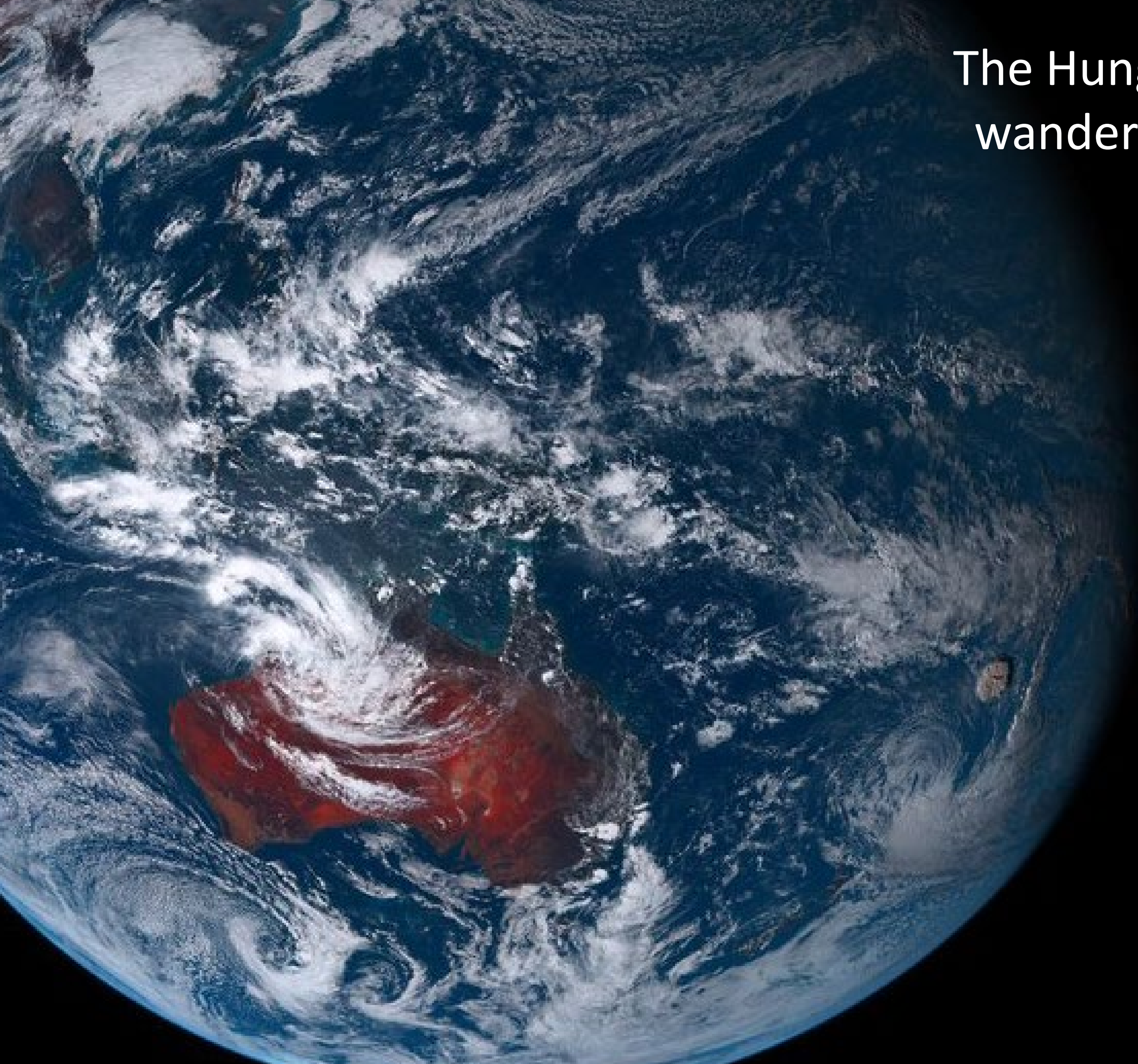
The Hunga Tonga-Hunga Ha'apai water vapor wandering within the atmosphere a ~2-year journey



HT-HH eruption seen by the Japanese satellite Himawari 8.
Credit: National Institute of Information and Communications Technology (NICT).

Luis Millán on behalf of the MLS team

Sun-Climate Symposium

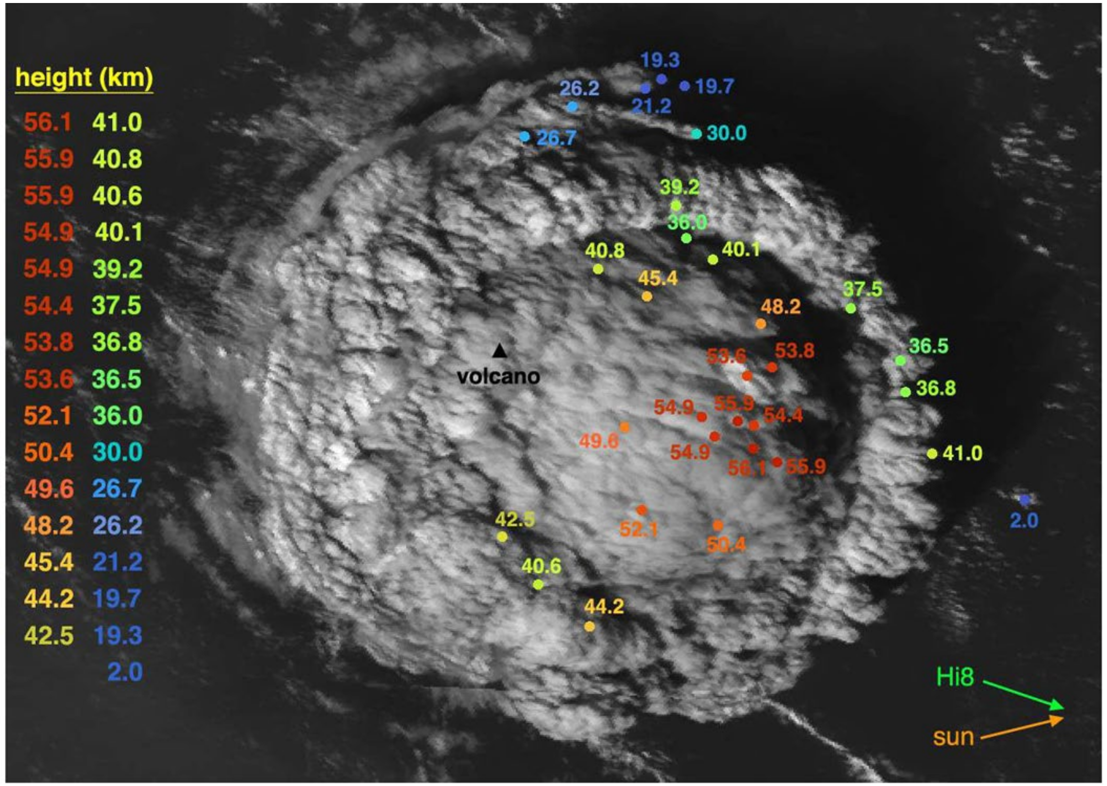
19 October 2023

Millán et al. 2022 – doi: 10.1029/2022GL099381

HT-HH impacts

The Hunga Tonga – Hunga Ha'apai (HT-HH) **underwater** volcano, in the South Pacific, erupted on 15 January 2022.

- **It sent a volcanic plume into the middle atmosphere as high as 58 km.**
- It triggered tsunamis around the world.
- It triggered atmospheric waves that circled the globe multiple times and generated ionospheric disturbances.
- It caused the largest enhancement in aerosol stratospheric loading in decades.



More info at: Carr, J. L., et al. (2022). *Geophysical Research Letters*, doi:10.1029/2022GL098131

