Evaluation of the chemistry and climate impact of the new solar forcing dataset for CMIP7 using the Whole Atmosphere Community Climate Model

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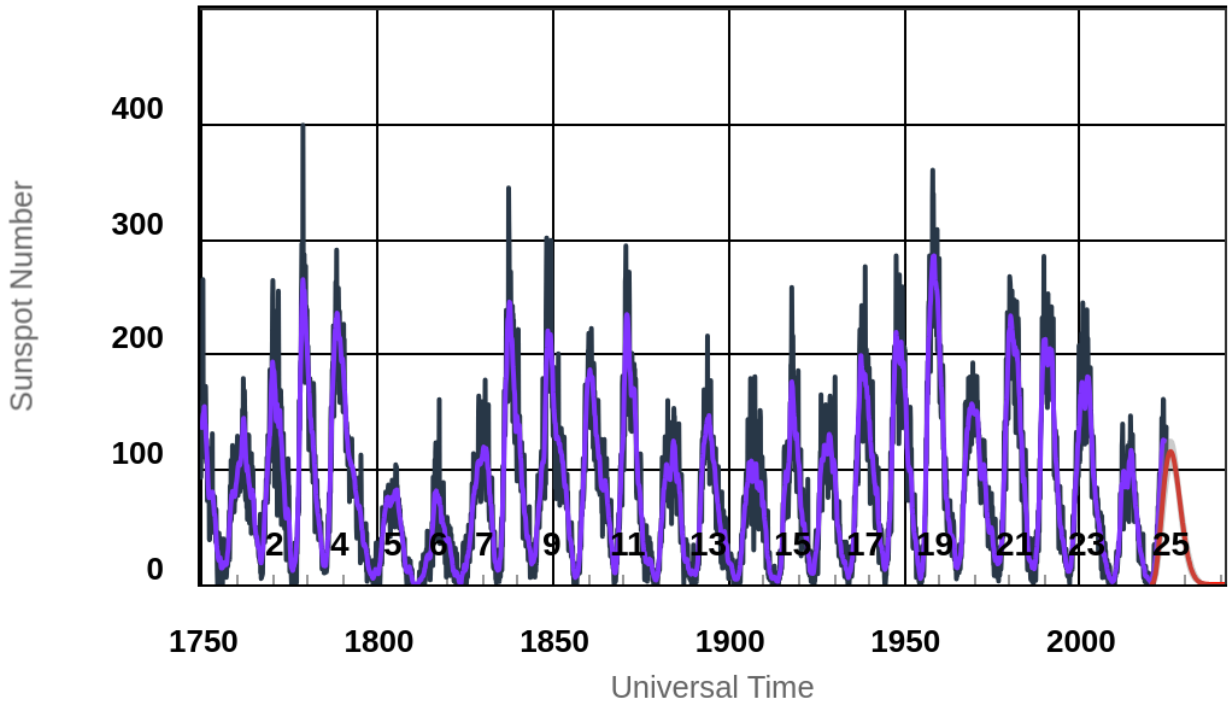
Outline

Solar Forcing Input	Examine the CMIP7 Reference Spectrum for Quiet Sun Conditions (UV to IR).
	Will show the difference between CMIP7 and CMIP6 simulations
WACCM6 Model Simulations (CMIP6 version)	Two 60 year Interactive chemistry / deep ocean simulations
	Examine Stratospheric Chemistry and Tropospheric Climate Impact
Potential Concerns for Tuning CMIP7 Models	Conclusions
	Next Step

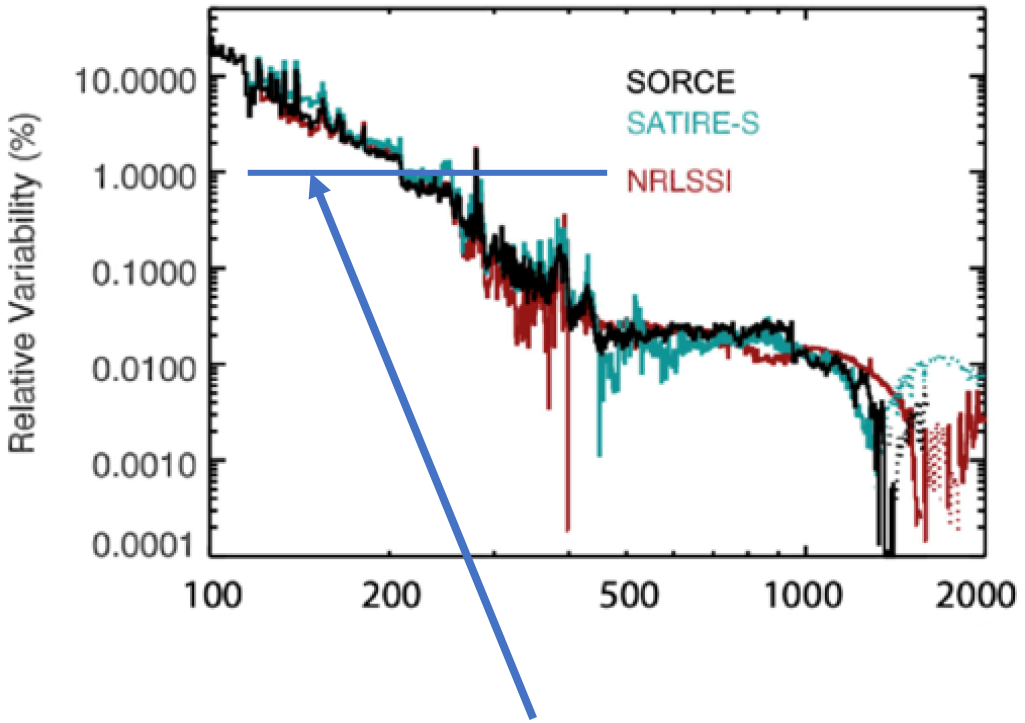
11-year Solar Variability

Sun-spot #



SS# changes are due to changes in the Suns magnetic field

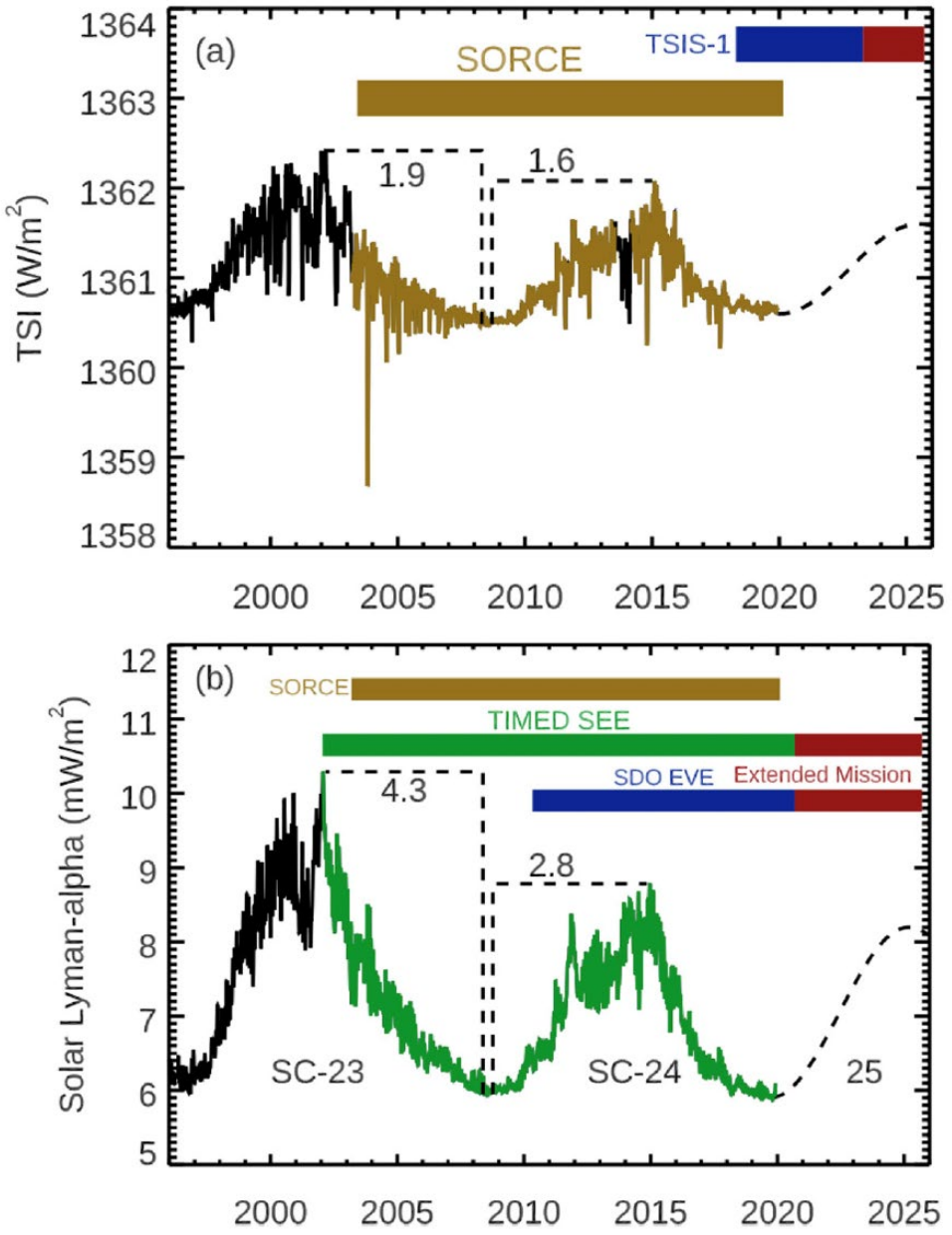
Variability over one Cycle 24



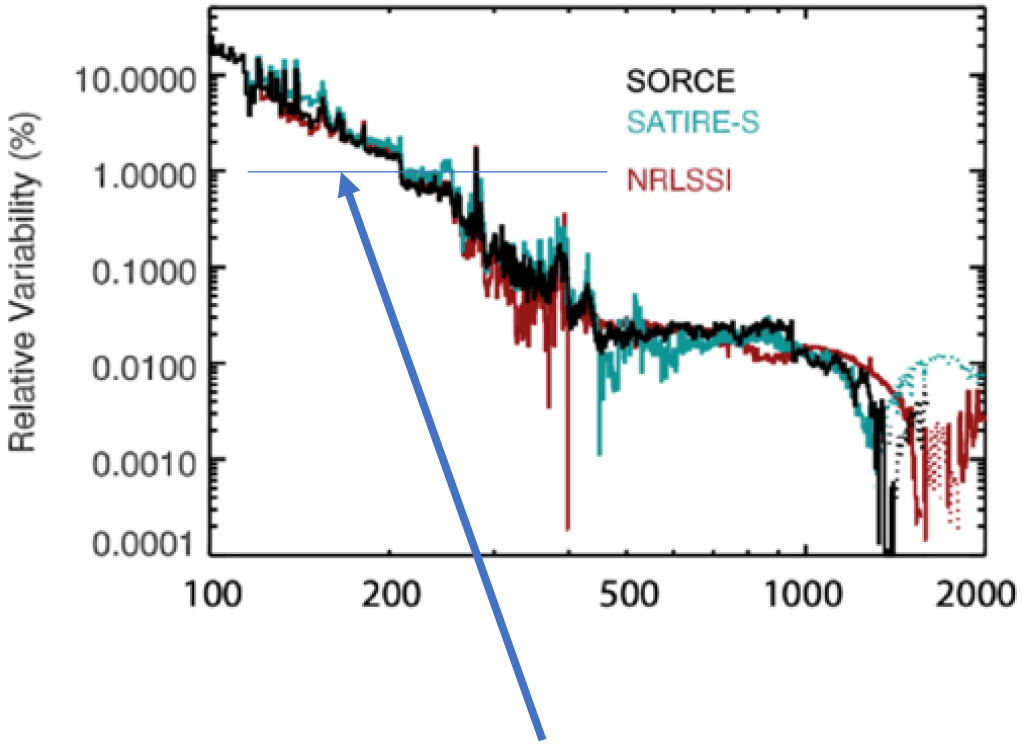
More UV/Vis Radiation at Solar Max vs Min

