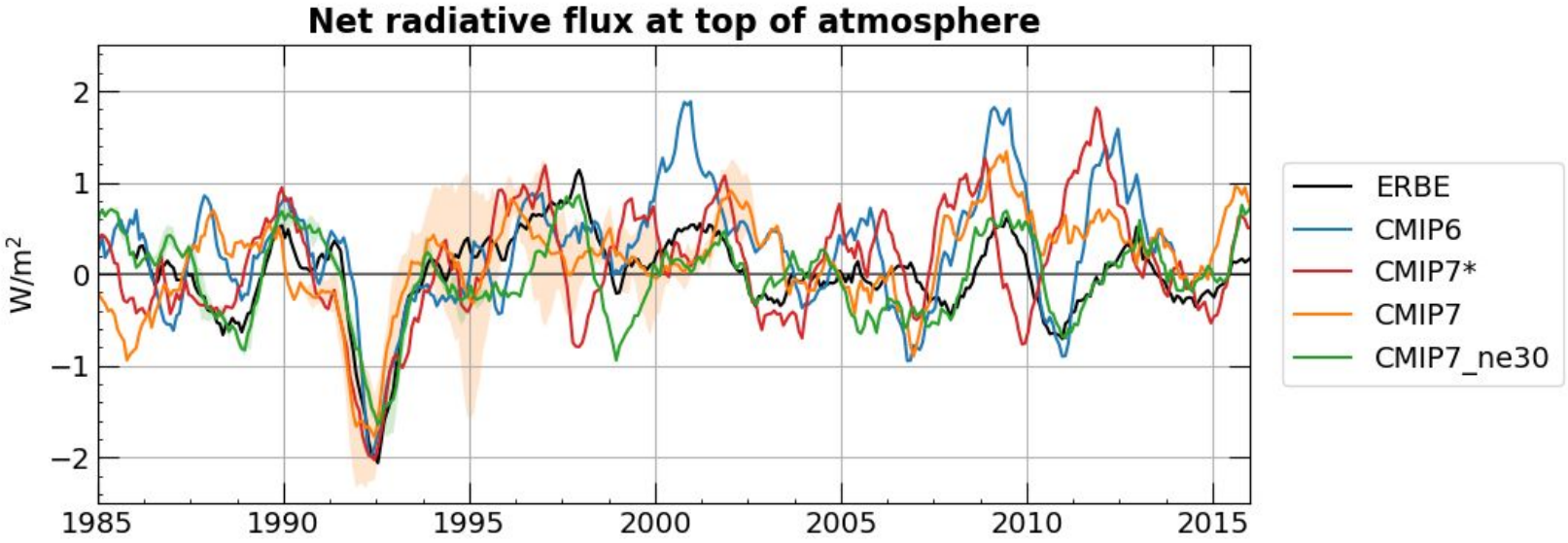
Raikoke (Russia, June 2019)
CMIP7: [0.8, 0.1, 0.01] Tg x h=[13, 18, 15]



