Stratospheric anomalies after the unprecedented water-rich Hunga Tonga eruption

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National Center for Atmospheric Research (NCAR)

NCAR

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NSF

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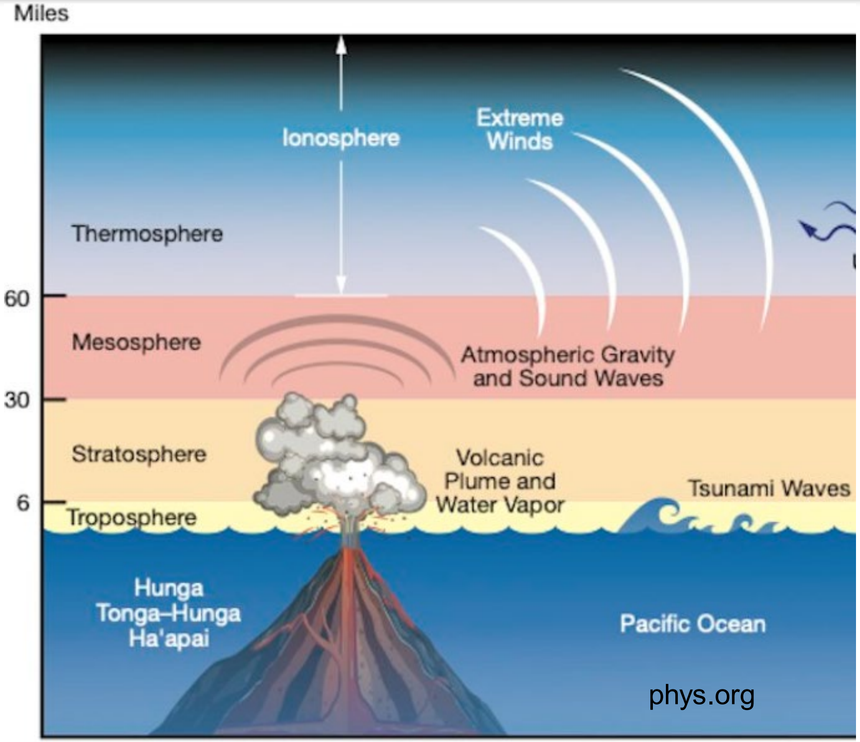
Unprecedented water -rich Hunga Tonga eruption



150 Tg water along with
0.4 Tg sulfur dioxide injection

additional source of water vapor → increases hydroxy radical (OH) → enhance HOx O_3 loss cycle

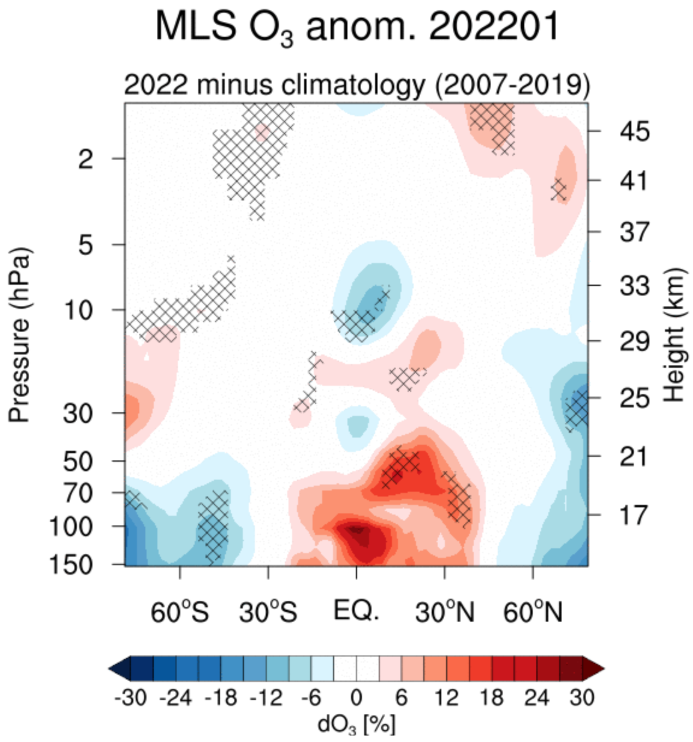
SO_2 injection forms sulfate aerosol → enhance the aerosol surface area density → facilitate heterogenous chemistry

→ adversely deplete stratospheric ozone

Zhu et al., Earth & Environment, 2022

2022 Ozone anomaly relative to climatology

Aura MLS - Microwave Limb Sounder



- ❑ 2007 to 2019 13 years climatology
- ❑ Hatched regions indicate where the 2022 anomalies are outside the range of all variability during 2007-2019
- ❑ Large anomaly over the SH mid-latitudes and Antarctic polar region (ozone hole)

