Modulation of the Northern Polar Vortex by the Hunga Tonga-Hunga Ha'apai Eruption and Associated Surface Response

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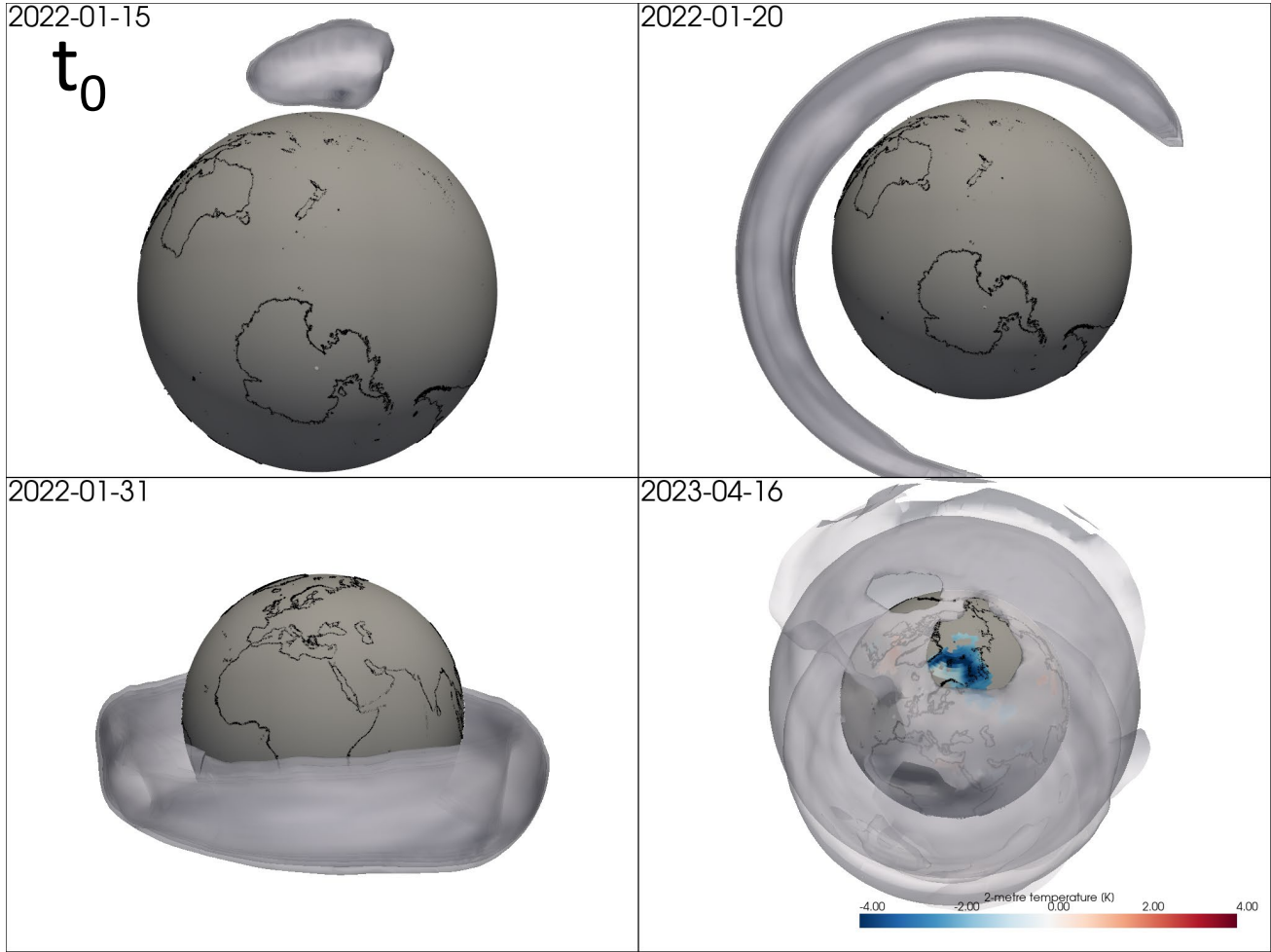
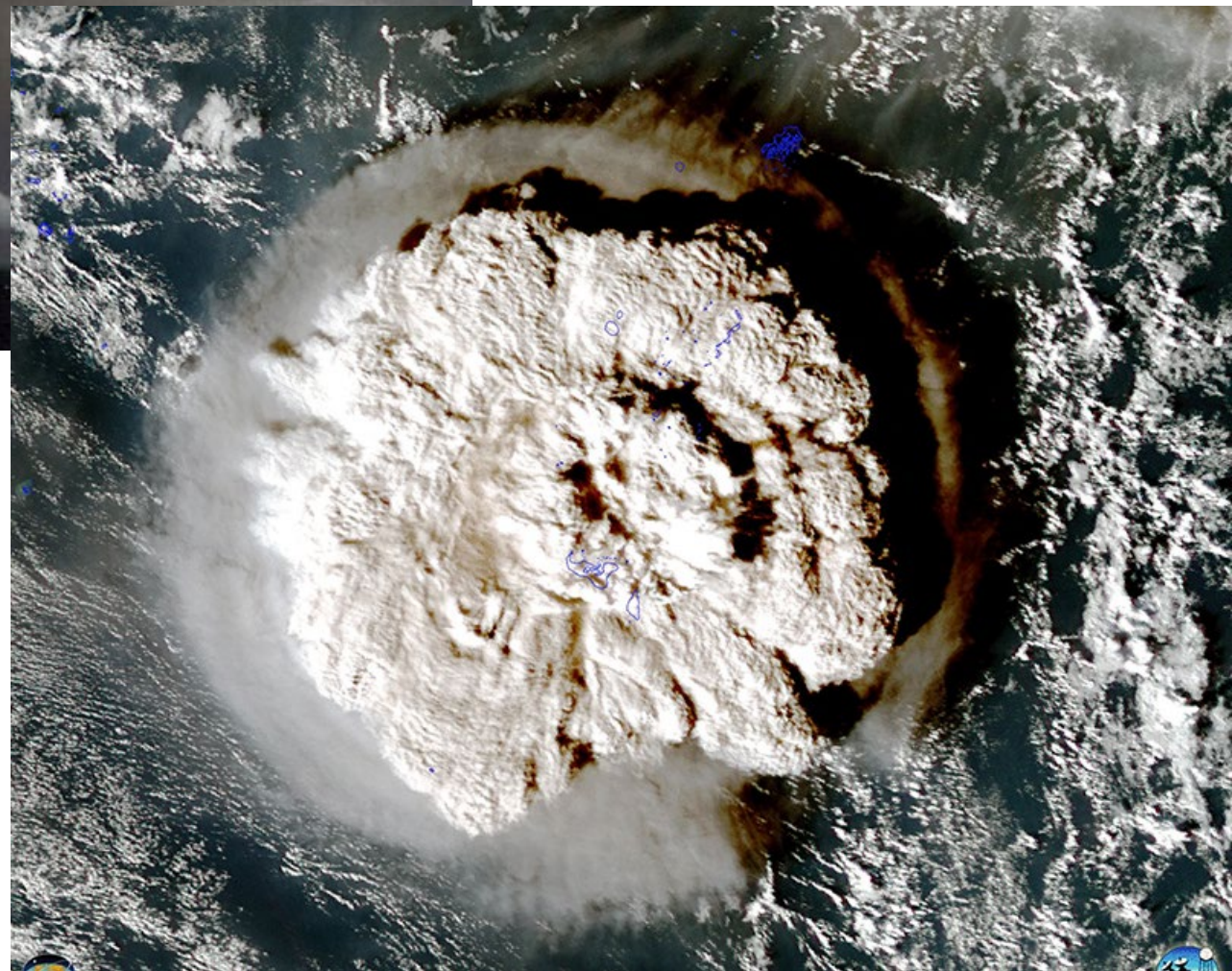
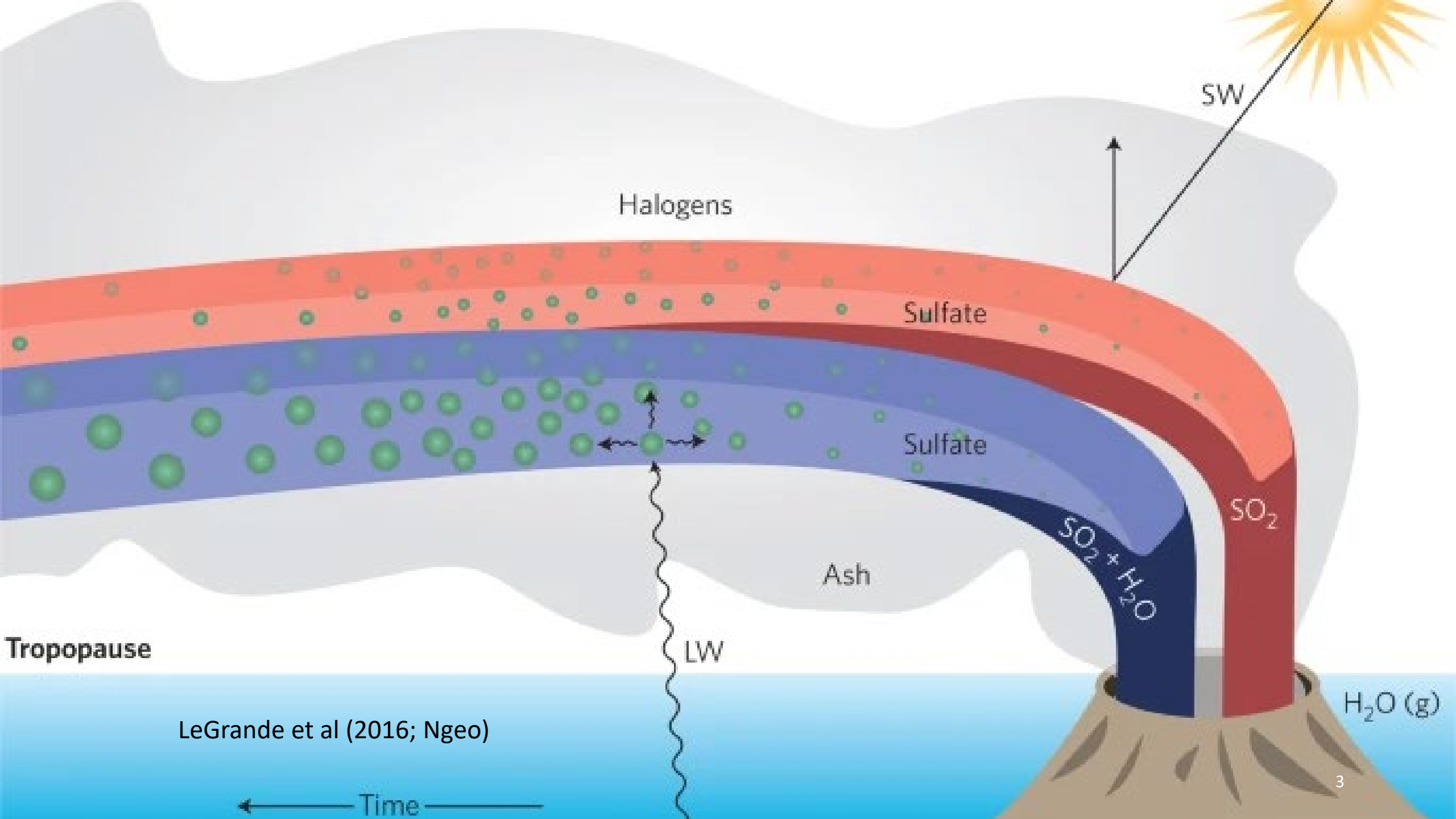
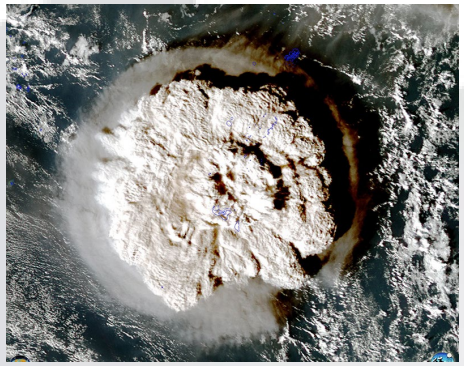




