

Atmospheric effects of the Hunga volcanic eruption

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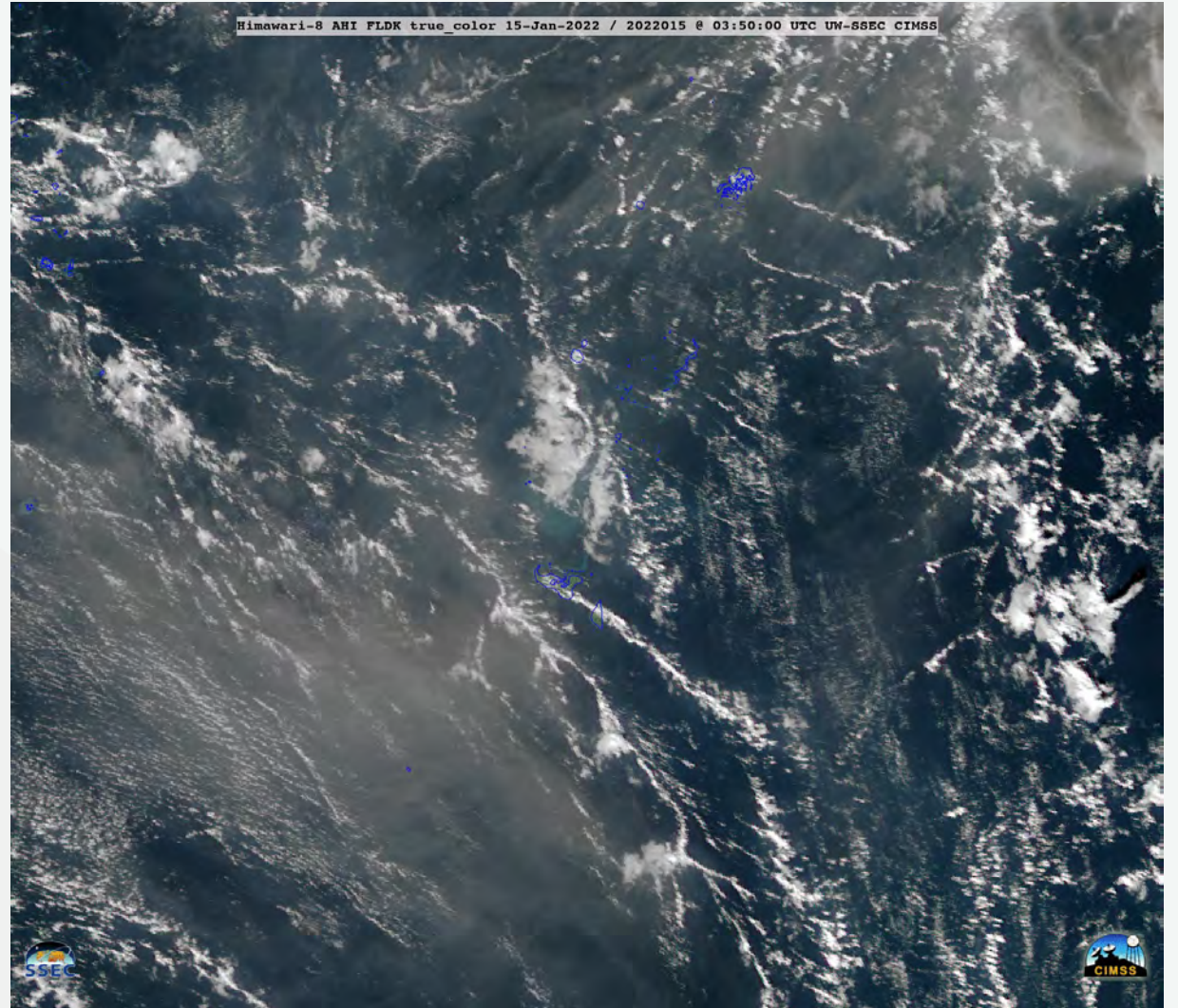
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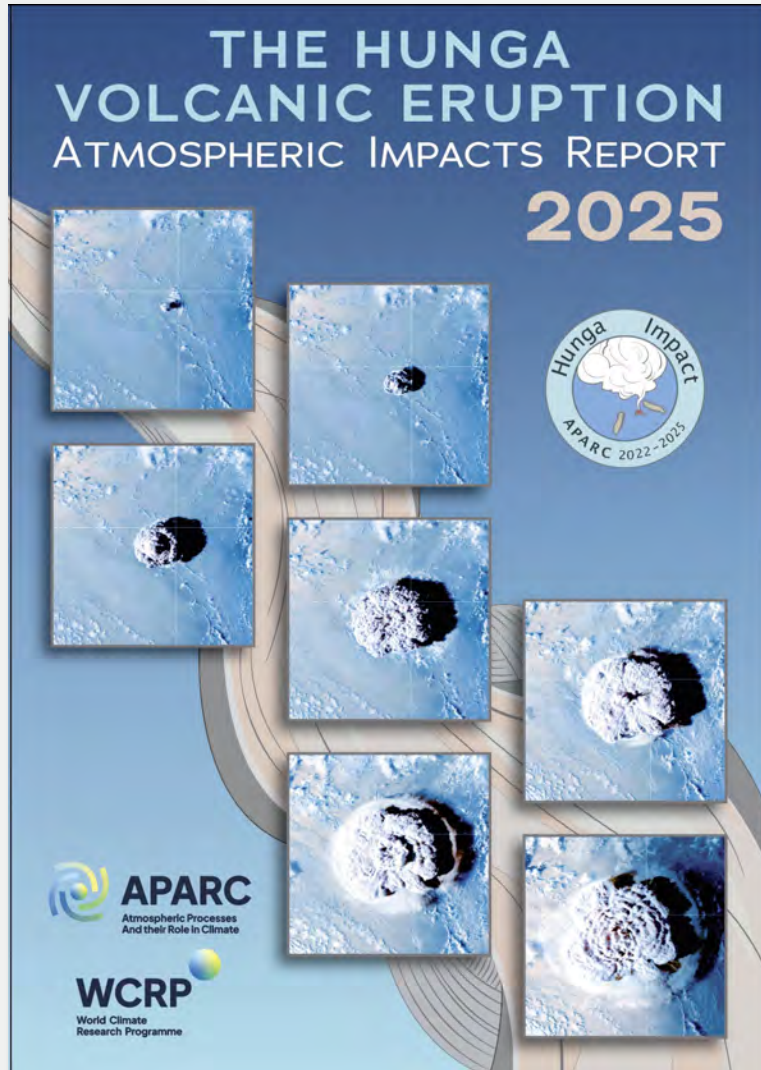
An unprecedented eruption in the satellite era

Jan 15, 2022

Hunga Volcano injected volcanic materials up to 57 km (Proud et al., 2022, Science). This is the first time a plume has been seen to penetrate the stratopause.