Review Paper: Ward et al., Role Of the Sun and the Middle atmosphere/thermosphere/ionosphere In Climate (ROSMIC): a retrospective and prospective view, Progress in Earth and Plantary Science, https://doi.org/10.1186/s40645-021-00433-8, 2021

Obs 11-year Solar Variability

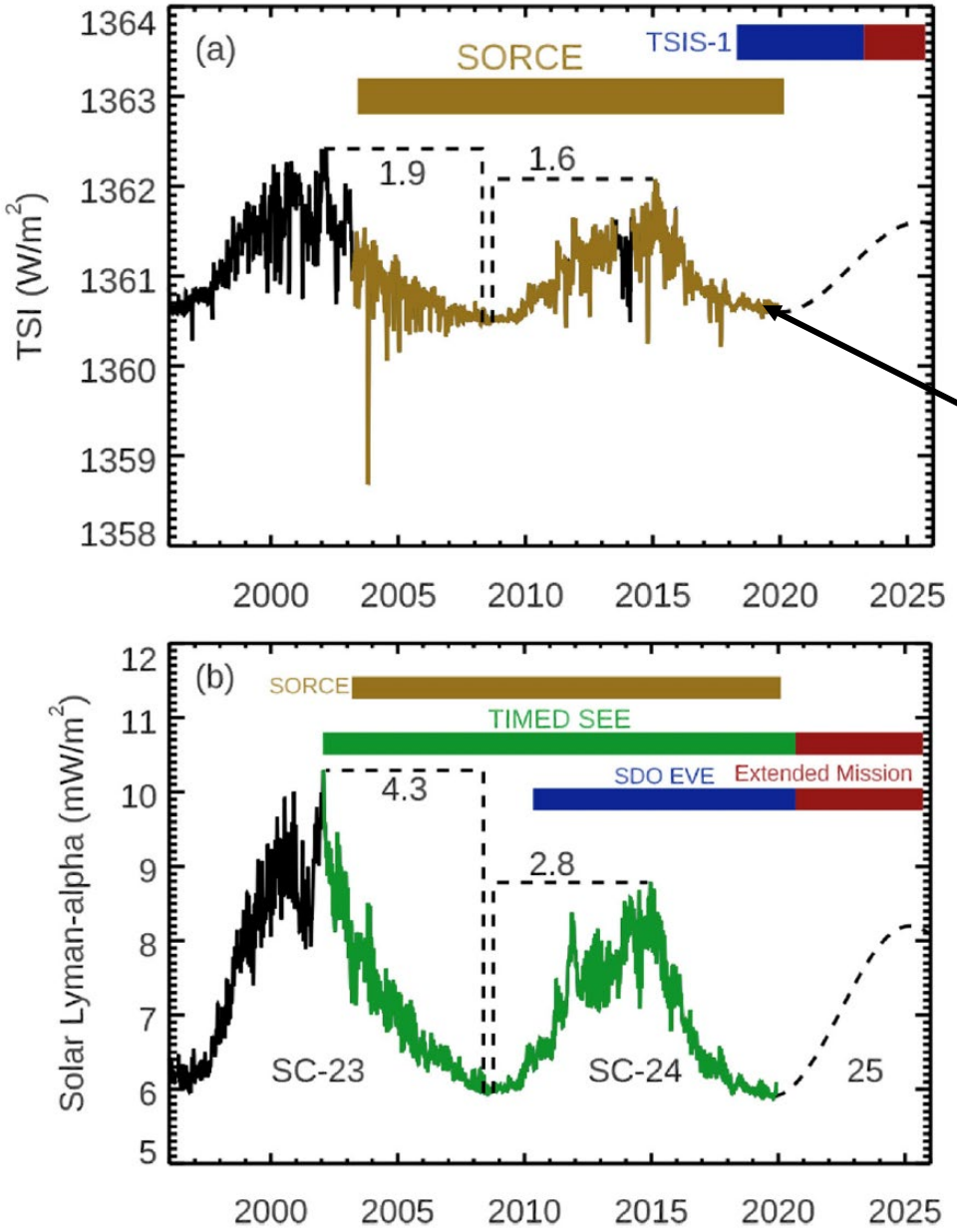


Variability over one Cycle 24

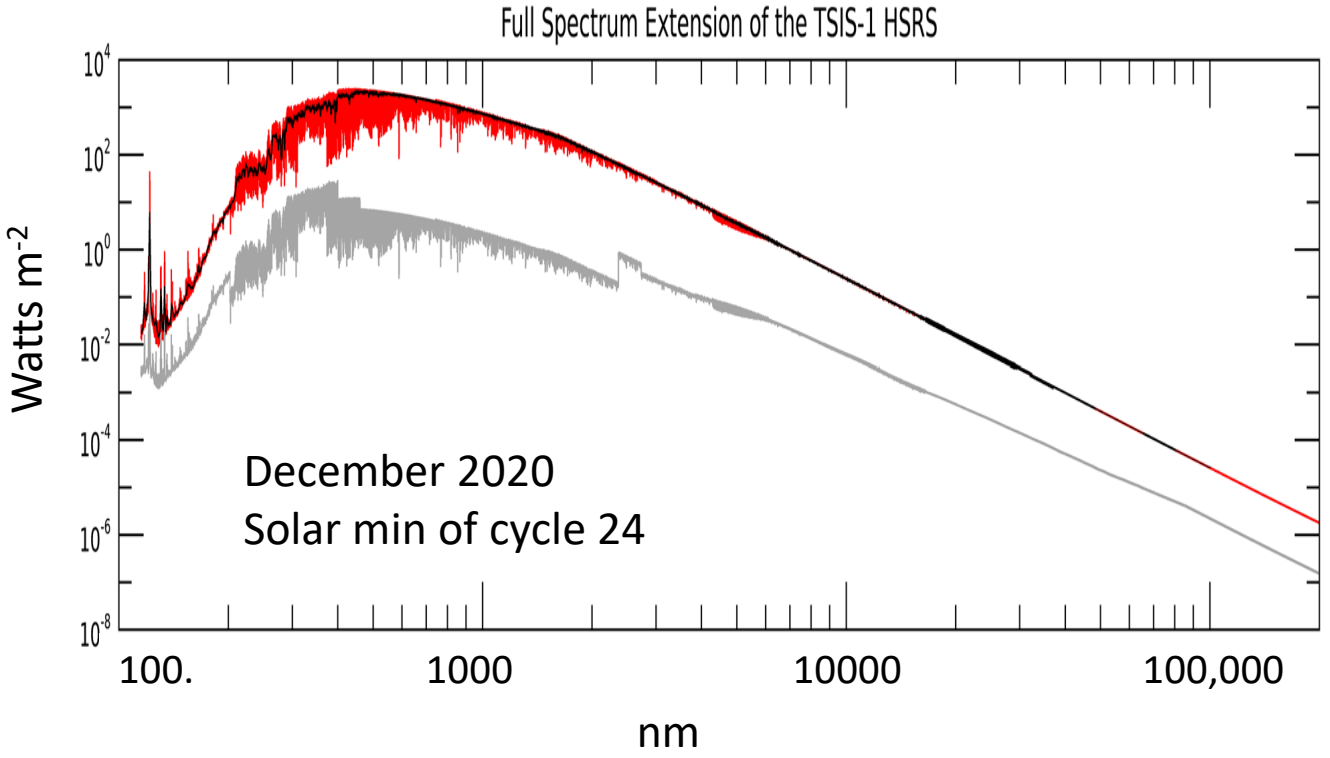


More UV/Vis Radiation at Solar Max vs Min

11-year Solar Variability



Quiet Sun Reference Spectrum for Cycle 24



Coddington et al., Earth and Space Sci, 2023

New Reference Spectrum for CMIP7 (TSIS-1)

- The Total and spectral Solar Irradiance Sensor (TSIS-1) is a new "quiet sun" reference spectrum (115 nm to 200 microns).
  - It was measured on board the International Space Station (ISS) for atmospheric radiative transfer and remote sensing applications (*Coddington et al.* 2023).
- The New TSIS-1 spectrum has moved more energy from the Near IR into the UV/Visible region.
  - The TSIS-1 is the solar spectrum proposed by the CMIP7 Solar Working Group and recently adopted by CMIP7 (*Funke et al., Geos. Model Dev.*, 2024).

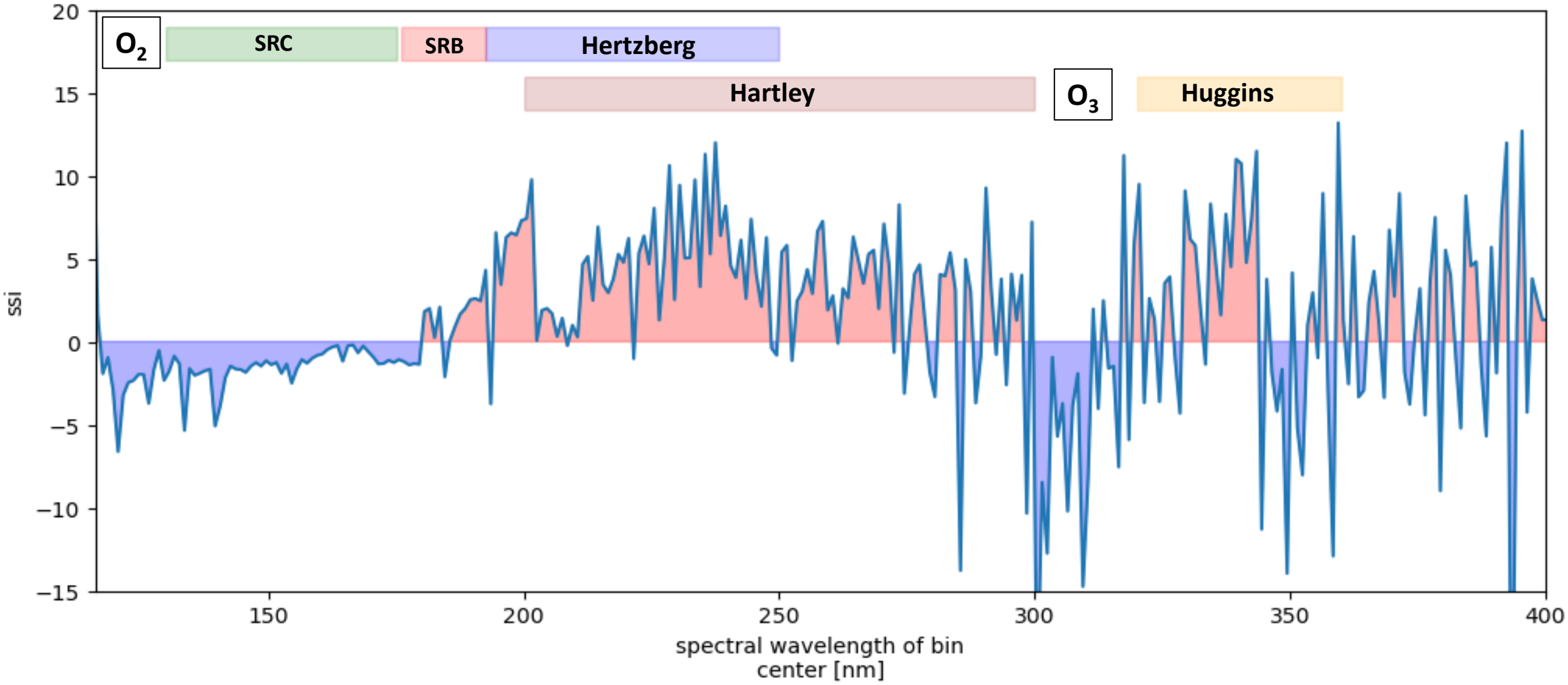
Model Description and Simulations

CESM2 - Whole Atmosphere Community Climate Model (used in CMIP6)

