Stratospheric climate anomalies and ozone loss caused by Hunga-Tonga volcanic eruption

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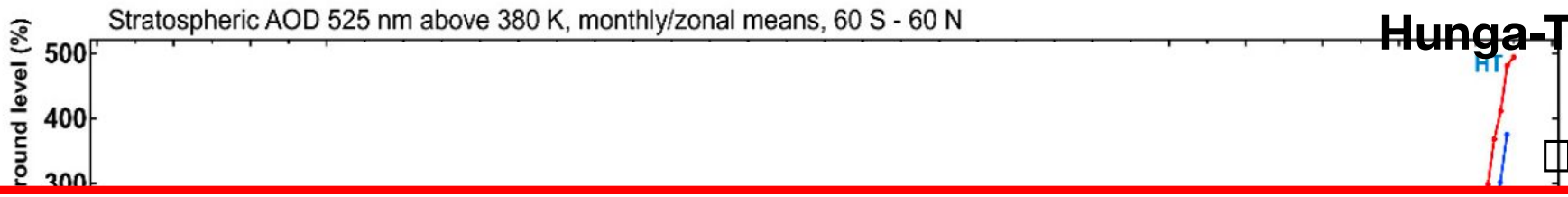
Under review in *Science*

Obs. stratospheric aerosol optical depth



Hunga-Tonga

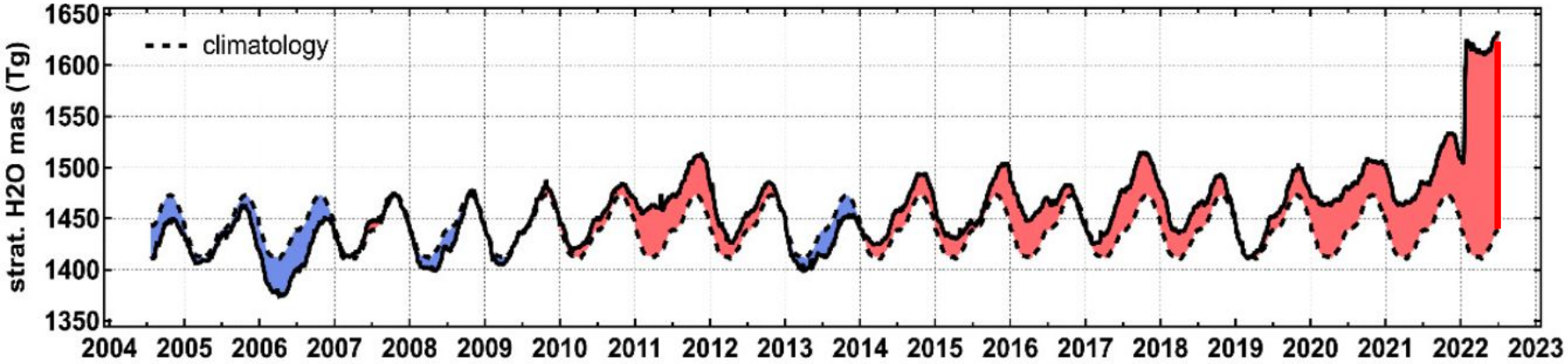
~0.42 Tg SO_2

sulfate aerosol

1. **What are the changes in temperature & circulation following the Hunga-Tonga volcanic eruption?**

2. **What are the changes in stratospheric O_3?**

Obs. global stratospheric H_2O mass (solid) and climatology (dashed)



~150 Tg H_2O

Khaykin et al. (2022)

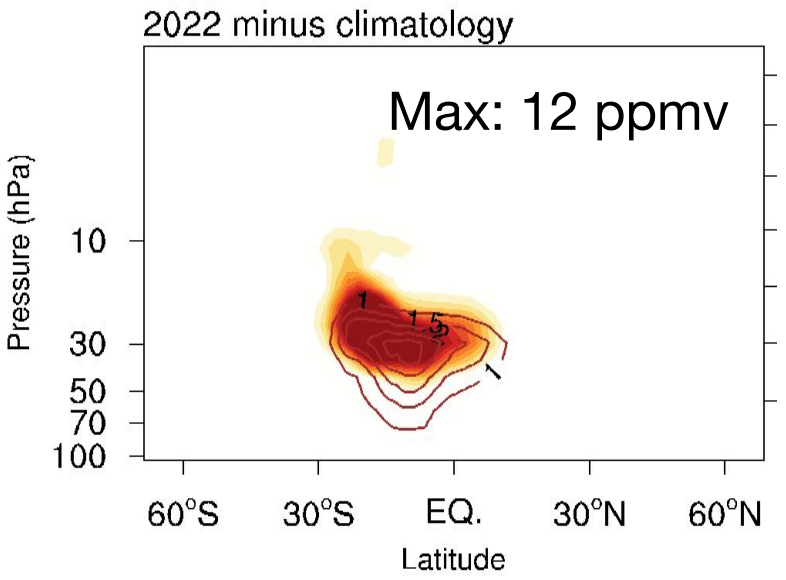
Model simulations

- The **control** case without SO_2 or H_2O (no volcanic forcing)
- The **SO_2 only** case with only SO_2 injection
- The **SO_2+H_2O** case with both SO_2 and H_2O injection (the total forcing of HTHH eruption)
- **Ten realizations for each scenario** in order to examine internal variability and isolate forced behavior, and run simulations till the end of 2023

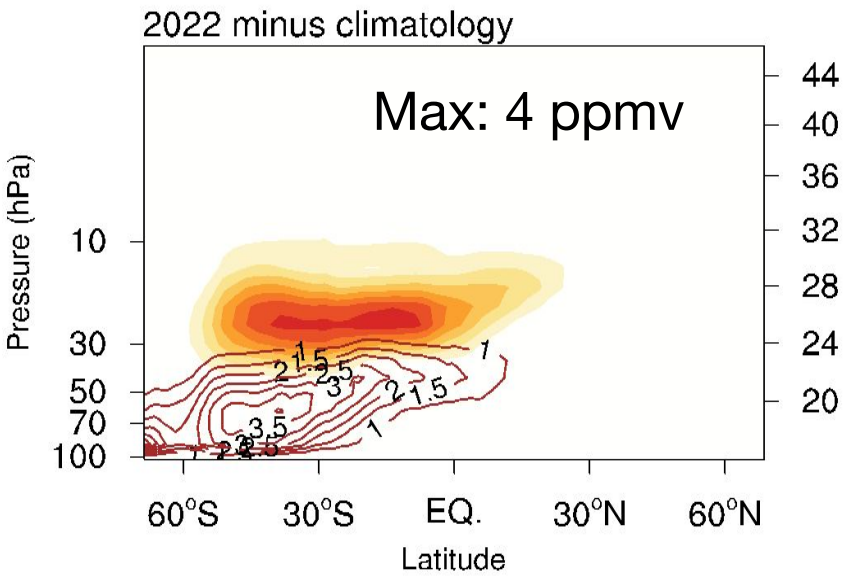
Zhu et al. (2022)
Commun. Earth Environ.

Volcanic plumes have persisted in the stratosphere

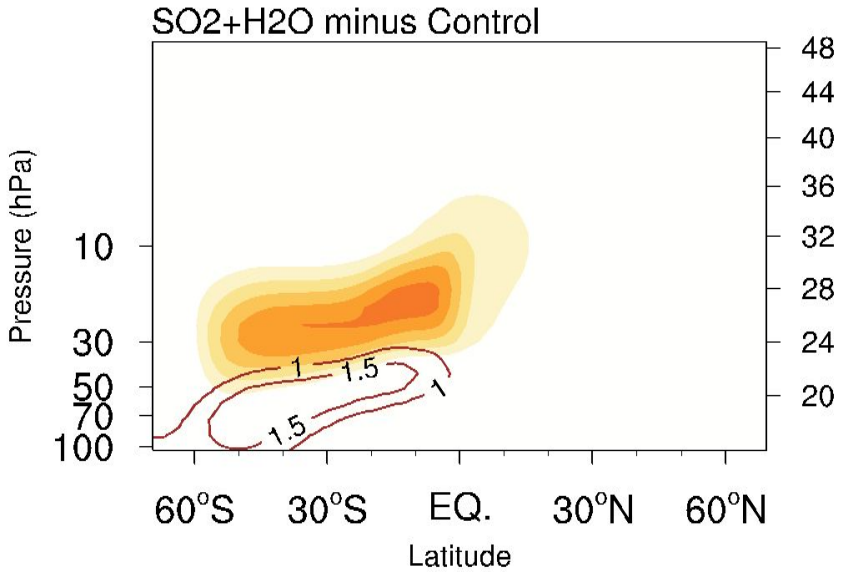
Obs. March



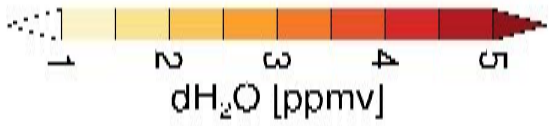
Obs. August



Modeled August



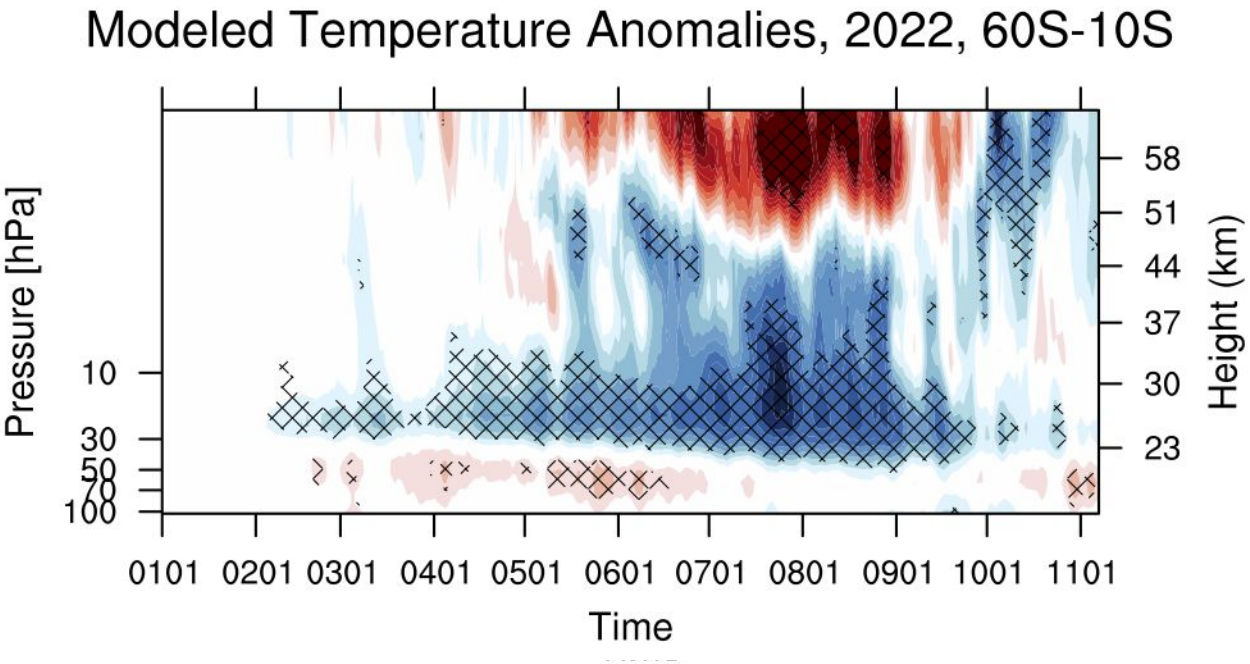
Sulfate aerosol (red contours, 10^{-3} km^{-1})