APARC Hunga Impact Activity 2022-2025

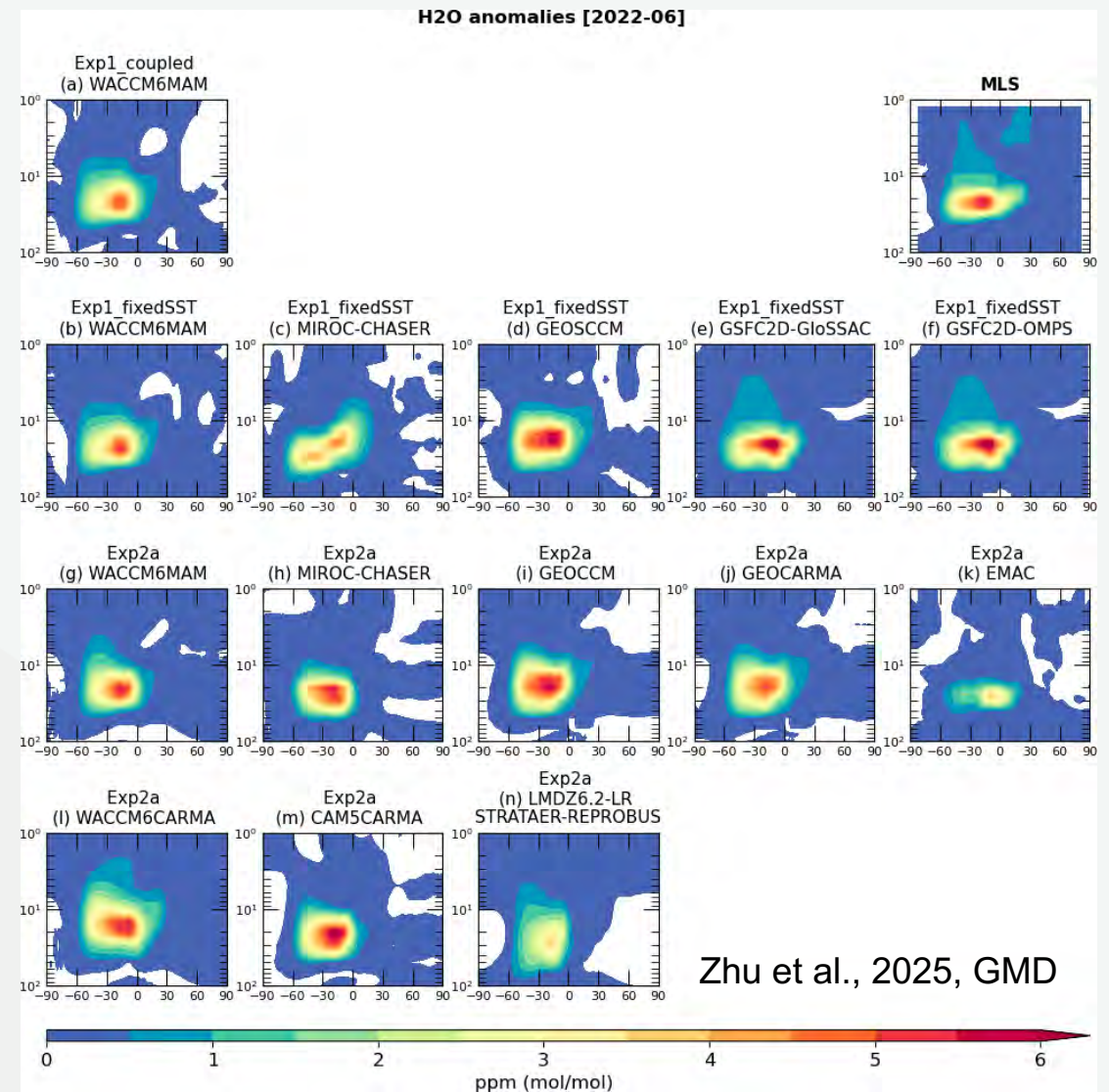


Starting November 2022, A 3-year APARC (Atmospheric Processes And their Role in Climate) activity was organized, aiming to write a special Hunga impacts report for publication in December 12, 2025. The report will directly feed into the upcoming 2026 [UNEP/WMO Scientific Assessment of Ozone Depletion](#) report, providing a benchmark synthesis of the impacts from this eruption.

APARC, 2025: The Hunga Volcanic Eruption Atmospheric Impacts Report. Yunqian Zhu, Graham Mann, Paul A. Newman, and William Randel (Eds.), APARC Report No. 11, WCRP-10/2025, doi: [10.34734/FZJ-2025-05237](https://doi.org/10.34734/FZJ-2025-05237), available at www.aparc-climate.org/publications/

Hunga Multi-model Intercomparison Project

- Hunga Tonga-Hunga Ha'apai volcano impact Model Observation Comparison (**HTHH-MOC**):
- We have 14 climate models participating in three experiments that feed in the Hunga Report chapters to help answer scientific questions, as well as for future public uses.



Worldwide participants

Co-chairs

Yunqian Zhu, Graham Mann, Paul Newman, William Randel

Lead authors for seven chapters

Simon Carn, Anja Schmidt, Elizabeth Asher, Bernard Legras, Sergey Khaykin, Adam Bourassa, Xinyue Wang, Lawrence Coy, Freja F. Østerstrøm, Michelle L. Santee, Corwin Wright, Jia Yue, Gera Stenchikov, Mark R. Schoeberl

And over 150 scientists' contributions.