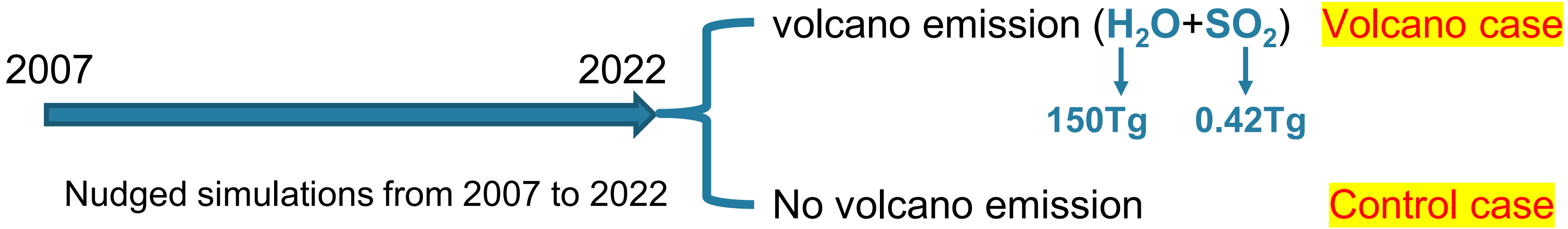
What is causing this ozone anomaly?

CESM Whole Atmosphere Community Climate Model

- **WACCM6, 110L**, horizontal resolution of ~**1.0º** and a vertical resolution of ~**500m** in the Upper Troposphere and Lower Stratosphere.

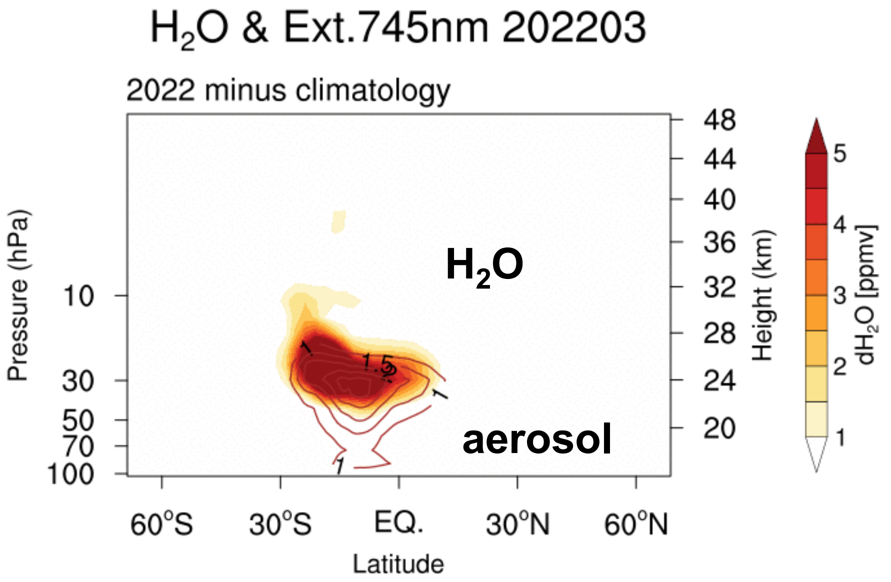
- Full interactive tropospheric and stratospheric chemistry.

- **Specified dynamics** – nudged towards MERRA-2 reanalysis fields (T, U, V).