- Interactive Middle Atmosphere Chemistry and Deep Ocean
- ~2 degrees horizontal; 70 levels (surface to 140km)
- Repeating the year 2000 GHG and EESC conditions (60 years; examining years 10-60)
- Ran two solar minimum Solar Spectral Irradiance (SSI) experiments.
  - CMIP7 (TSIS-1)
  - CMIP6

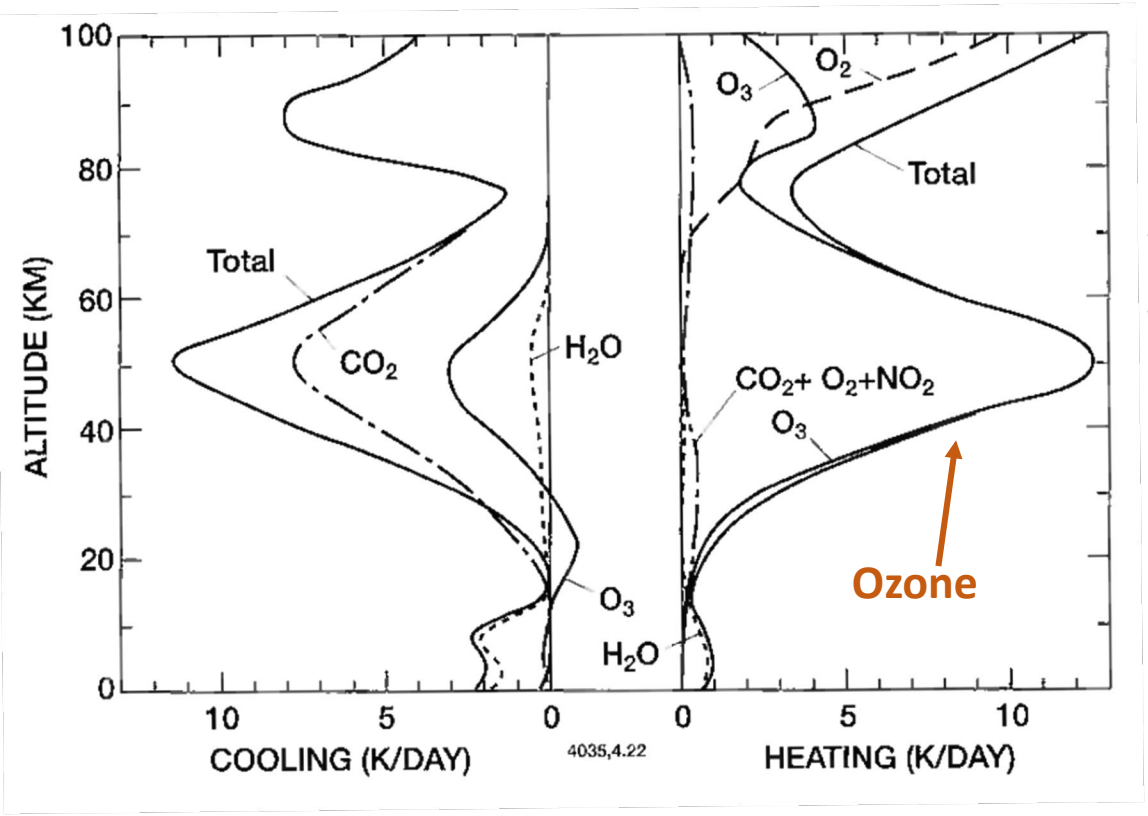
Comparison of Solar Spectral Irradiances

CMIP7 – CMIP6/CMIP6 (%)

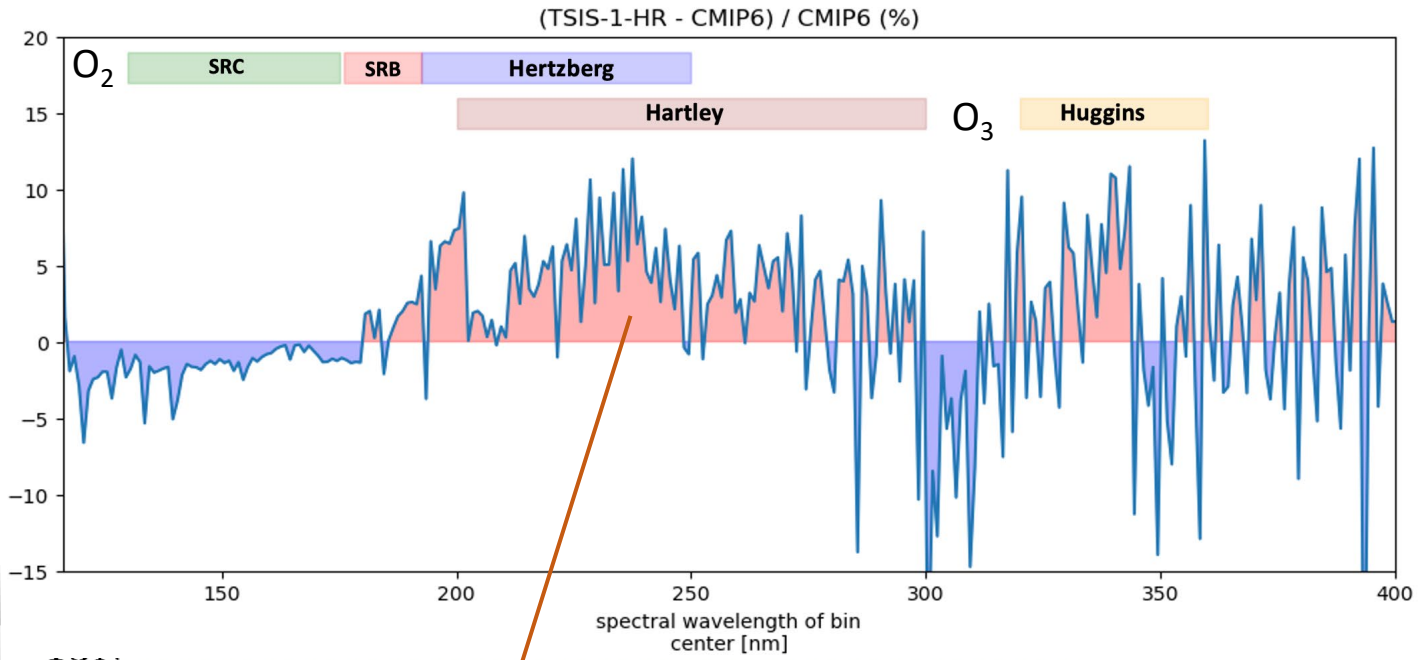


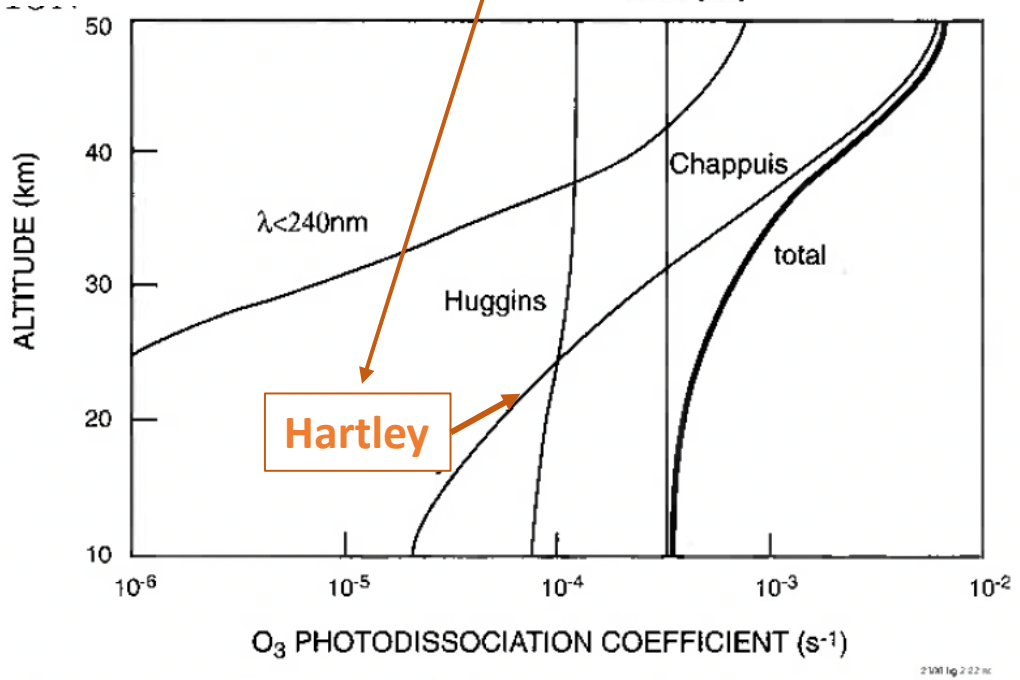
NOTE: CMIP6 Ref. Spectrum is an average of SATIRE and NRL2SSI (Matthes et al., 2017)