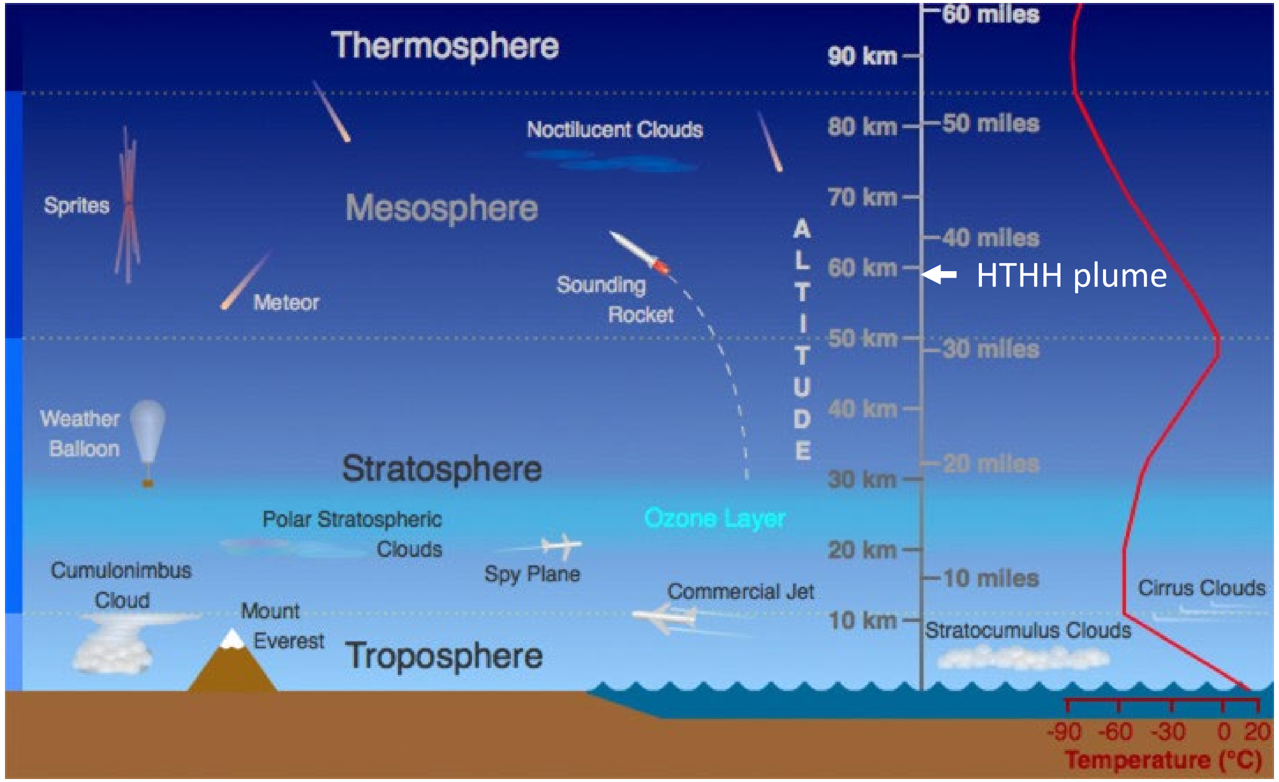


Diagram of Atmosphere Layers, UCAR, Center for Science Education

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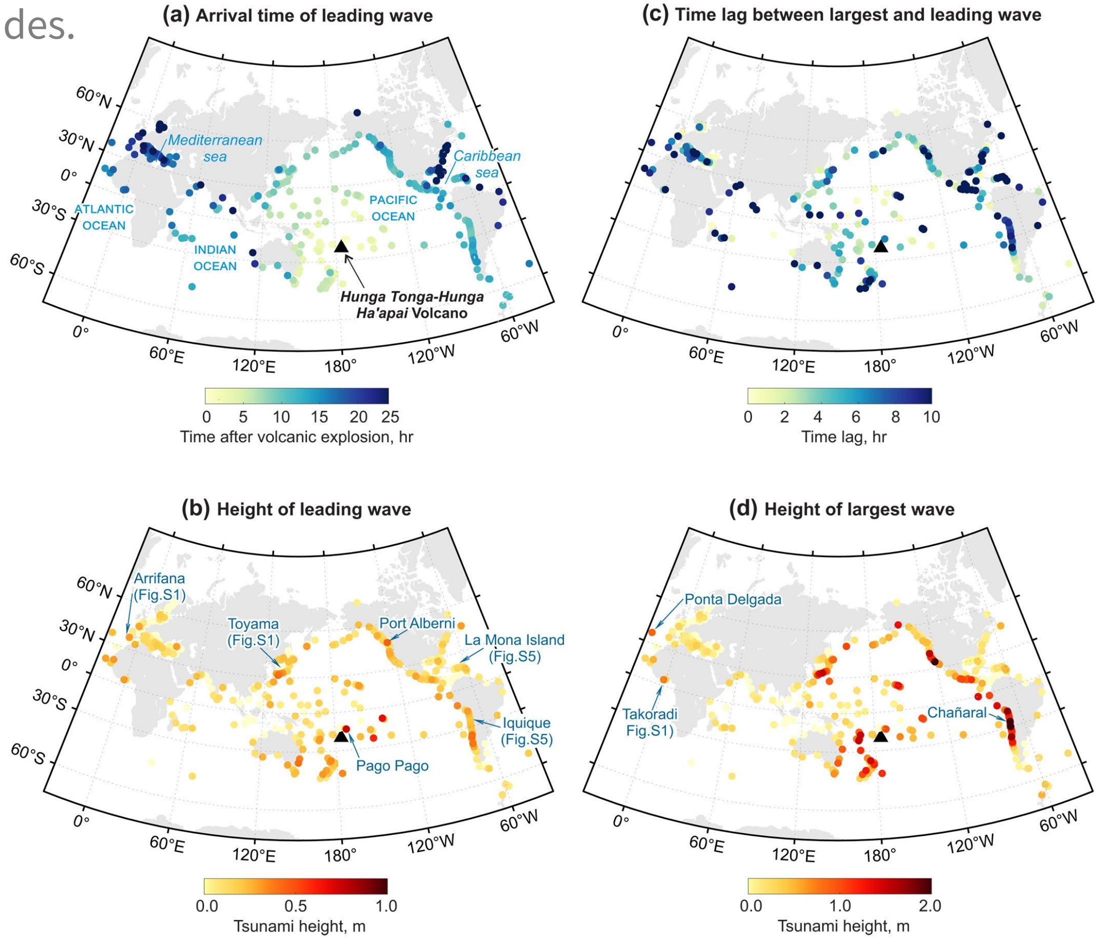

More info at:
Carvajal M. *et al.* (2022) *Geophysical Research Letters*, doi:10.1029/2022GL098153

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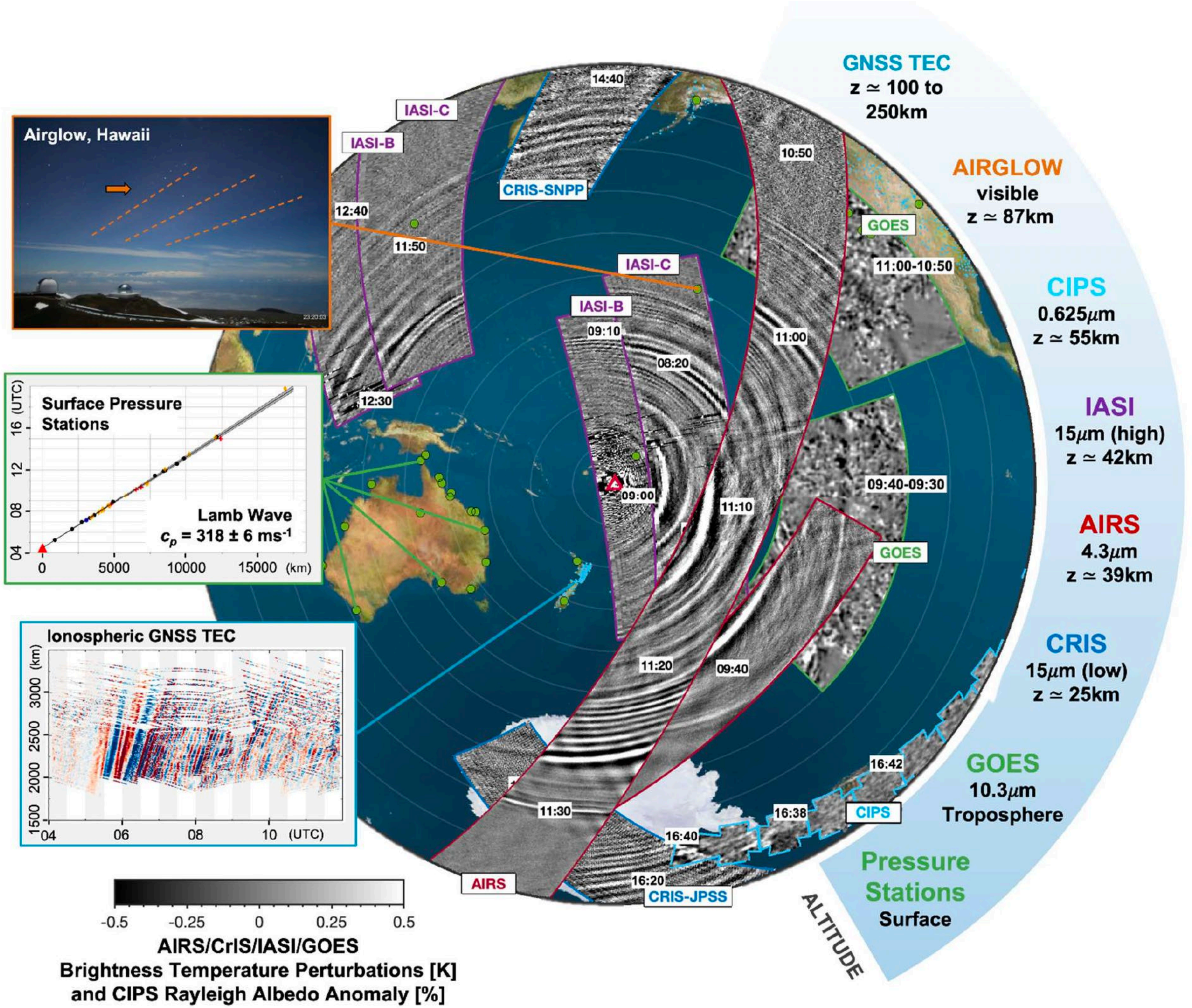
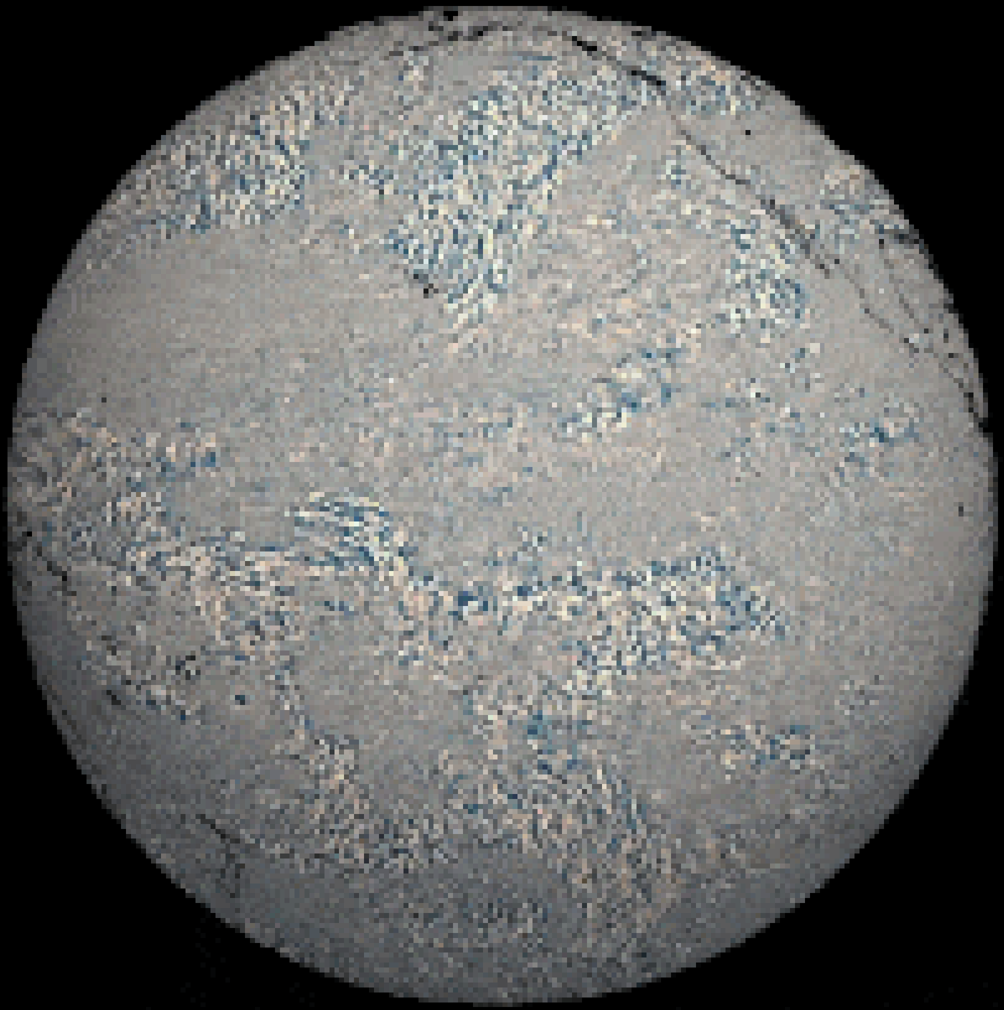
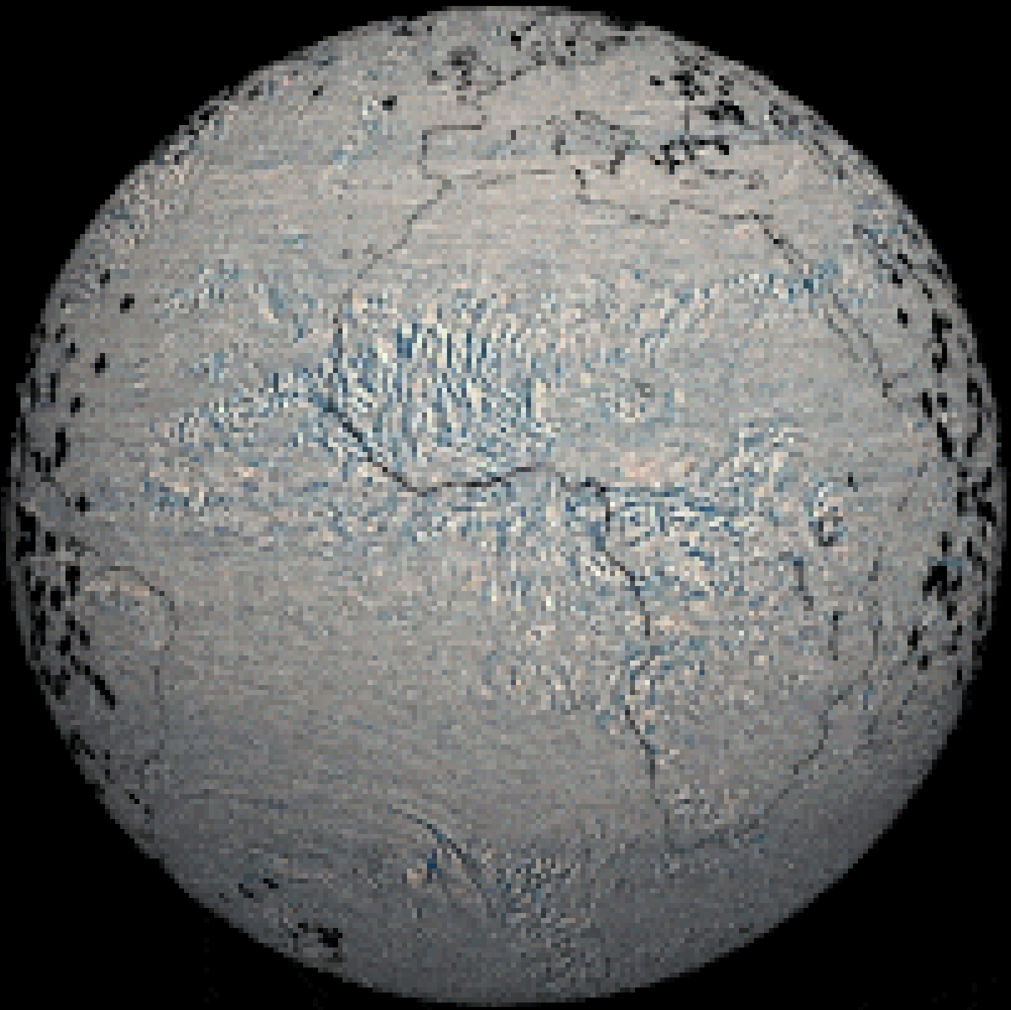