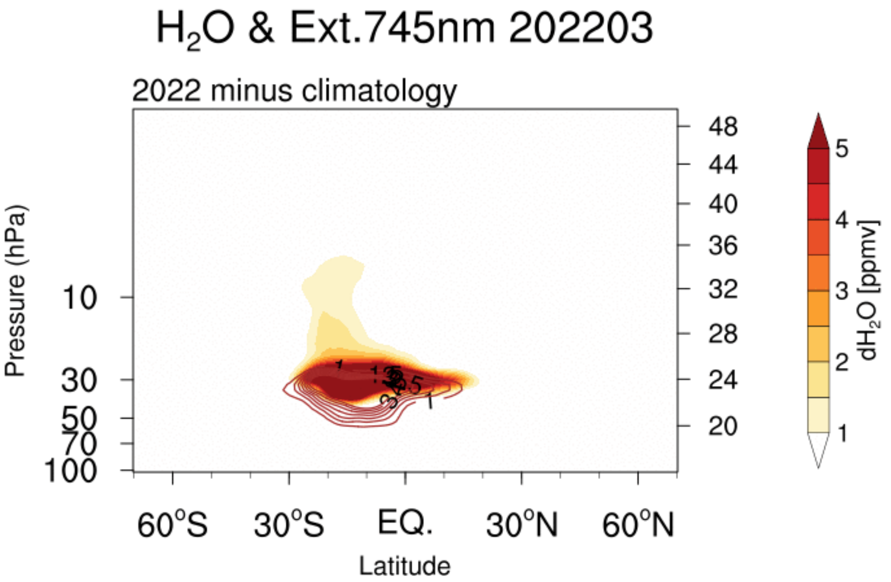


Water vapor and aerosol plume evolution

Observed

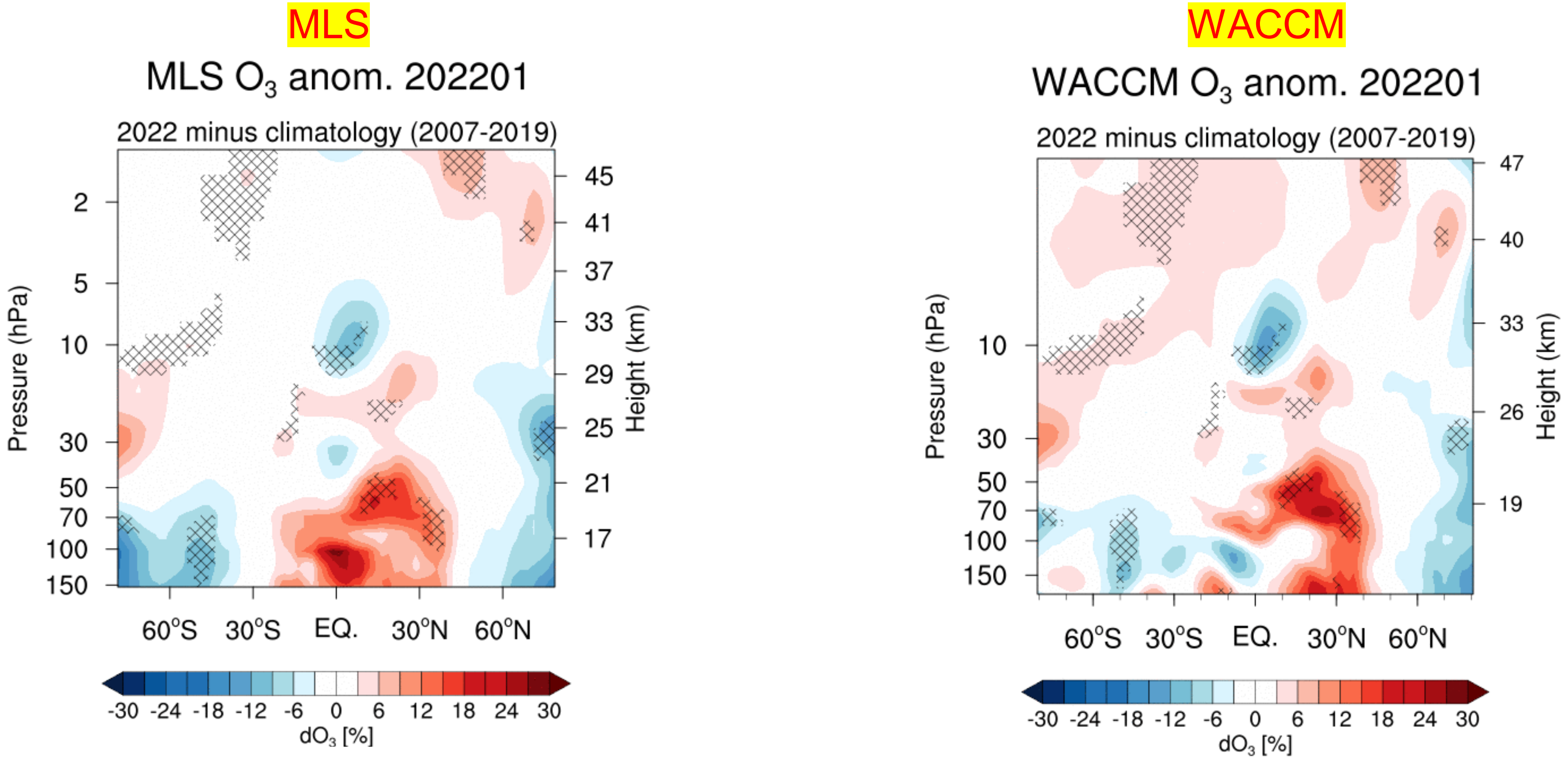


WACCM



- Water plume propagates from SH subtropics to high-latitude in 2022.
- The separation of the H_2O and aerosol plumes over time due to the sedimentation of the aerosols.