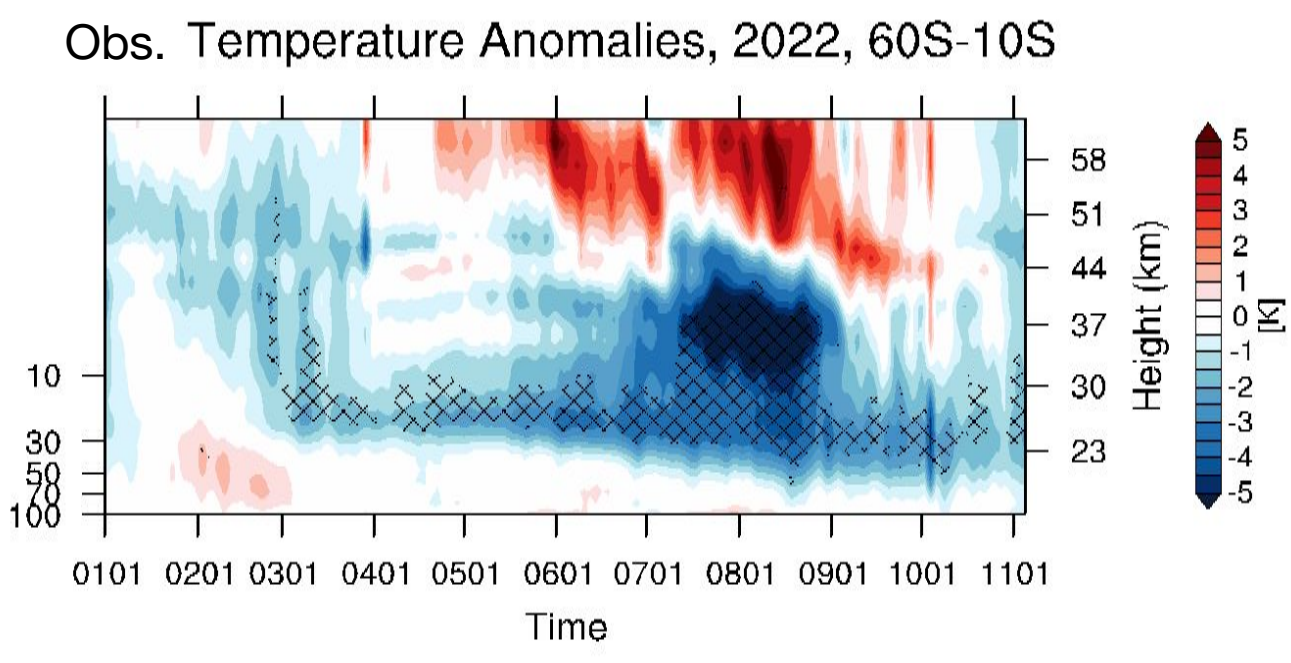


- Model can track the evolving H_2O and aerosol plumes.

Cool strato. Warm strato. ?Temperature

Unprecedented stratospheric cooling in Southern Hemisphere (SH)

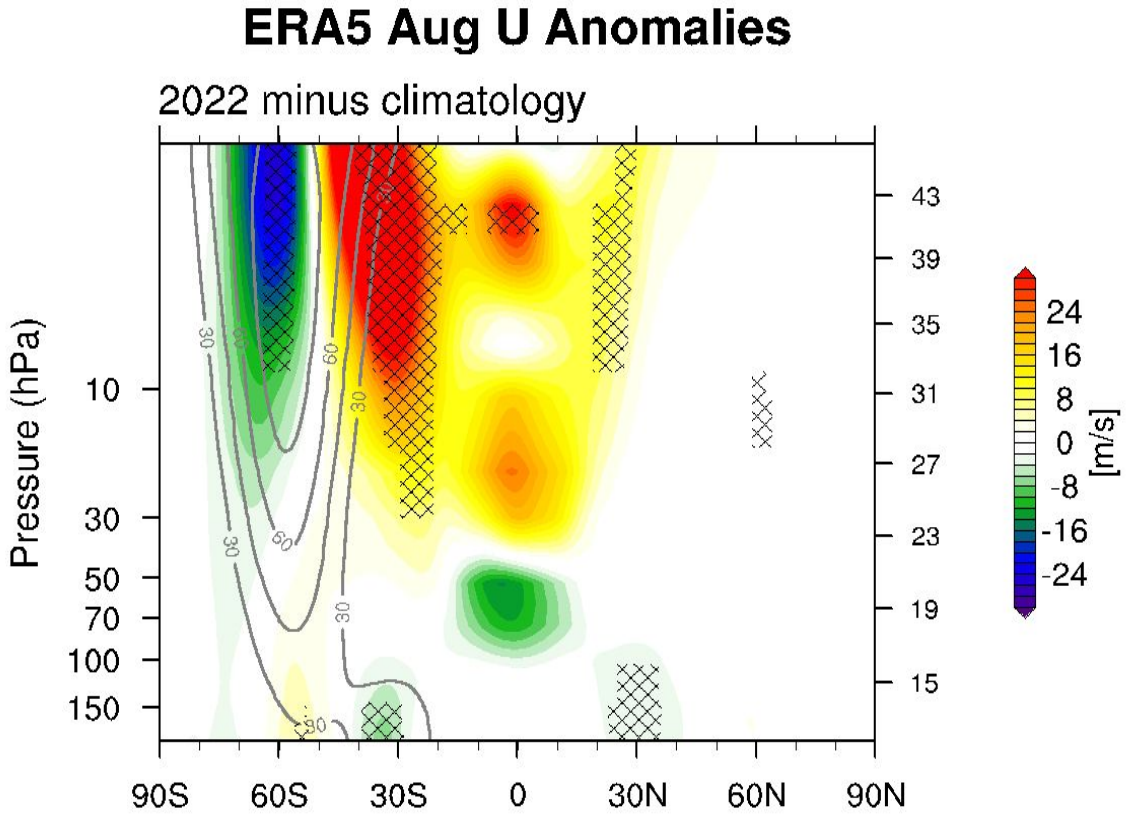




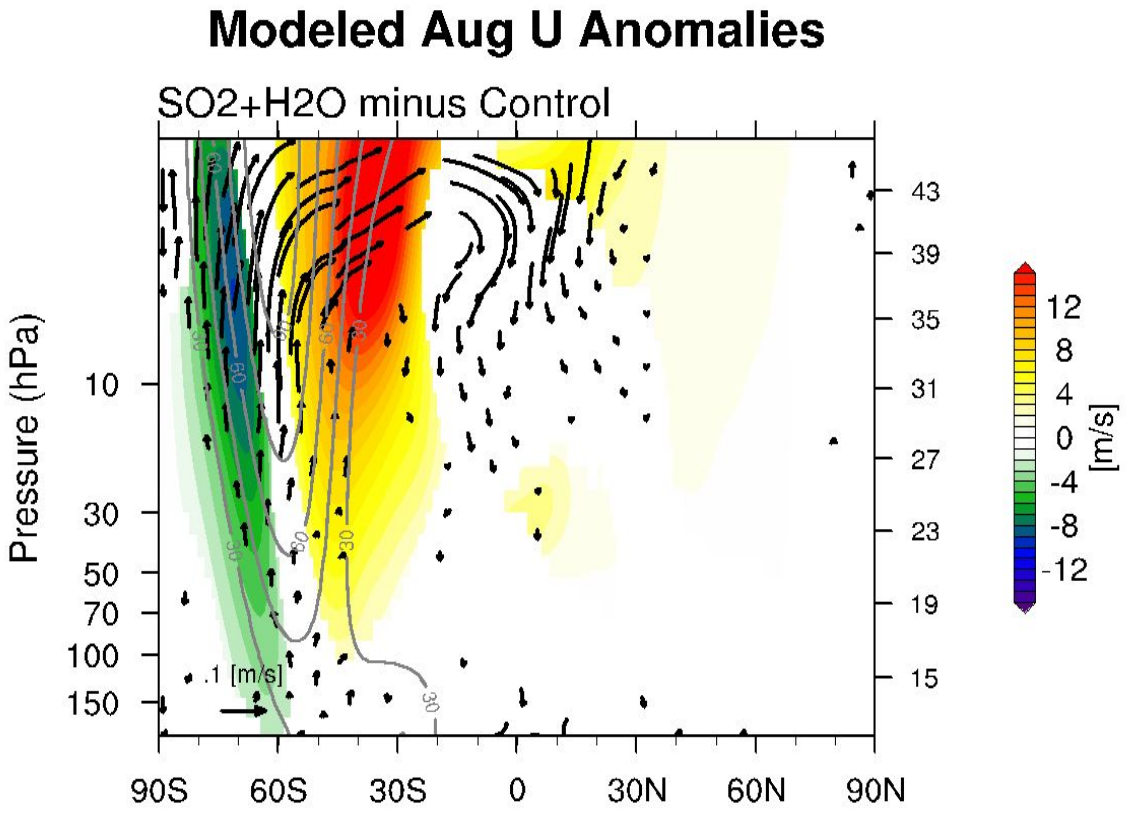
Hatched regions indicate where the 2022 temperature anomalies are outside internal variability

- A fingerprint of the forced response to the Hunga-Tonga eruption
- Combined effects of both H_2O and sulfate aerosol are important

Large circulation anomalies due to volcanic influences

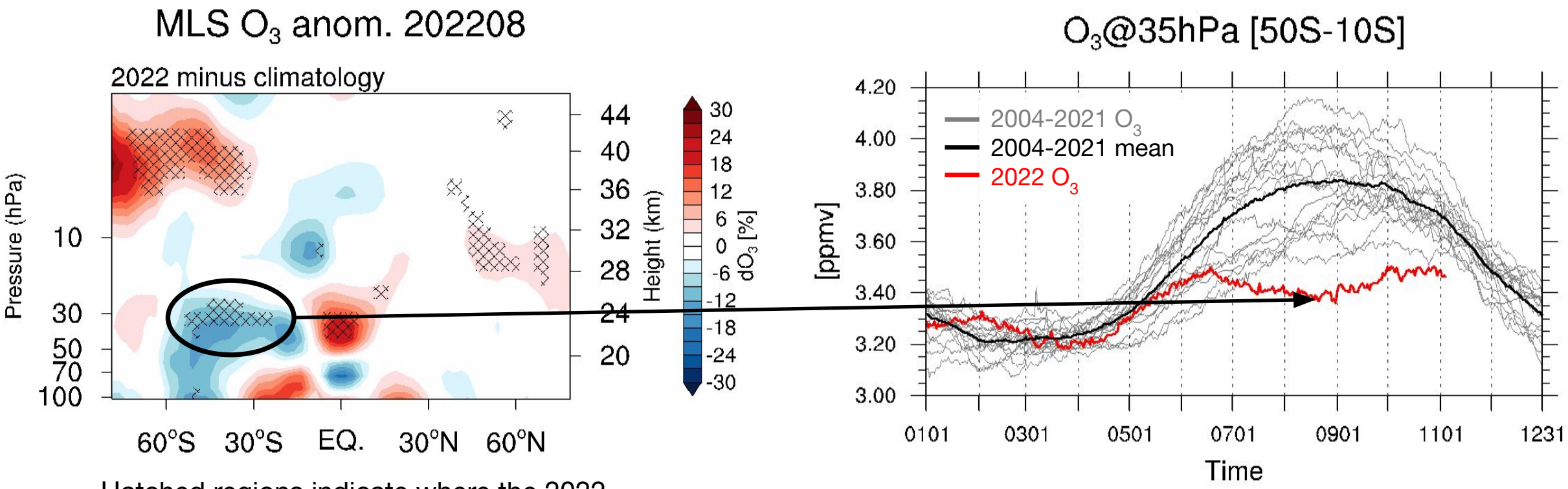


Hatched regions indicate where the 2022 U anomalies are outside internal variability