Hunga Tonga eruption



LeGrande et al (2016; Ngeo)



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Indirect pathway of stratospheric heating

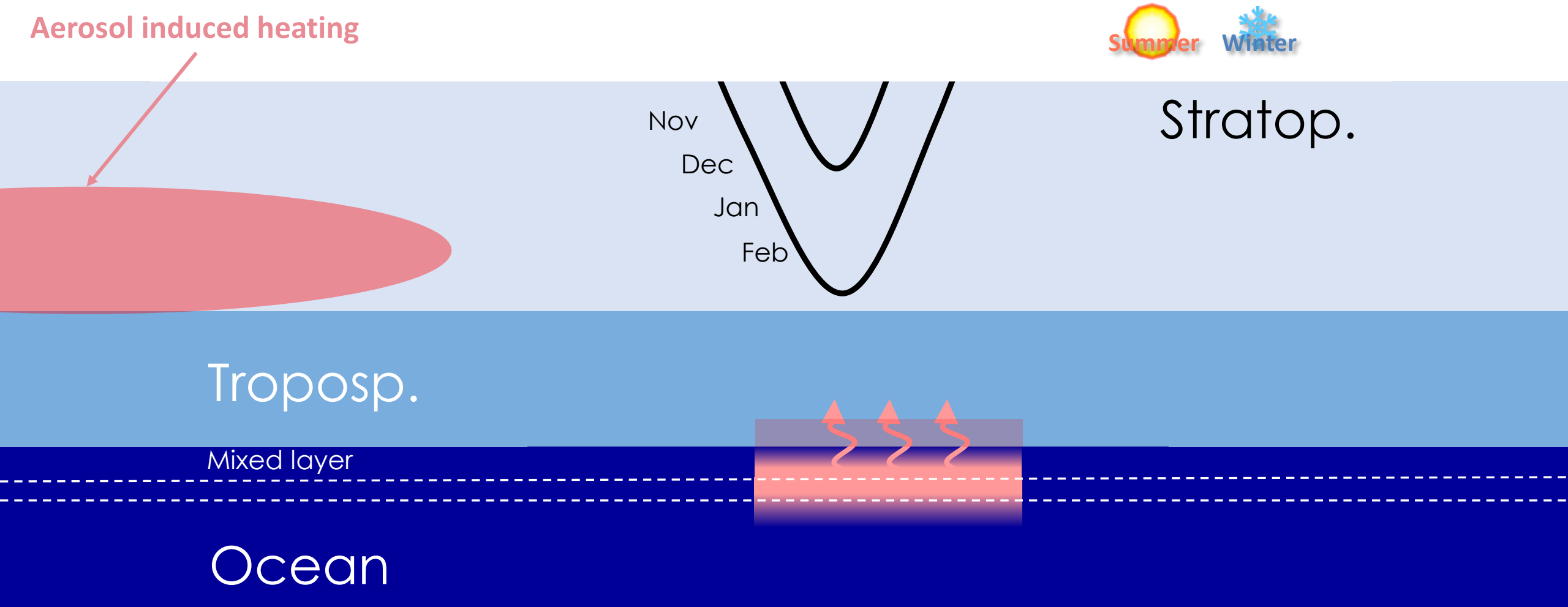
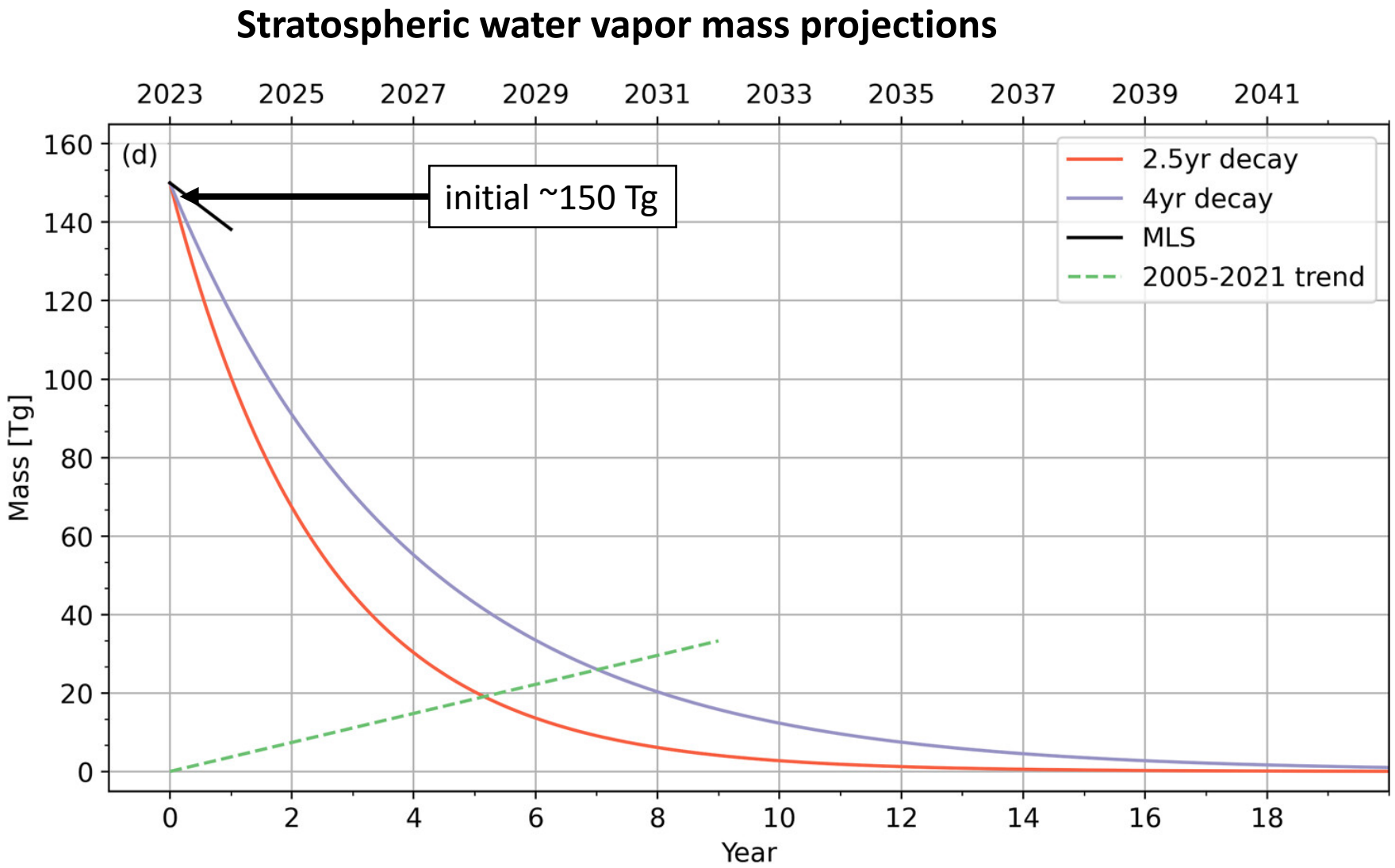