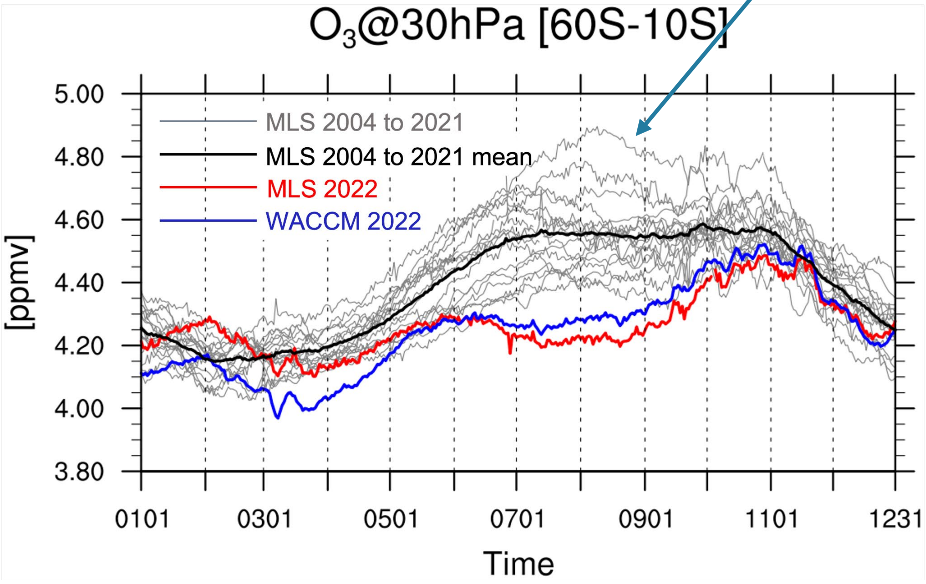
2022 Ozone anomaly MLS and WACCM comparison

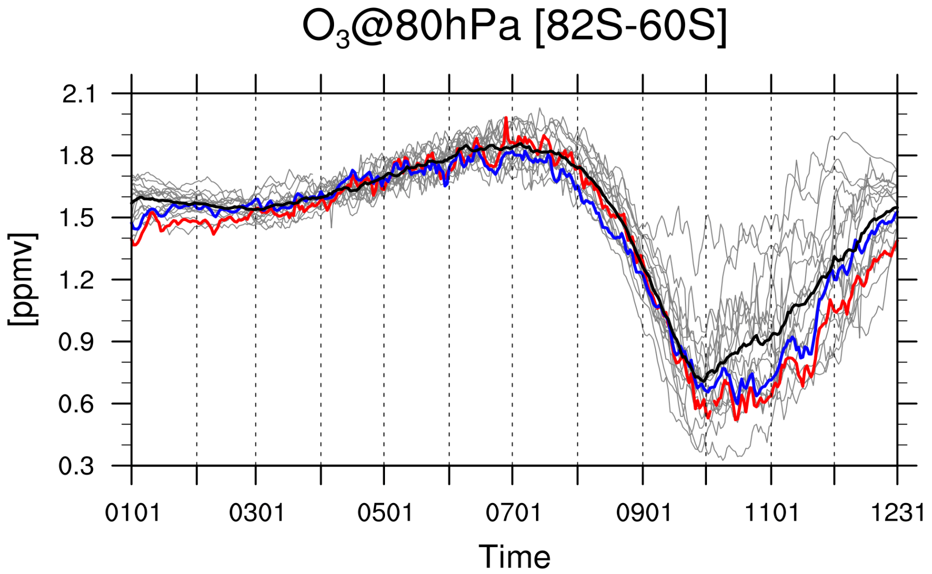


- WACCM shows very good agreement with MLS across the whole year 2022, and fully represent the ozone anomaly over SH midlatitudes and Antarctic region.