- Equatorward shift of the Antarctic polar vortex
- The BDC is weakening

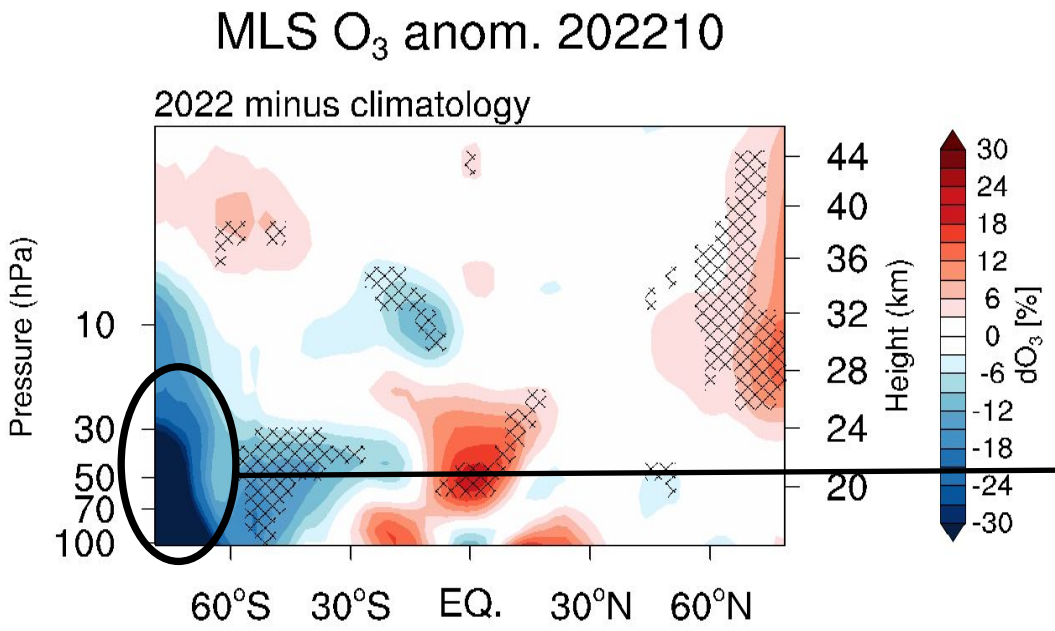
Low O_3 in the SH midlatitude lower stratosphere

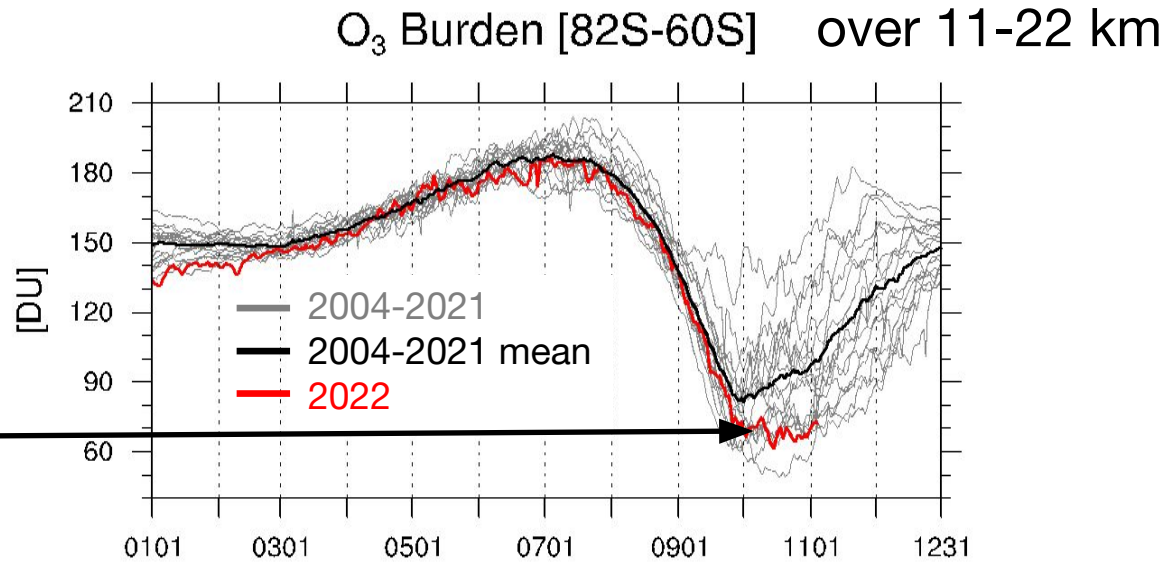


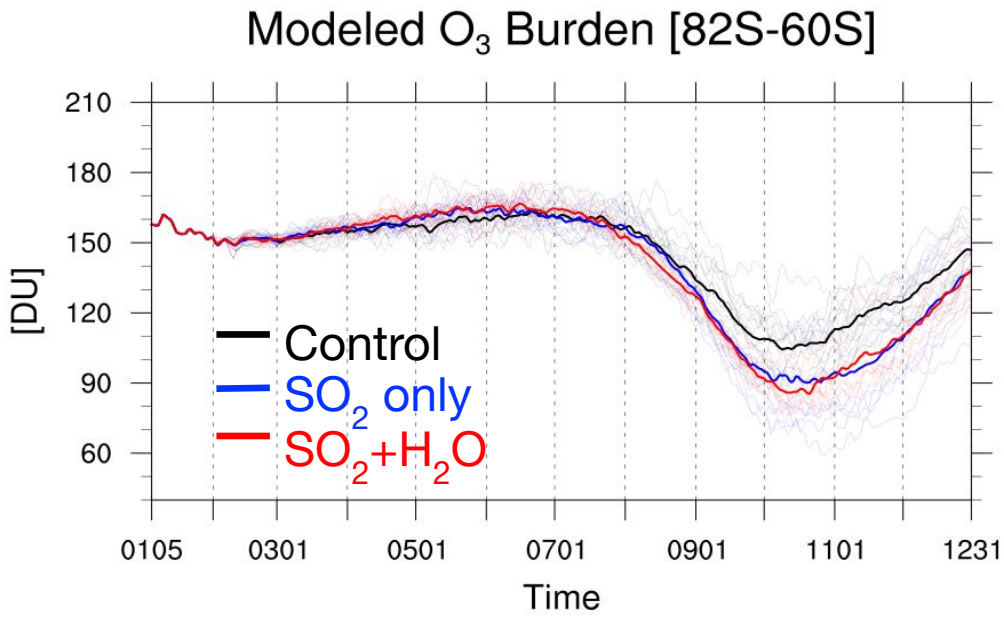
Hatched regions indicate where the 2022 O_3 anomalies are outside internal variability

- Mid-latitude O_3 reduction is linked to winter circulation changes (dynamics)

Large Antarctic O_3 hole in 2022







- Antarctic O_3 losses are due to sulfate aerosol (chemistry)

Key points

- Large-scale SH stratospheric cooling
- Equatorward shift of the Antarctic polar vortex
- Slowing of the Brewer-Dobson circulation
- Persistent ozone reduction in the SH wintertime midlatitudes.
- Large springtime Antarctic ozone losses in 2022
- Model can track the plumes and capture volcanic responses

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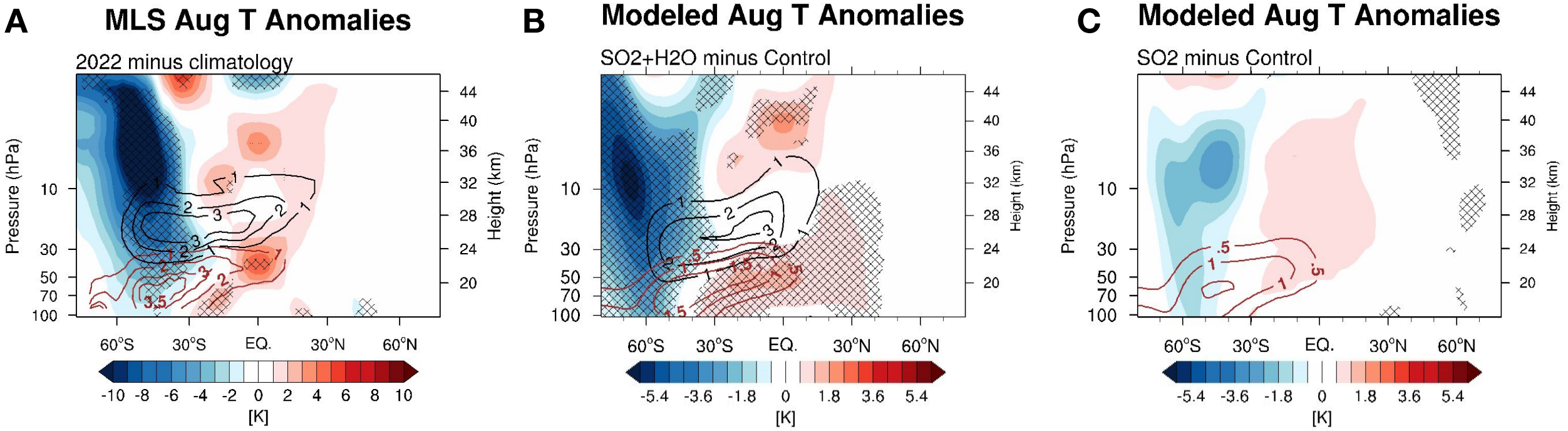
Wang et al., under review in *Science*

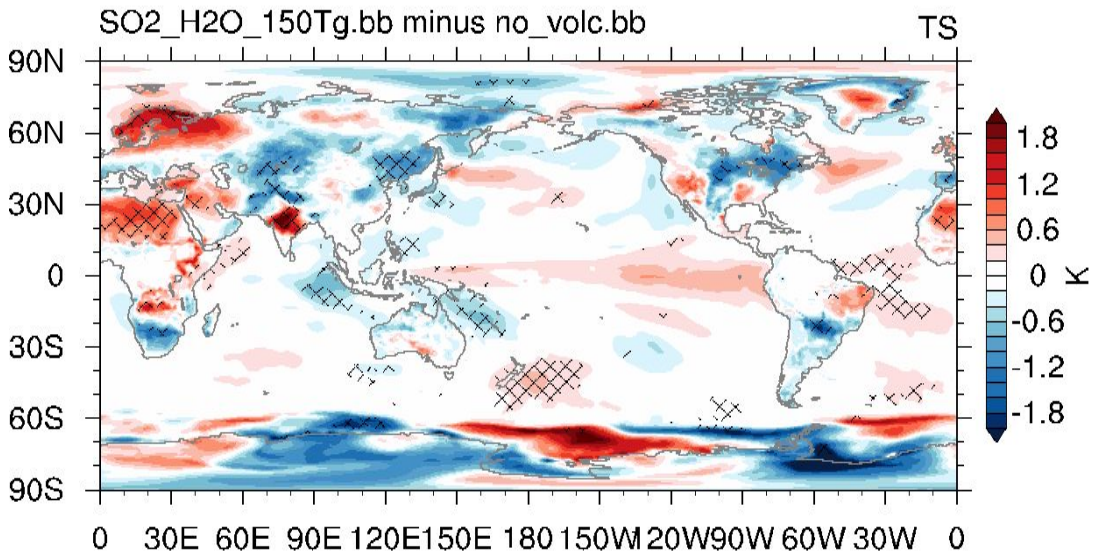
Both H_2O and SO_2 (sulfate aerosol) forcings are important for realistic simulation of the HTHH responses