Ozone absorption in the Hartley Band is Important for Heating Rates

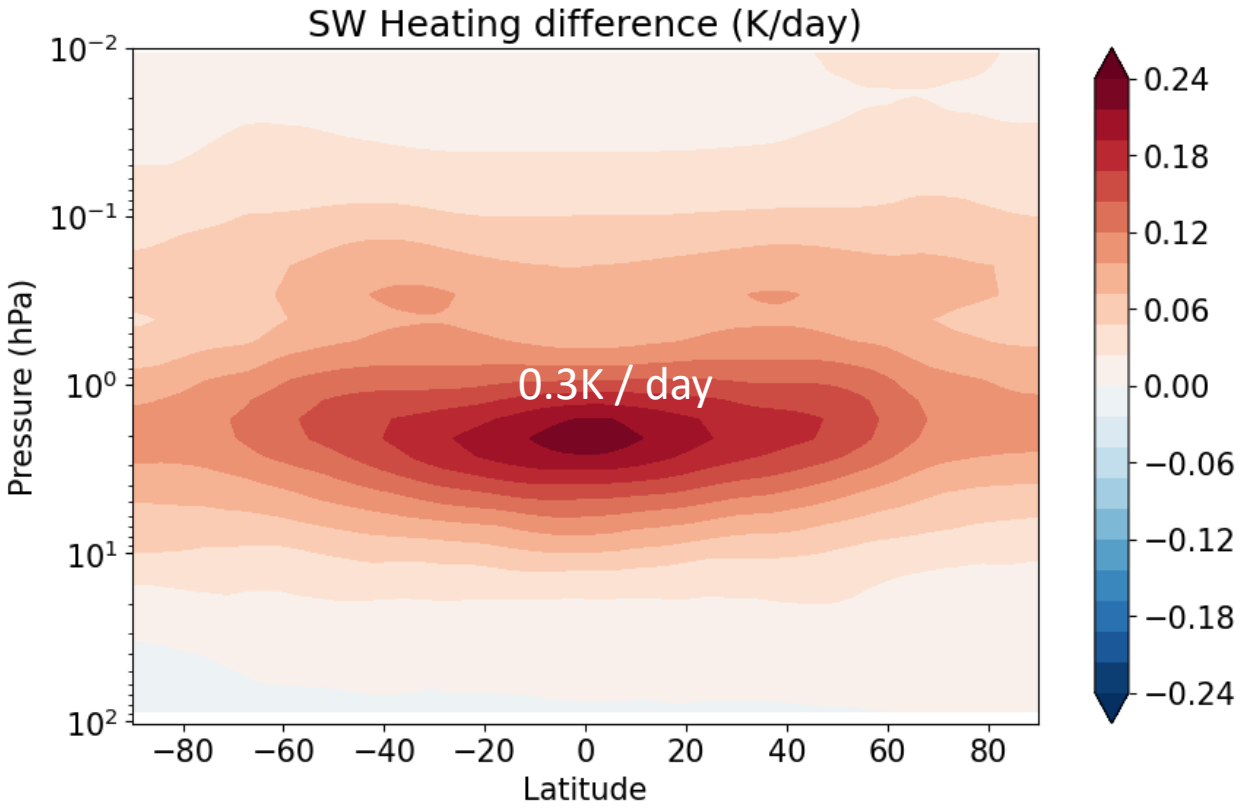


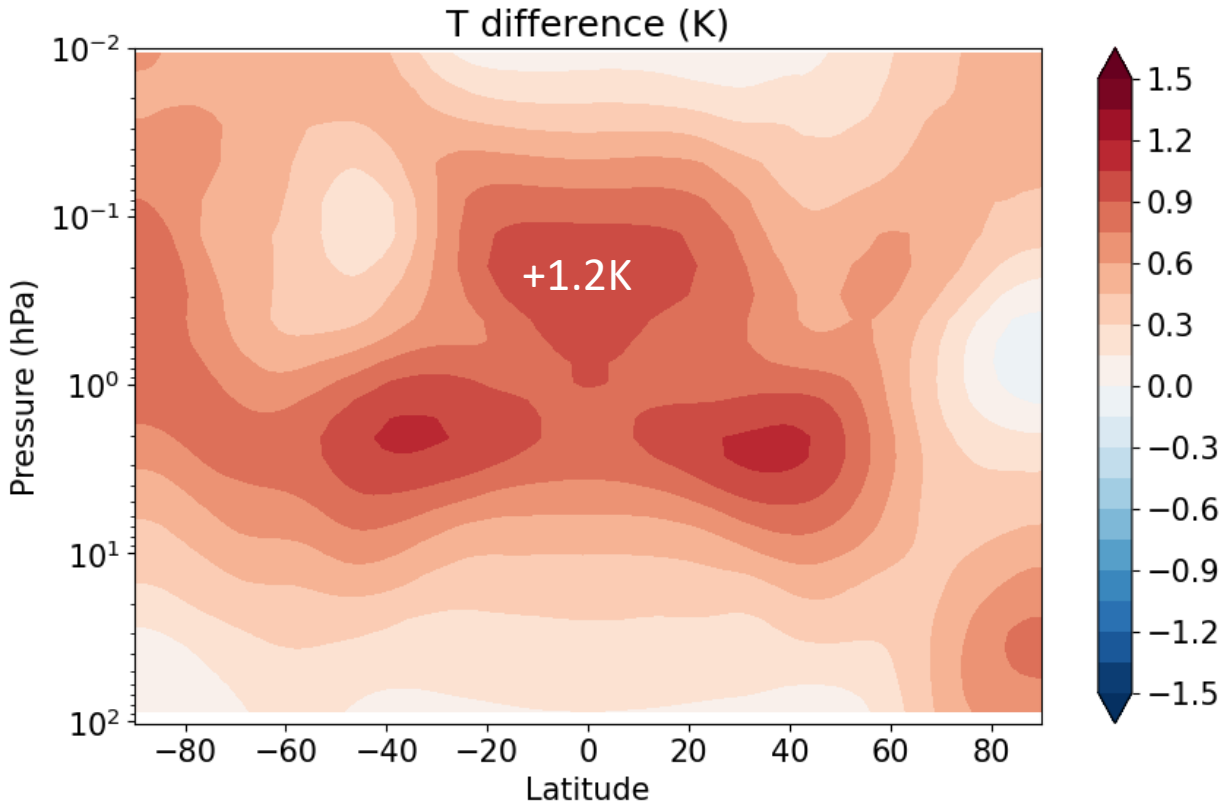
Brasseur and Solomon, 2005





CMIP7 – CMIP6 *** Annual Mean *** 50 year Climatology





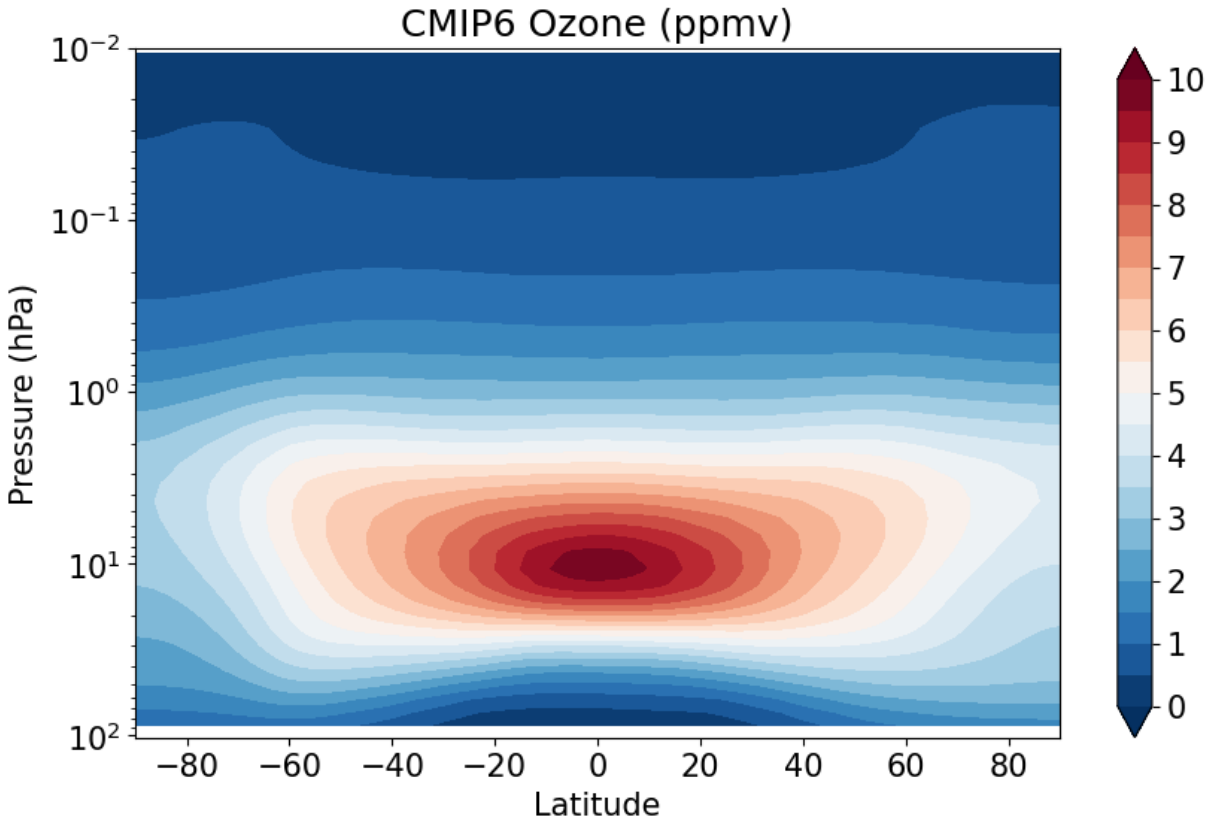
Shortwave heating rates (2-3% increase) and temperature increases throughout the middle atmosphere. The temperature change is comparable to the 11-year solar cycle change.