More info at:
Wright, C.J. *et al.* (2022) *Nature,* doi:10.1038/s41586-022-05012-5

GOES-17



Meteosat-11



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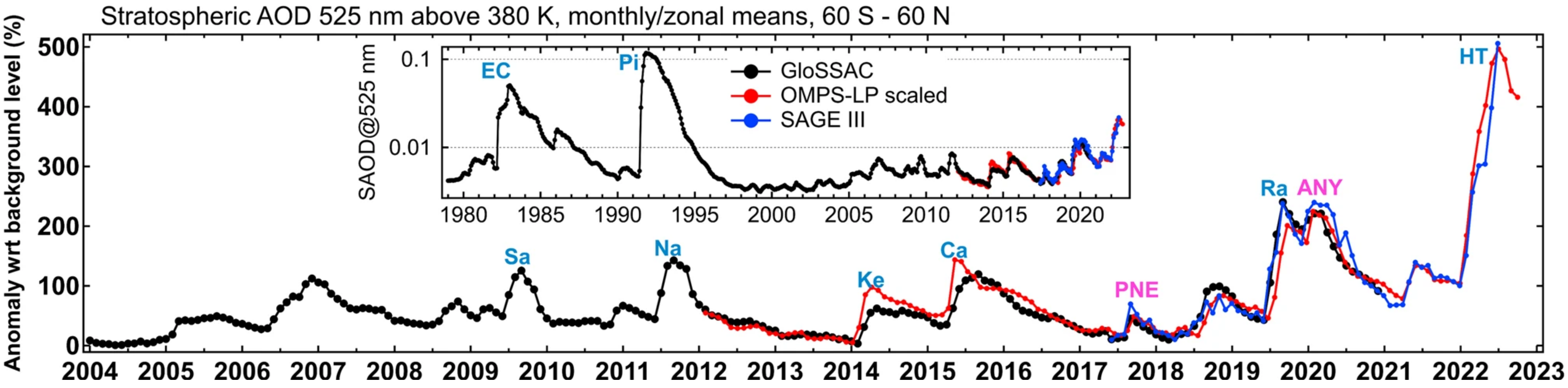


More info at:
Khaykin, S. *et al.* (2022) *Commun Earth Environ,* doi:10.1038/s43247-022-00652-x

HT-HH Island destruction (before, during, and after)

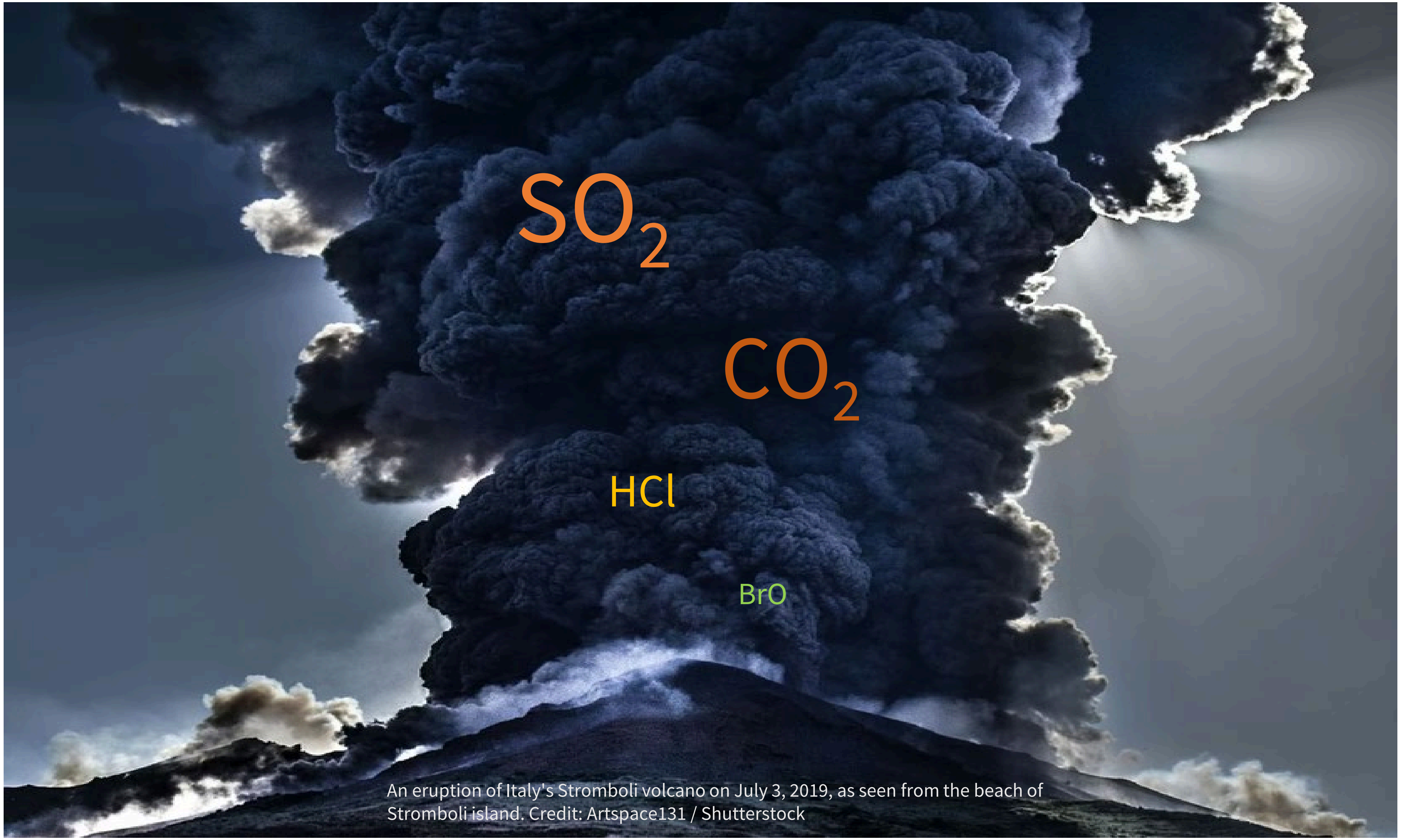
The HT-HH island was obliterated by the eruptions.

All that remains are two small land masses separated by the sea.