Illustration: Yunqian Zhu, NOAA / CIRES

Motivation

Relevancy for seasonal and decadal projections

Importance on various timescales

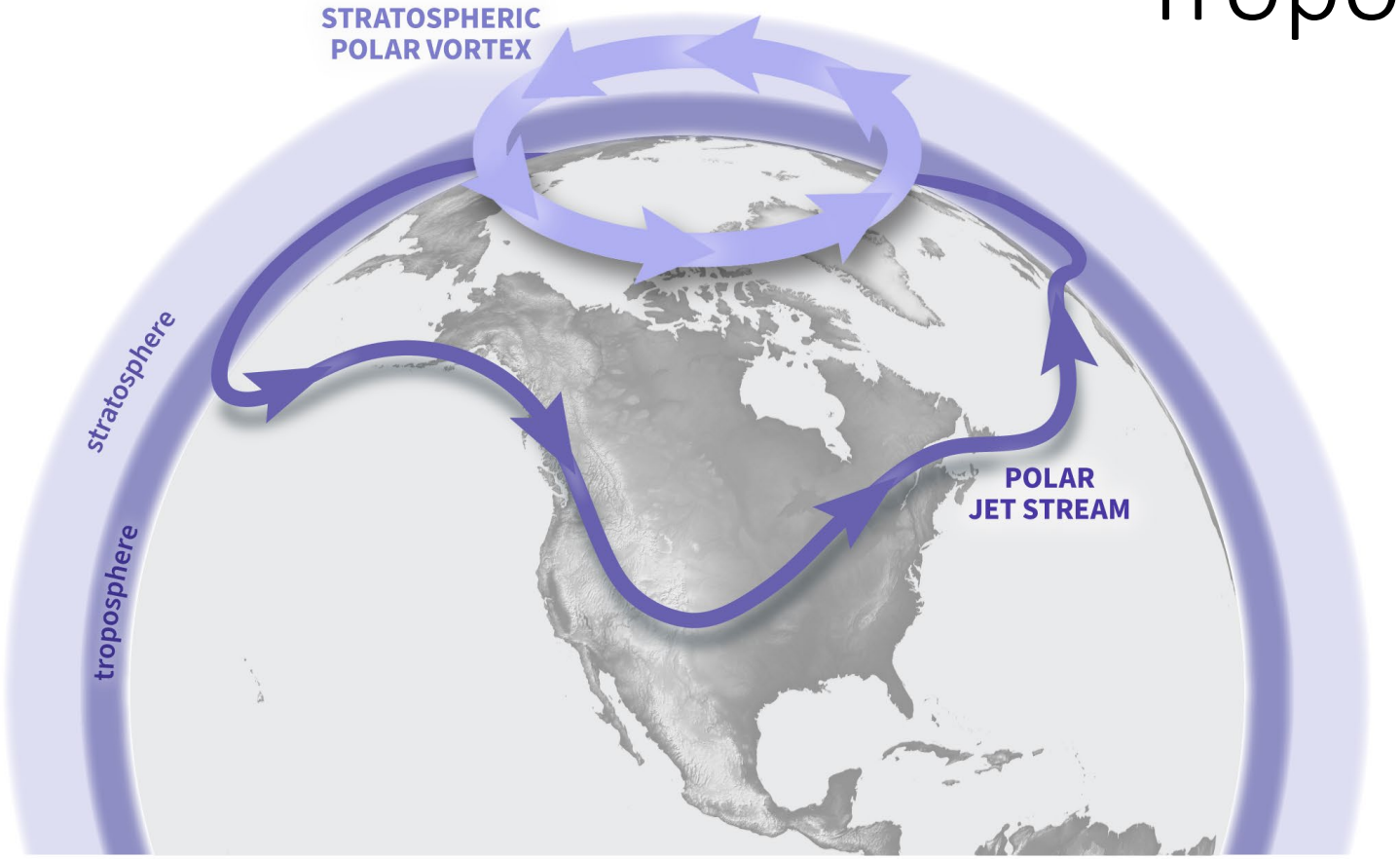


Millán et al (2024)

Stratospheric polar vortex

vs.

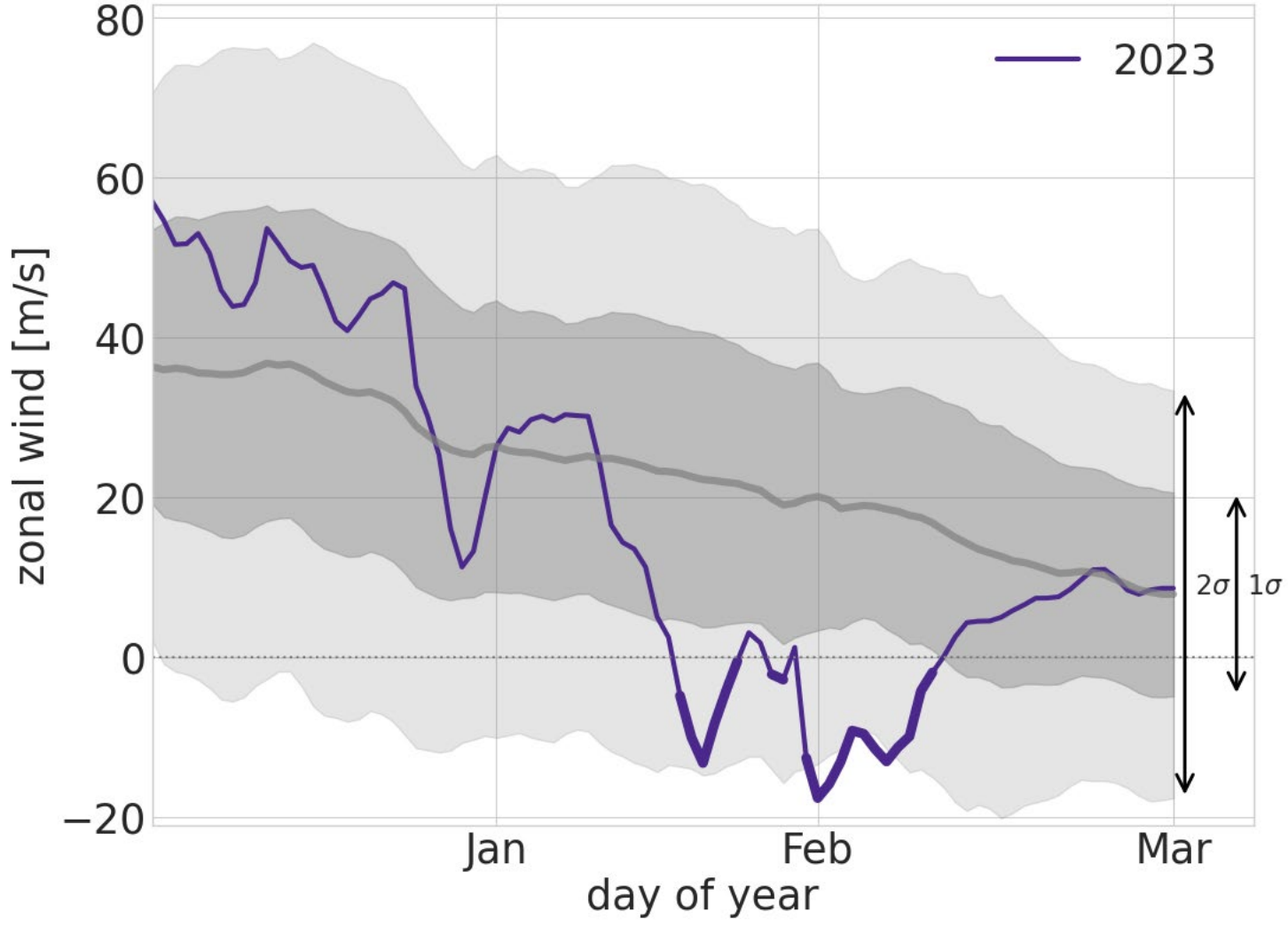
Tropospheric jet stream



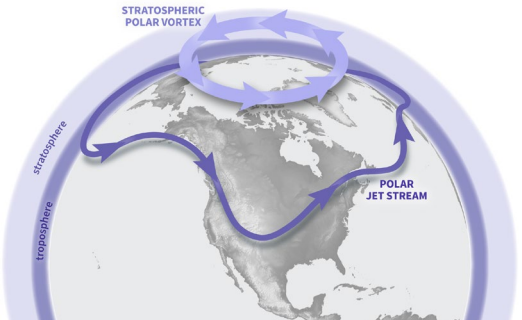
NOAA Climate.gov
Data: Waugh et al., 2017

Stratospheric polar vortex post Hunga-Tonga eruption

at 10 hPa, 60°N



Waugh et al (2017)



Stratospheric polar vortex post Hunga-Tonga eruption

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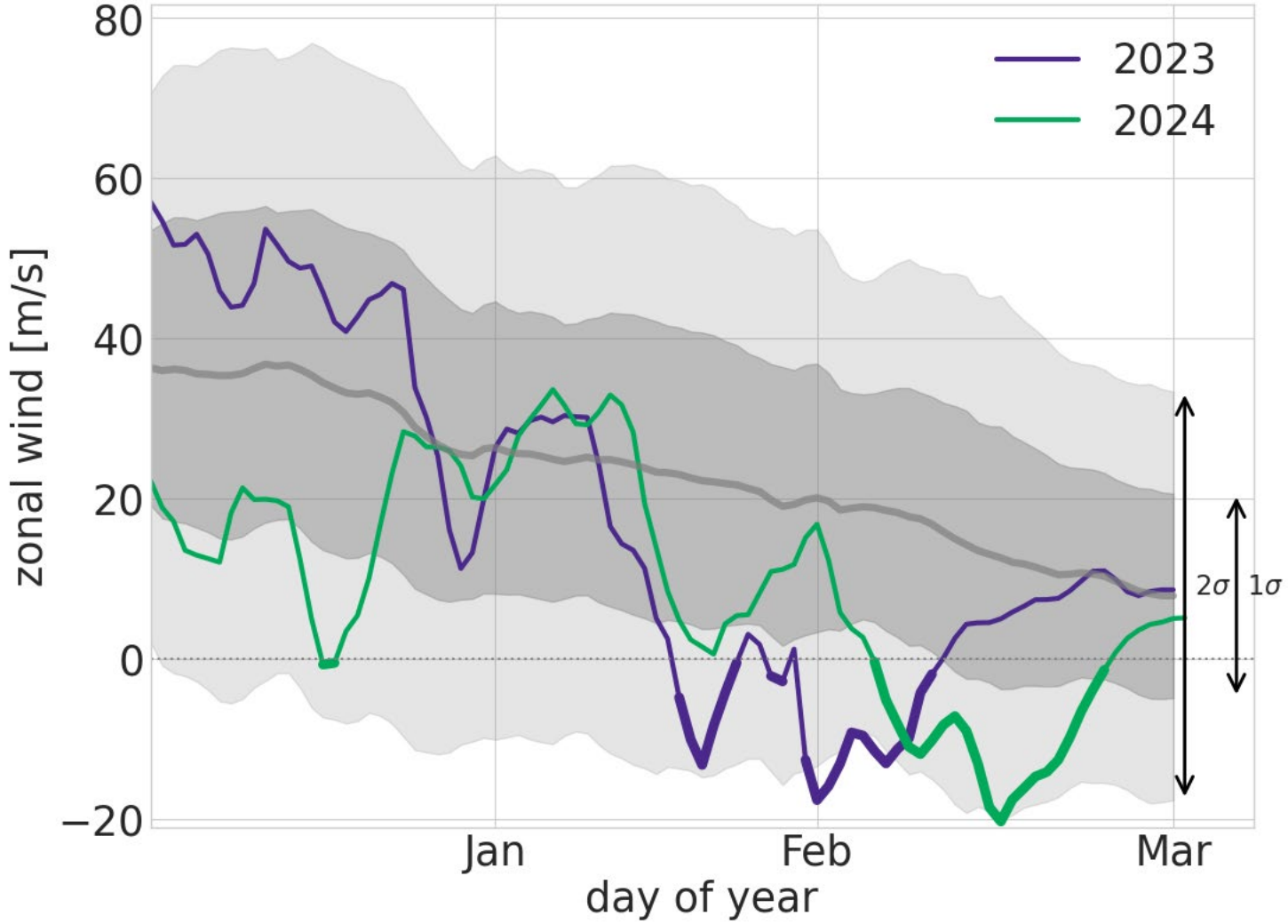

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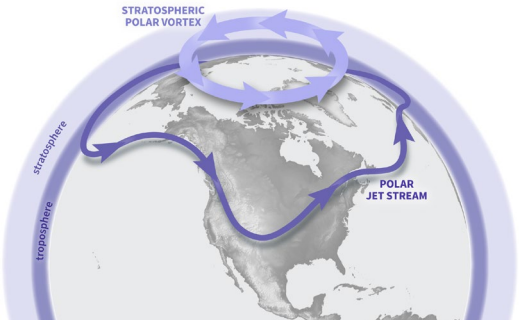