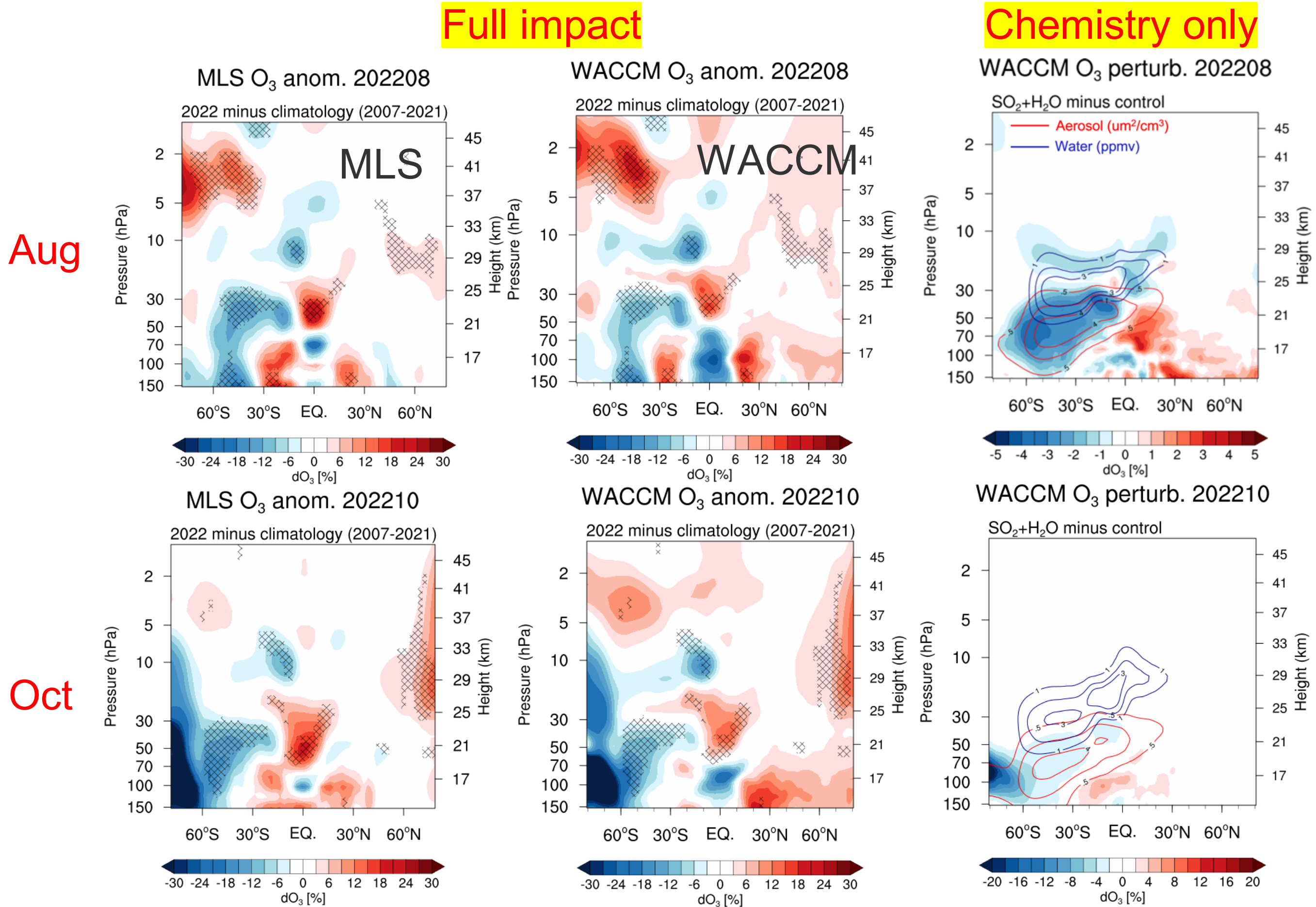
2022 Ozone anomaly

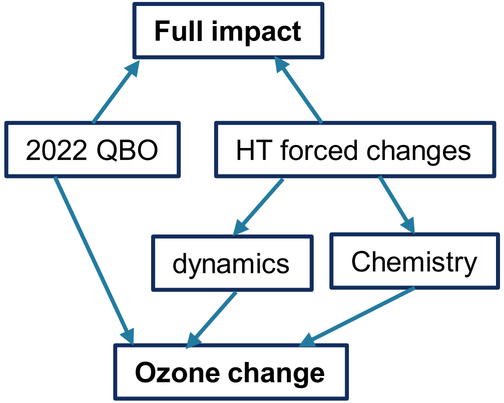
large winter variability related to the QBO





Quantify chemistry contribution to the ozone change





In the mid-latitudes and Antarctica, chemistry contributes to ~30% of total ozone loss.

WACCM free -running

Volcano case: H_2O + SO_2 injection (10 ensemble)

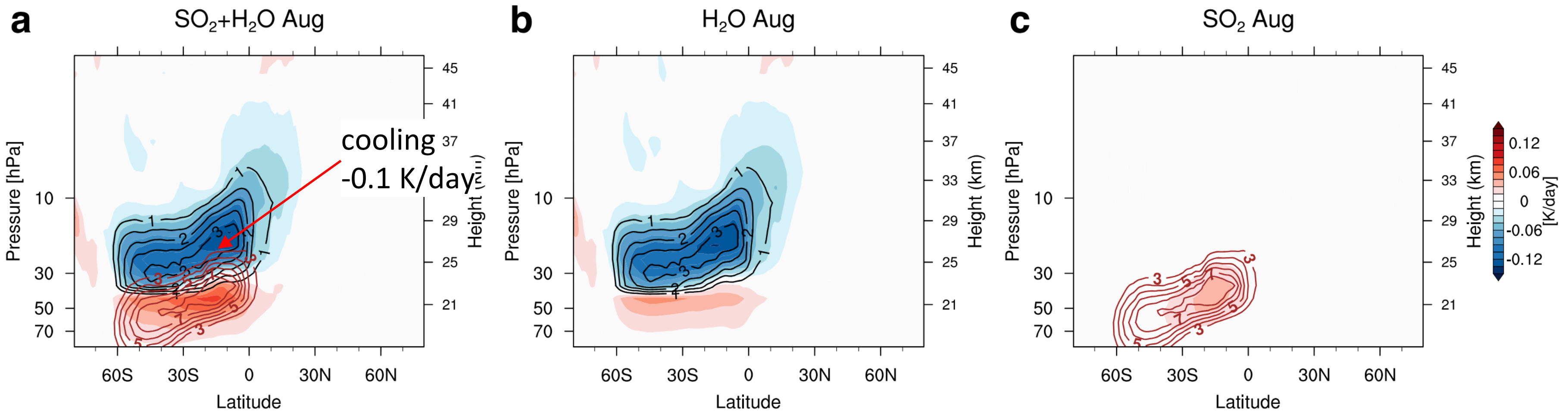
Control case: no Hunga Tonga eruption (10 ensemble)