HT-HH before, during and after the eruption Credit: Maxar Technologies

Eruptions can loft large quantities of gases into the stratosphere

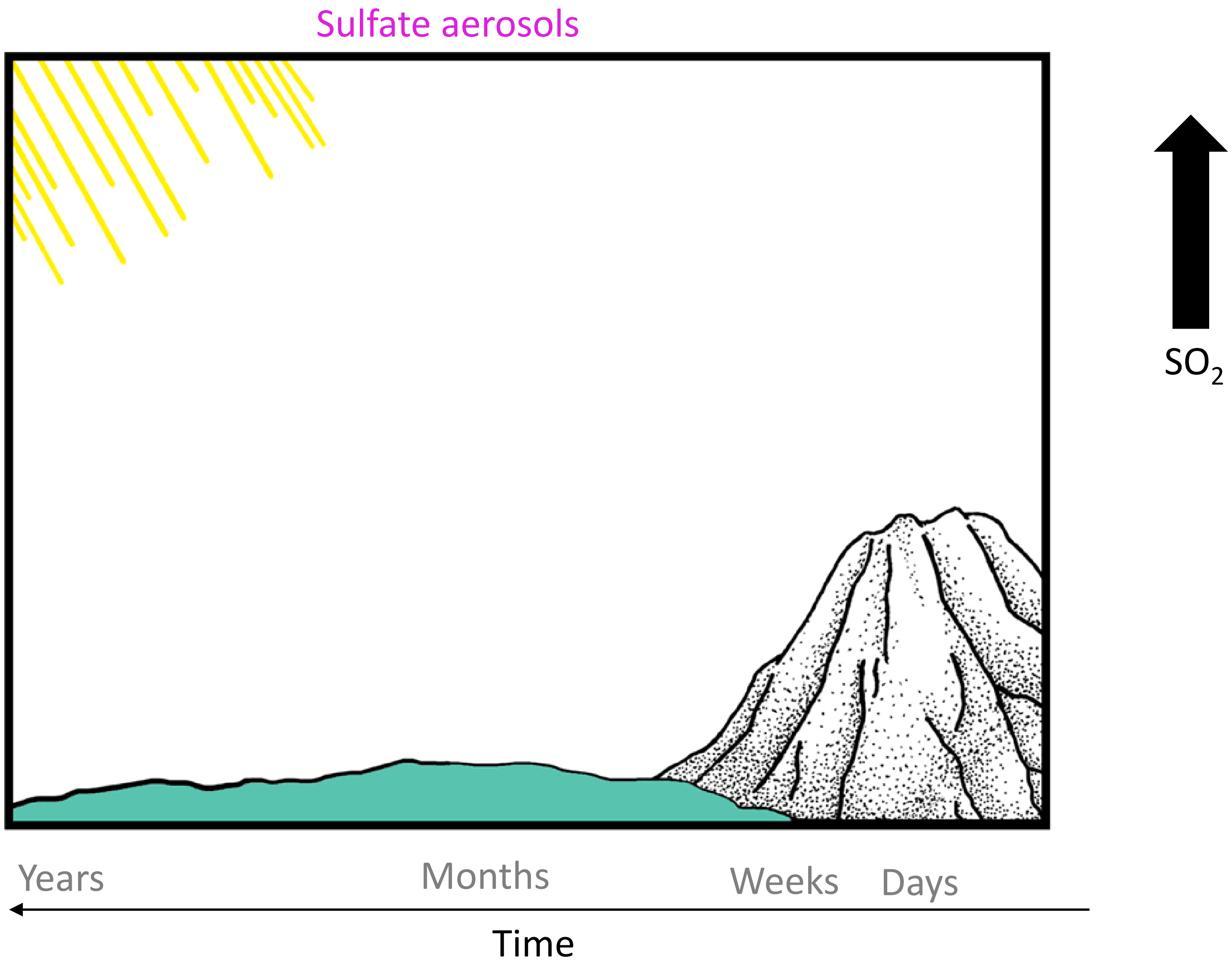
Volcanic SO_2 reacts with H_2O and OH to form submicron sulfate aerosols



An eruption of Italy's Stromboli volcano on July 3, 2019, as seen from the beach of Stromboli island. Credit: Artspace131 / Shutterstock

Volcanic induced sulfate aerosols can briefly cool the Earth surface

Mount Pinatubo caused a global temperature decrease of about 0.5 degree Celsius over the following 15 months



Iris Gottlieb for The New York Times


Aura - Microwave Limb Sounder

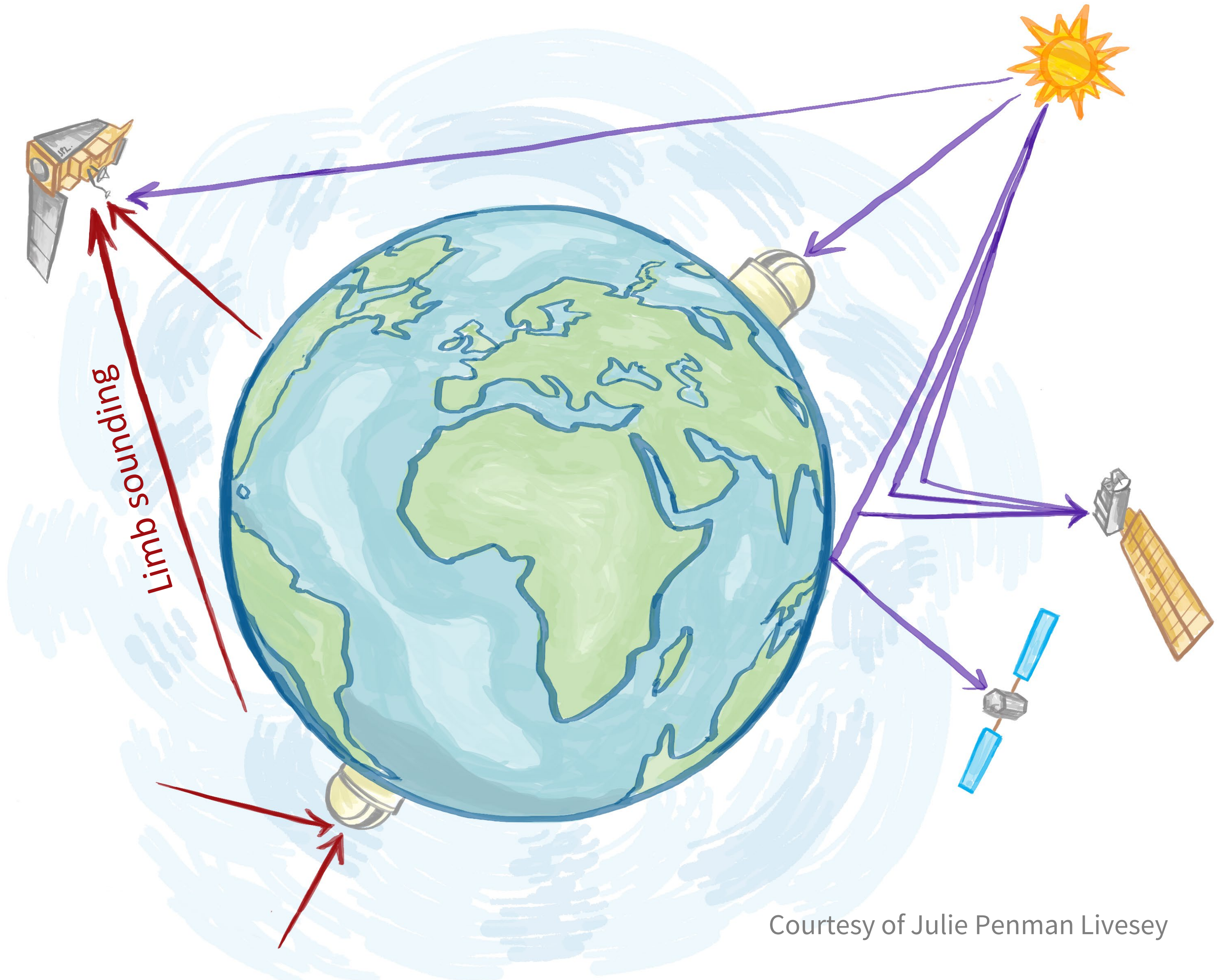

Aura - Microwave Limb Sounder
Also a 50% reduction in the budget

Limb sounding technique

Passive thermal emission measurements can be made continuously day and night

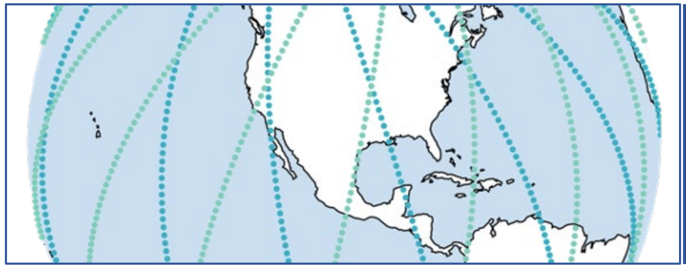
Better vertical resolution (~1–6 km) than nadir sounding (but coarser horizontal resolution)

The longer path through the atmosphere yields a stronger signal for tenuous trace species

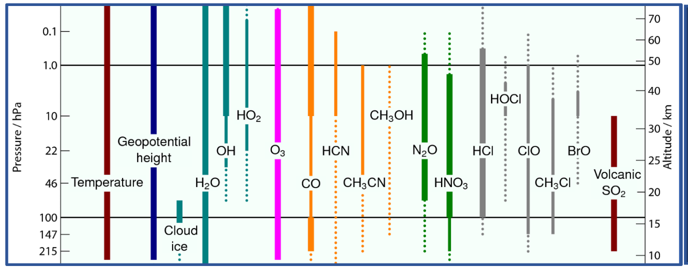


Courtesy of Julie Penman Livesey

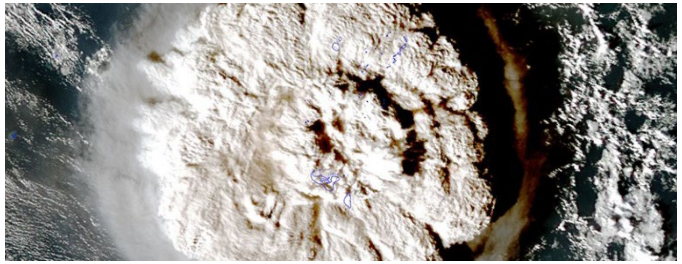
MLS is ideally suited to study the HT-HH eruption