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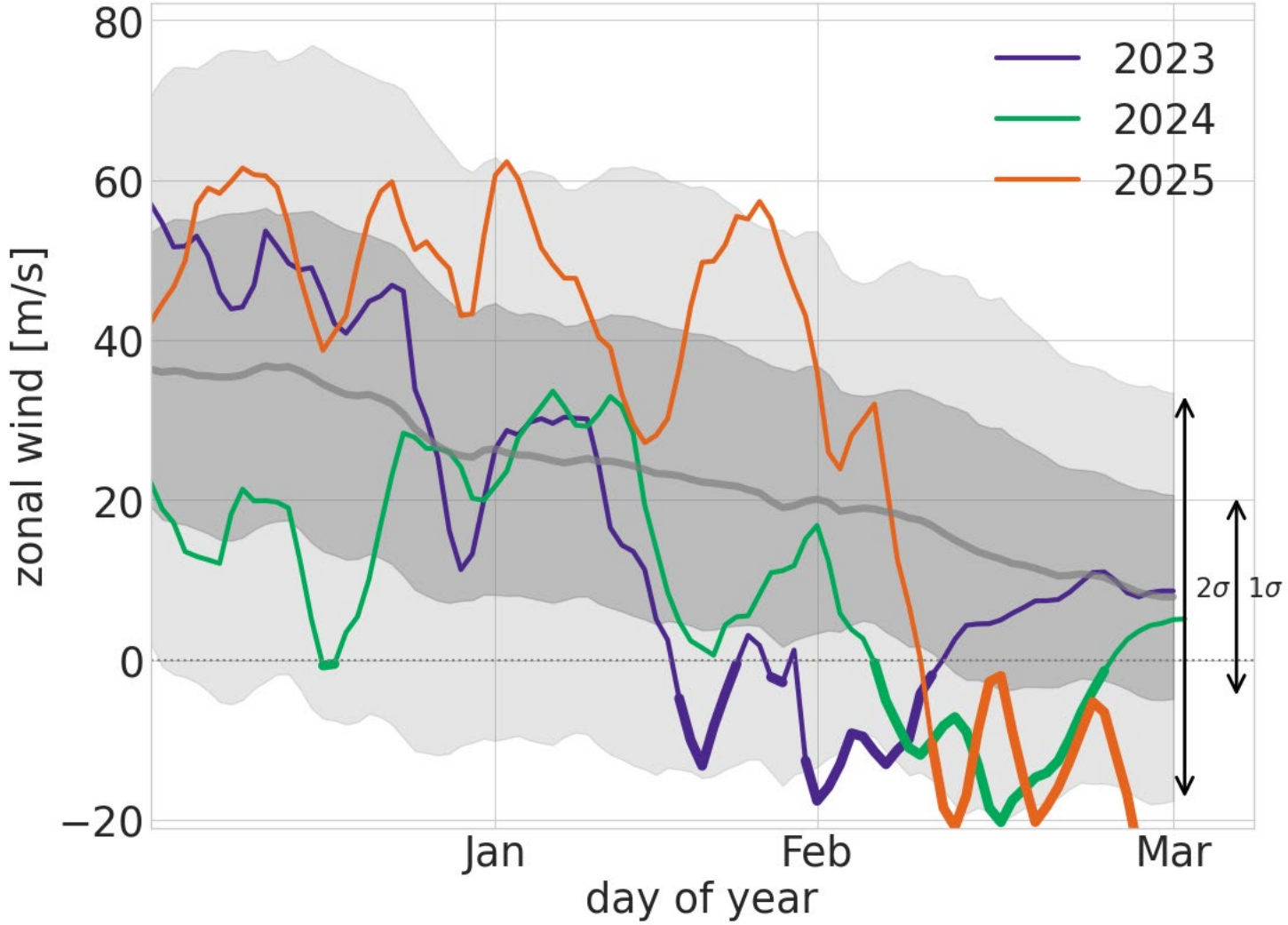

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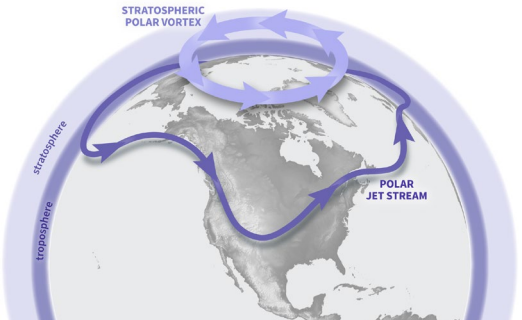
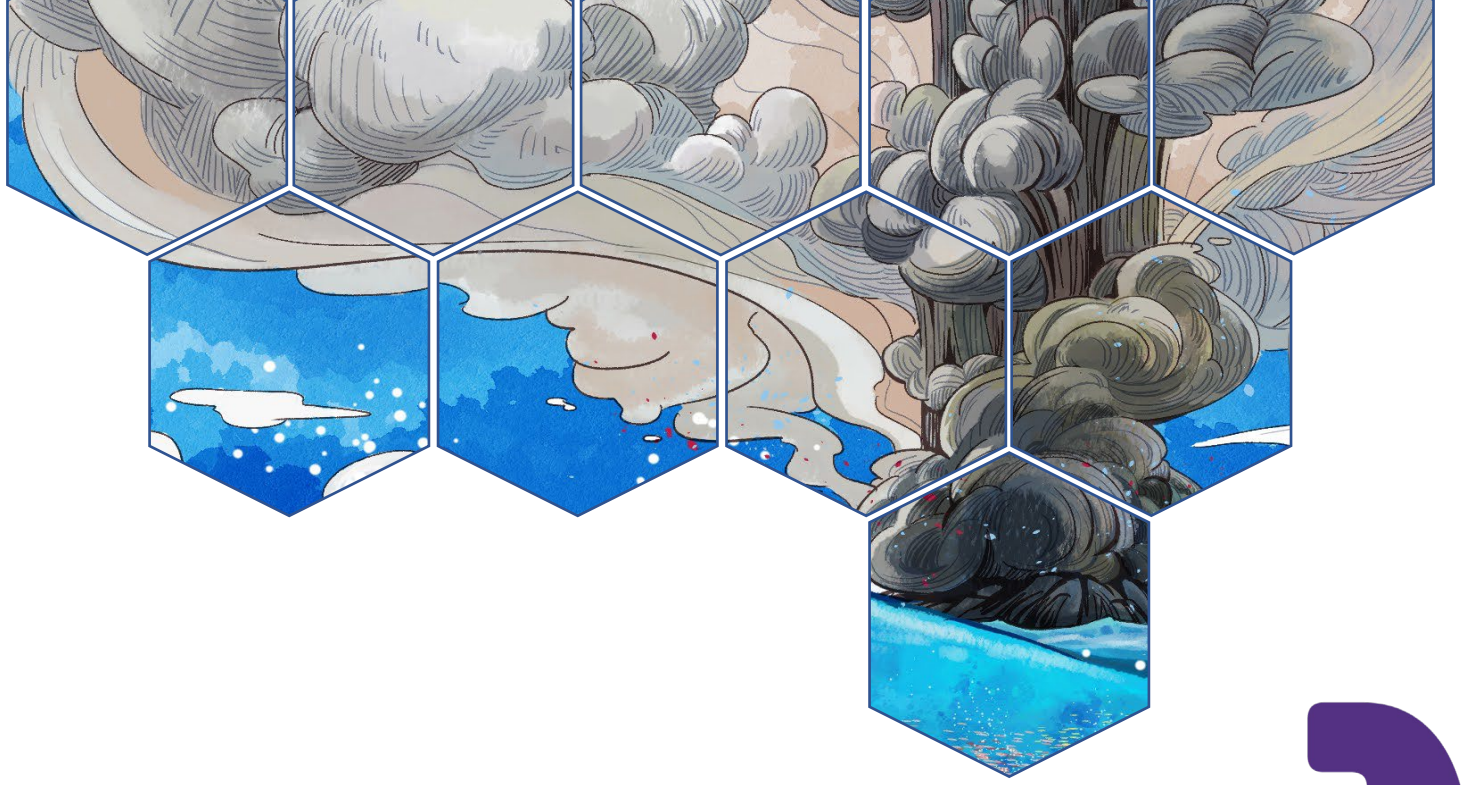
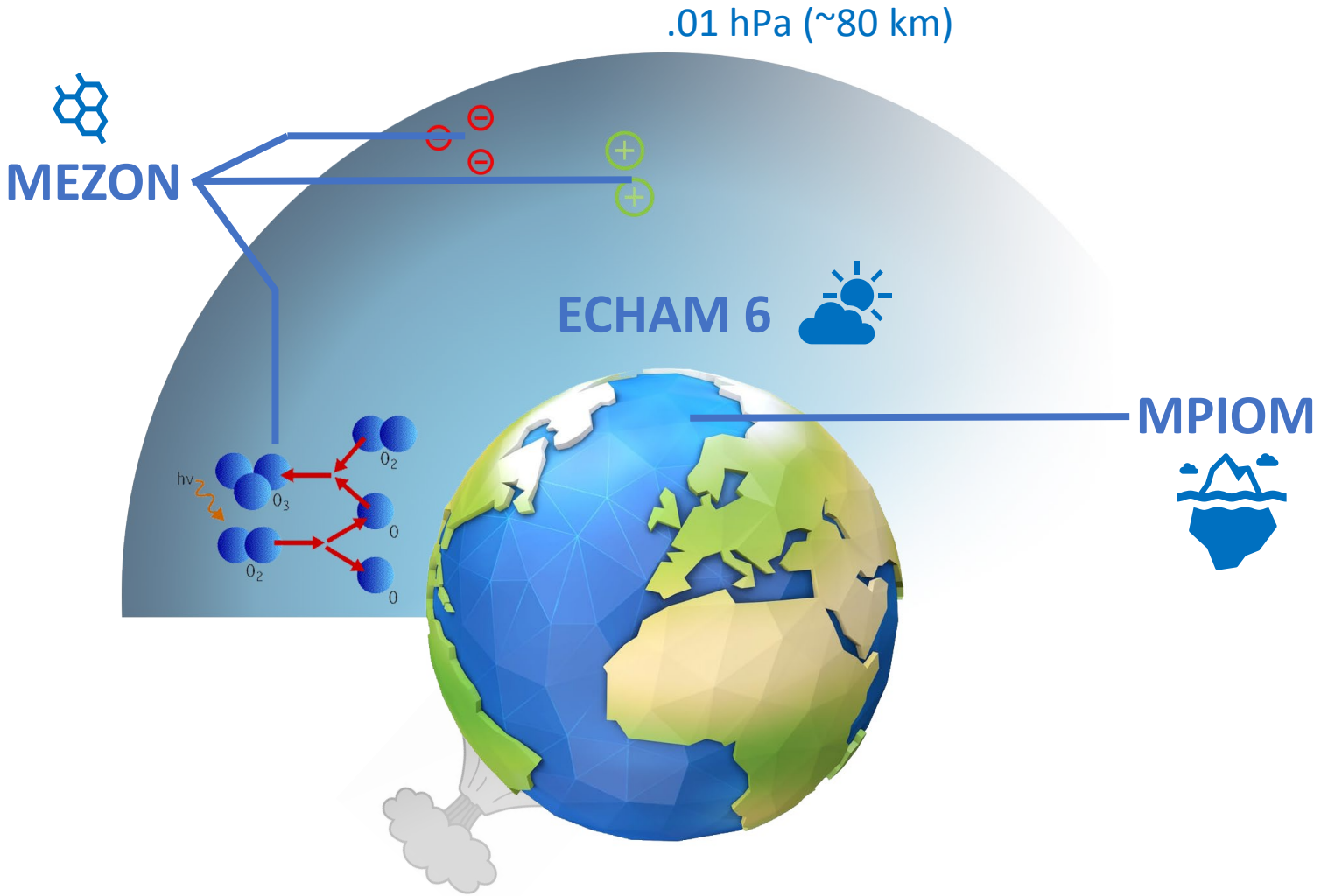