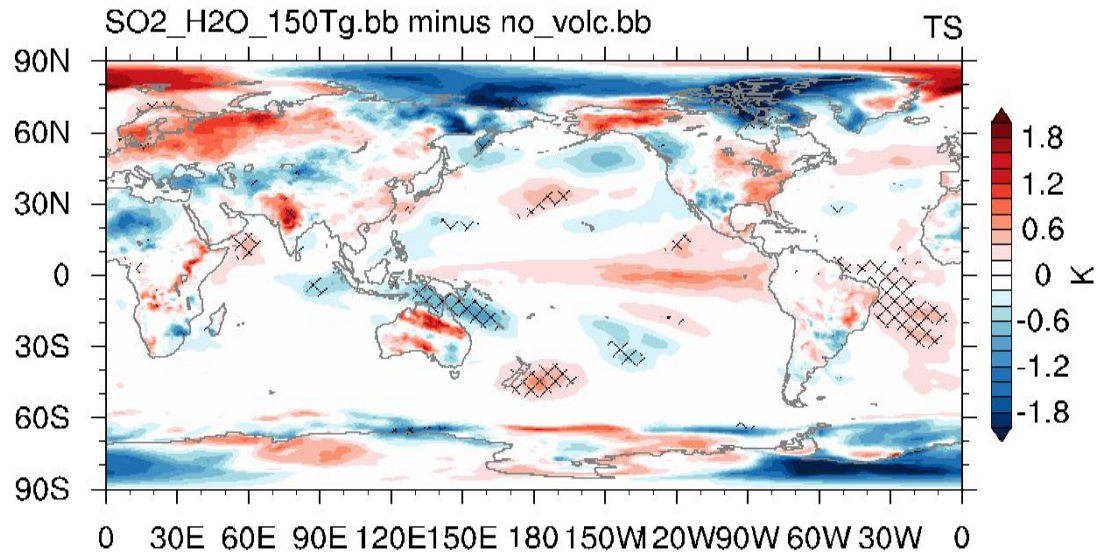
Hatched regions indicate where the 2022 anomalies are outside the range of all variability during 2004-2021

- Combined effects of both H_2O and sulfate aerosol are important

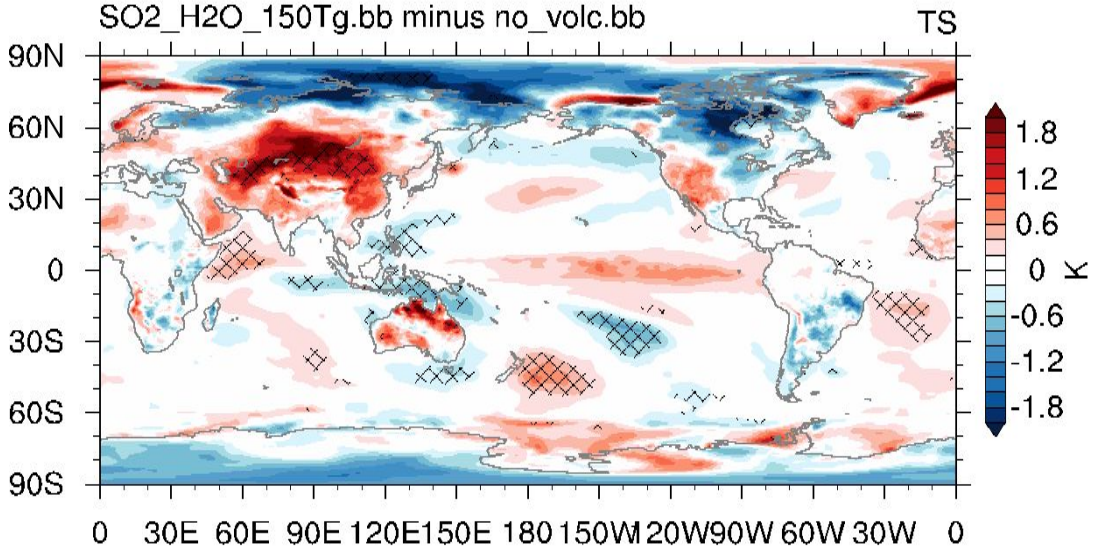
Sep



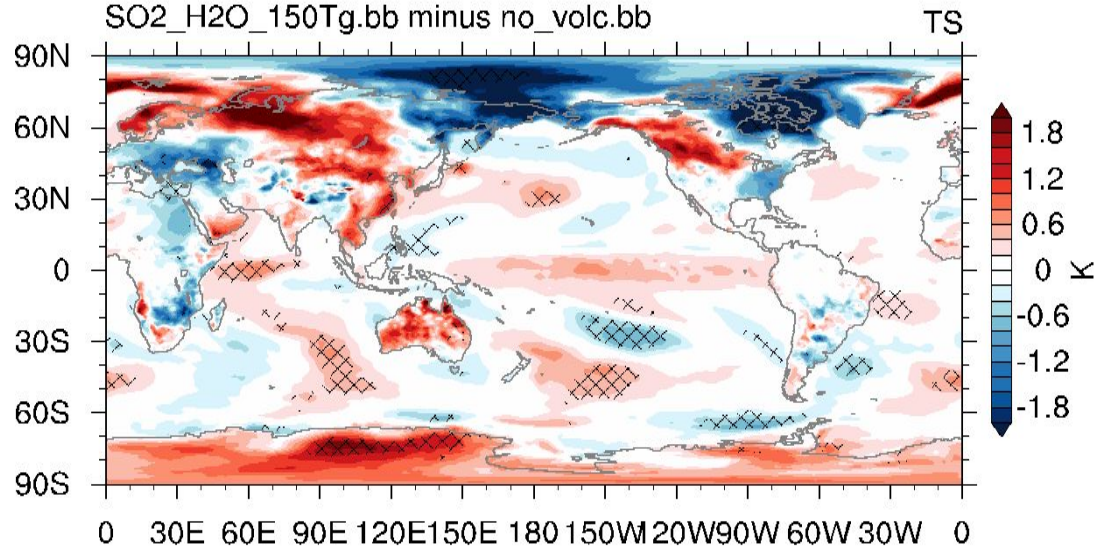
Oct



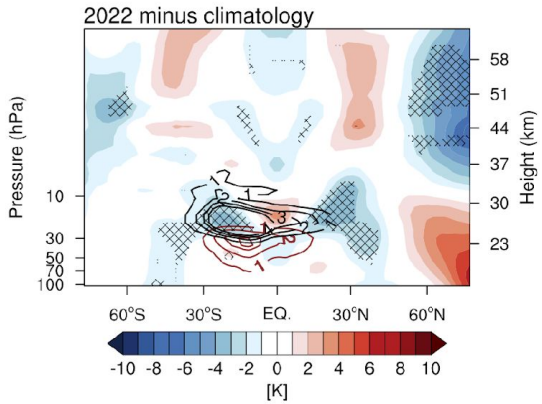
Nov



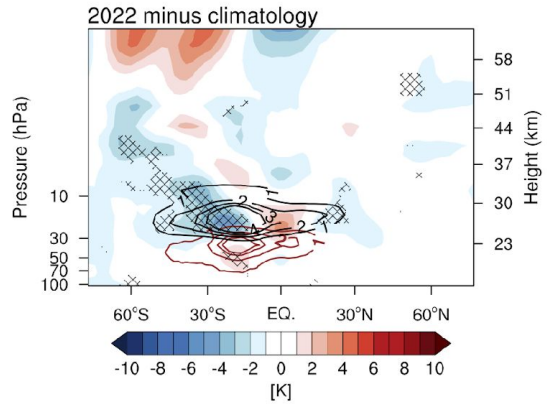
Dec



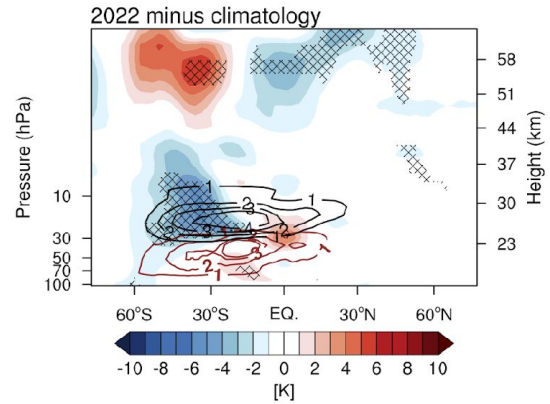
MLS Apr T Anomalies



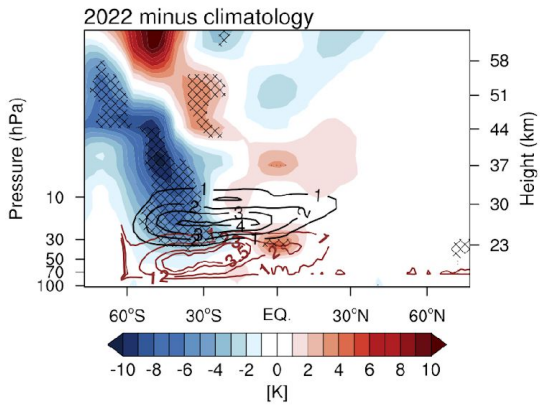
MLS May T Anomalies



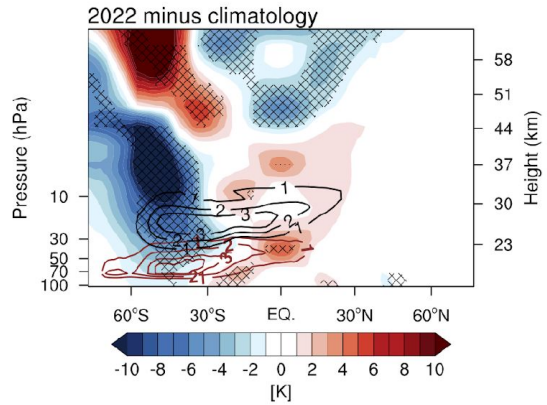
MLS Jun T Anomalies



MLS Jul T Anomalies



MLS Aug T Anomalies



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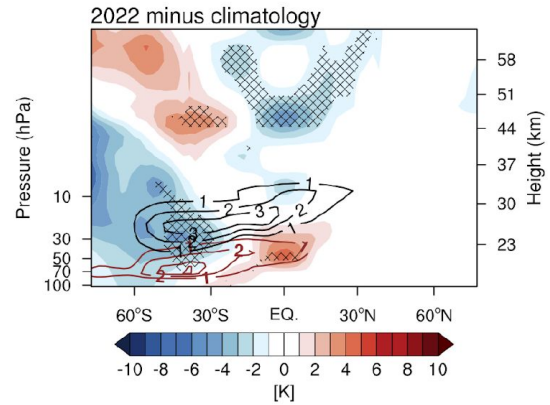
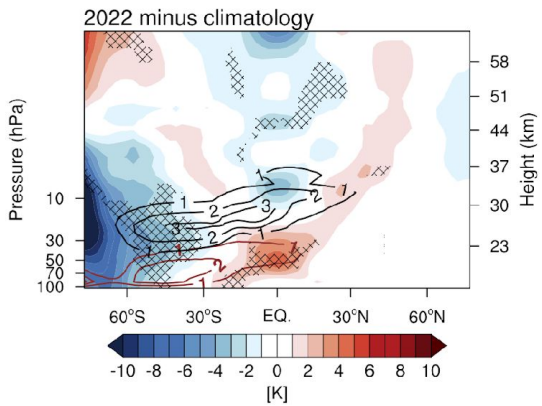
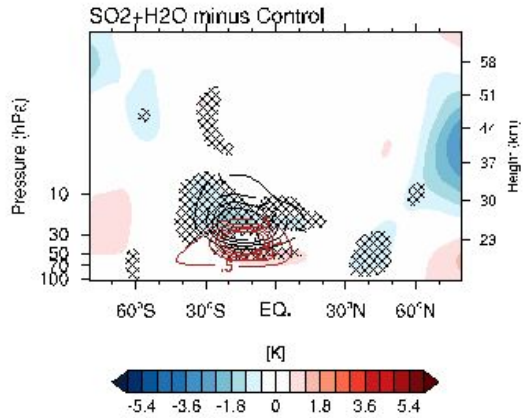