Dense spatial coverage every day

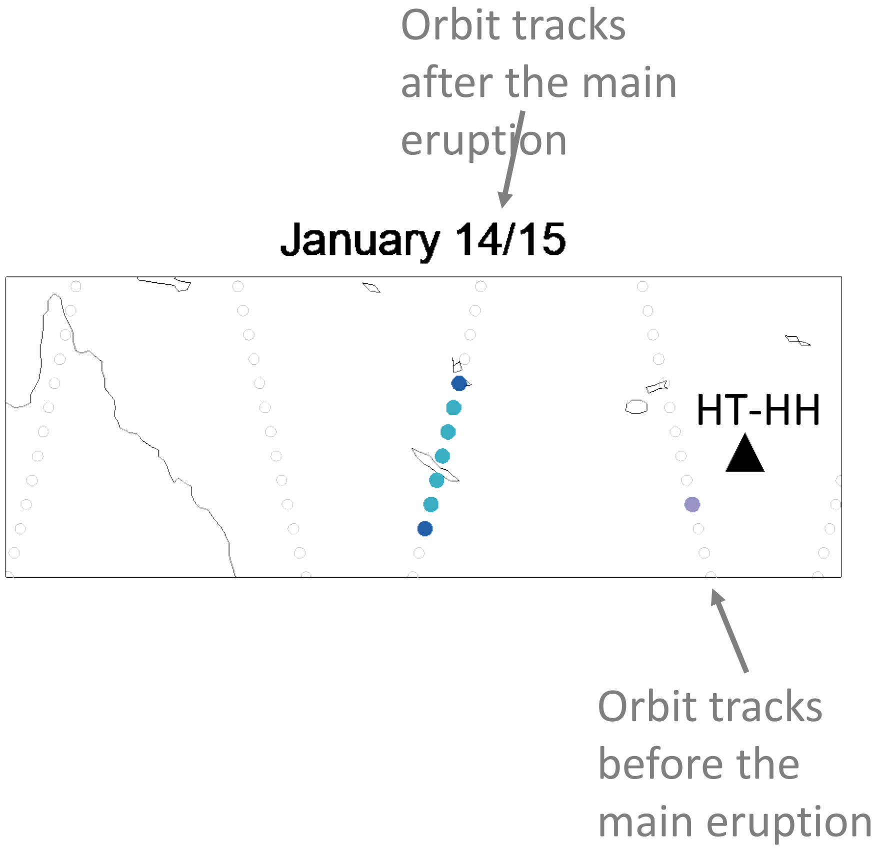


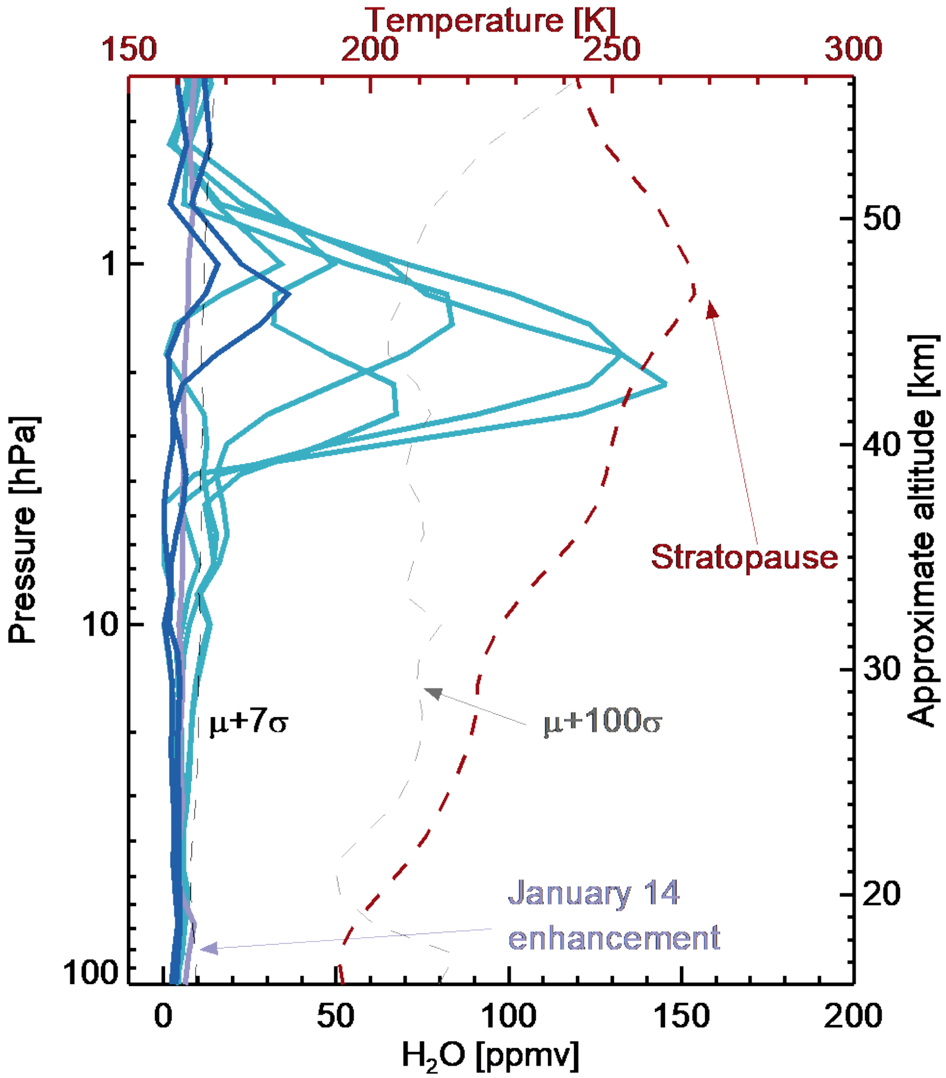
Extensive measurement suite



Insensitive to aerosols and all but the thickest clouds

Ten hours after the eruption, MLS observed >100σ water vapor enhancements

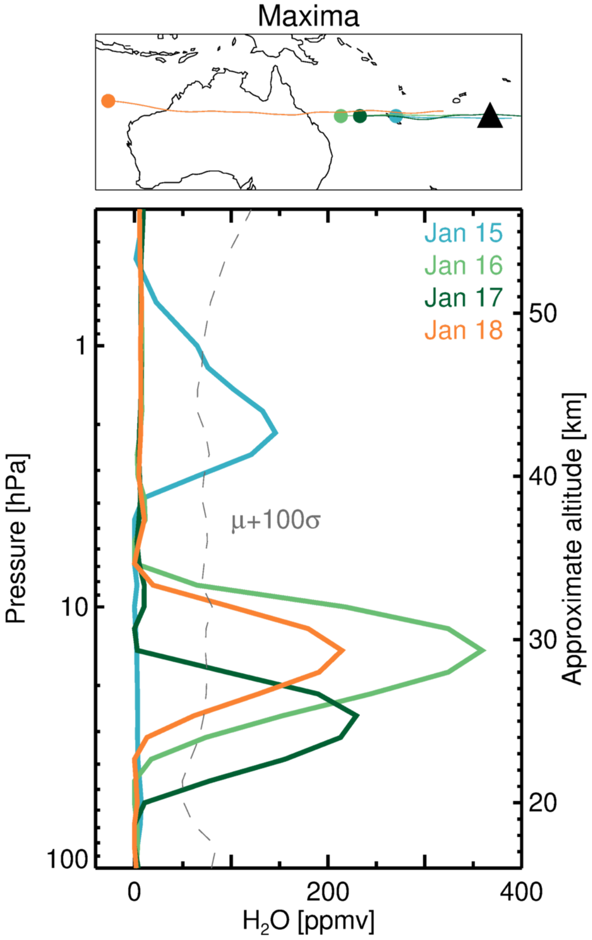


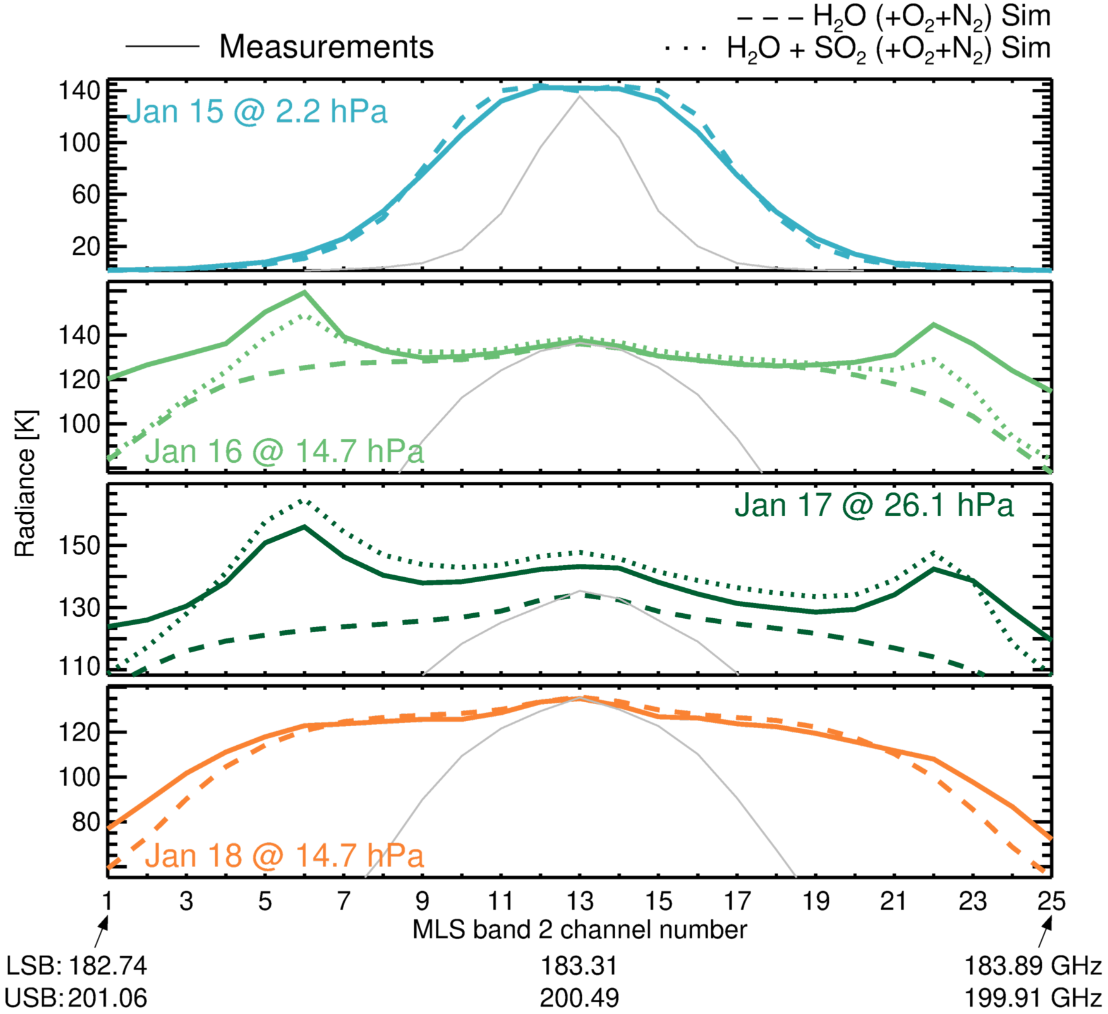


Trajectories and radiance simulations confirmed the water vapor came directly from the volcanic eruption

Locations of maximum H_2O measured by MLS on **15**, **16**, **17**, and **18** January 2022. Lines display back trajectories from these measurements to the eruption time. The triangle marks the volcano location.