Dataset

Mostly SOCOLv4 ESM in addition to other mostly observational datasets (reanalysis: M2-SCREAM, MERRA2; space-based data records: SWOOSH, GloSSAC)

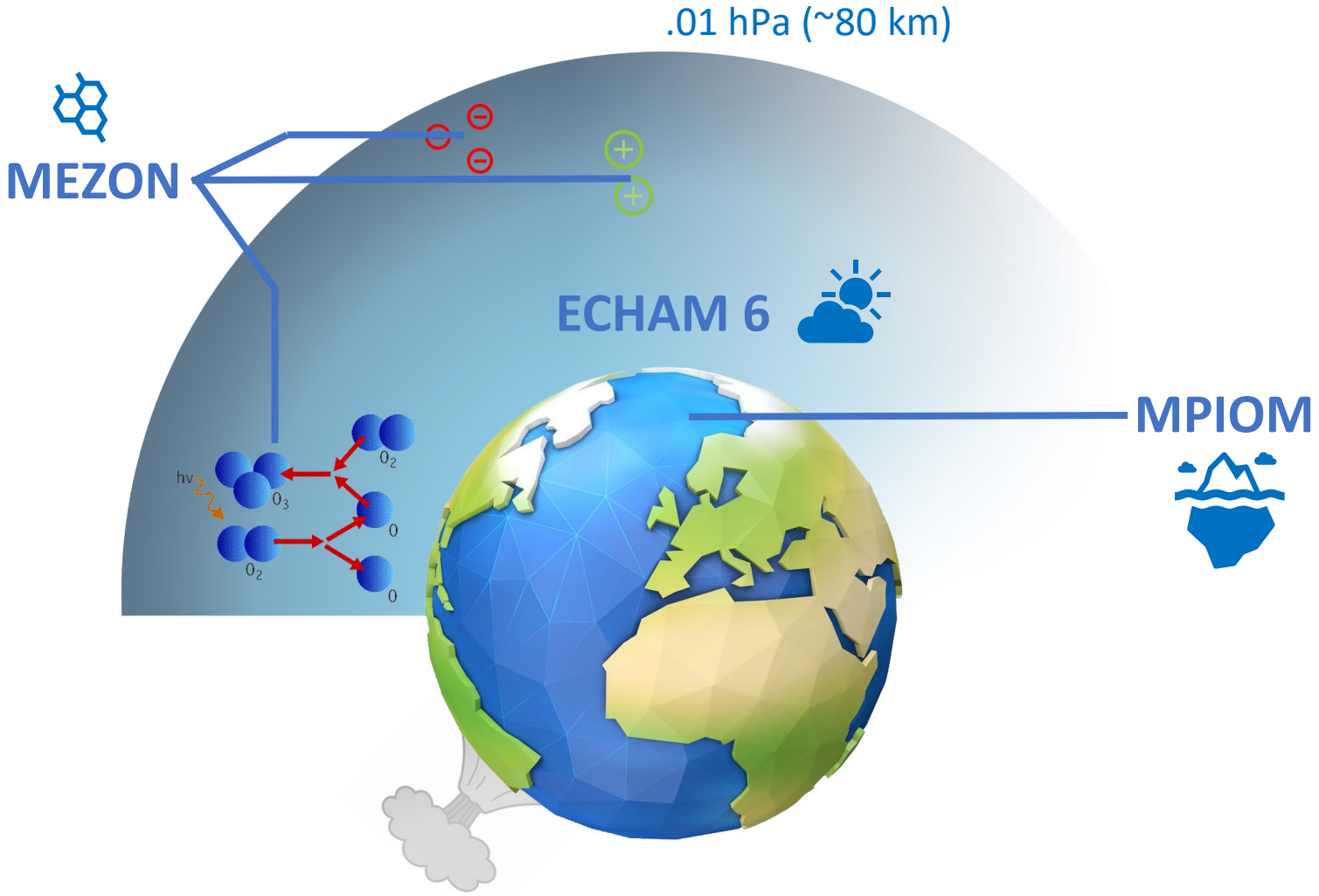
AOCCM SOCOLv4



Sulfate aerosol microphysics AER

Sukhodolov et al., 2021

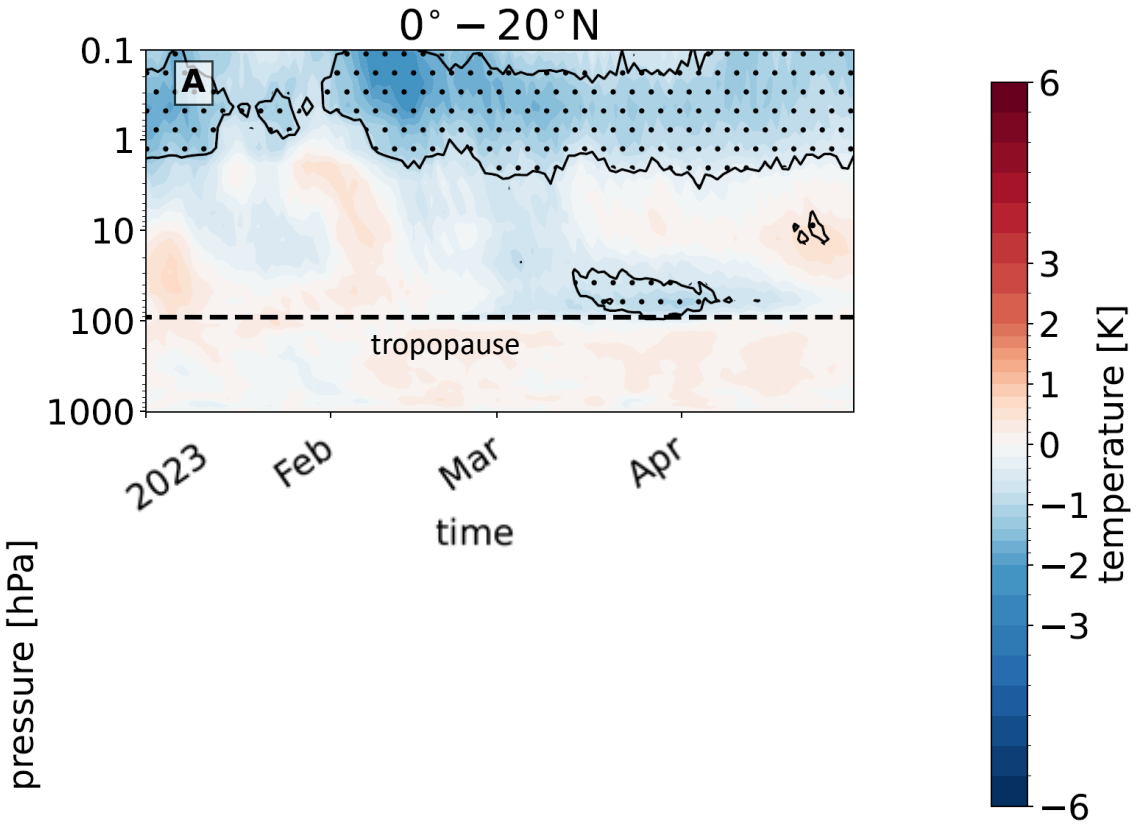
AOCCM SOCOLv4



Sulfate aerosol microphysics AER

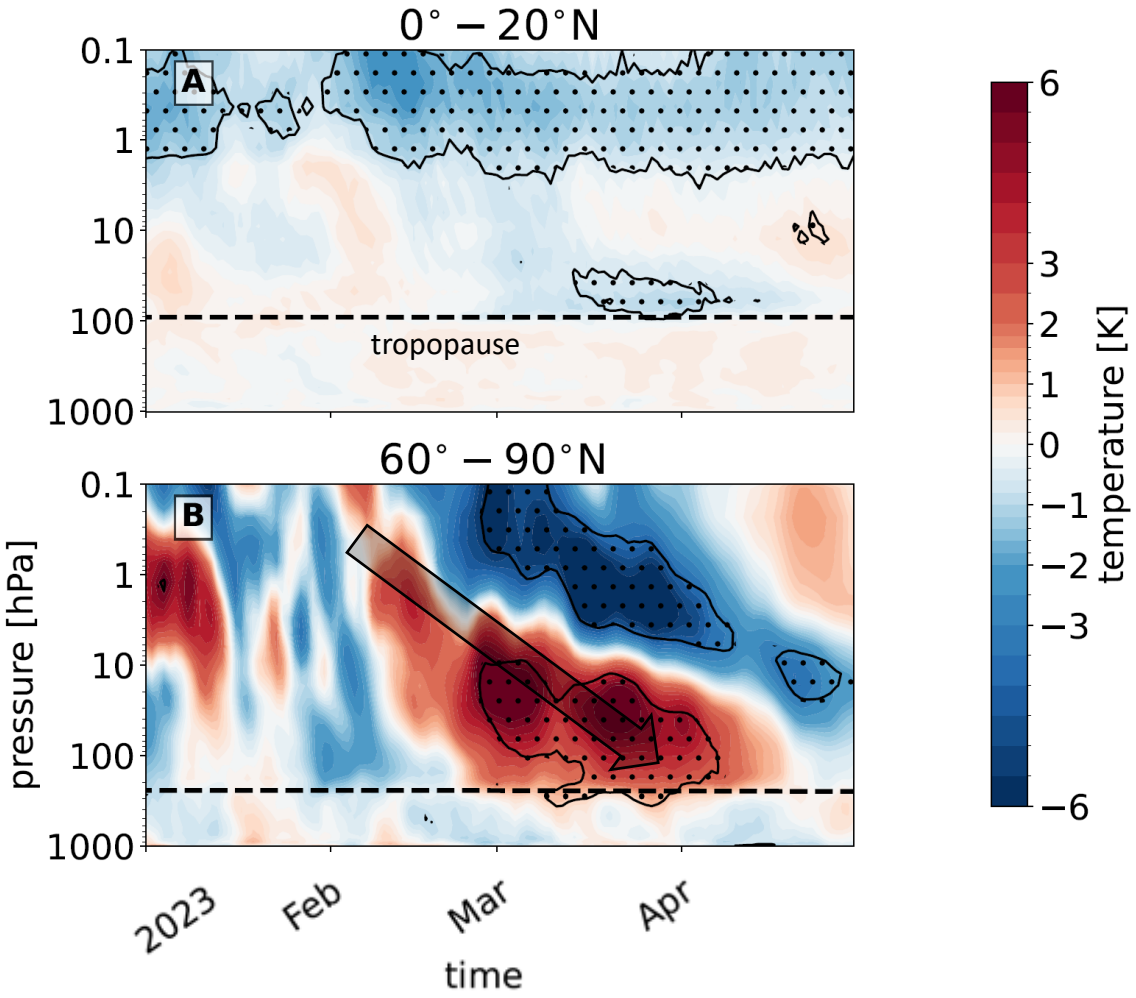
- Fully **free-running** transient set up: 5-year spinup prior to HT ⇒ fully diverged ocean state
- Nudged QBO
- 10 ensemble members with and without the HT (SO_2 + H_2O) forcing
- Water freezing around the emission region (25-30 km) was switched off for several days to mimic 150 Tg