CIESRDS participation

- Co-chair: Yunqian Zhu (CSL)
- Lead author for ch2: Elizabeth Asher (GML)
- Co-authors: Alexandre Baron and Ewa M. Bednarz (CSL)
- Reviewer: Eric Jensen (CSL)
- Editorial team: Catherine Burgdorf Rasco (CSL)

NOAA Tonga Rapid Response Experiment – TR²Ex

January 19 – 28, 2022

Remote Sensing

In-Situ

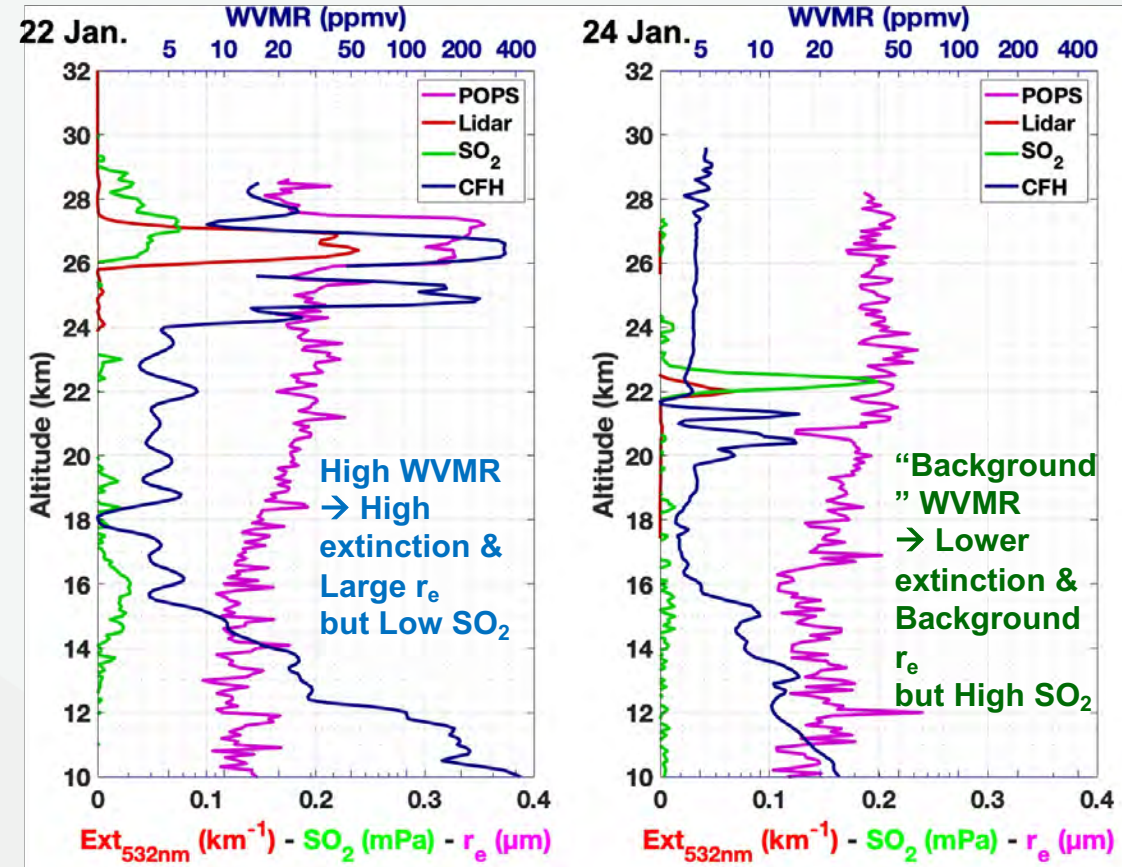
3 Lidar systems

>15 Balloon launches

ECC	Ozone
POPS	Optical Particle Counter
COBALD	Aerosol Backscatter
SO ₂ sonde	SO ₂
LOAC	Optical Particle Counter
CFH	Water Vapor



CIERSDS Staff: Elizabeth Asher, Micheal Todt, Alex Baron



Instrumental synergy has enabled the detection of rapid conversion of SO₂ gas into sulfate aerosols in a wet plume.

Highlight of the Hunga Report

- Increased global stratospheric water vapor by ~10% (still present in 2025)
- Caused 0.5–1°C cooling in mid-to-upper stratosphere, >1°C in mesosphere
- Minor impact on Antarctic ozone hole and surface climate
- Surface cooling (~0.05°C) was indistinguishable from natural variability
- 2023–2024 record temperatures were *not* caused by the eruption

CIESRDS Lead Hunga peer review publications

- Asher et al., Unexpected rapid aerosol formation in the Hunga Tonga plume, *Proceedings of the National Academy of Sciences*, doi:10.1073/pnas.2219547120, 2023.
- Baron et al., Early evolution of the stratospheric aerosol plume following the 2022 Hunga Tonga-Hunga Ha'apai eruption: Lidar observations from Reunion (21°S, 55°E). *Geophysical Research Letters*, 50, e2022GL101751. <https://doi.org/10.1029/2022GL101751>, 2023
- Bednarz et al., Indirect climate impacts of the Hunga eruption, *Atmos. Chem. Phys.*, 26, 197–215, <https://doi.org/10.5194/acp-26-197-2026>, 2026
- Bednarz et al., Multi-model assessment of impacts of the 2022 Hunga eruption on stratospheric ozone and its chemical and dynamical drivers, *EGUsphere* [preprint], <https://doi.org/10.5194/egusphere-2025-4609>, 2025.
- Zhu et al., Hunga Tonga-Hunga Ha'apai volcano impact Model Observation Comparison (HTHH-MOC) project: Experiment protocol and model descriptions, *Geophysical Model Development*, doi:10.5194/gmd-18-5487-2025, 2025.
- Zhu et al., Perturbations in stratospheric aerosol evolution due to the water-rich plume of the 2022 Hunga-Tonga eruption, *Communications Earth & Environment*, doi:10.1038/s43247-022-00580-w, 2023.
- Zhu et al., Stratospheric ozone depletion inside the volcanic plume shortly after the 2022 Hunga Tonga eruption, *Atmospheric Chemistry and Physics*, doi:10.5194/acp-23-13355-2023, 2023.
- And serve as co-authors to more than 10 other peer review publications: Quaglia et al., 2026, ACP; Millet et al., 2025, ACP; Sicard et al., 2025, ACP; Zhuo et al., 2025, ACP; Deshler et al., 2024, GRL; Li et al., 2024, GRL; Zhang et al., 2024a, GRL; Zhang et al., 2024b, JGR; Evan et al., 2023, Science; Wang et al., 2023, JGR; Yu et al., 2023, JGR.

Thank you!