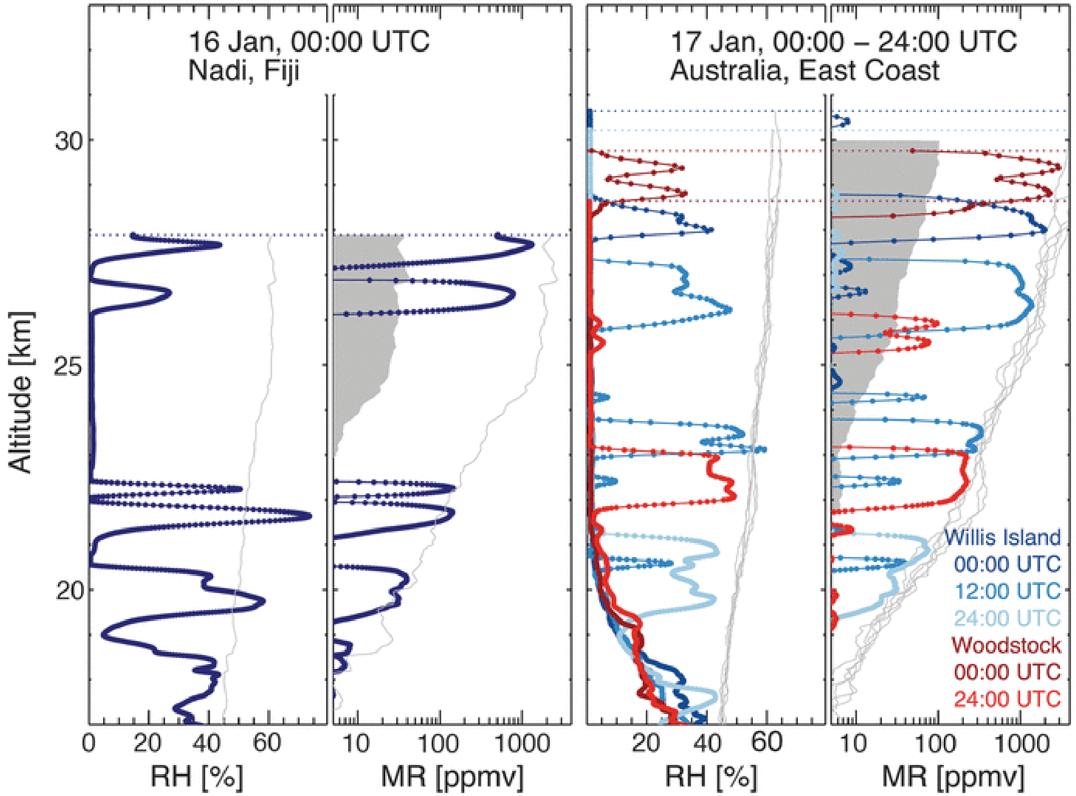
Measured spectra (solid) are well represented by radiance simulations (dashed).
Gray lines show radiances in unperturbed conditions).



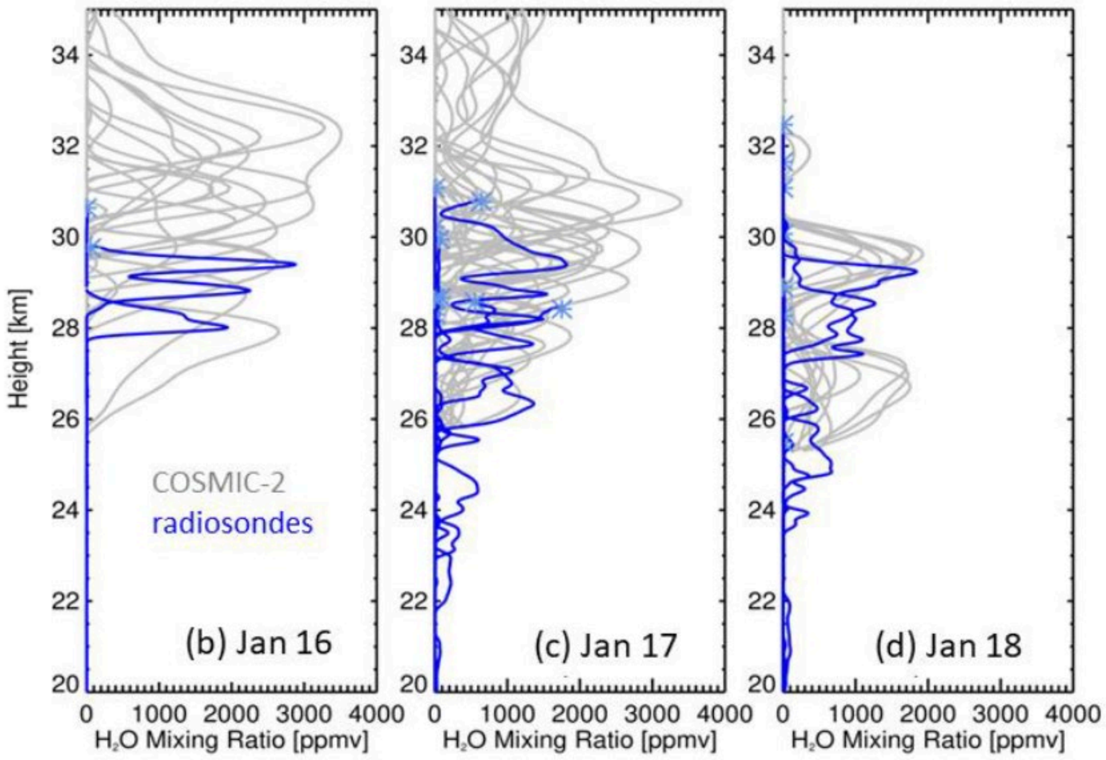


Since then, other measurements have confirmed these results

Typical stratospheric values are around 4ppmv



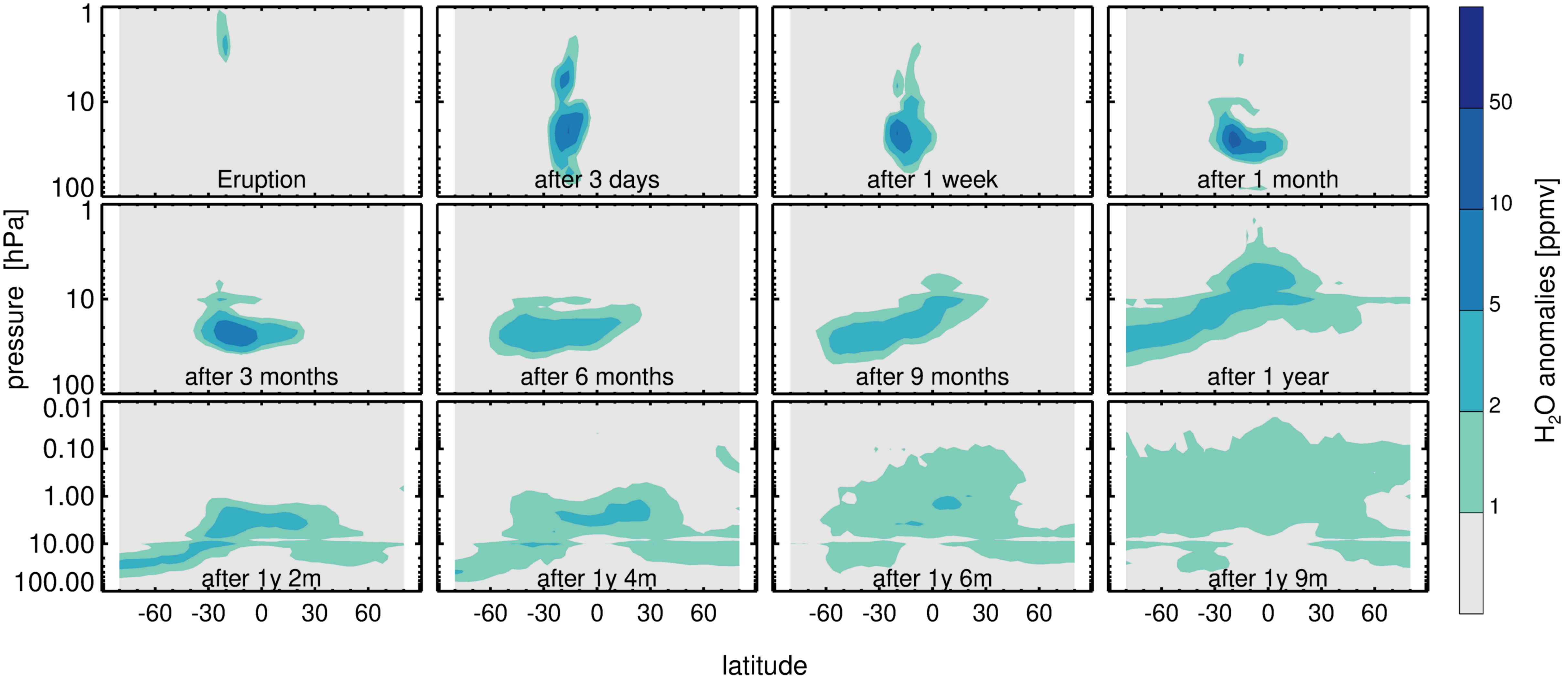
Balloon soundings within 48 hours after eruption.
Vömel et al. (2022) - doi:10.1126/science.abq2299