Sukhodolov et al., 2021



Mechanism

Zonally-averaged temperature anomalies



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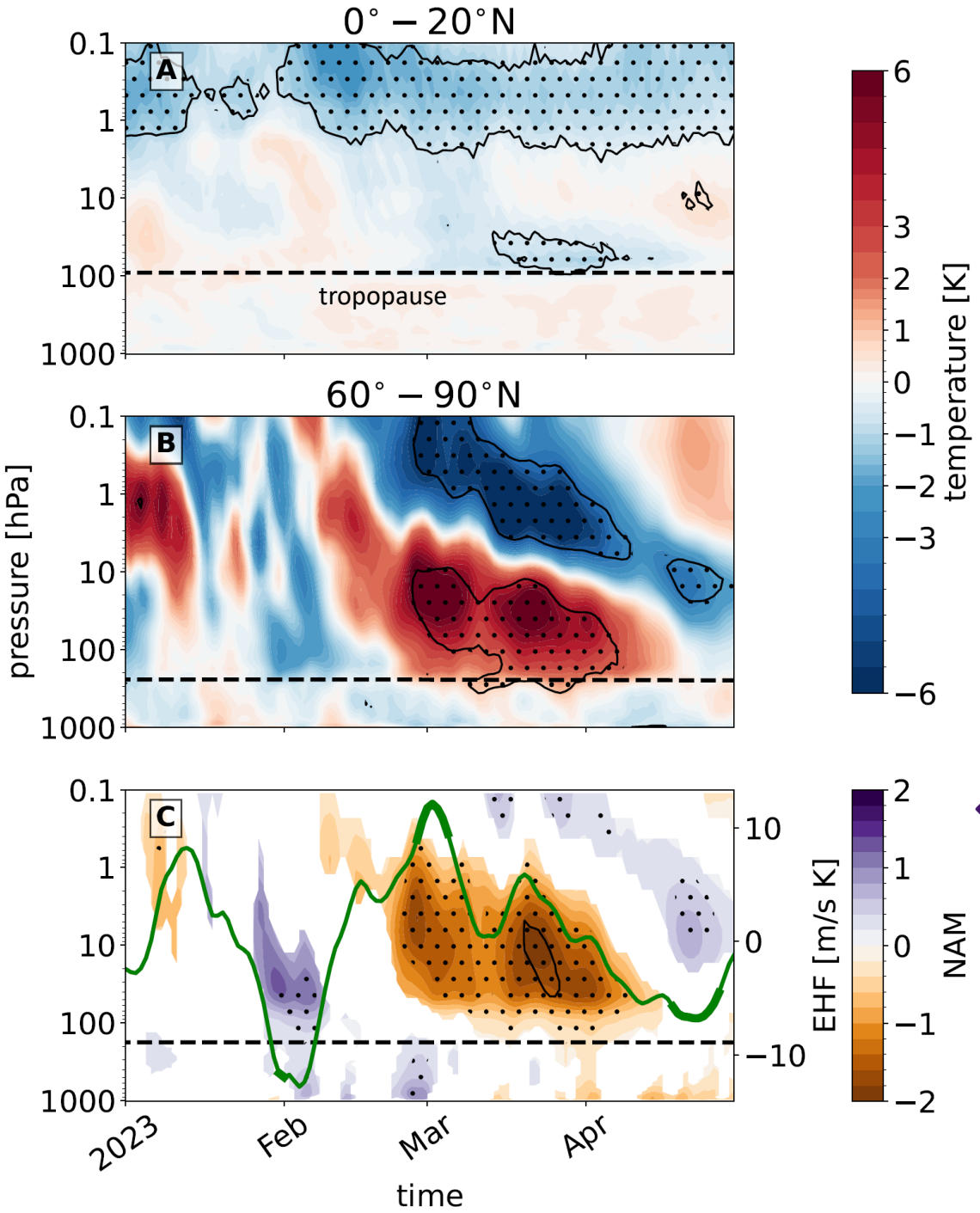