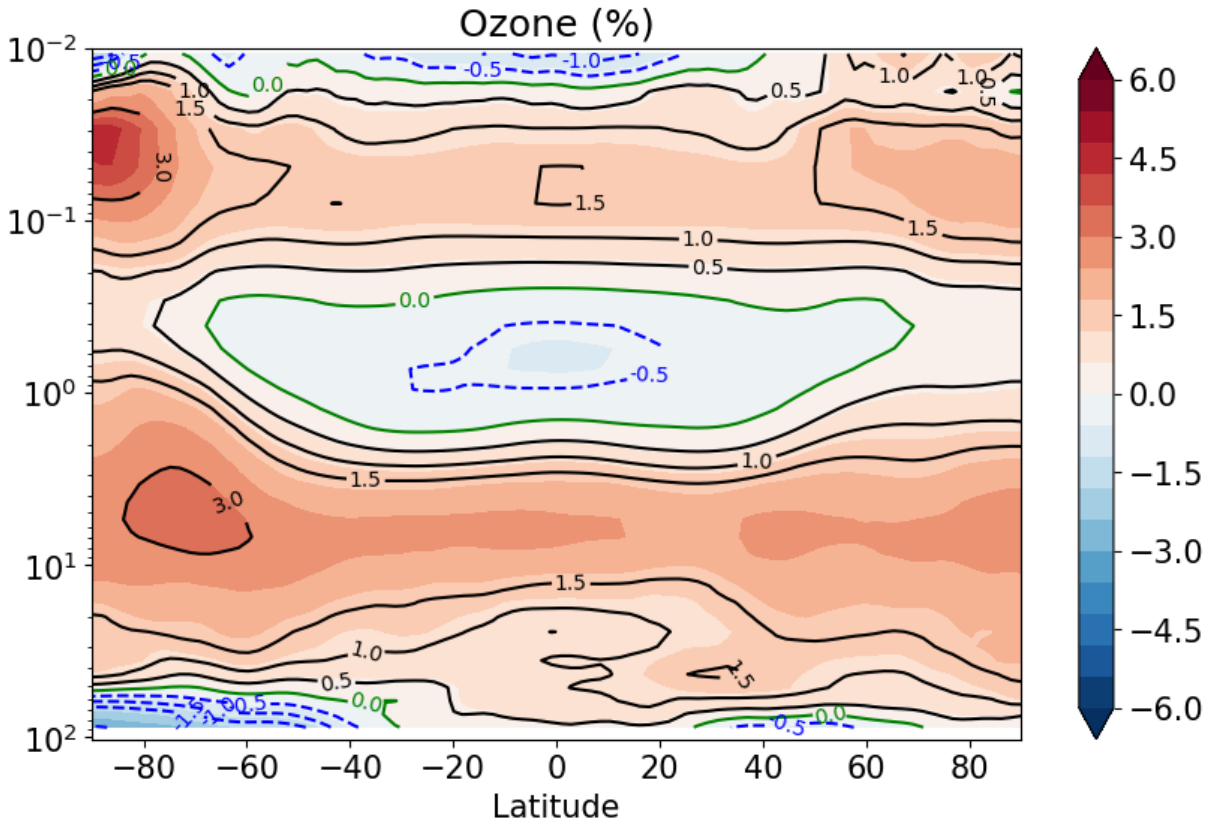
NCAR

WACCM

Whole Atmosphere Community Climate Model

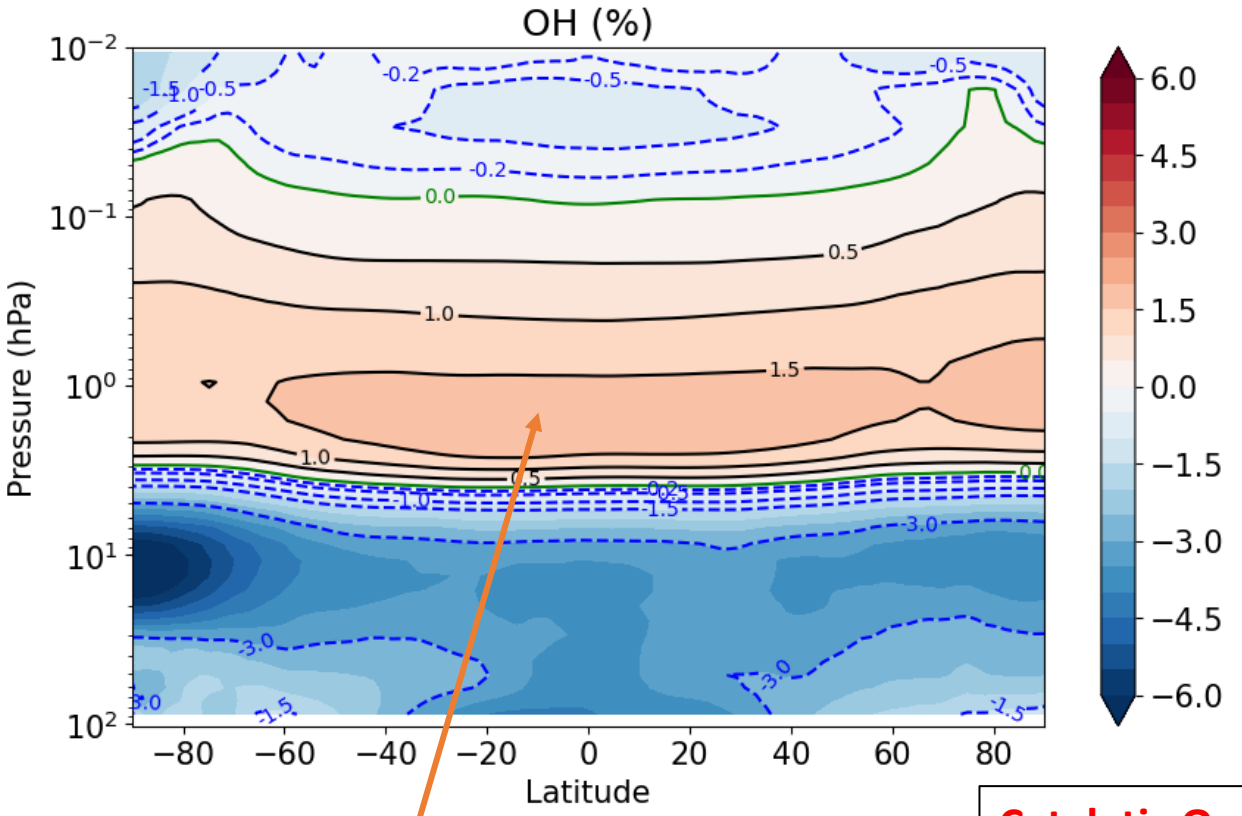
CMIP7 – CMIP6 *** Annual Mean *** 50 year Climatology

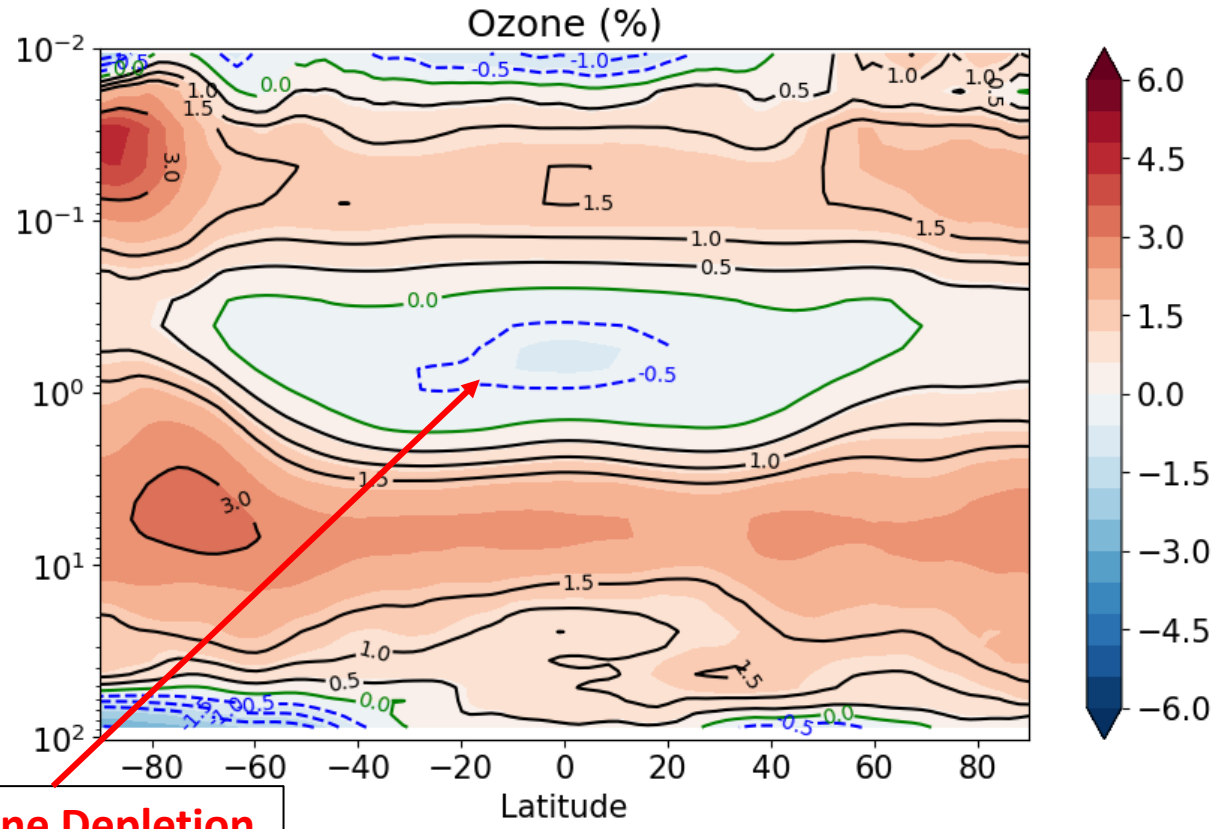




Ozone decreases near the stratopause, why?