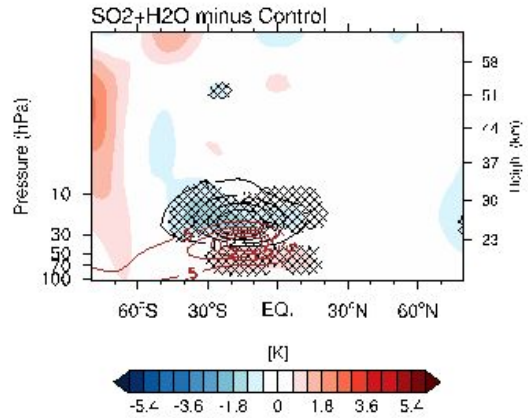
MLS Oct T Anomalies



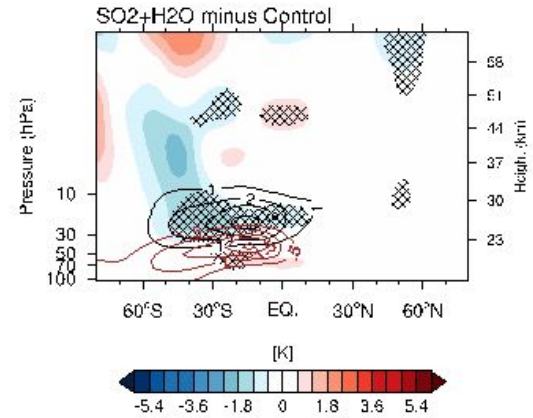
Modeled Apr T Anomalies



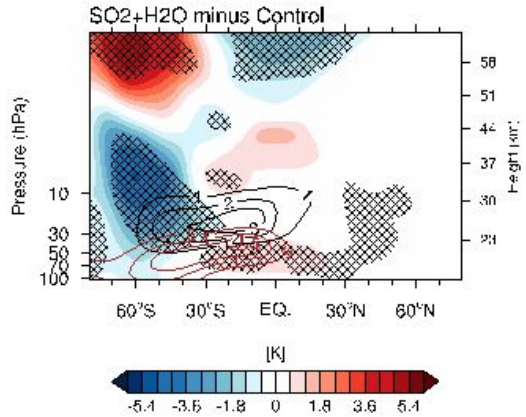
Modeled May T Anomalies



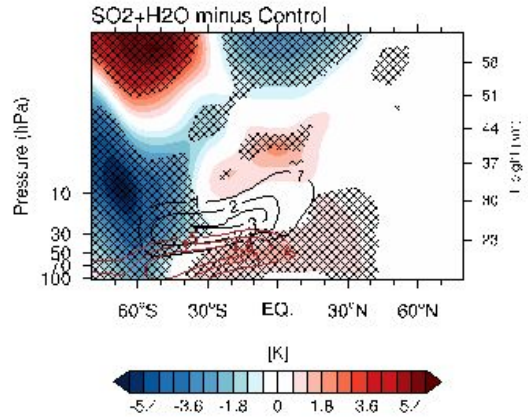
Modeled Jun T Anomalies



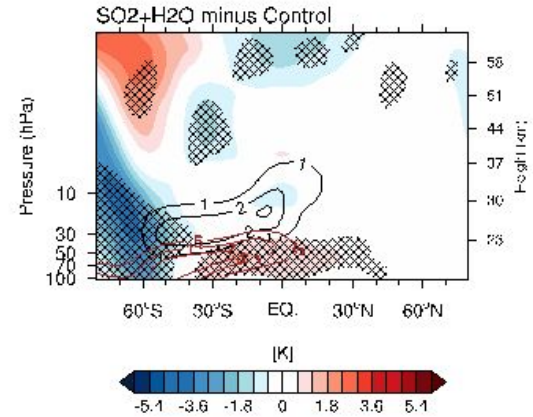
Modeled Jul T Anomalies



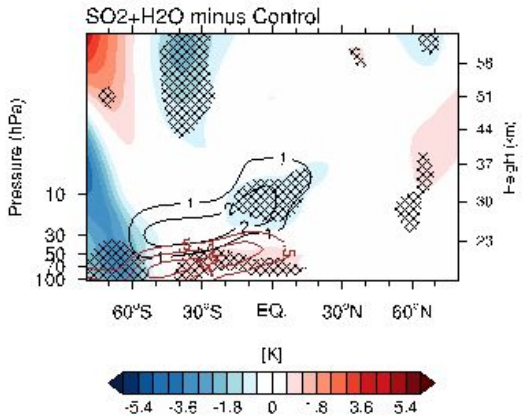
Modeled Aug T Anomalies



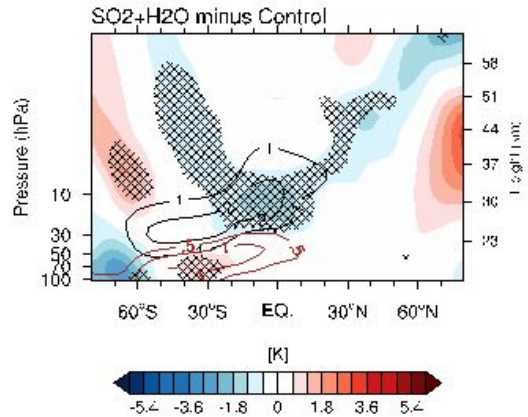
Modeled Sep T Anomalies



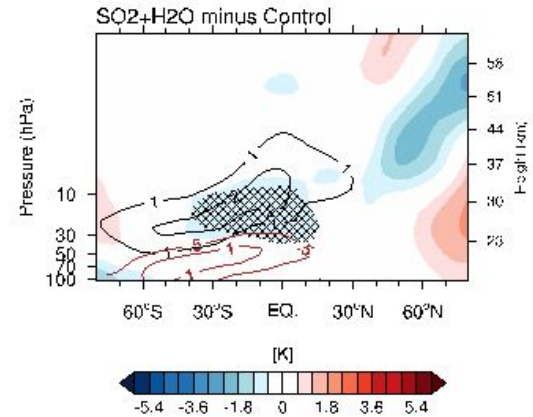
Modeled Oct T Anomalies

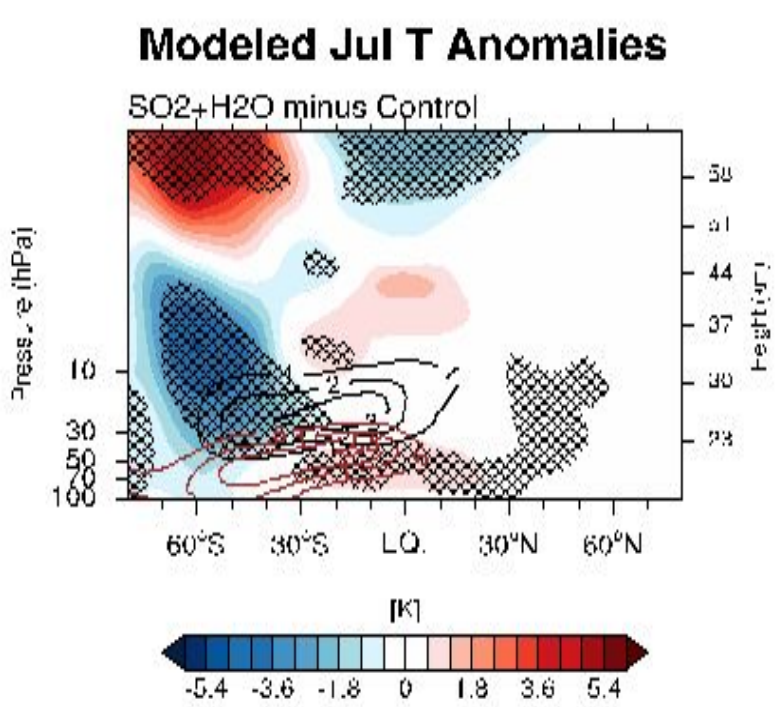