Water vapor profiles inside the HTHH plume derived using COSMIC-2
Randel et al. (2023) - doi:10.3390/rs15082167

Evolution of the water vapor plume

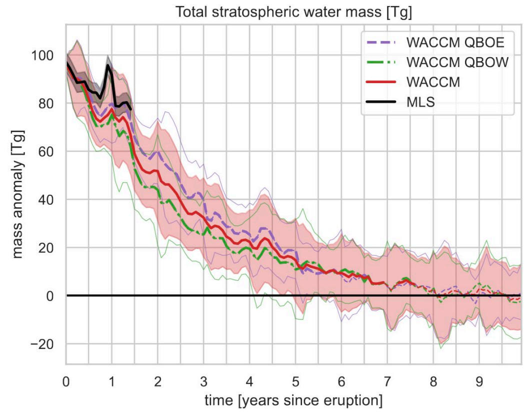
Evolution of the water vapor plume

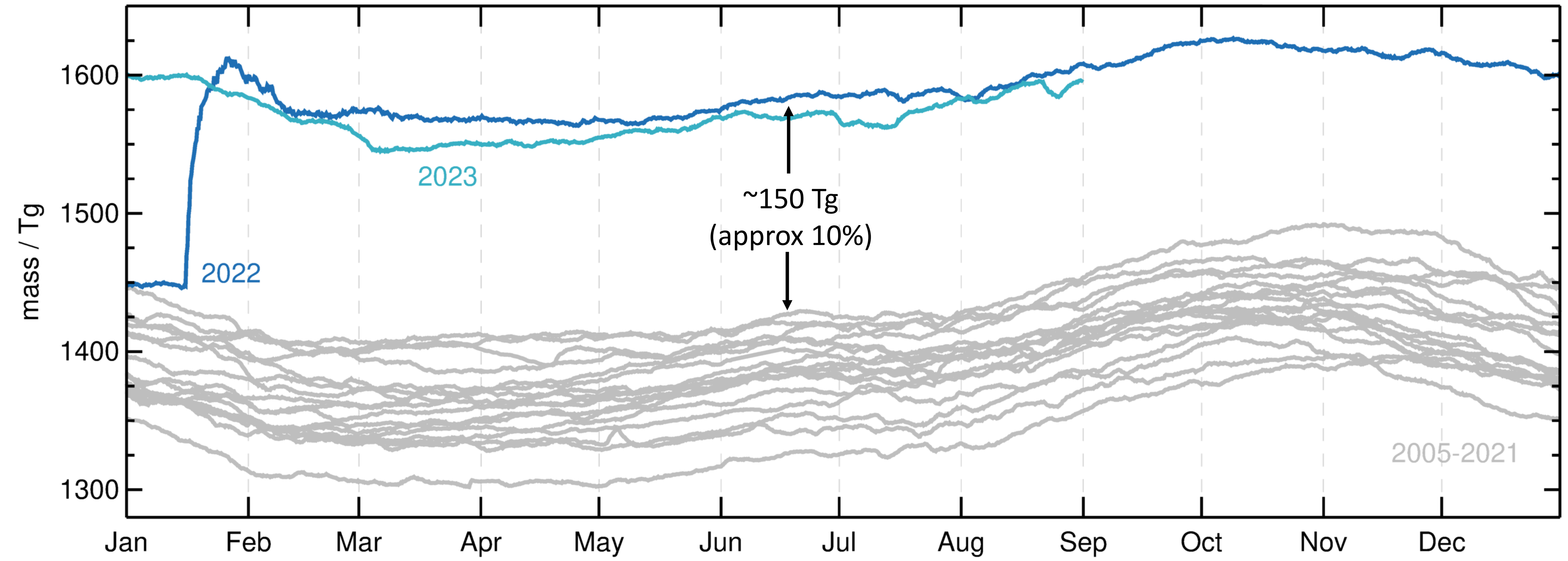


HT-HH increased total stratospheric H_2O by ~10%

The excess H_2O is likely to linger for years

Adapted from Jucker et al (2023) –
doi:10.22541/essoar.169111653.36341315/v1

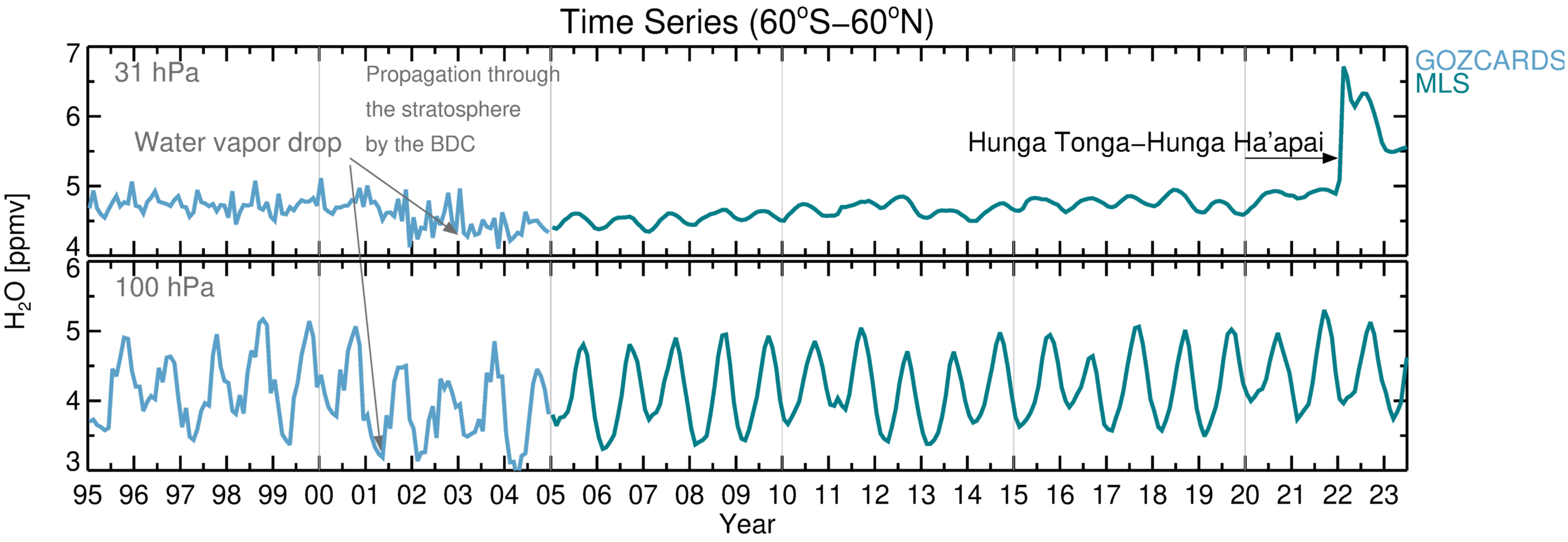




More info at Millán et al. 2022 – doi: 10.1029/2022GL099381

HT-HH may be the first eruption observed to warm the surface

Radiative effects of excess water vapor may overwhelm cooling by sulfate aerosols



Time series of near-global (60◦S to 60◦N) H_2O at 100 and 31 hPa.
H_2O abundances are based on GOZCARDS (a limb satellite merged record) and MLS data (after 2005).

Updated from Millán et al. 2022 – doi: 10.1029/2022GL099381

HT-HH may be the first eruption observed to warm the surface

Radiative effects of excess water vapor may overwhelm cooling by sulfate aerosols

Sulfate aerosols typically fall out of the stratosphere in 2-3 years

Radiative effects of excess water vapor will linger for least 8 years

Time

Adapted from Iris Gottlieb for The New York Times

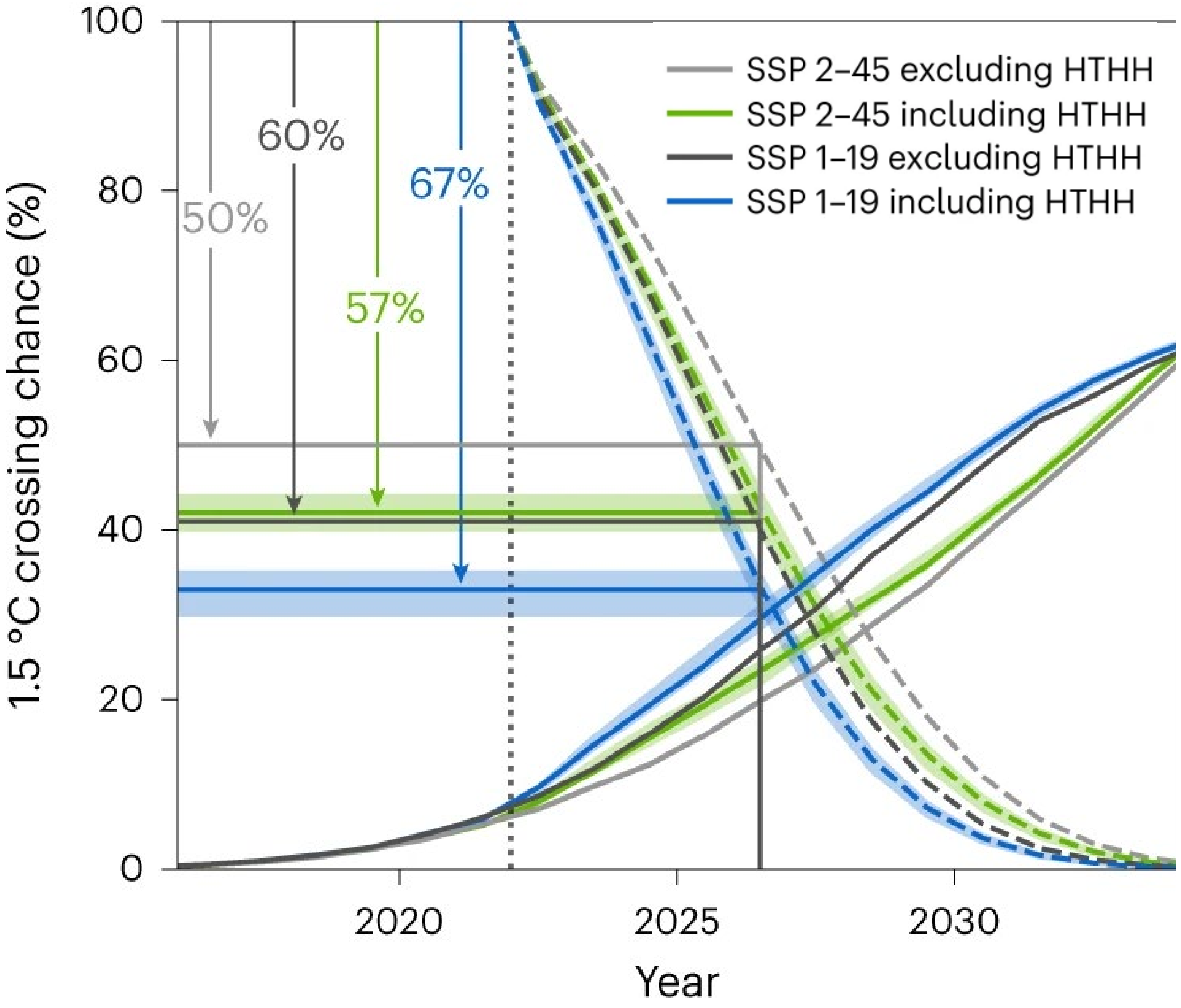
HTHH water vapor injection may temporarily push Earth surface temperatures closer to 1.5°C of warming