CMIP7 – CMIP6 *** Annual Mean *** 50 year Climatology





Enhanced Ozone
Hartley Band Photolysis

$O_3 + hv \Rightarrow O(^1D) + O_2$

$O(^1D) + H_2O \Rightarrow 2OH$

Catalytic Ozone Depletion

$OH + O_3 \Rightarrow HO_2 + O_2$

$HO_2 + O \Rightarrow OH + O_2$

Net: $O_3 + O \Rightarrow 2O_2$

NCAR

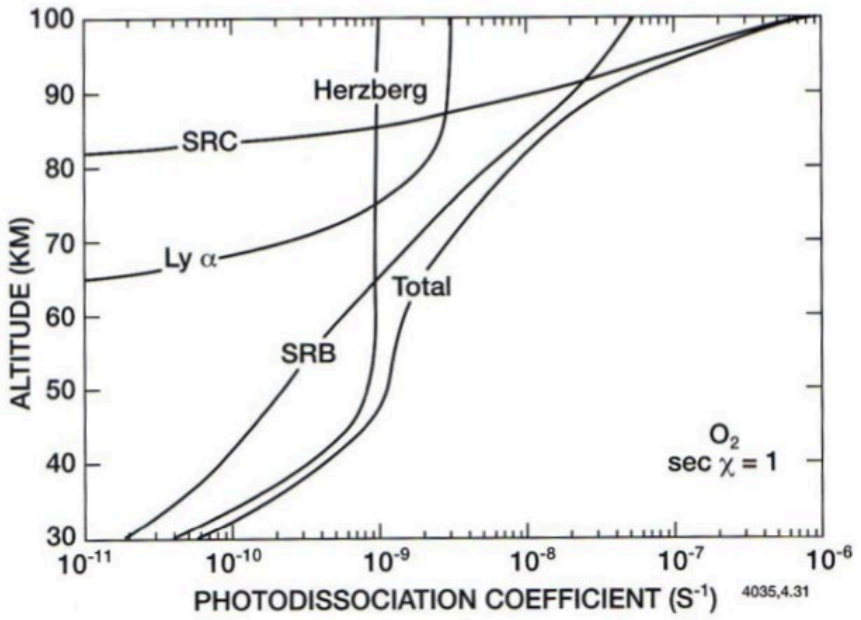
WACCM

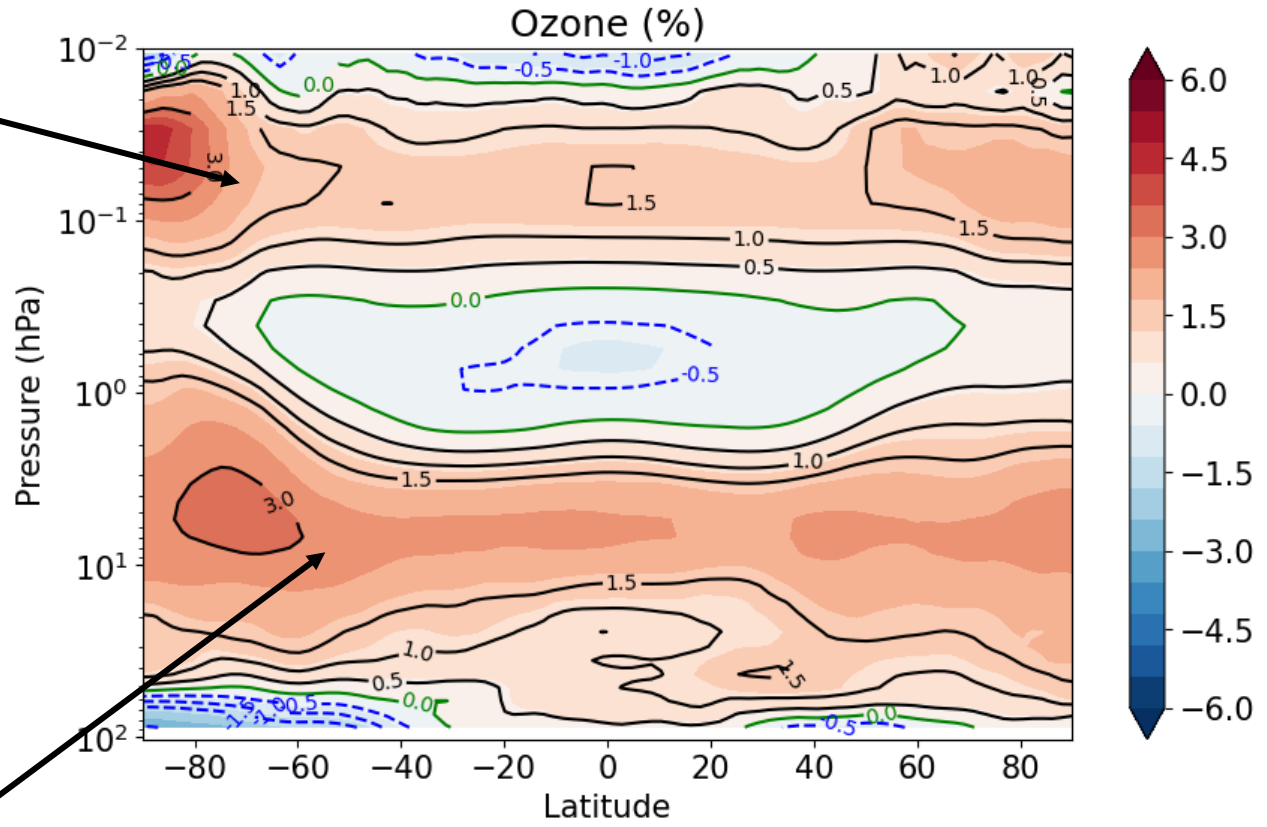
Whole Atmosphere Community Climate Model

TSIS1 – CMIP6 *** Annual Mean *** 50 year Climatology

Production of OddOx from Enhanced SRB Band Photolysis

O_2 + hv => 2O



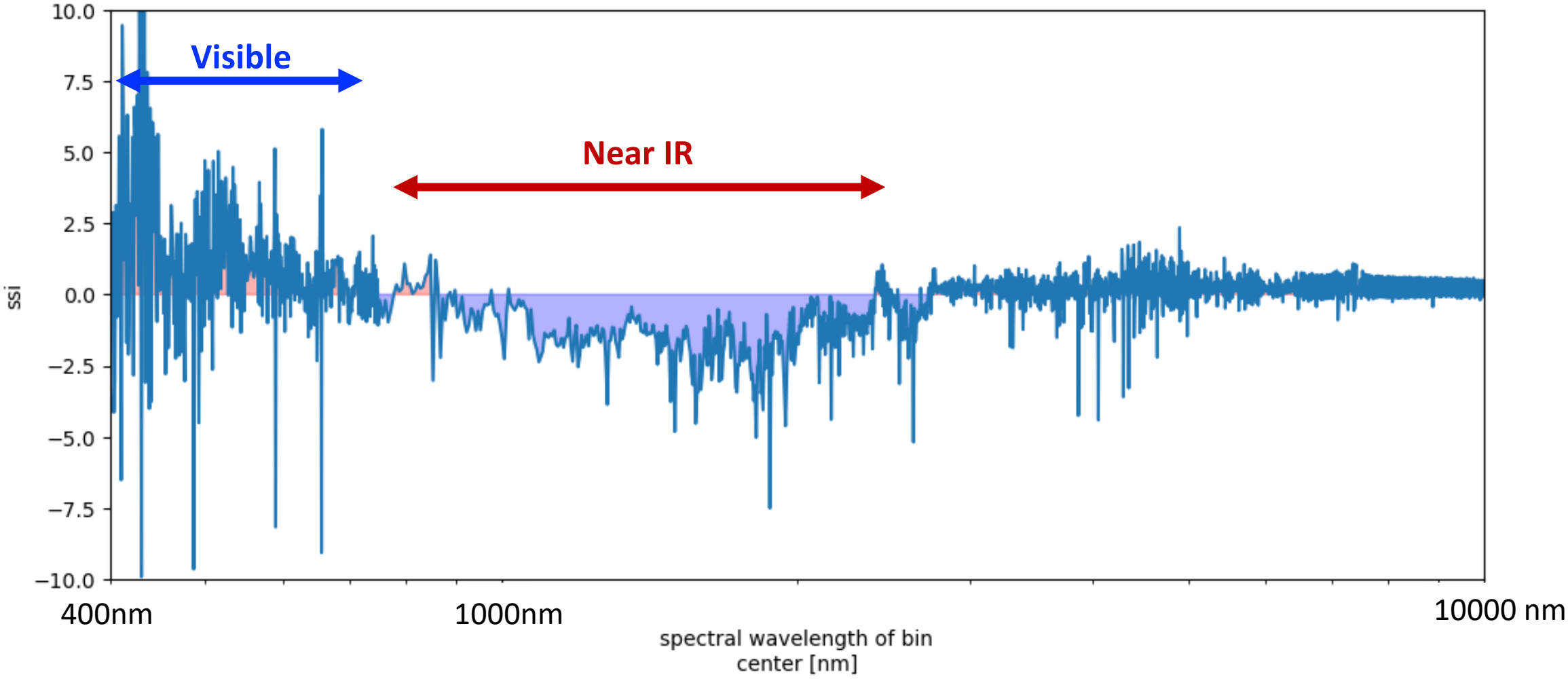


Production of OddOx from Enhanced Hertzberg Continuum Photolysis

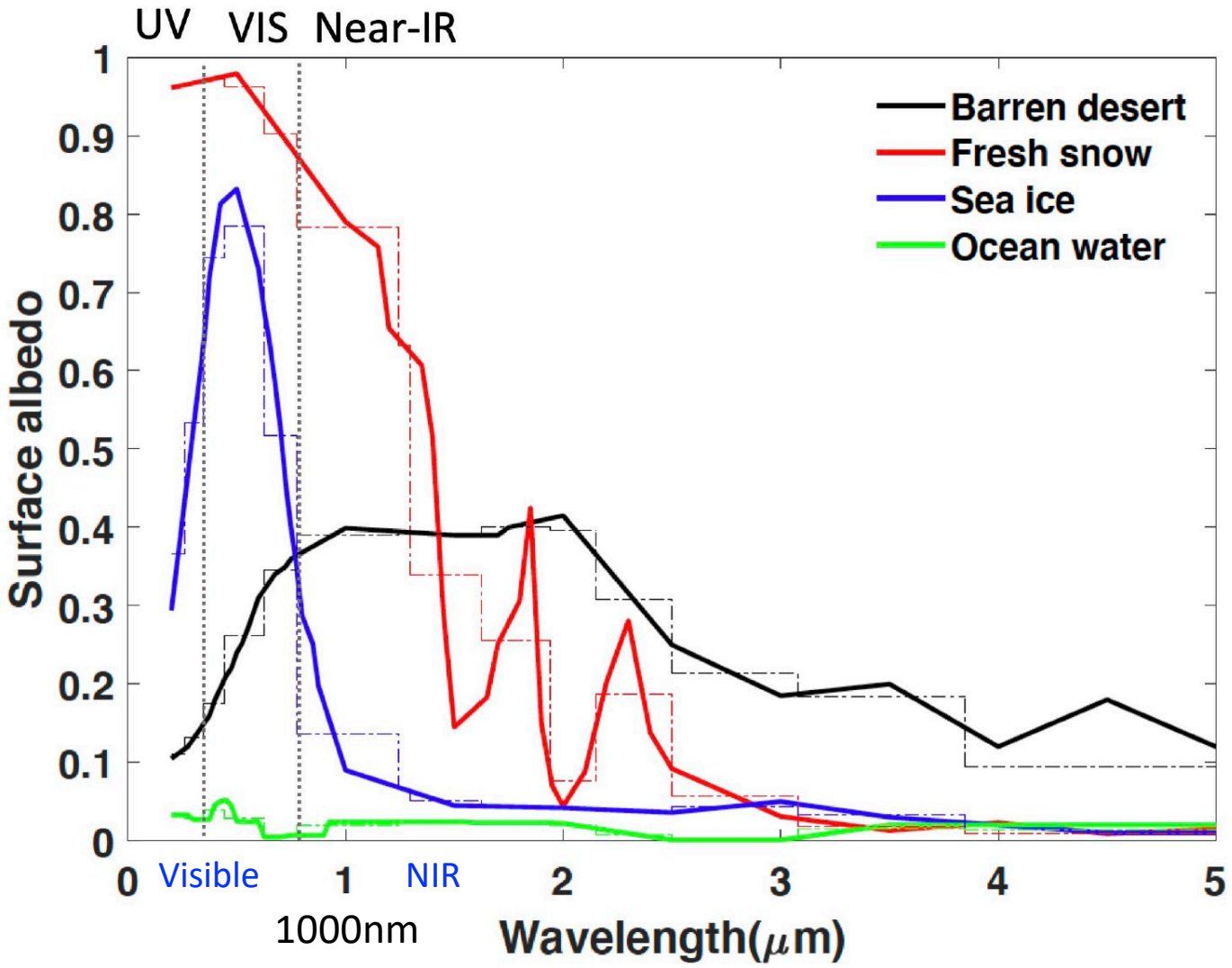
O_2 + hv => 2O

Comparison of Solar Spectral Irradiances in the Near IR

CMIP7 – CMIP6/CMIP6 (%)



Surface Albedo Sensitivity



Jing et al., J. of Climate, 2021

Note 1: The contrast **icy surface** vs **open water** in terms of the **Visible** and **Near IR** surface spectral albedo

Note 2: This implies that the **variation of SSI** in the Vis and NIR can directly affect the **amount of solar radiance being absorbed by the surfaces.**

This will affect the surface radiative budget (i.e., cools the surface with new CMIP7 SSI!