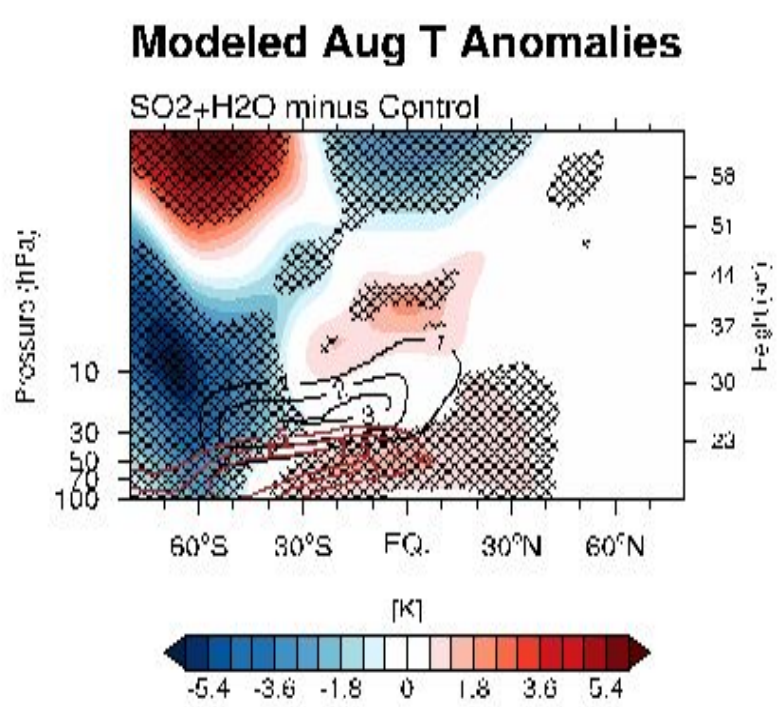
Modeled Nov T Anomalies

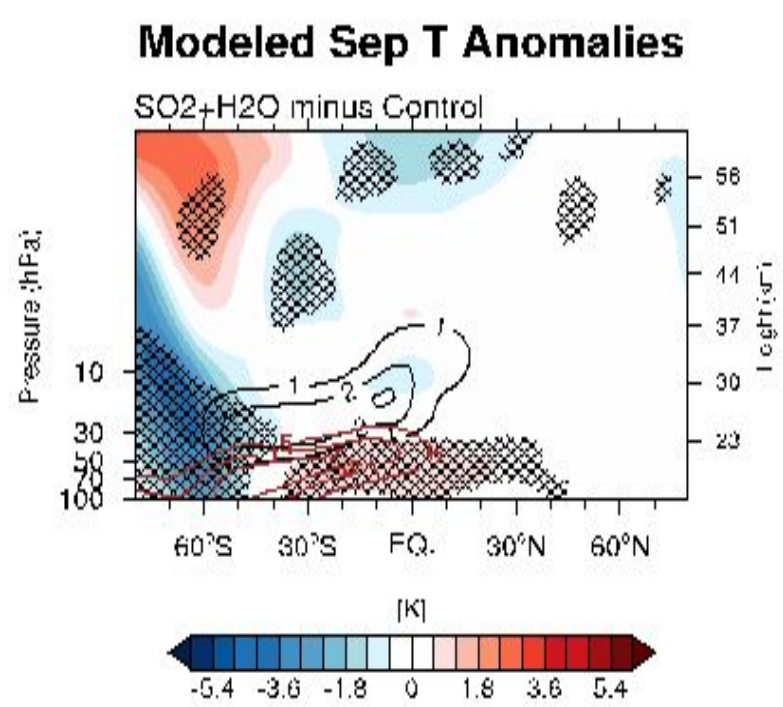


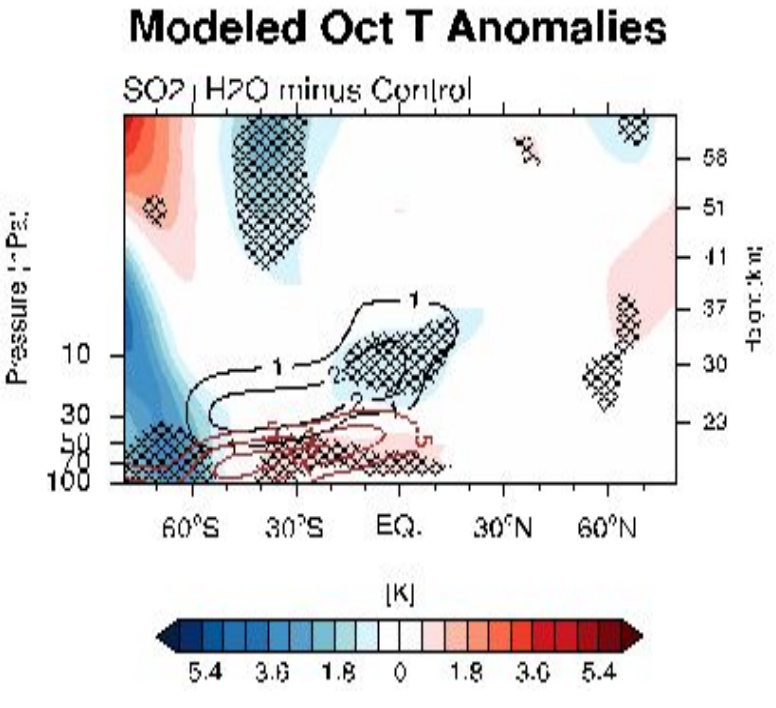
Modeled Dec T Anomalies

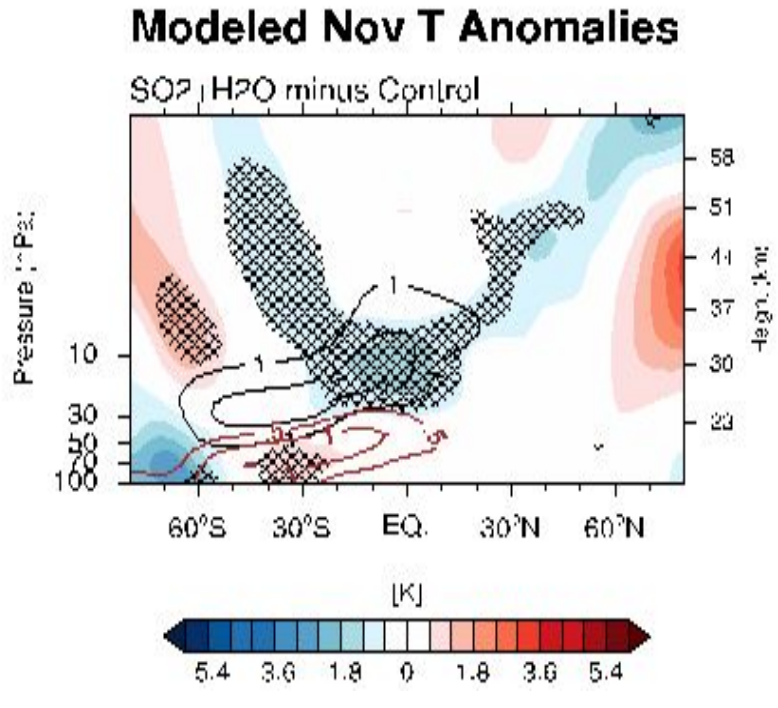


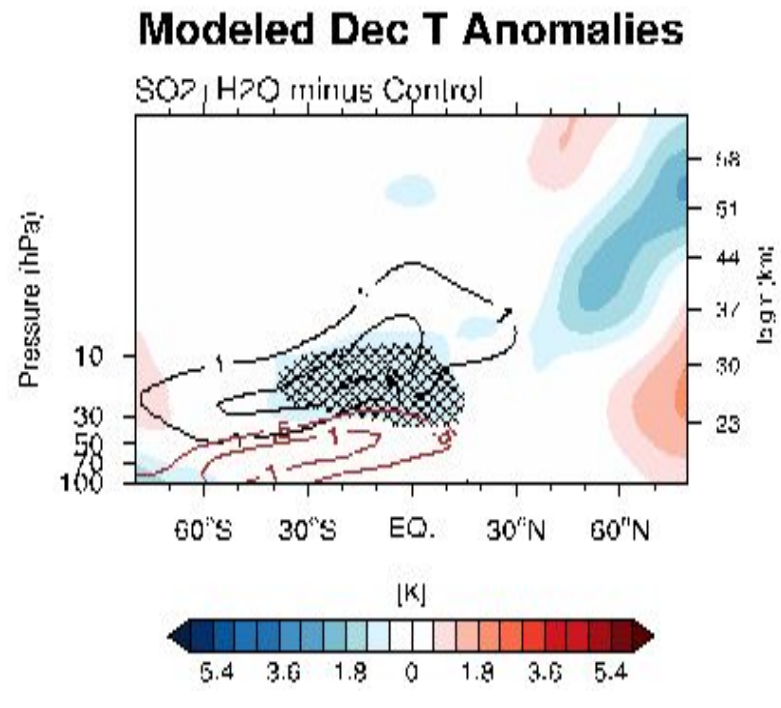

Modeled Jul T Anomalies
SO2+H2O minus Control
Pressure (hPa)
10
30
50
100
60°S
30°S
EQ.
30°N
60°N
[K]
-5.4 -3.6 -1.8 0 1.8 3.6 5.4

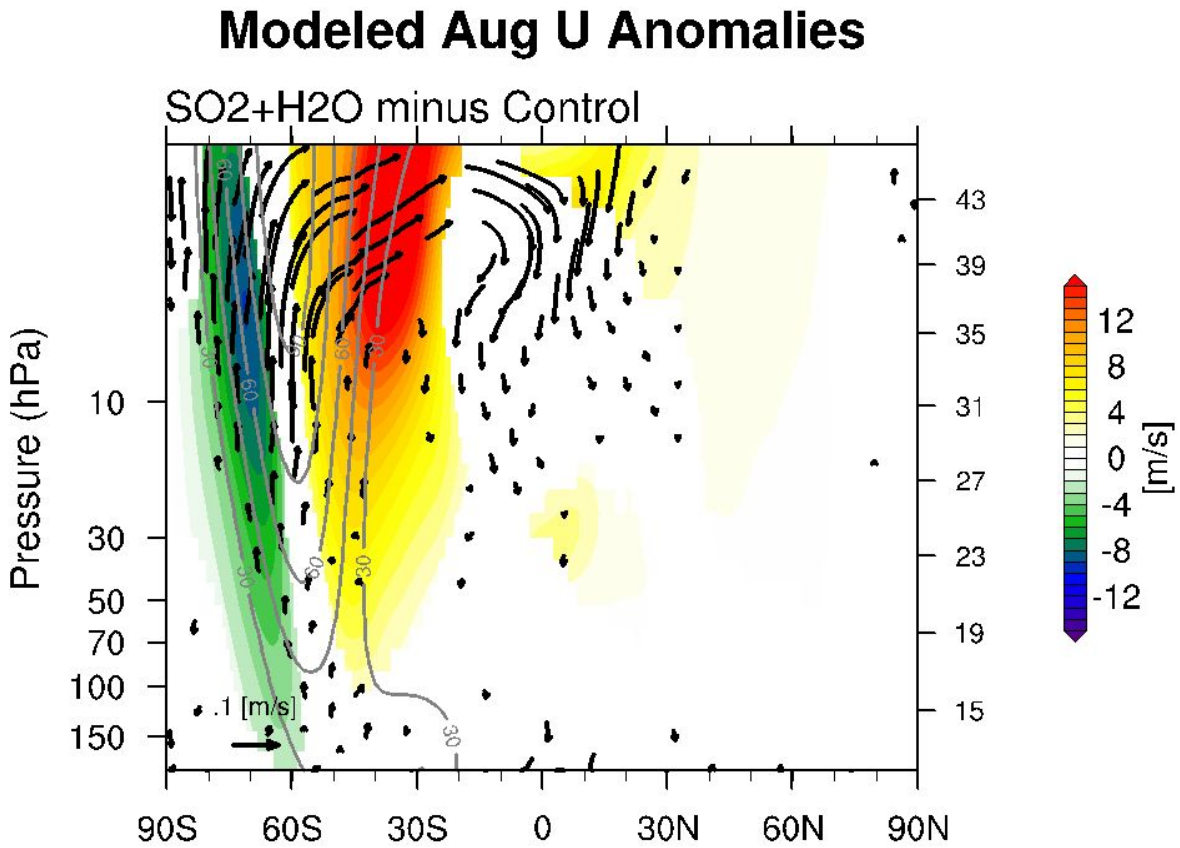

Modeled Aug T Anomalies
SO2+H2O minus Control
Pressure (hPa)
10
30
50
100
60°S
30°S
EQ.
30°N
60°N
[K]
-5.4 -3.6 -1.8 0 1.8 3.6 5.4