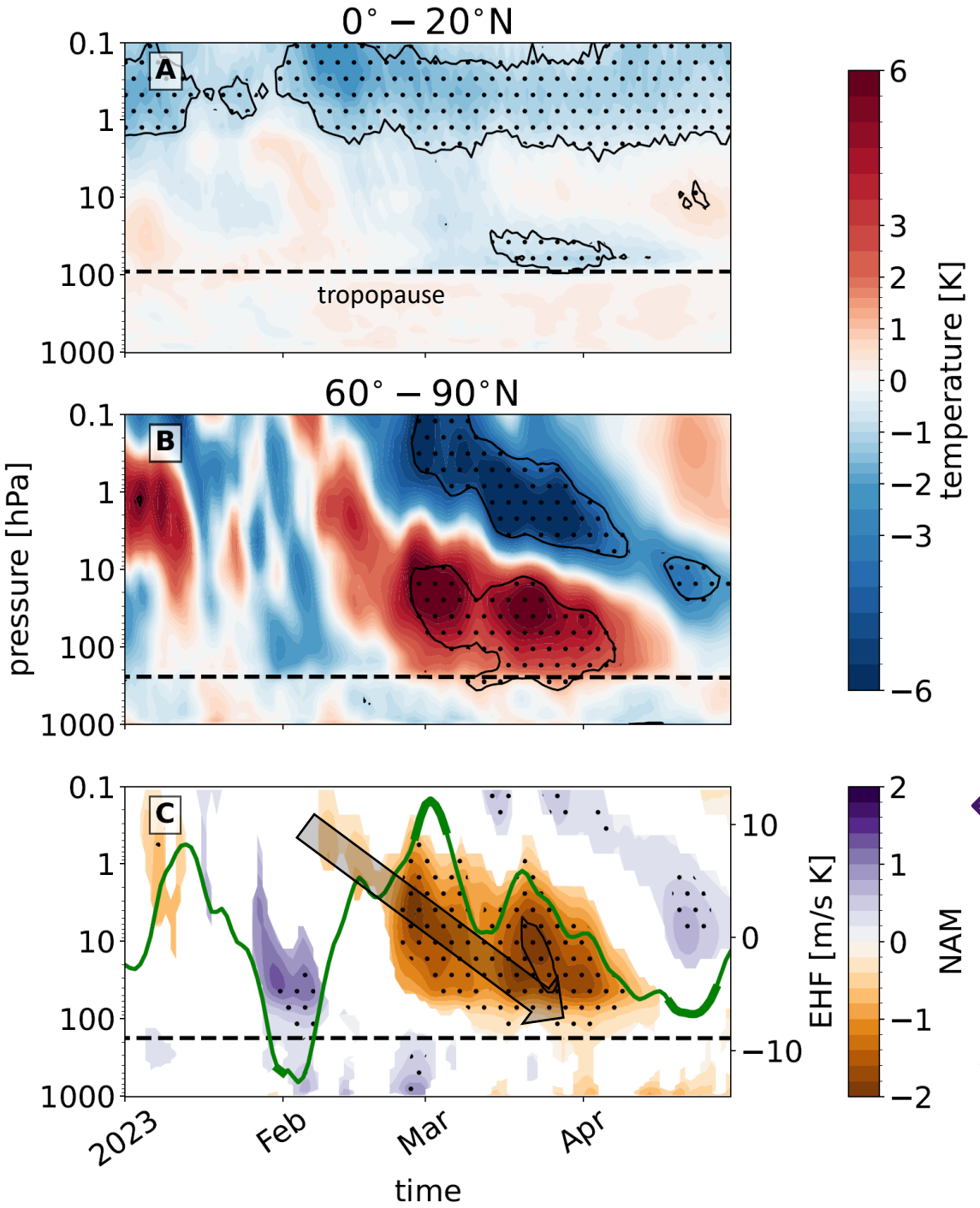
Mechanism

Zonally-averaged temperature anomalies

← **stronger polar vortex**

Northern Annular Mode (NAM)
& Eddy Heat Flux (EHF) anomaly

← **weaker polar vortex**



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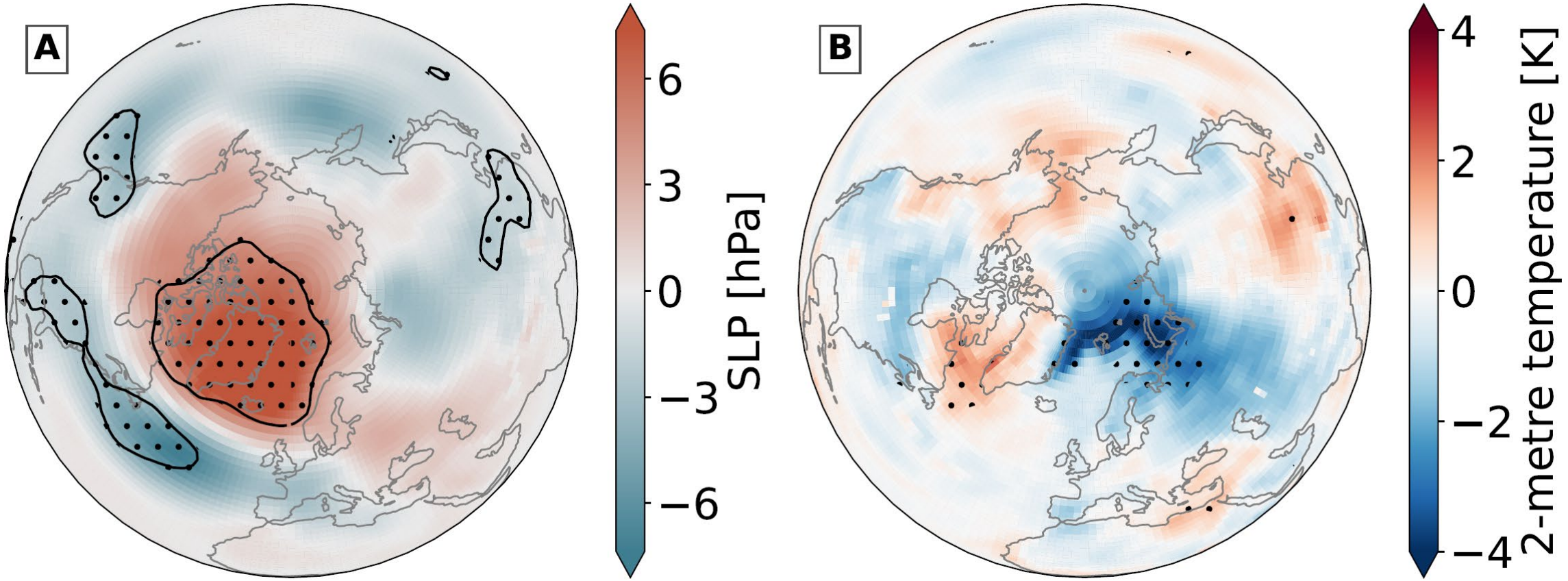
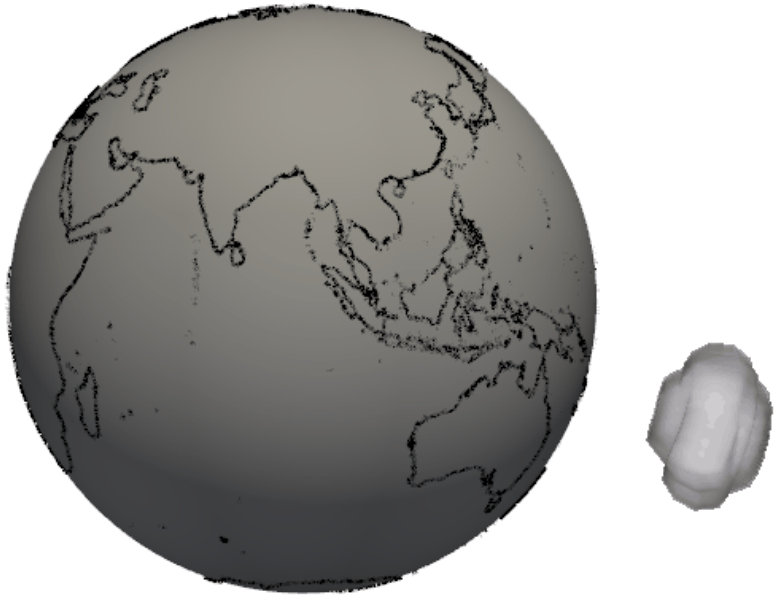
Surface response in April 2023



2022-01-15 Water vapour anomalies in SOCOLv4

Conclusions

- Novel pathway linking water-rich volcanic eruptions to surface climate anomalies



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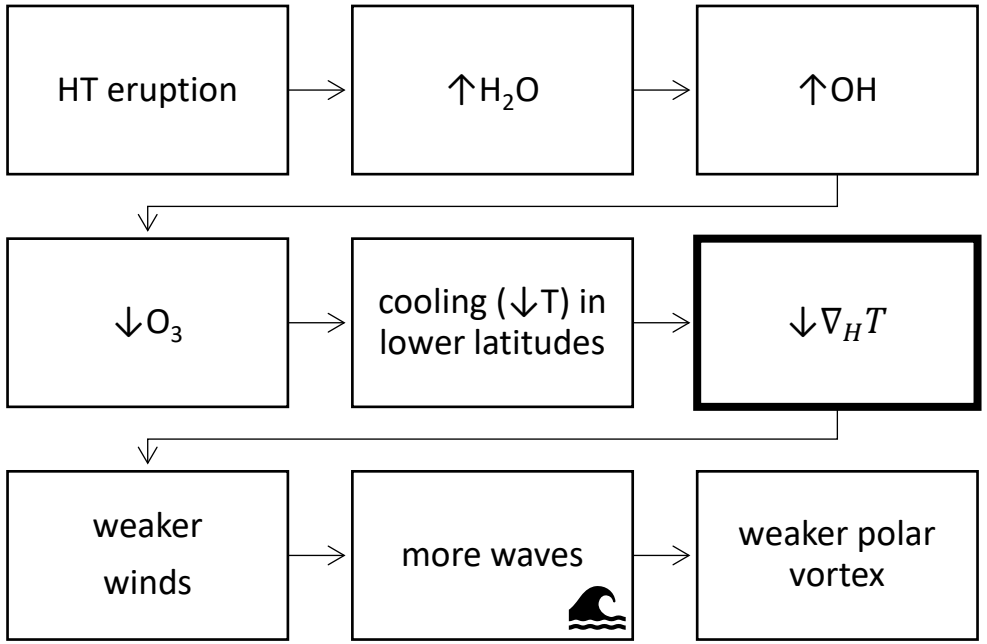
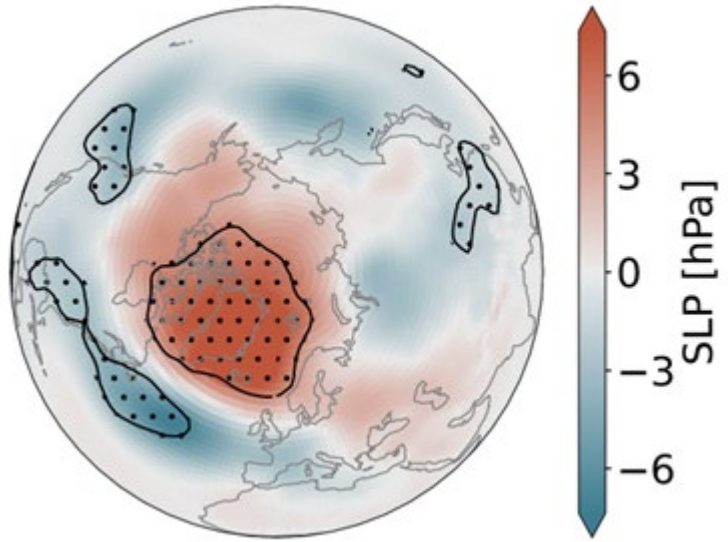
Conclusions

- Novel pathway linking water-rich volcanic eruptions to surface climate anomalies

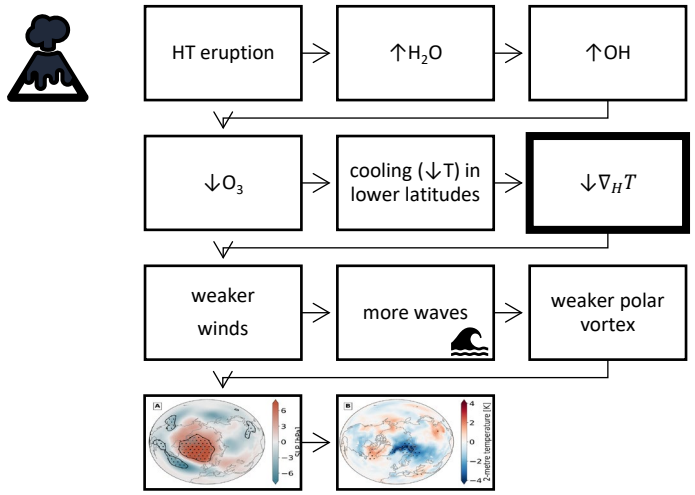


modeled surface response in April 2023



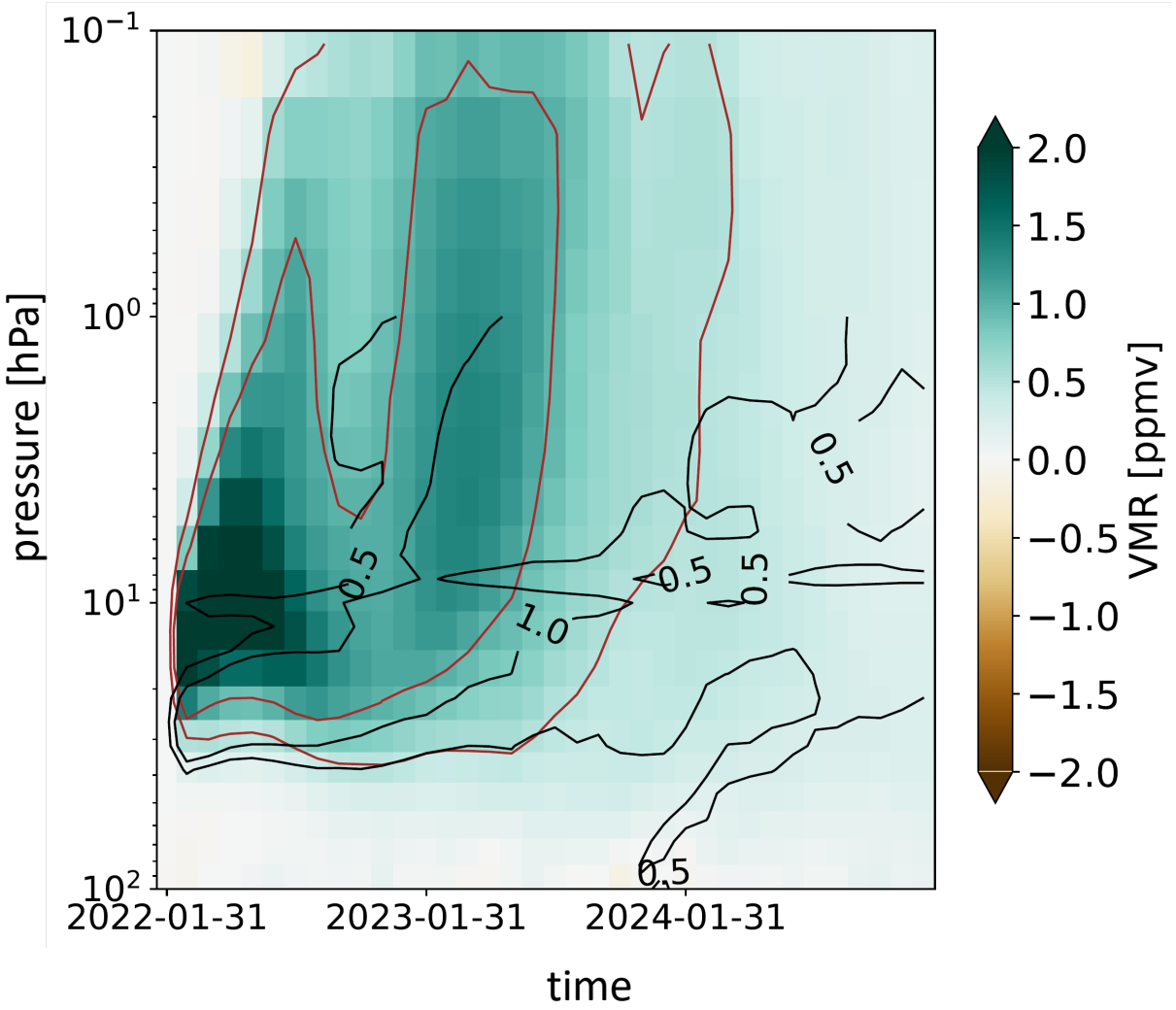
Conclusions

- Novel pathway linking water-rich volcanic eruptions to surface climate anomalies



- In 2023 or 2024 or both?