Surface climate cooling impact on Sea Ice (annual avg, zonal mean)

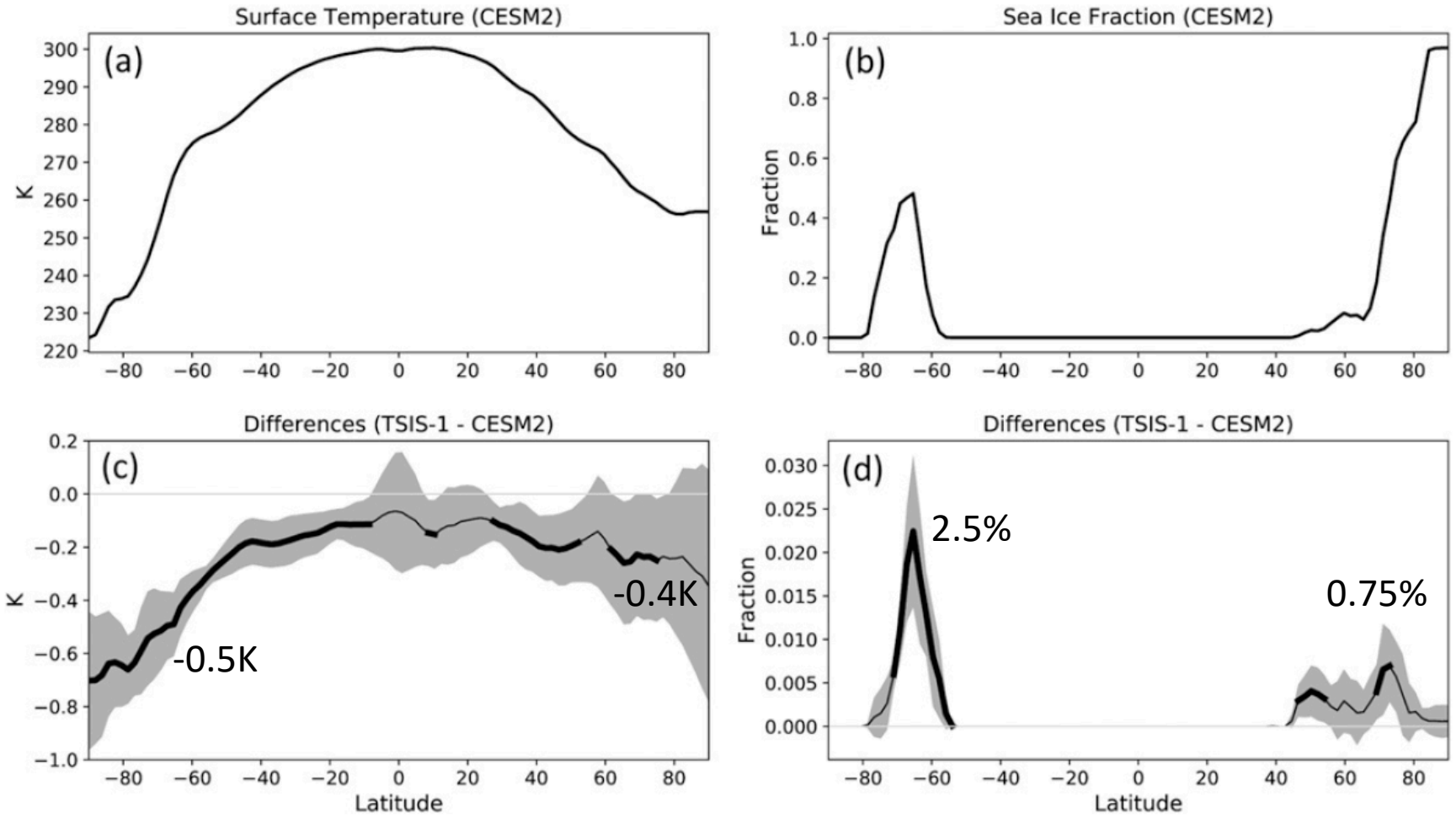
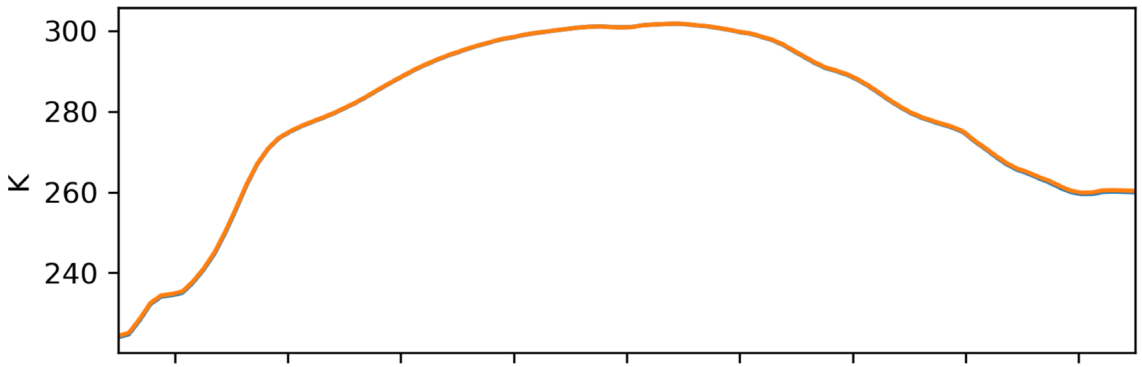


FIG. 5. (a),(b) Zonal-mean surface temperature and sea ice fraction climatology for the CESM2 ensemble simulation. (c) The differences in zonal-mean surface temperature climatology between the TSIS-1 and CESM2 simulations. Shaded areas denote $\pm 1\sigma$ of annual-mean temperature differences. Thickened portions of the line indicate statistically significant differences (5% significance level). (d) As in (c), but for the sea ice fraction differences.

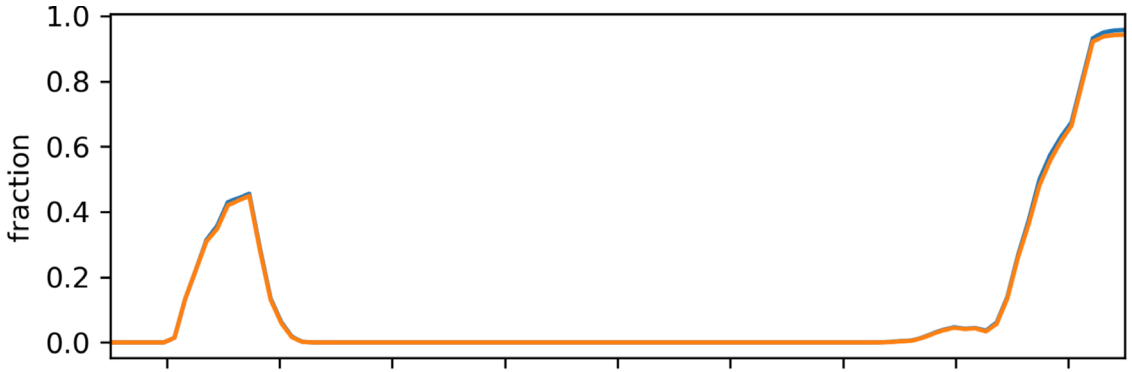
Jing et al.

Surface climate cooling impact on Sea Ice (annual avg, zonal mean)

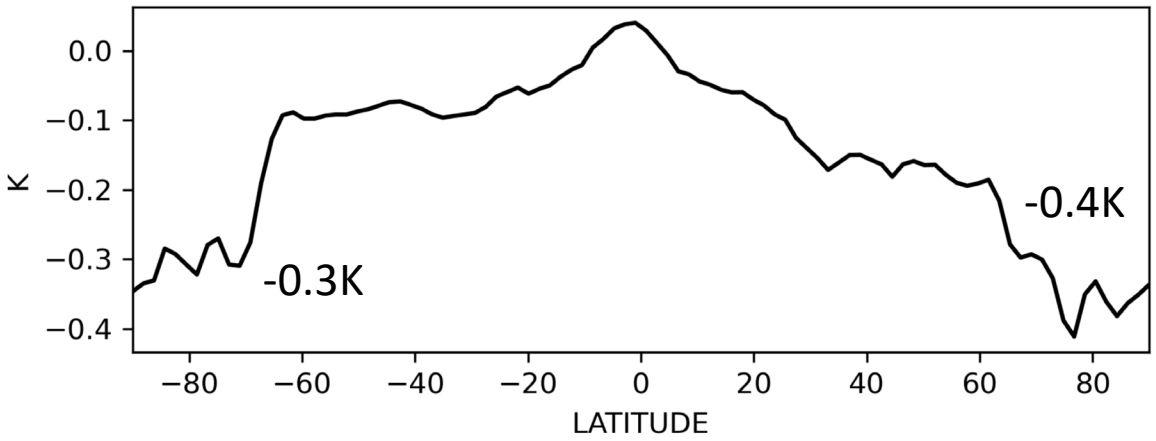
Temperature



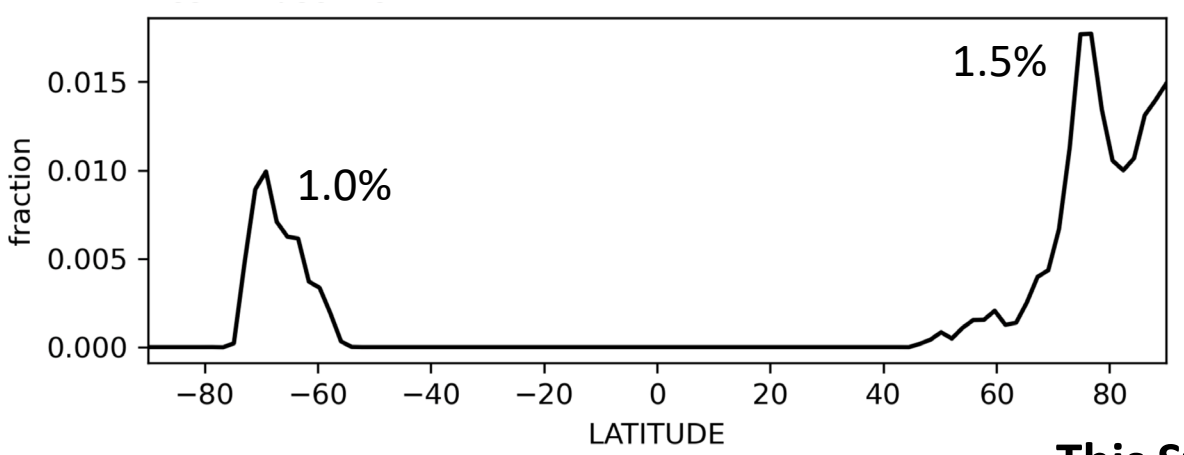
Sea ice Fraction



CMIP7-CMIP6 (K)



CMIP7-CMIP6 (fractional change)