University of Colorado Boulder

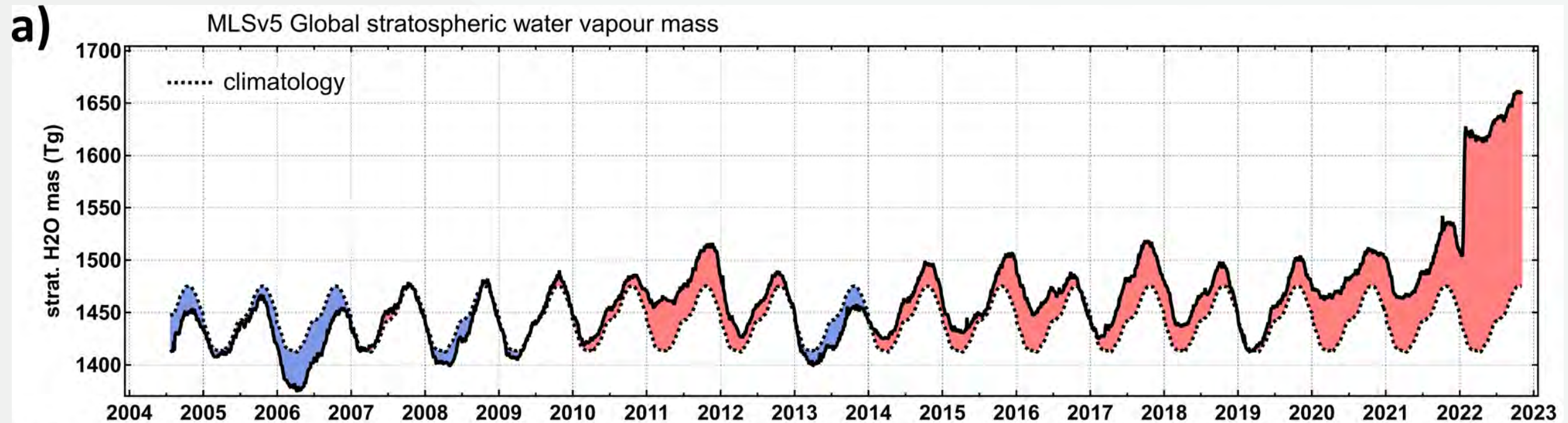


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Highlight of the Hunga Report 1

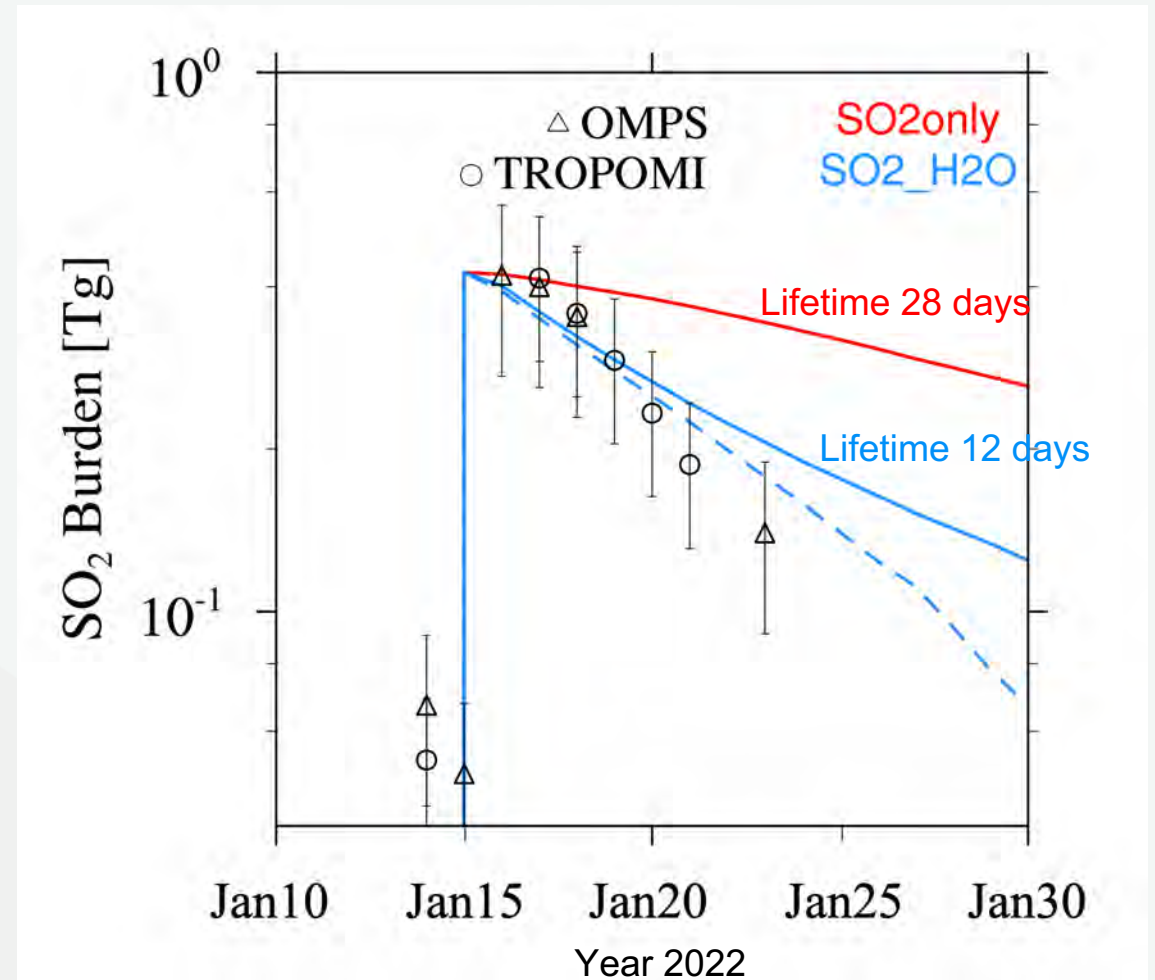
The 2022 Hunga volcano was a high-magnitude (Volcanic Explosivity Index 6) submarine eruption unique in the satellite era, Which injected an unprecedented amount of water into the stratosphere (~ 150 Tg).