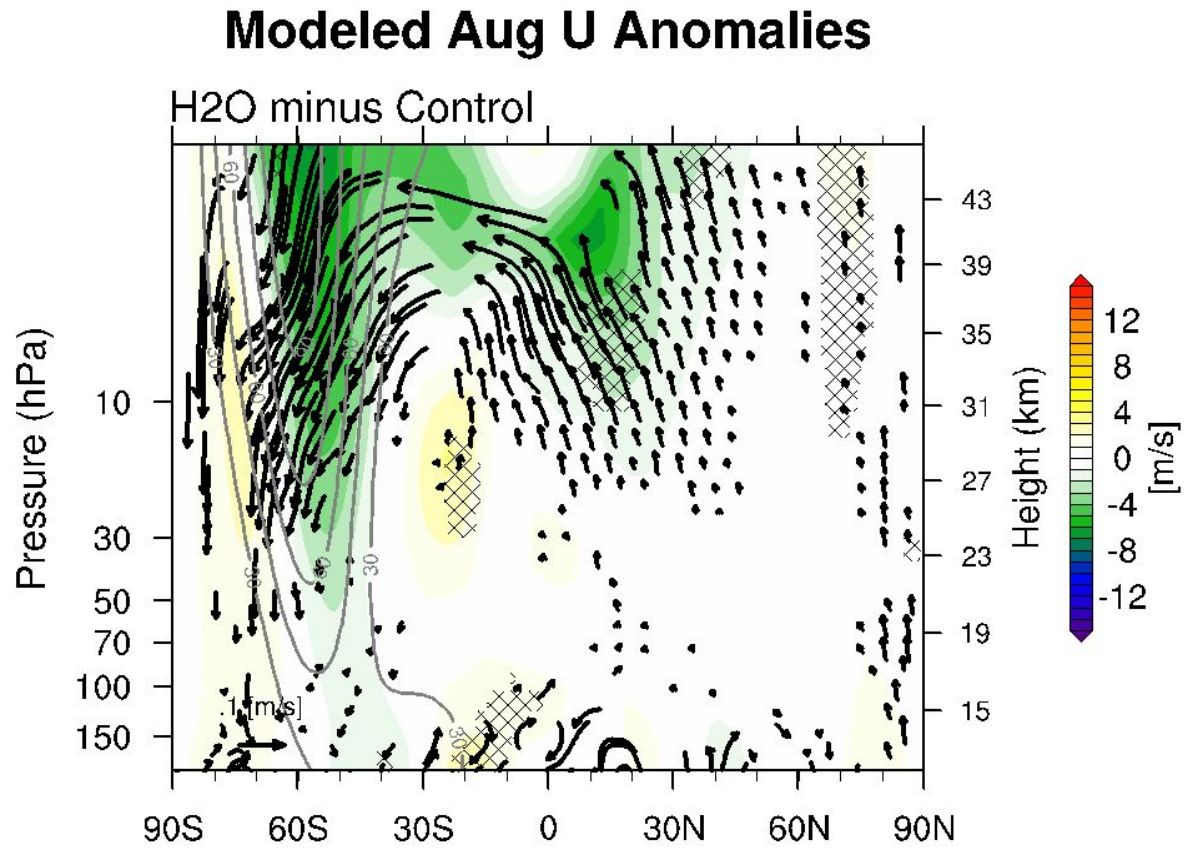

Modeled Sep T Anomalies
SO2+H2O minus Control
Pressure (hPa)
10
30
50
100
60°S
30°S
EQ.
30°N
60°N
[K]
-5.4 -3.6 -1.8 0 1.8 3.6 5.4

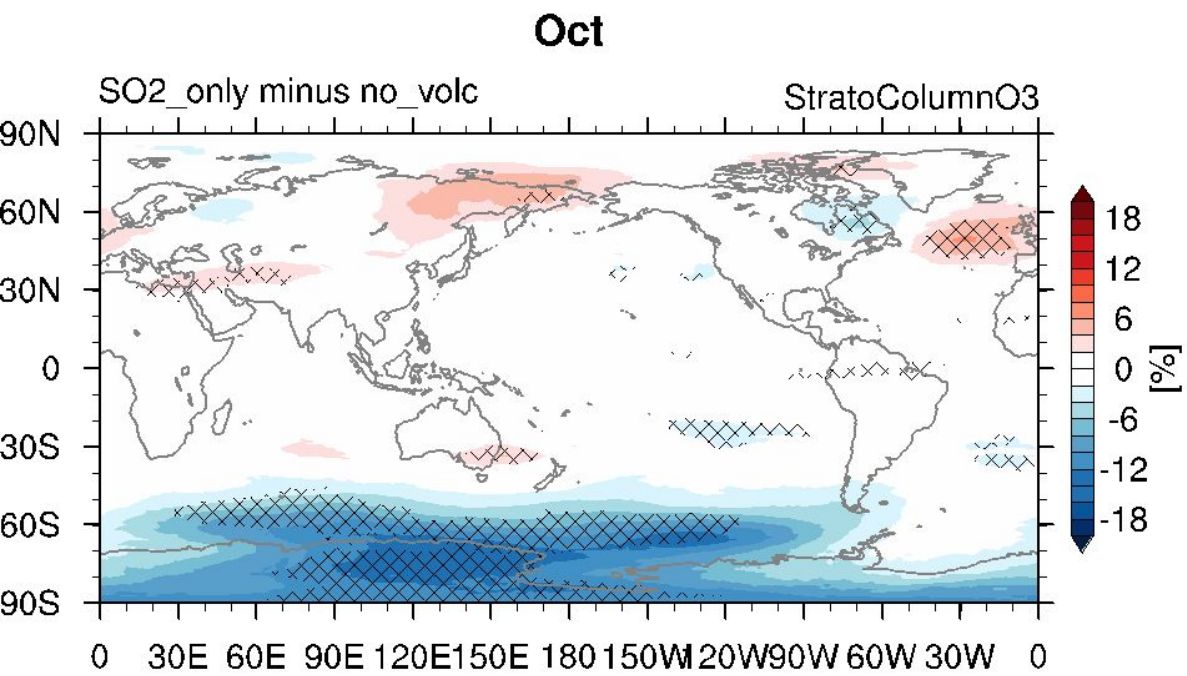

Modeled Oct T Anomalies
SO2+H2O minus Control
Pressure (hPa)
10
30
50
100
60°S
30°S
EQ.
30°N
60°N
[K]
5.4 3.6 1.8 0 1.8 3.6 5.4

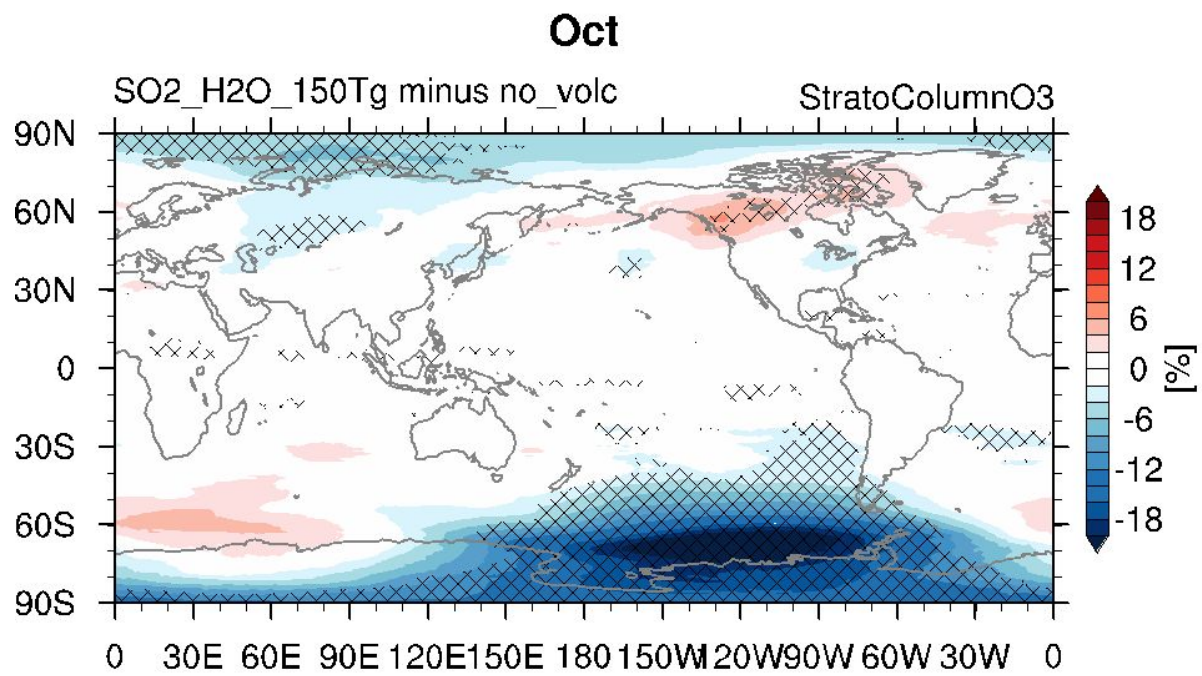

Modeled Nov T Anomalies
SO2+H2O minus Control
Pressure (hPa)
10
30
50
100
60°S
30°S
EQ.
30°N
60°N
[K]
5.4 3.6 1.8 0 1.8 3.6 5.4

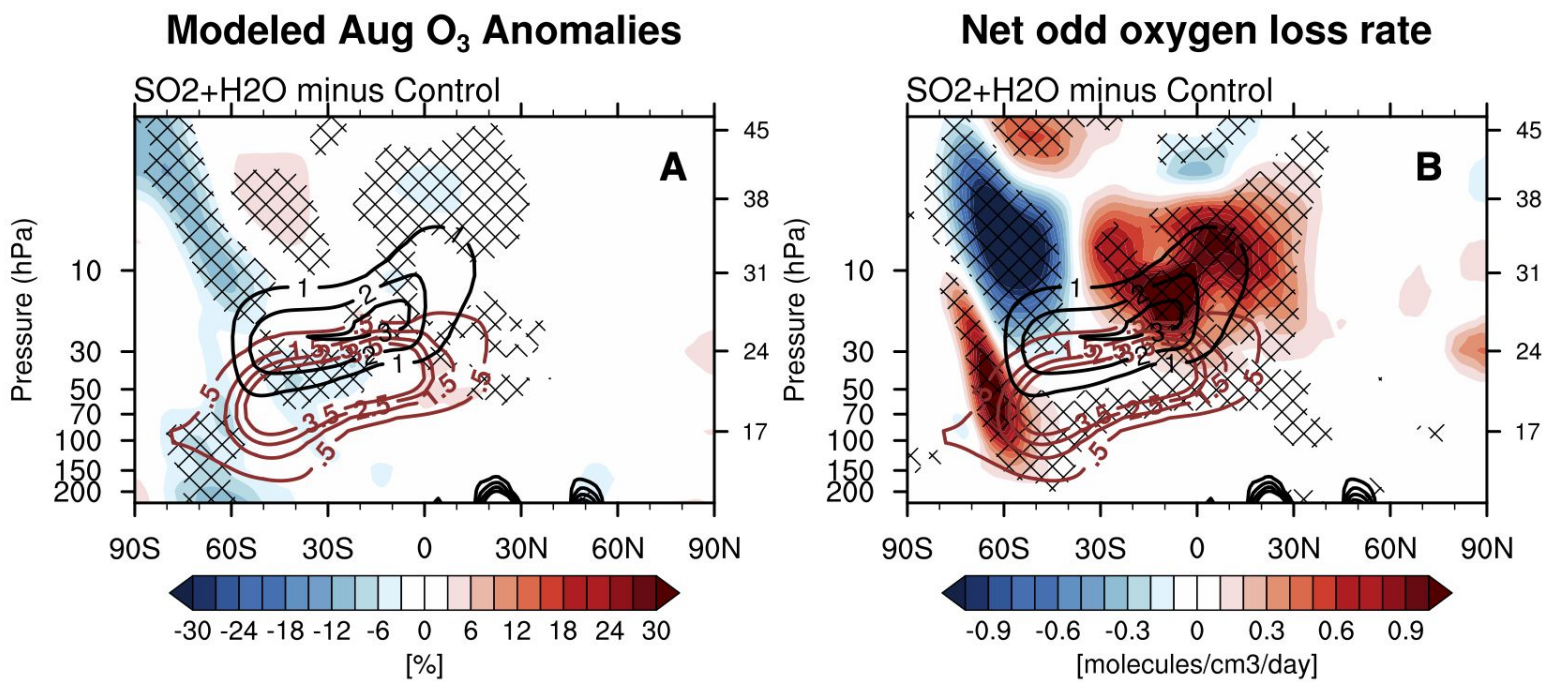

Modeled Dec T Anomalies
SO2+H2O minus Control
Pressure (hPa)
10
30
50
100
60°S
30°S
EQ.
30°N
60°N
[K]
5.4 3.6 1.8 0 1.8 3.6 5.4