2022 2031

Stratospheric Climate Anomalies and Ozone Loss Caused by the Hunga Tonga-Hunga Ha'apai Volcanic Eruption

Xinyue Wang[1,2], William Randel[2], Yunqian Zhu[3,4,5], Simone Tilmes[2], Jon Starr[2], Wandi Yu[6,7], Rolando Garcia[2], Owen B. Toon[1,4], Mijeong Park[2], Douglas Kinnison[2], Jun Zhang[2], Adam Bourassa[8], Landon Rieger[8], Taran Warnock[8], and Jianghanyang Li[3,9]

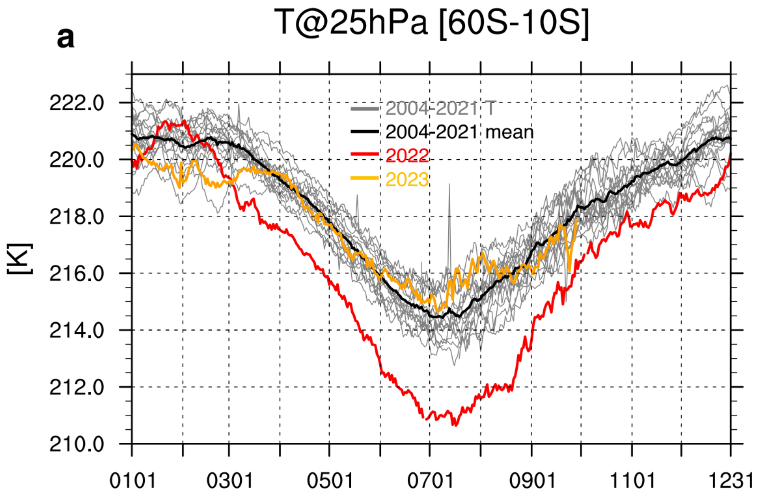
Radiative heating rates of volcanic plumes

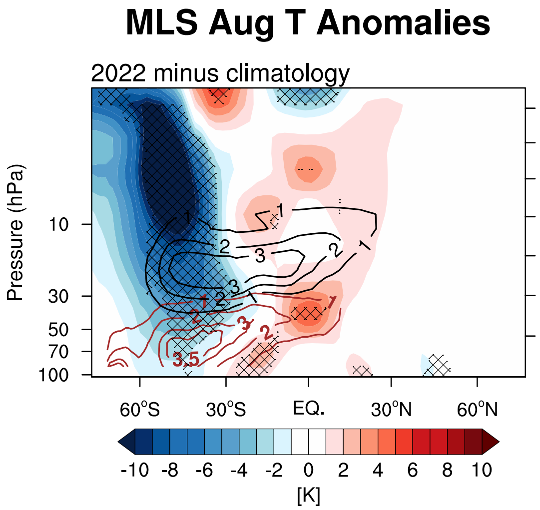


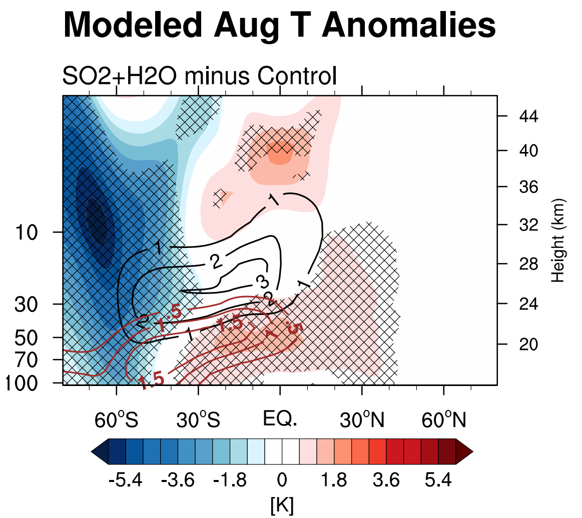
H_2O cools the stratosphere while aerosol warms the stratosphere