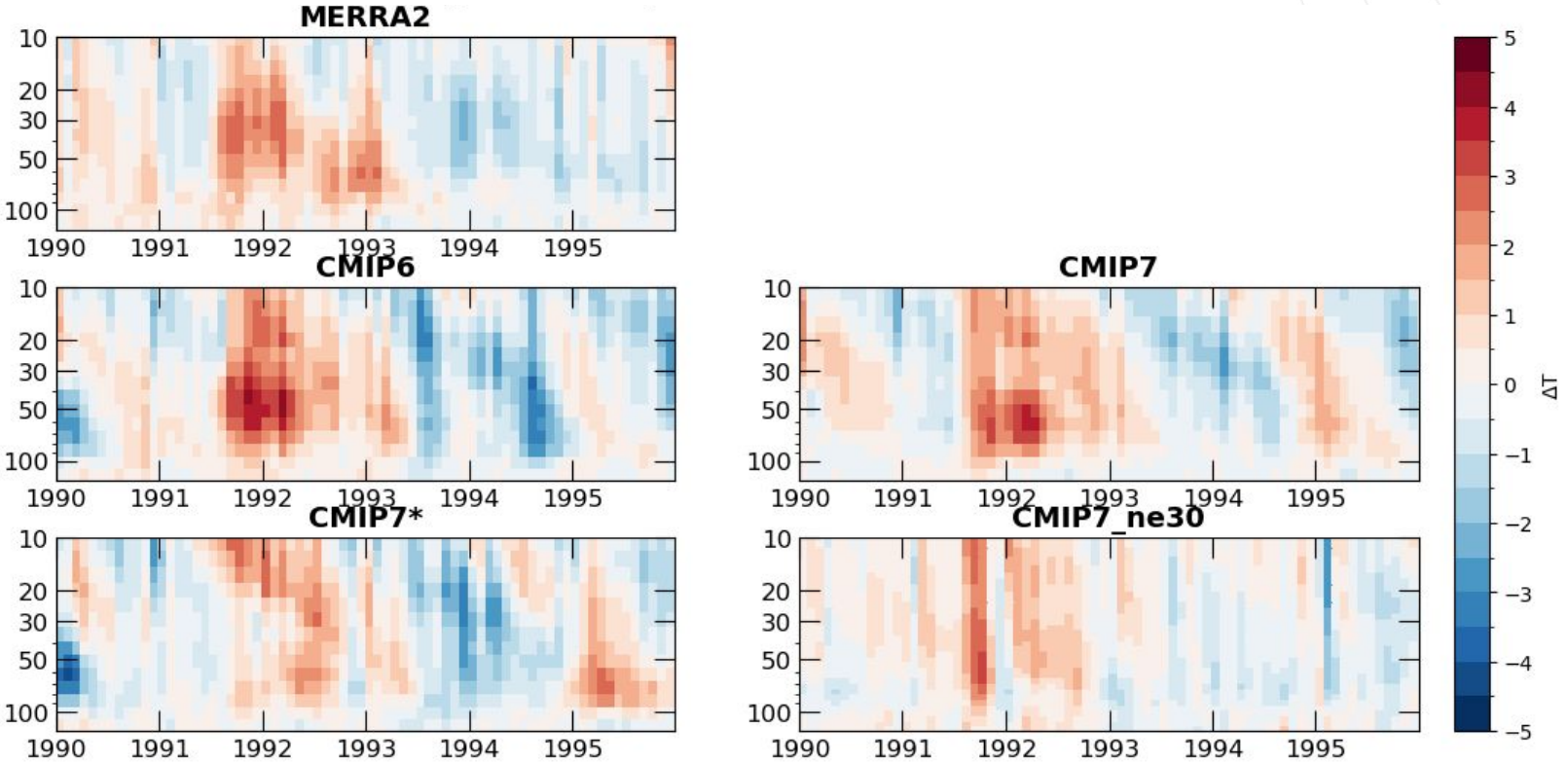


CMIP6 and CMIP7 Volcanic emission impact: Results: Radiative Forcing at TOA