Highlight of the Hunga Report 2

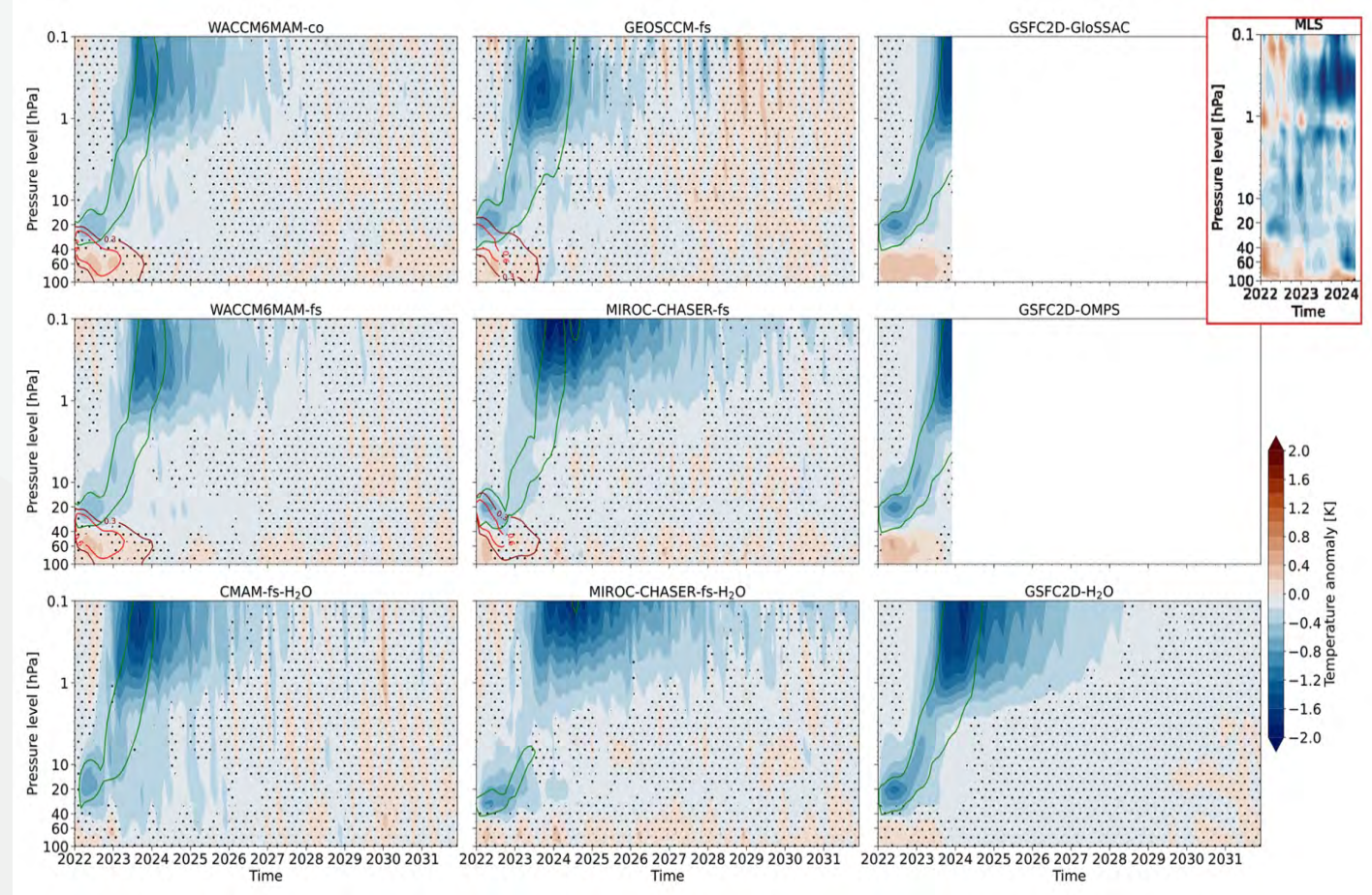
Because of the large amount of water vapor, the water injection significantly shortens the SO_2 lifetime by providing abundant OH.

Sulfate aerosol formed unusually fast inside the water-rich plume.



Highlight of the Hunga Report 3

Hunga water vapor led to a cooling of 0.5–1 K in the global mid-to-upper stratosphere over the first two years after the eruption and > 1 K in the mesosphere afterwards.