Changes are mostly from longwave radiation

Unprecedented mid-stratospheric cooling in winter months



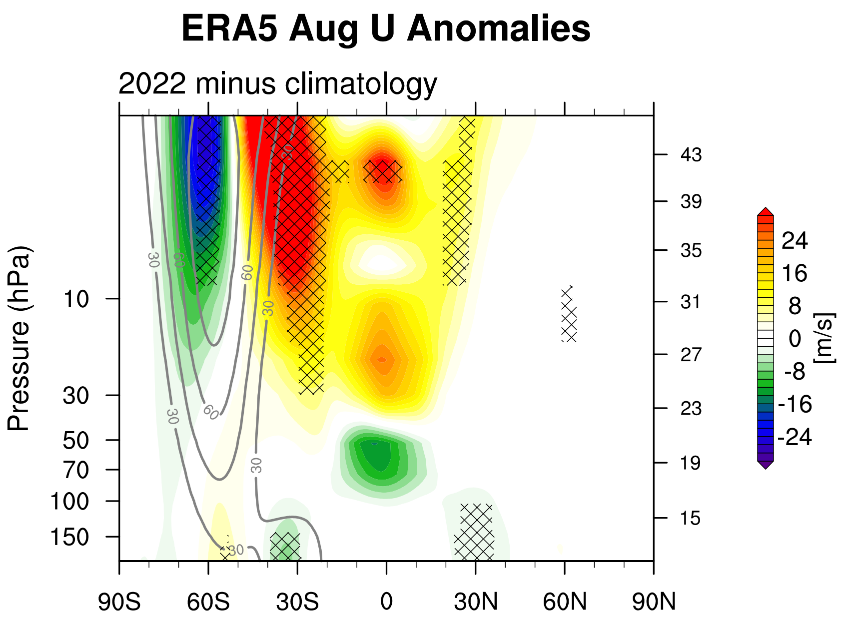




Hatched regions indicate where the 2022 Tanom are outside internal variability

A fingerprint of the forced response to the HTHH eruption

Large circulation anomalies due to volcanic influences



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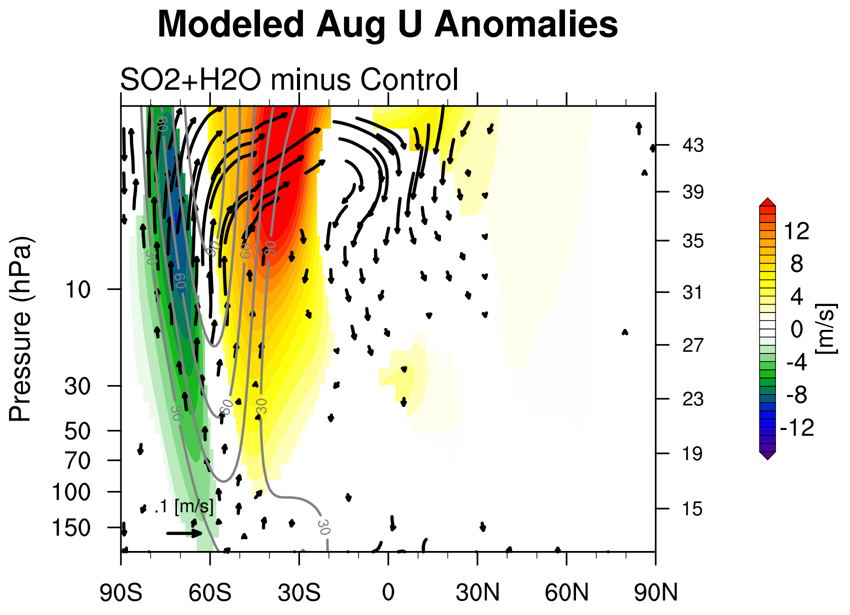
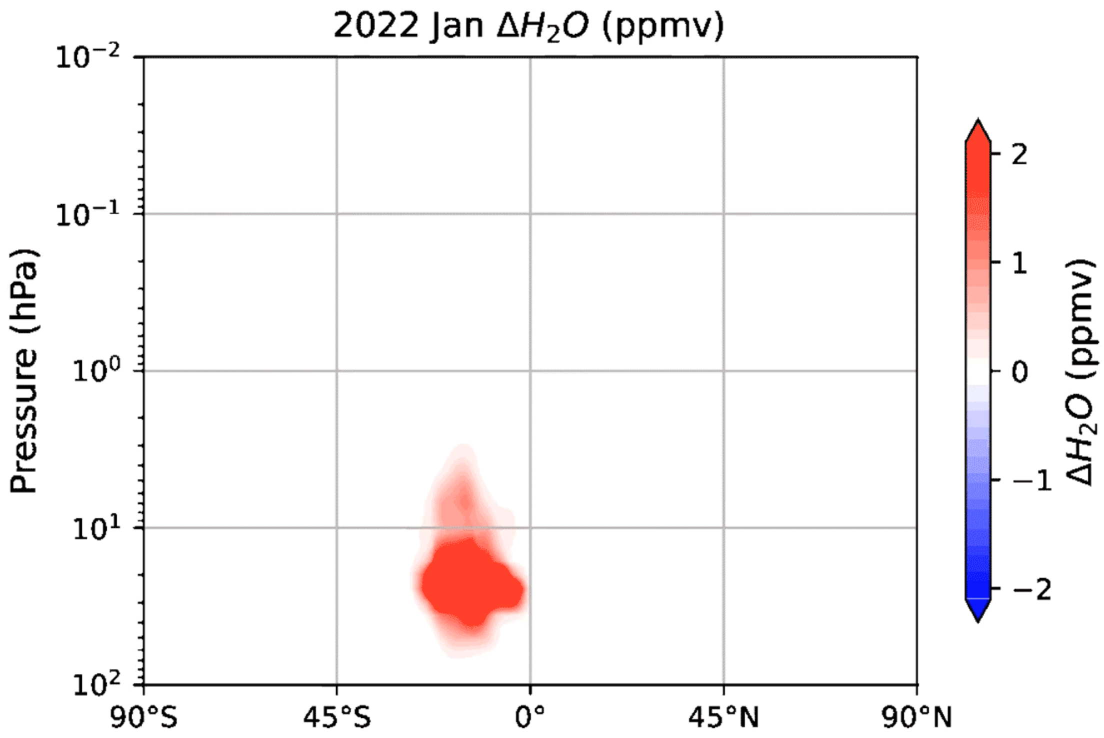