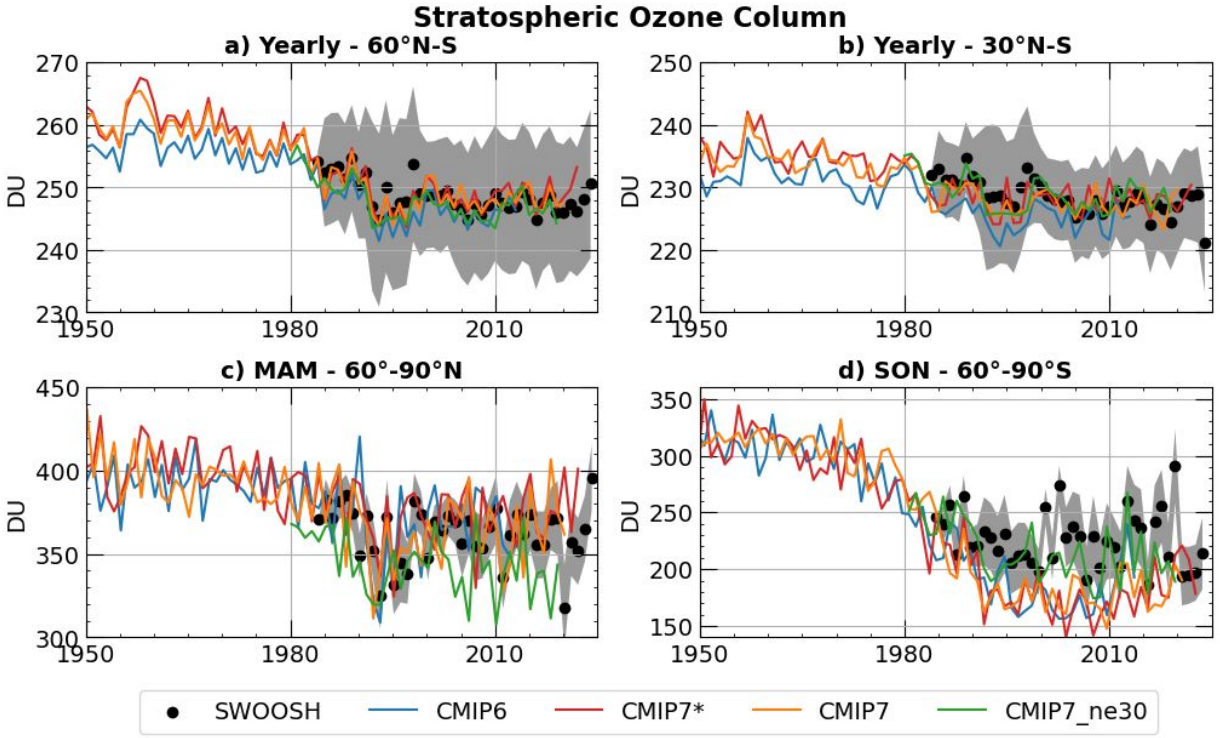
RF at TOA calculated by detrending and with respect to the timeseries.