SOCOLv4 (model) vs **SWOOSH** (obs) water vapour anomalies



Publication available

ACP Letters | Highlight paper | 27 Mar 2025

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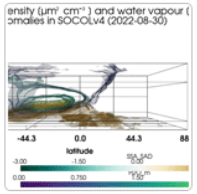

Ales Kuchar, Timofei Sukhodolov, Gabriel Chiodo, Andrin Jörimann, Jessica Kult-Herdin, Eugene Rozanov, and Harald H. Rieder

Abstract

The January 2022 Hunga Tonga–Hunga Ha'apai (HT) eruption injected sulfur dioxide and unprecedented amounts of water vapour (WV) into the stratosphere. Given the manifold impacts of previous volcanic eruptions, the full implications of these emissions are a topic of active research. This study explores the dynamical implications of the perturbed upper-atmospheric composition using an ensemble simulation with the Earth system model SOCOLv4. The simulations replicate the observed anomalies in the stratospheric and lower-mesospheric chemical composition and reveal a novel pathway linking water-rich volcanic eruptions to surface climate anomalies. We show that in early 2023 the excess WV caused significant negative anomalies in tropical upper-stratospheric and mesospheric ozone and temperature, forcing an atmospheric circulation response that particularly affected the Northern Hemisphere polar vortex (PV). The decreased temperature gradient leads to a weakening of the PV, which propagates downward similarly to sudden stratospheric warmings (SSWs) and drives surface anomalies via stratosphere–troposphere coupling. These results underscore the potential of HT to create favorable conditions for SSWs in subsequent winters as long as the near-stratopause cooling effect of excess WV persists. Our findings highlight the complex interactions between volcanic activity and climate dynamics and offer crucial insights for future climate modelling and attribution.

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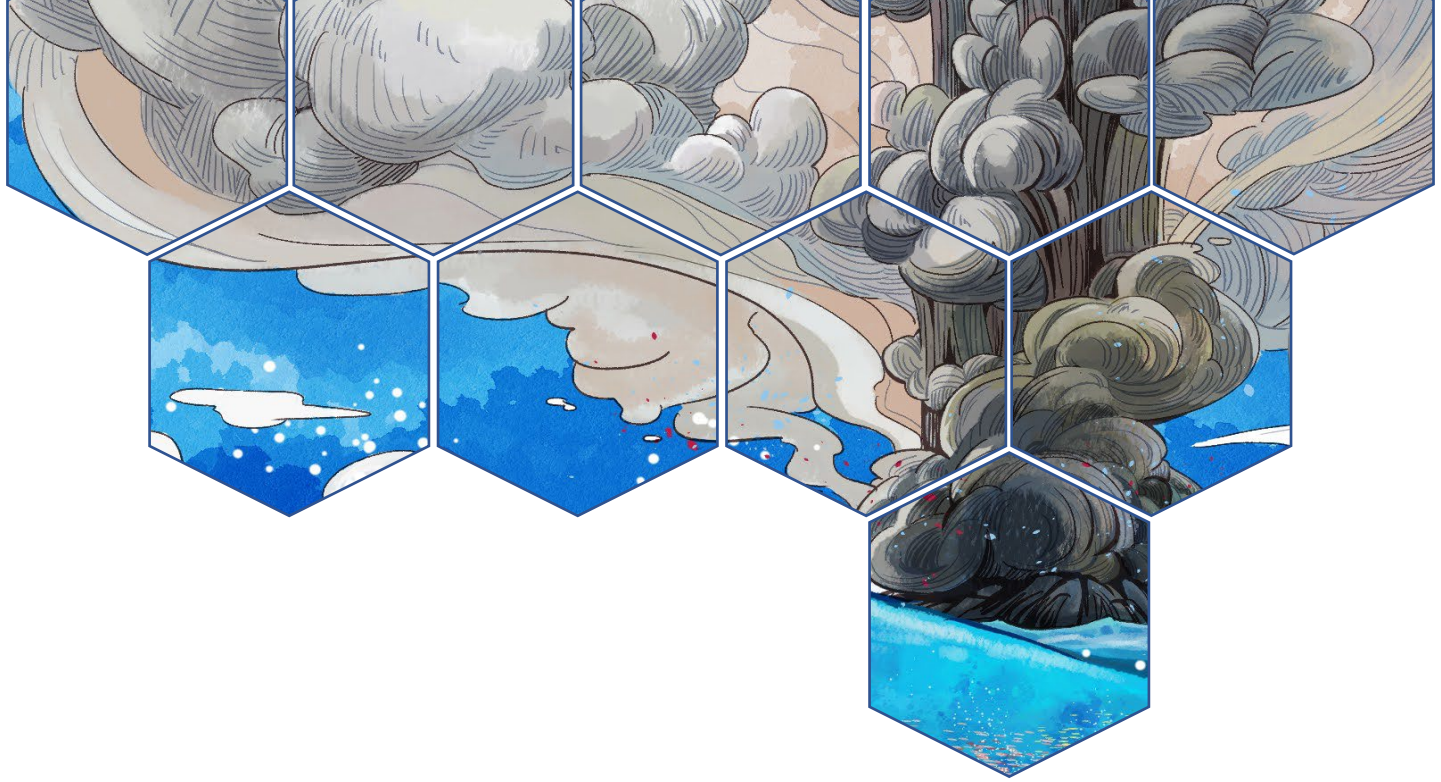
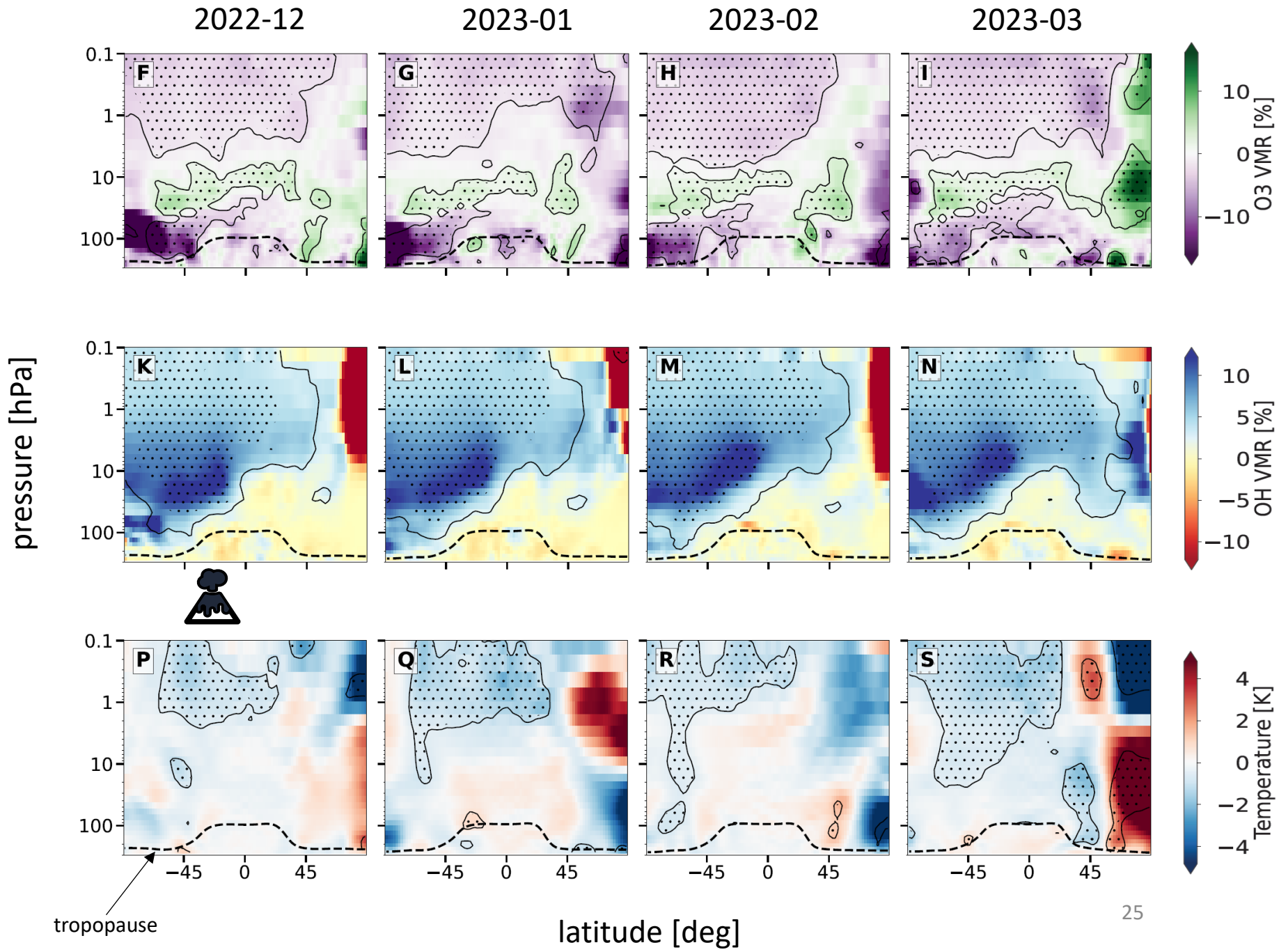


Backup

Ozone mixing ratio anomaly

OH radical mixing ratio anomaly

Temperature anomaly



dots … p-values < 0.05
contours … FDR p-values < 0.3

Surface area density (µm2/cm3) and water vapour (ppmv) anomalies in SOCOLv4 (2022-08-30)

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