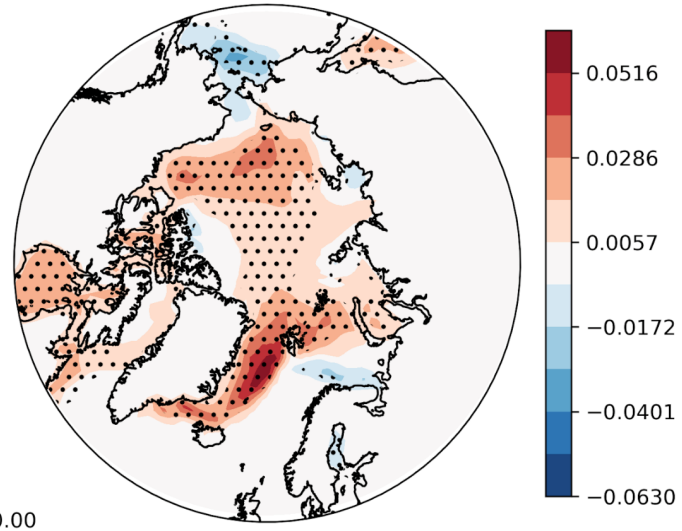


This Study

Polar Projections, CMIP7 – CMIP6, Annual Average

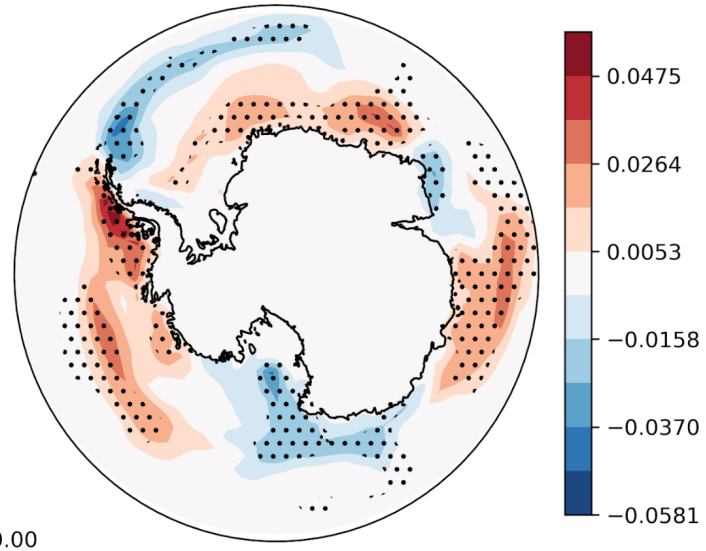
SEA Ice Fraction =>

Diff in Sea ice Fraction, NH



Mean: 0.00
Max: 0.06
Min: -0.02

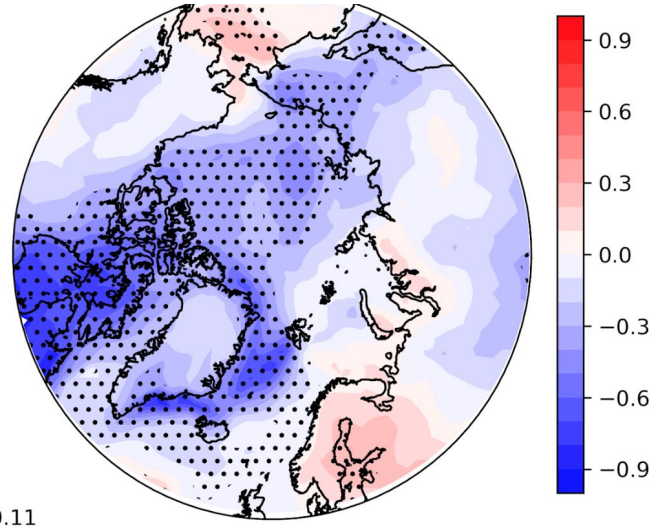
Diff in Sea ice Fraction, SH



Mean: 0.00
Max: 0.04
Min: -0.03

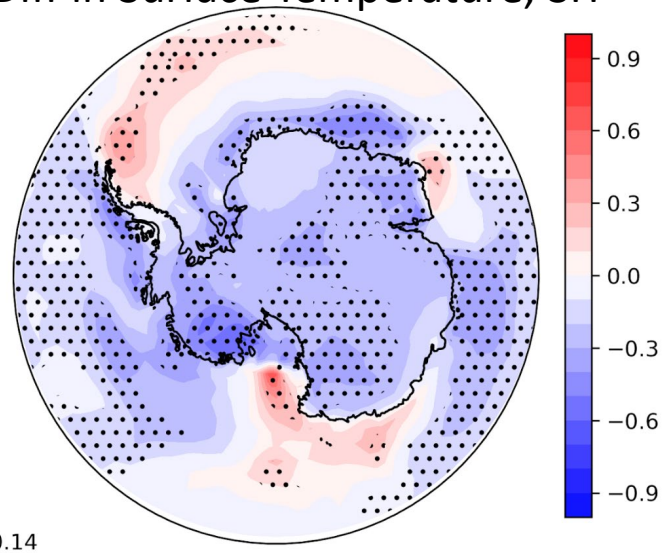
Temperature =>

Diff in Surface Temperature, NH



Mean: -0.11
Max: 0.29
Min: -0.75

Diff in Surface Temperature, SH



Mean: -0.14
Max: 0.60
Min: -0.51

This Study

Conclusions

CMIP7 – CMIP6

- Shortwave heating and temperature increase throughout the middle atmosphere.
- Ozone increases in the middle mesosphere and lower stratosphere from O_2 Photolysis in the Schumann Runge Band and Hertzberg Continuum respectively.
- Ozone decreases near the stratopause due to an increase in OH from Ozone Hartley band photolysis (O_3 +hv => O^1D; O^1D + H_2O => 2OH).
- Sea-ice albedo differences between Near IR and Visible conditions cause a surface cooling and increase in sea ice extent.

Recommendations for CMIP7 solar forcing data

- The pre-industrial control forcing (**pictontrol**) includes time-averaged historical data corresponding to 1850-1873 (SC9+SC10) mean conditions.

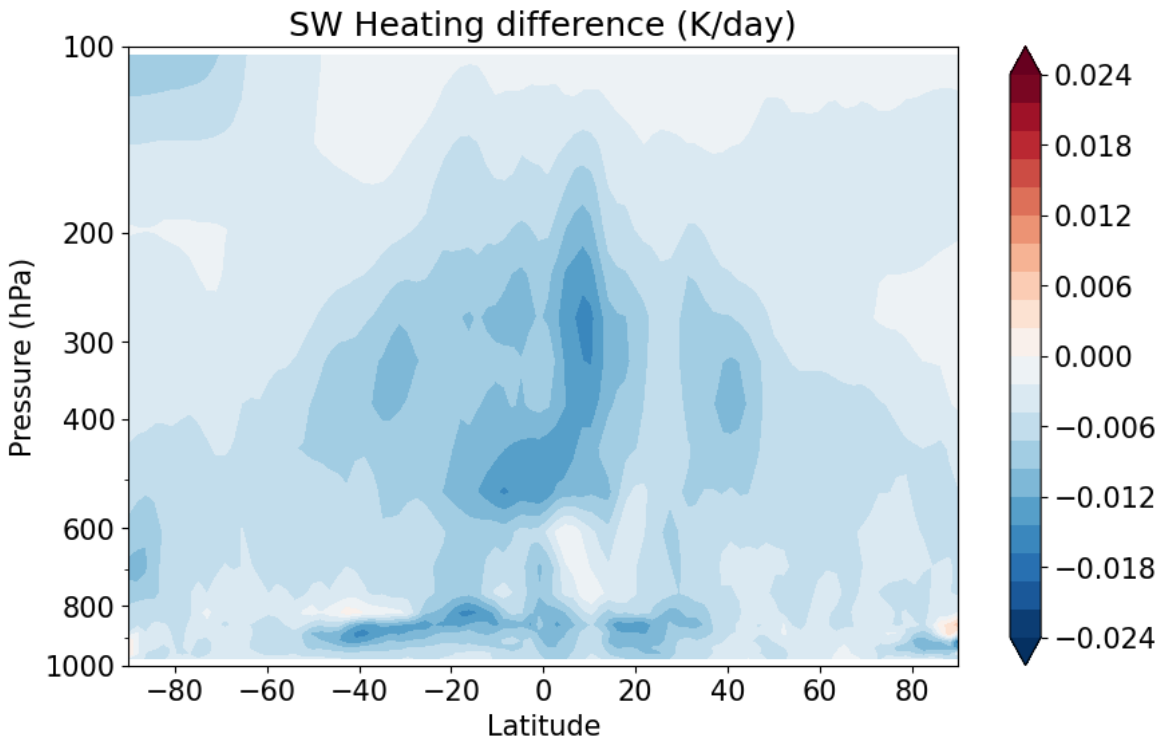
- The TSI is not very different from CMIP6 - should be around 1371.3 W/m2.

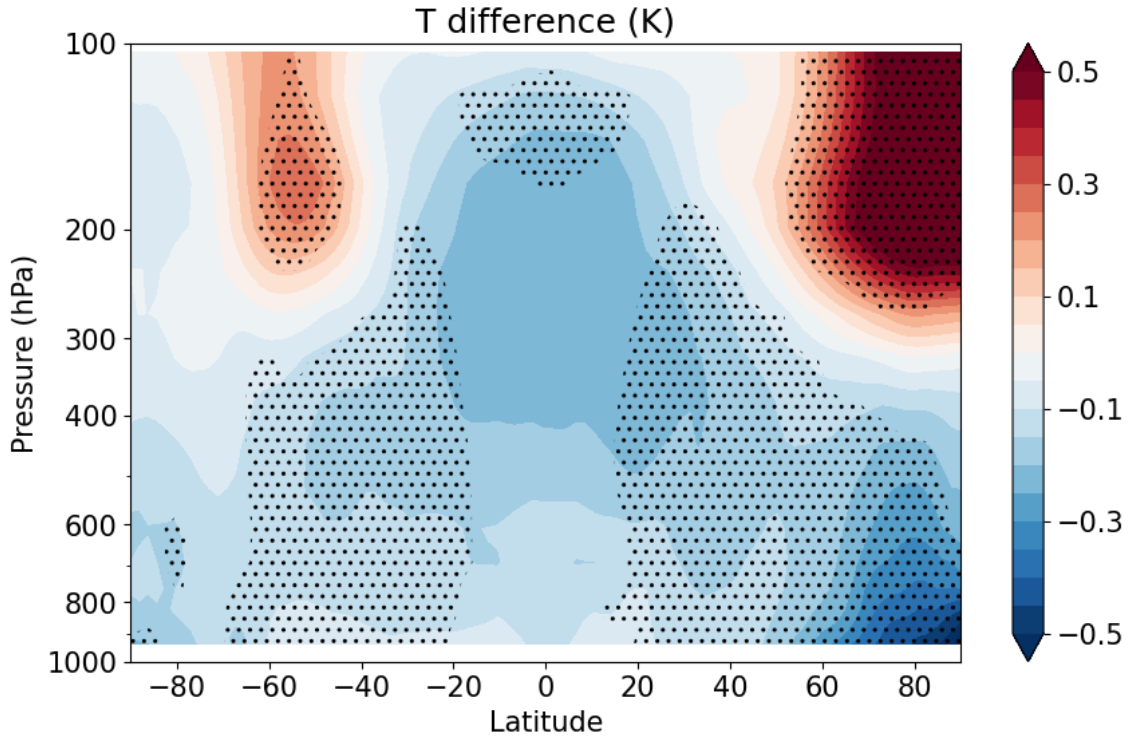
https://solarisheppa.geomar.de/solarisheppa/cmip7

Extra Slide

Troposphere is cooling

CMIP7 – CMIP6





Annual average climatology difference (K)