1.5°C is the threshold beyond which severe impacts from climate change become unavoidable

HTHH climate response for two mitigation pathways
SSP 2–45: current policy trajectory
SSP 1–19: ambitious mitigation pathway

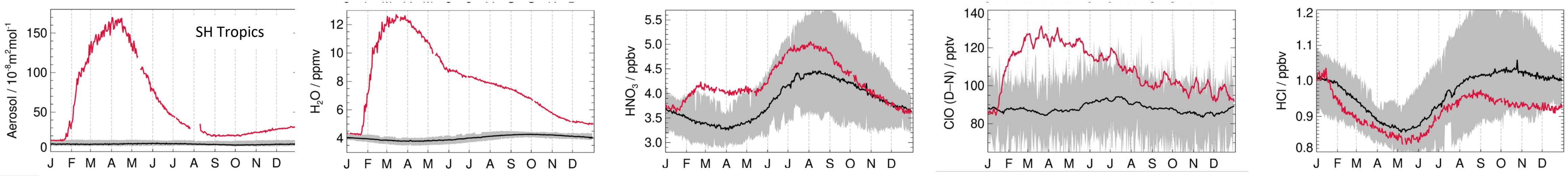
Note that this study only considered the effects of the water vapor plume

More info at:
Jenkings et al. (2023) - doi:10.1038/s41558-022-01568-2



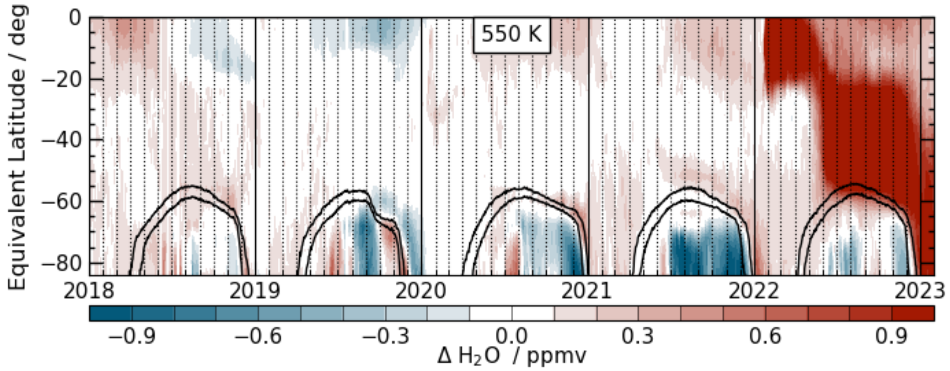
HT-HH prompted heterogeneous chemical reactions to occur in regions where they are not normally active

However, it did not lead to appreciable chemical ozone loss; ozone remained primarily controlled by transport



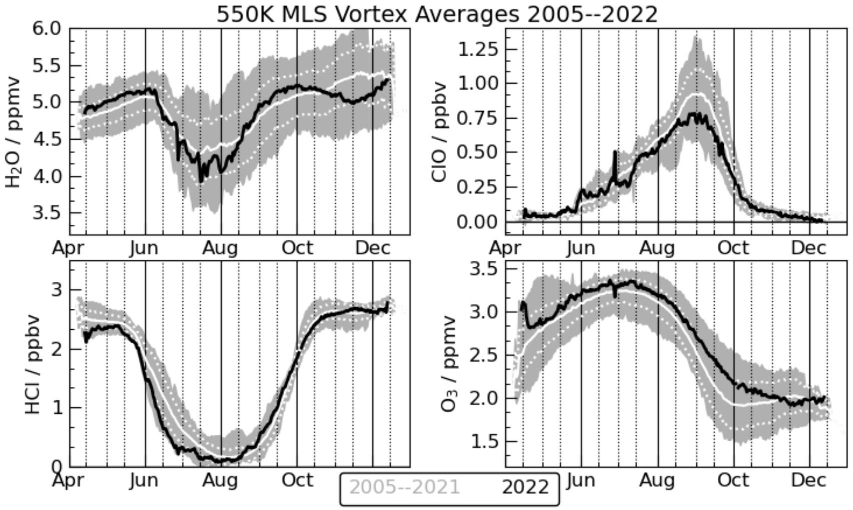
Time series of aerosol and trace gases averaged over 6S–22S equivalent latitude (Southern Hemisphere tropics) at 620 K (~25 km altitude): **2022** vs. **climatology** and **range** of values over 2005–2019.
More info at Santee et al. (2023) doi:10.1029/2023JD039169

The HT-HH H_2O plume did not significantly influence Antarctic ozone in 2022



MLS water vapor anomalies from the 2005–2021 climatology for 2018–2022 at about 22 km altitude; black contours indicate the stratospheric polar vortex edge.

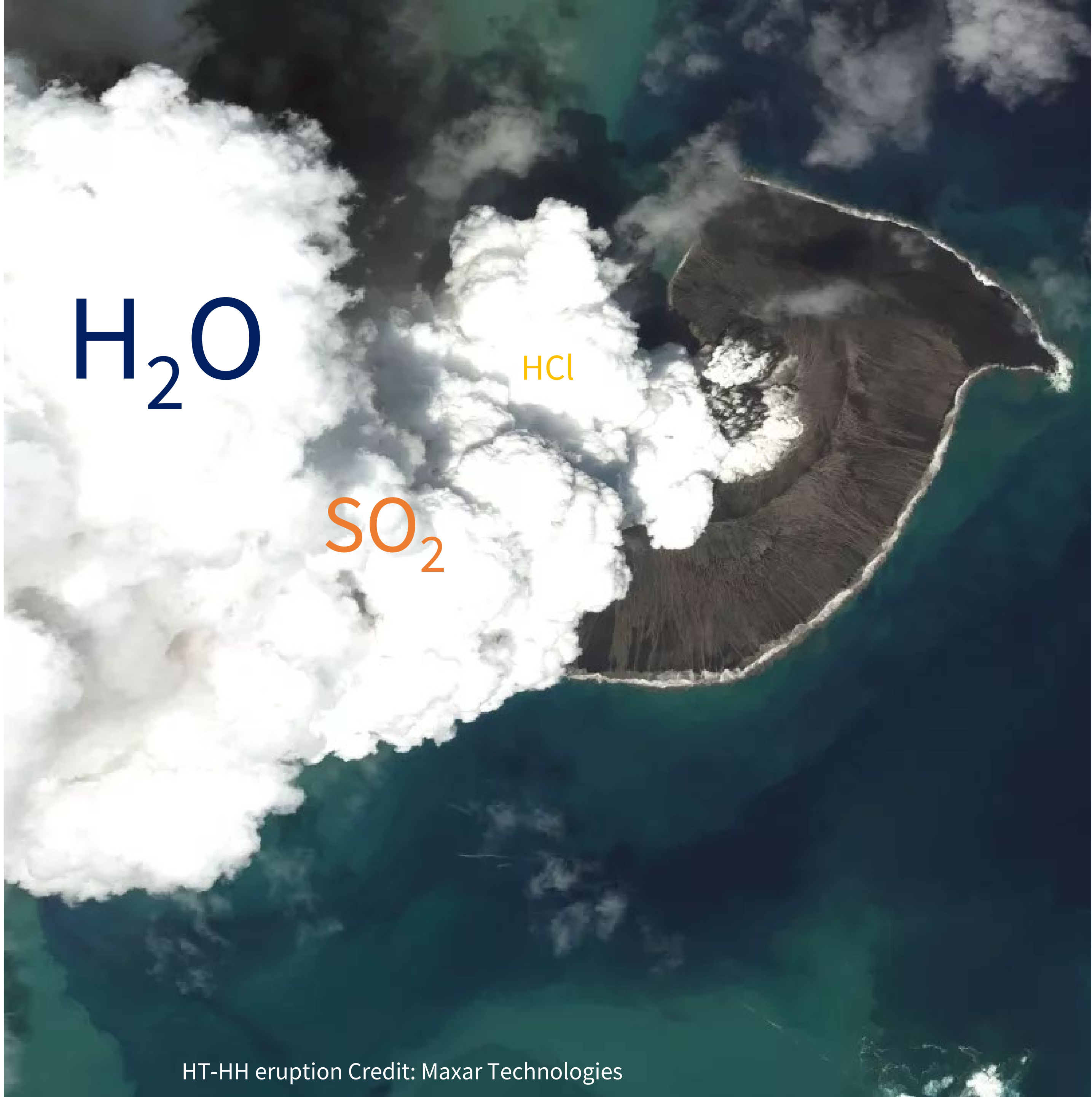
More info at: Manney et al. (2023) doi:10.1029/2023GL103855



MLS species involved in polar chemical processing, averaged within the vortex.

In summary, an exceptional amount of H_2O was injected directly into the stratosphere by the HT-HH eruption

This is the first observed eruption with the potential to impact climate not only through surface cooling due to sulfate aerosols, but also through surface warming due to the excess stratospheric H_2O forcing



Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov

HT-HH mass estimation