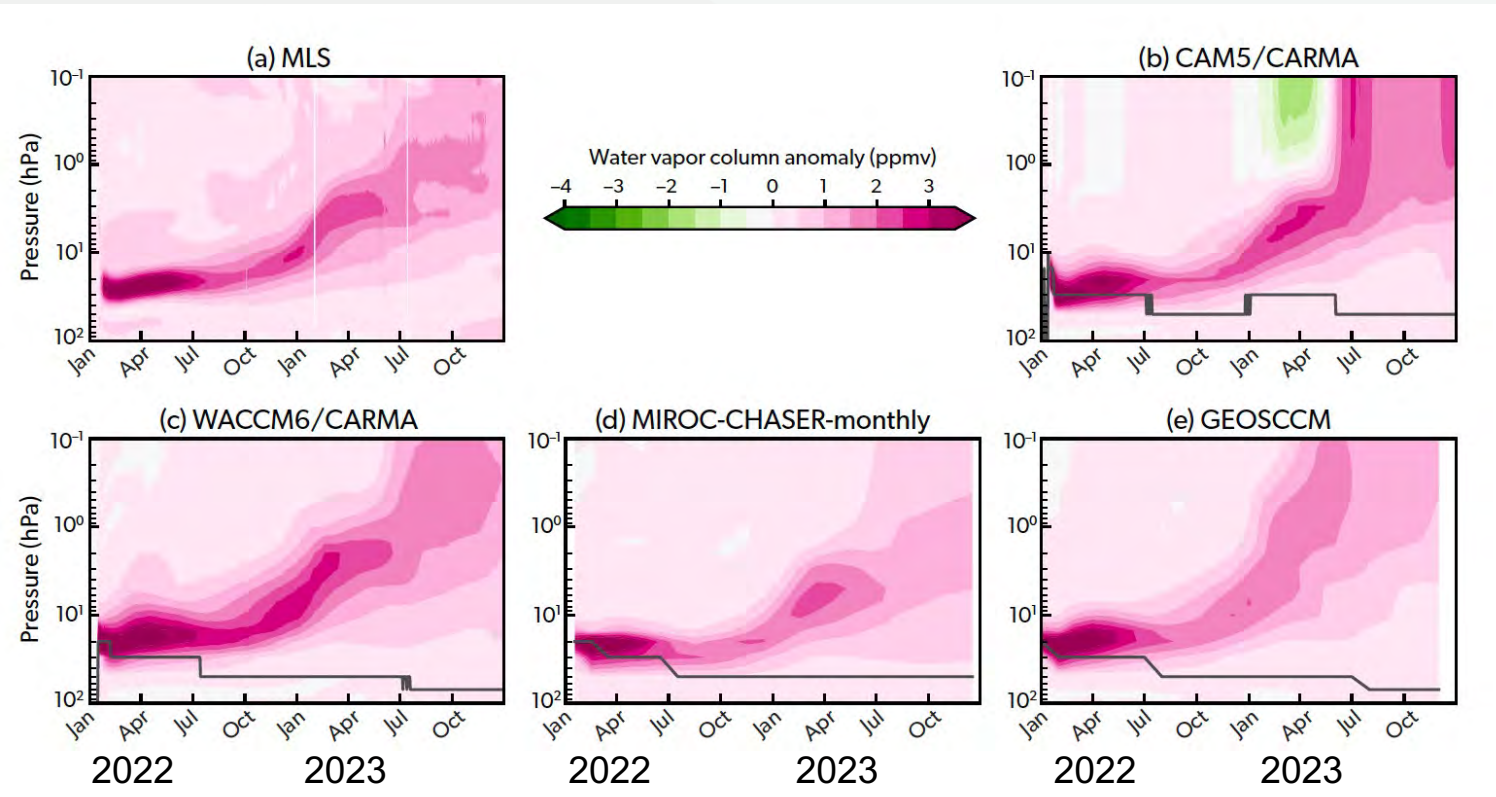


This temperature response has been reproduced by six global models participating HTHH-MOC. (Zhuo et al., 2025, ACP)

Highlight of the Hunga Report 4

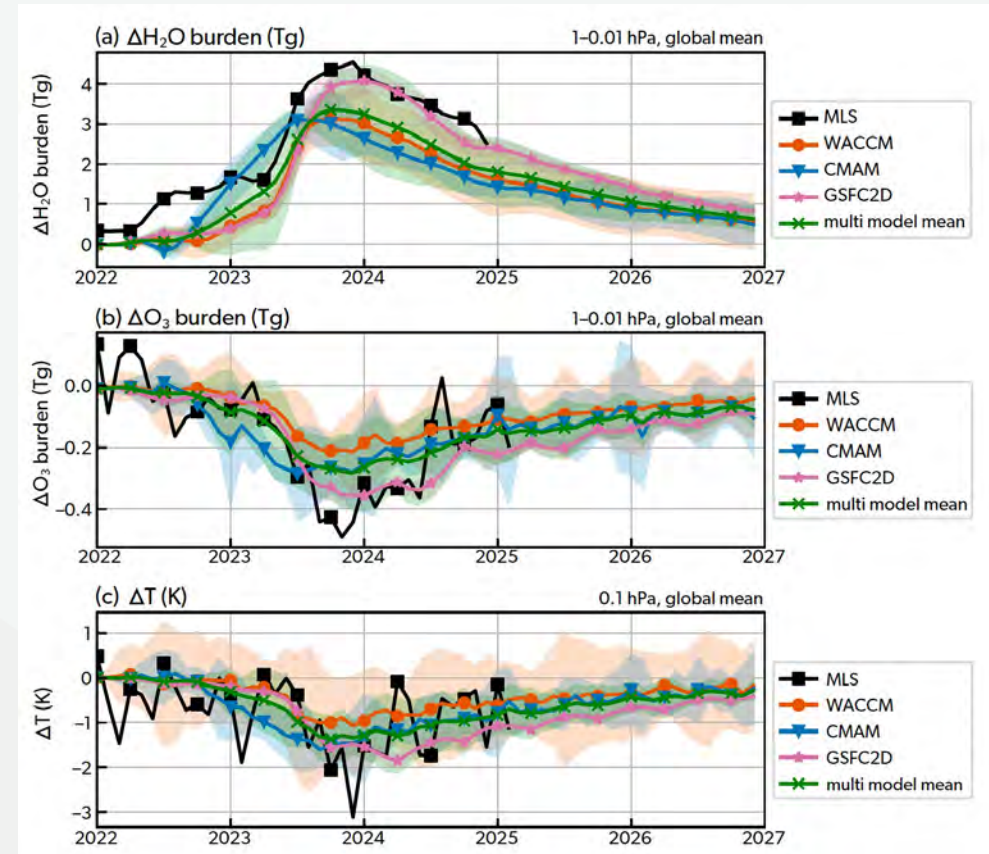
Besides temperature change, Global chemistry–climate models also consistently reproduce key aspects of the observed the middle-atmospheric transport and mesospheric ozone response.