Equatorward shift of the Antarctic polar vortex

The Brewer-Dobson Circulation is weakening

HT Water plume evolution from 2022 to 2025



NCAR Whole Atmosphere Community Climate Model version 6 (WACCM6) simulation of HTHH water plume anomaly evolution from 2022 to 2025. Figure: Wandi Yu, LLNL; Xinyue Wang, NCAR; LASP Web Team

Summary

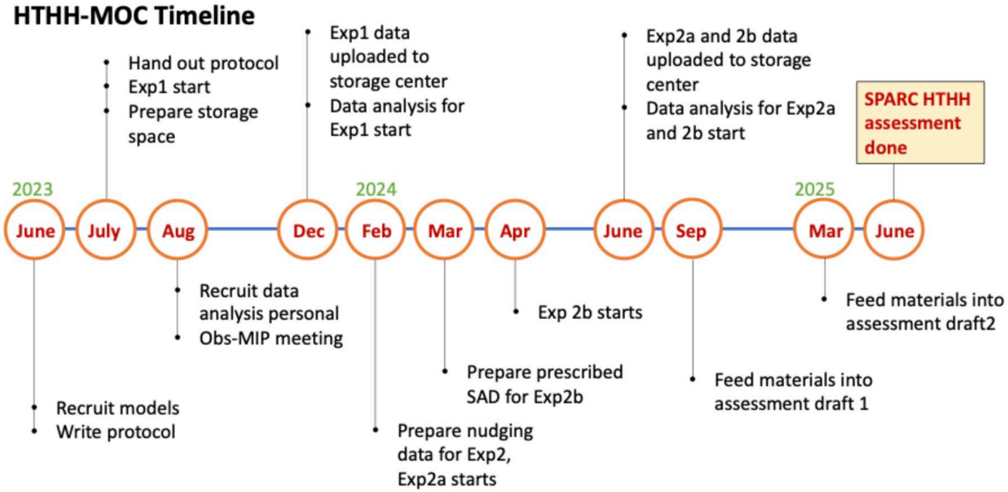
- HTHH eruption in January 2022 caused persistent stratospheric H_2O and aerosol plumes, and caused large impacts on temperature, circulation and ozone.
    - Large-scale SH stratospheric cooling
    - Equatorward shift of the Antarctic polar vortex
    - Slowing of the Brewer-Dobson circulation
    - Persistent ozone reduction in the SH wintertime midlatitudes.
    - Large springtime Antarctic ozone losses in 2022
- WACCM6 simulation accurately captures the evolution of the volcanic plume and the record low ozone levels at mid-latitudes resulting from the eruption.
- The majority of ozone depletion is ascribed to internal variability and dynamical changes induced by the eruption.

HT SPARC/APARC activity

APARC
Atmospheric Processes And their Role in Climate

WCRP
World Climate Research Programme

HTHH Model Observations Comparison (HTHH-MOC)



This HTHH community assessment spans multiple research topics but is focused on the following three science themes:

A. Plume evolution, dispersion and large-scale transport

B. Impacts on stratospheric aerosols and the ozone layer

C. Radiative forcings from the eruption and surface climate impacts

Activity leaders:
Yunqian Zhu, NOAA
Graham Mann, University of Leeds
Paul A. Newman, NASA
William Randel, NSF NCAR

https://csl.noaa.gov/assessments/hthh/moc.html