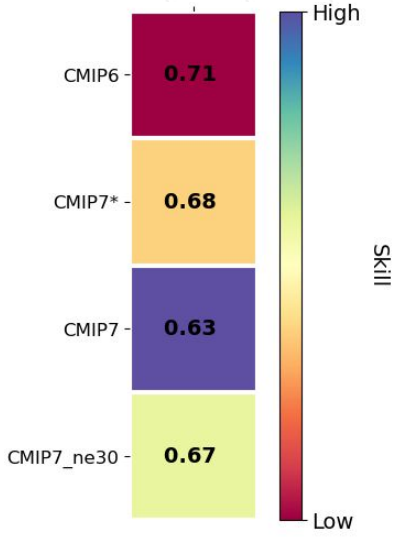
CMIP6 and CMIP7 Volcanic emission impact: Results: Tropical Temperature Anomalies



CMIP6 and CMIP7 Volcanic emission impact: Results: Total ozone column

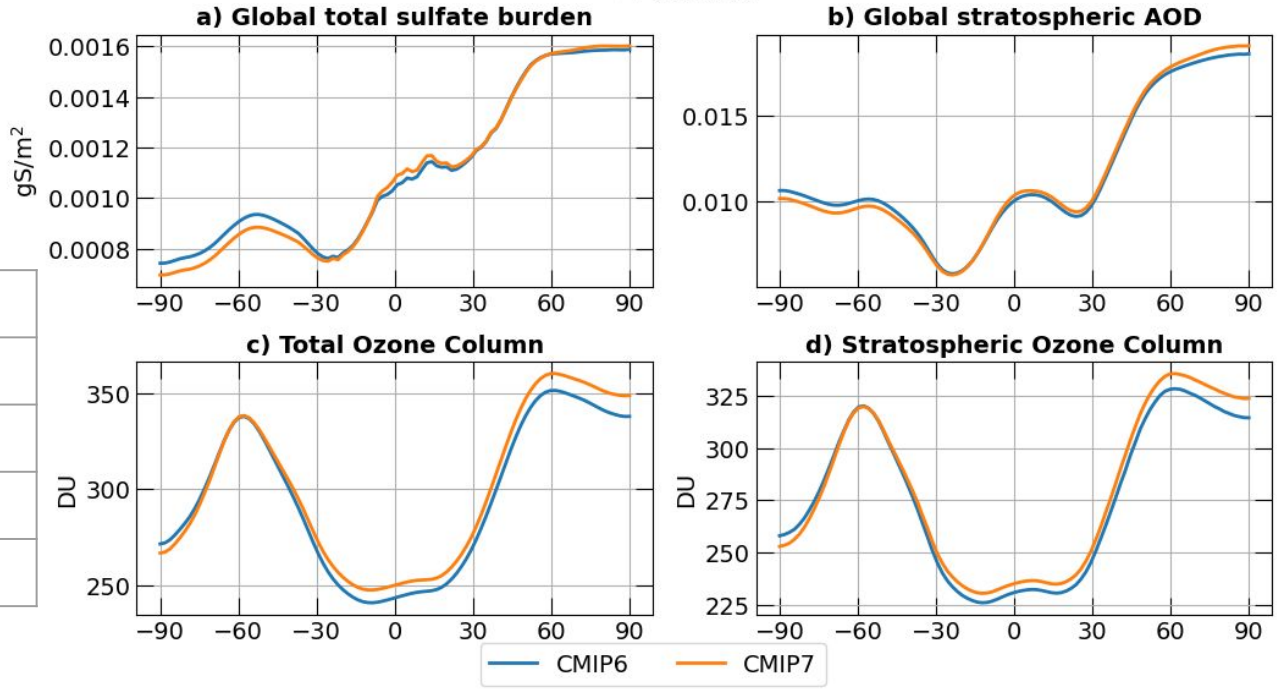


Weighted Root Mean Square Error over 1984-2013

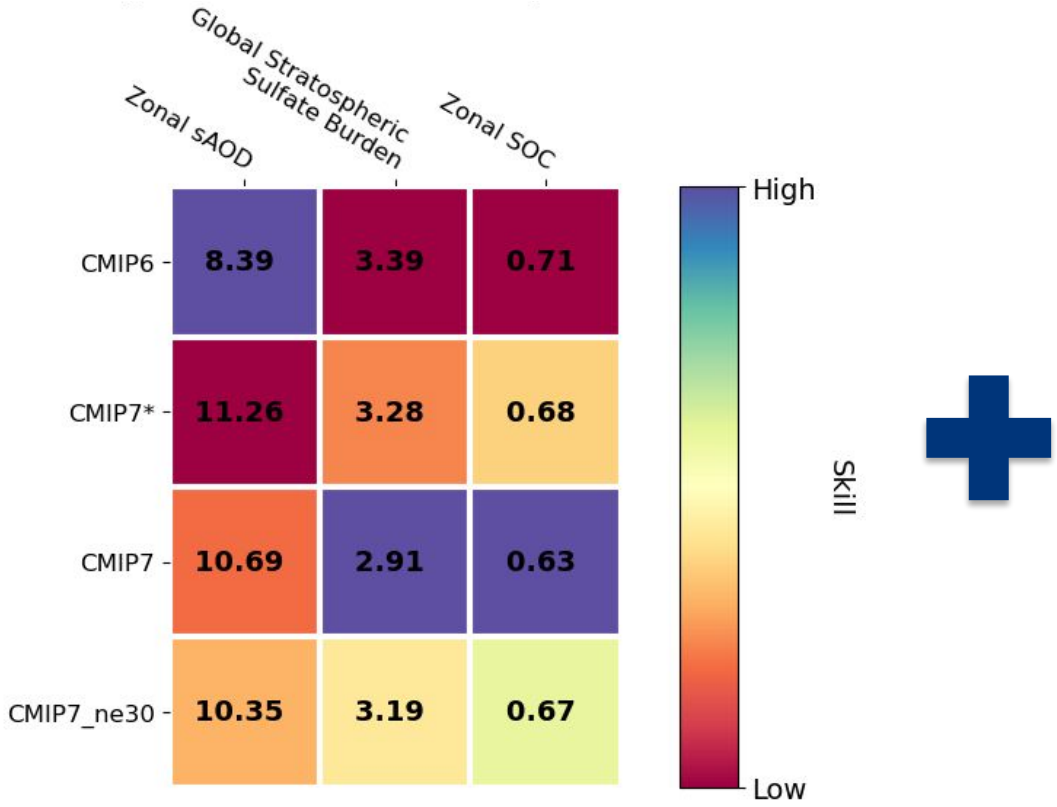


CMIP6 and CMIP7 Volcanic emission impact: Results

	CMIP6	CMIP7
Burd	0.55	0.54
sAOD	0.01	0.01
TOC	282.3	288
SOC	263.2	267.4



Final Remarks



Generally, a better representation of spatial distribution in CMIP7 of

- Extinction
- Tropical temperature anomalies
- Stratospheric ozone column