water-vapor transport



APARC Hunga Report, Ch3. Figure Courtesy: Valentina Aquila

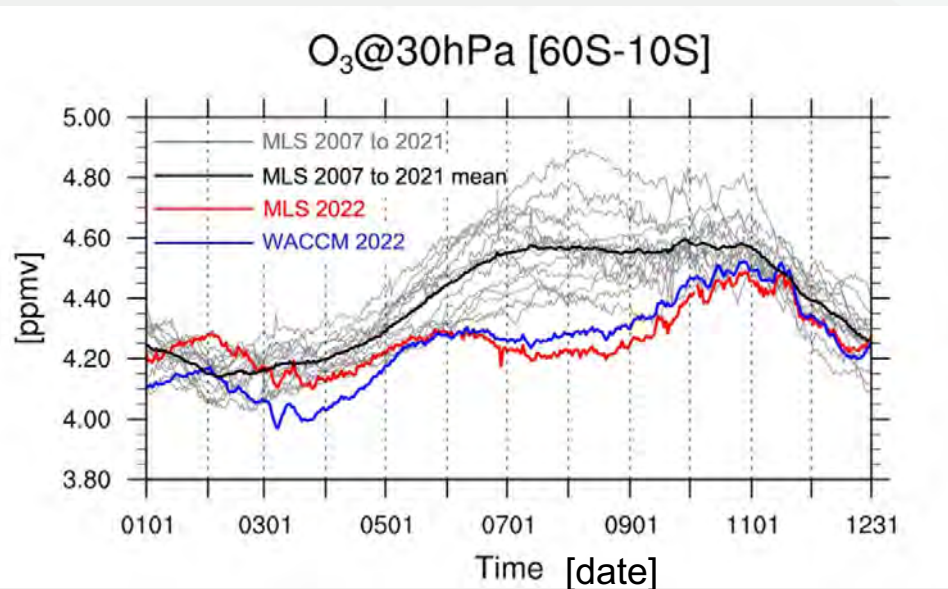
Mesospheric water vapor and responses



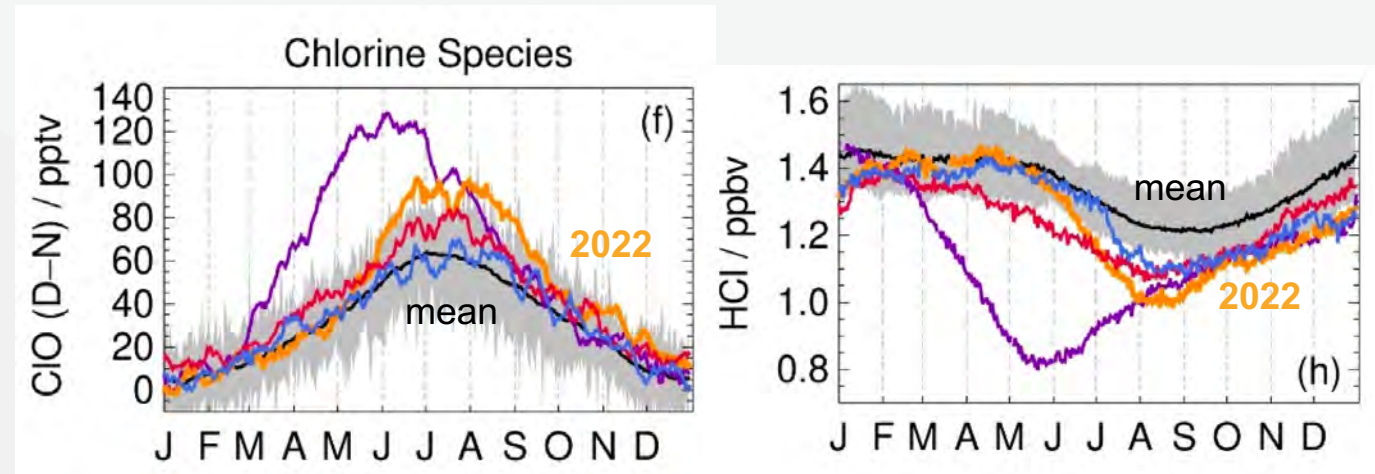
APARC Hunga Report, Ch6. Figure Courtesy: Wandu Yu

Highlight of the Hunga Report 5

In the months following the eruption, substantial perturbations in stratospheric ozone and related trace gases were observed throughout the Southern Hemisphere caused by Hunga altered dynamics and chemistry.