Modeled Aug U Anomalies
SO2+H2O minus Control
Pressure (hPa)
10
30
50
70
100
150
90S
60S
30S
0
30N
60N
90N
43
39
35
31
27
23
19
15
.1 [m/s]
12
8
4
0
-4
-8
-12
[m/s]

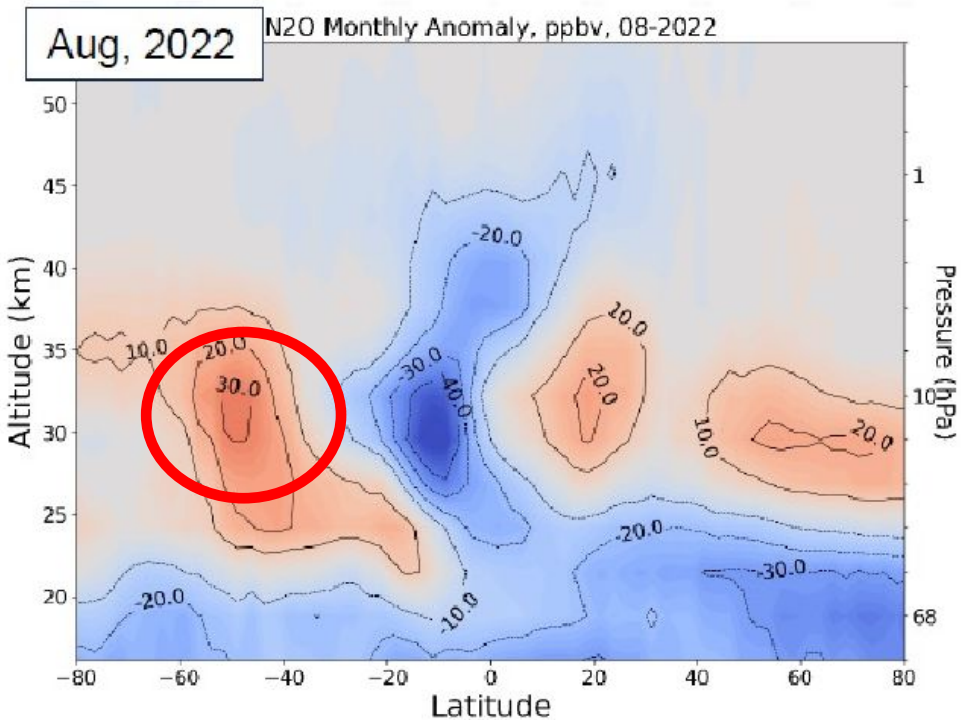

Modeled Aug U Anomalies
H2O minus Control
Pressure (hPa)
10
30
50
70
100
150
90S
60S
30S
0
30N
60N
90N
43
39
35
31
27
23
19
15
Height (km)
.1 [m/s]
12
8
4
0
-4
-8
-12
[m/s]


Oct
SO2_only minus no_volc
StratoColumnO3
90N
60N
30N
0
30S
60S
90S
0 30E 60E 90E 120E 150E 180 150W 120W 90W 60W 30W 0
18
12
6
0
-6
-12
-18
[%]

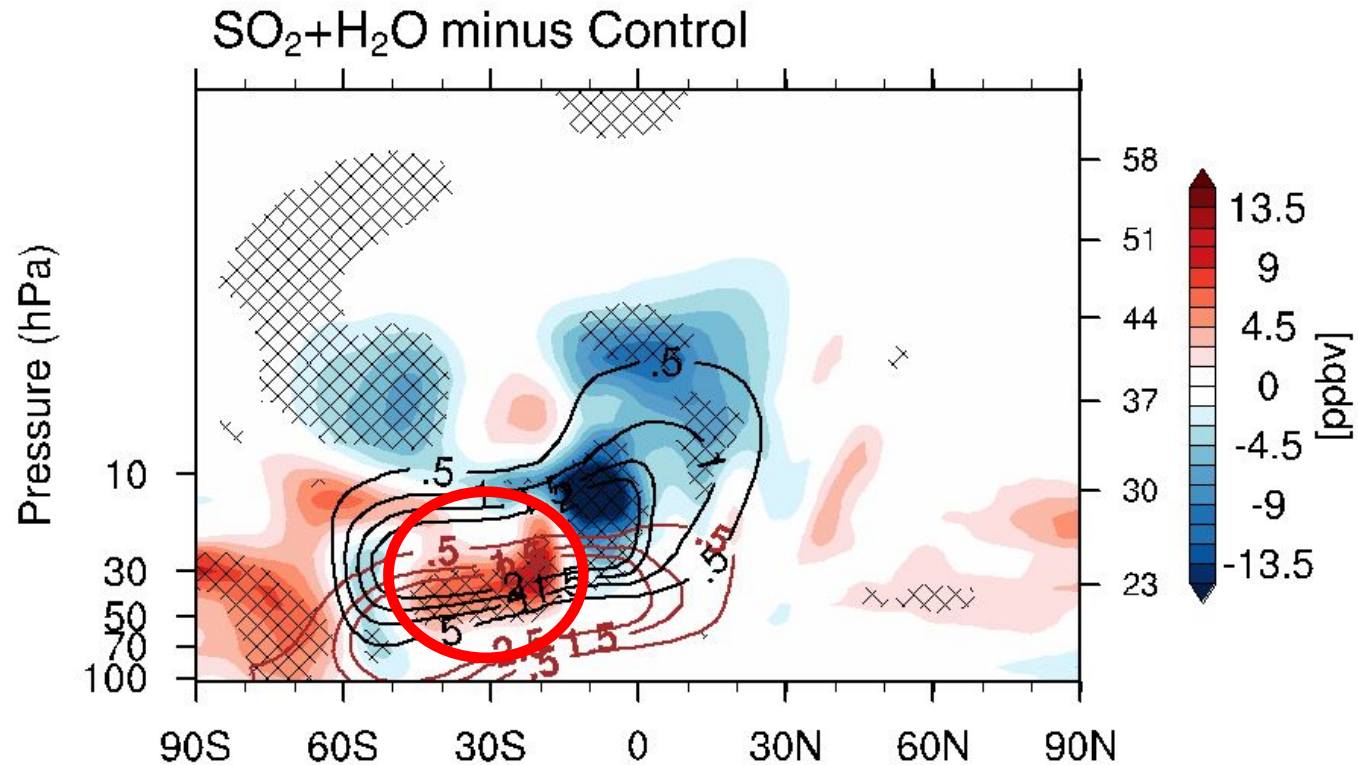

Oct
SO2_H2O_150Tg minus no_volc
StratoColumnO3
90N
60N
30N
0
30S
60S
90S
0 30E 60E 90E 120E 150E 180 150W 120W 90W 60W 30W 0
18
12
6
0
-6
-12
-18
[%]

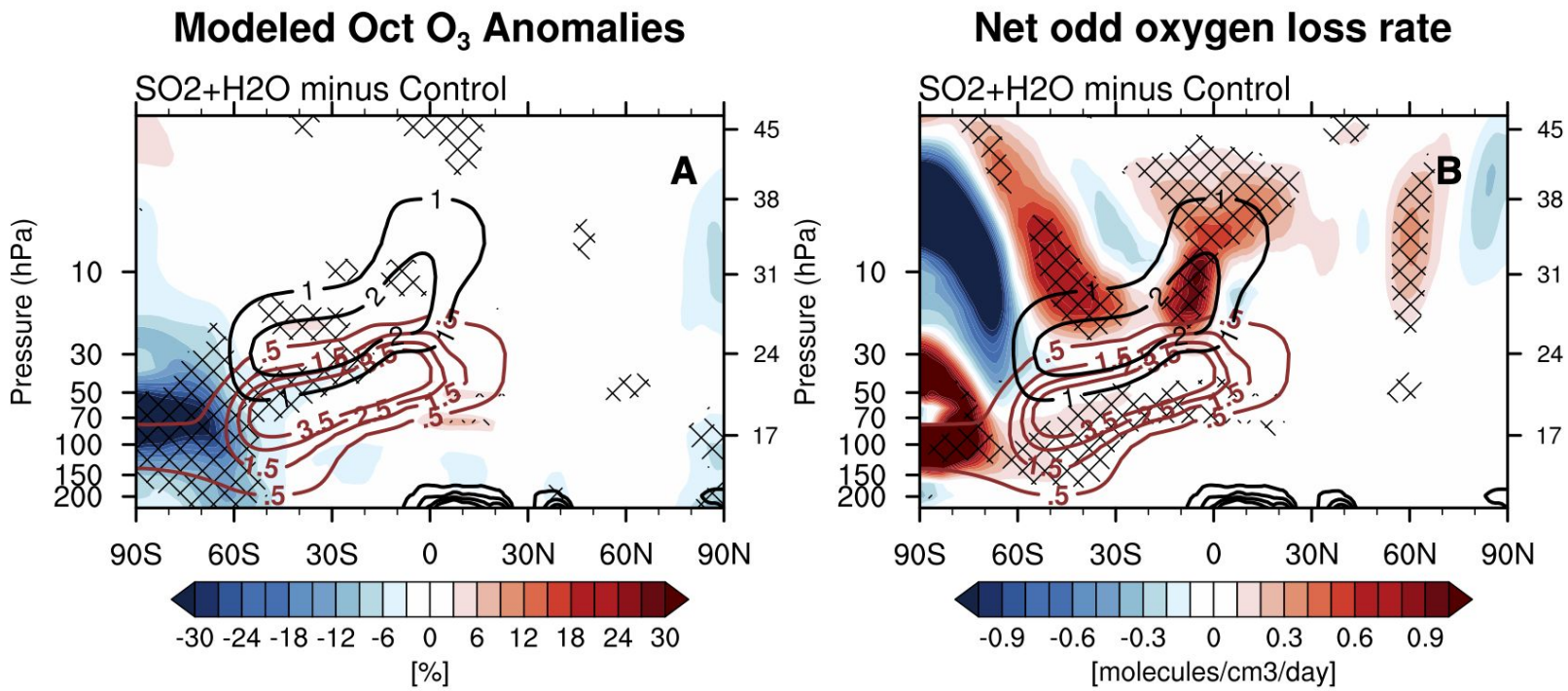

Modeled Aug O_3 Anomalies
SO2+H2O minus Control
A
Pressure (hPa)
10
30
50
70
100
150
200
45
38
31
24
17
90S
60S
30S
0
30N
60N
90N
-30 -24 -18 -12 -6 0 6 12 18 24 30
[%]
Net odd oxygen loss rate
SO2+H2O minus Control
B
-0.9 -0.6 -0.3 0 0.3 0.6 0.9
[molecules/cm3/day]

MLS August N_2O Anomaly



Modeled August N_2O Anomaly




Modeled Oct O_3 Anomalies
SO2+H2O minus Control
A
Pressure (hPa)
10
30
50
70
100
150
200
45
38
31
24
17
90S
60S
30S
0
30N
60N
90N
-30 -24 -18 -12 -6 0 6 12 18 24 30
[%]
Net odd oxygen loss rate
SO2+H2O minus Control
B
-0.9 -0.6 -0.3 0 0.3 0.6 0.9
[molecules/cm3/day]