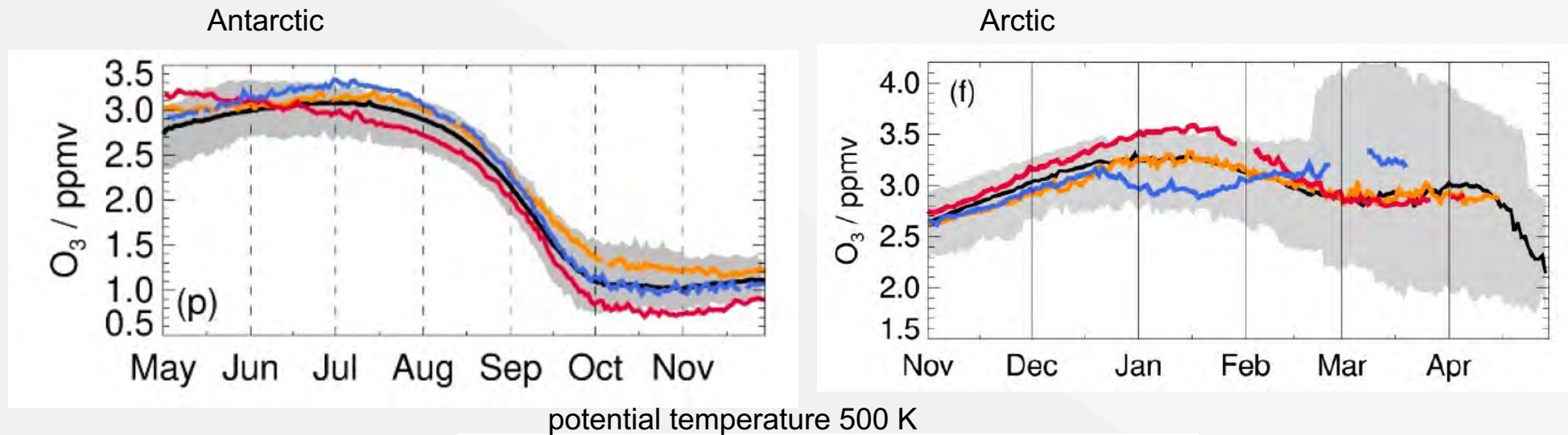
Zhang et al., (2024), GRL



APARC Hunga Report Ch5.; Santee et al., 2023, JGR

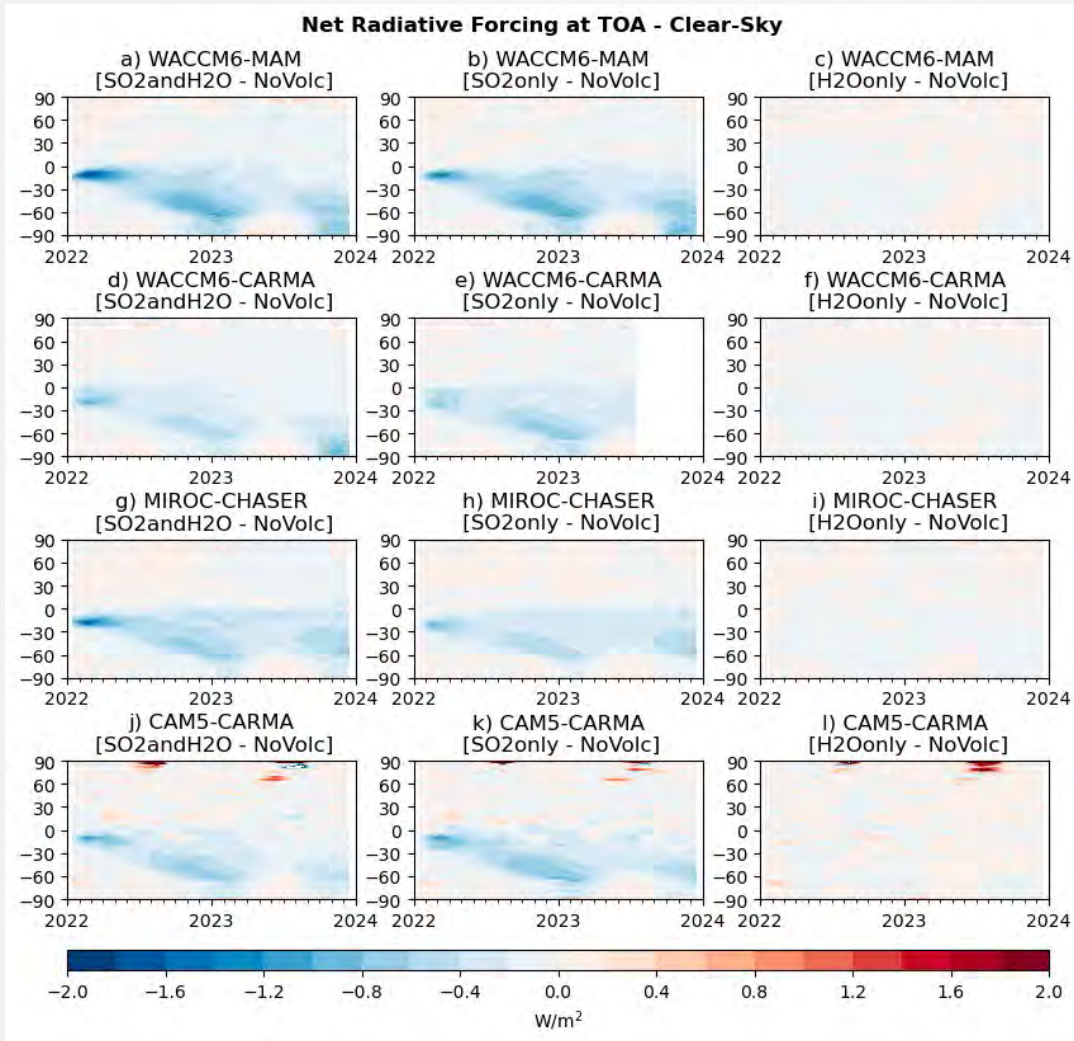
Highlight of the Hunga Report 6

The Hunga hydration had no significant impact on the Antarctic ozone hole or ozone in the Arctic stratosphere.



2022	2023	2024	mean	range
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Highlight of the Hunga Report 7



APARC Hunga Report, Ch7.; Quaglia et al., 2026, ACP

The net Hunga radiative forcing (RF) was dominated by aerosol cooling in the first two years. The net global average volcanic RF was about $-0.2 \sim -0.4 \text{ w/m}^2$.

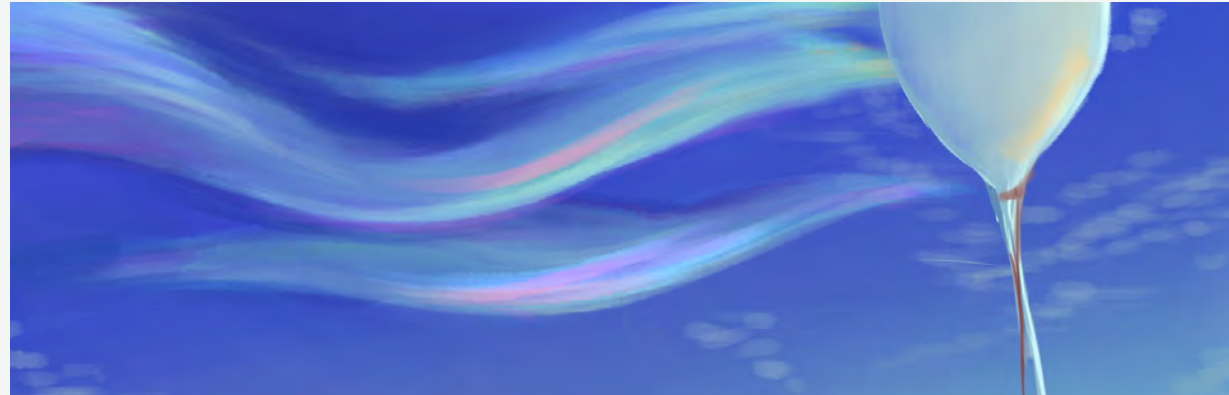
The record-high global surface temperatures in 2023/2024 were not due to the Hunga eruption.

After 2024, the Hunga aerosol loading largely disappeared. The remaining Hunga stratospheric water vapor positive radiative forcing is expected to be negligible.

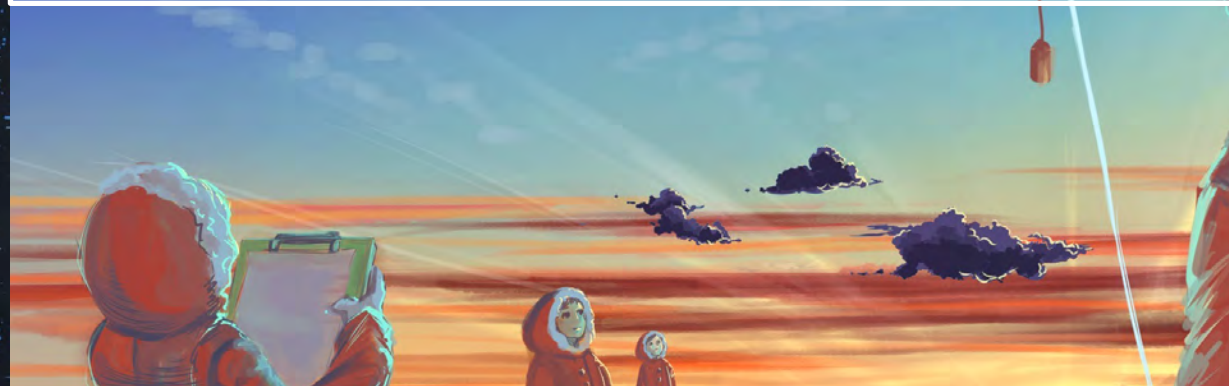
Highlight of the Hunga Report 8

Comprehensive understanding of Hunga impact relies on satellites, balloons, and ground observation networks developed over the last few decades by many countries.

MLS, SAGE III, CALIPSO, GOES, Himawari, ACE-FTS, OMPS, OSIRIS, MISR, MODIS, GPS-RO, DSCOVR/EPIC, N20/NPP NM, OMI, TROPOMI, IASI, ...



NDACC, TR2Ex, NOAA B2SAP, TAC/BUFR radiosonde, AERONET, WMO GAW, GNSS, BraVo, ...



Maintaining observational capabilities are critical to understand the impacts of episodic stratospheric events.