The chemical effect of increased water vapor from the Hunga Tonga-Hunga Ha'apai eruption on the Antarctic ozone hole

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Observations

- Microwave Limb Sounder (MLS) satellite data Version 5

Model

- ATLAS Chemistry and Transport Model
- Model resolution 150 km
- Driven by ECMWF ERA5 reanalysis
- Comprehensive chemistry and PSC scheme (NAT, STS, ice)
- Dehydration by simple scheme that removes all water vapor above a supersaturation of 0.7
- Denitrification by DLAPSE scheme (nucleation, growth, sedimentation, and evaporation of individual particles)

Runs

- Reference run initialized with MLS data from 1 May 2023
- Sensitivity run uses exactly the same setup, with the exception of the initialization of MLS water vapor, which is taken from the preceding year on 1 May 2022 (i.e., without the effect of Hunga Tonga on water vapor).

Reference

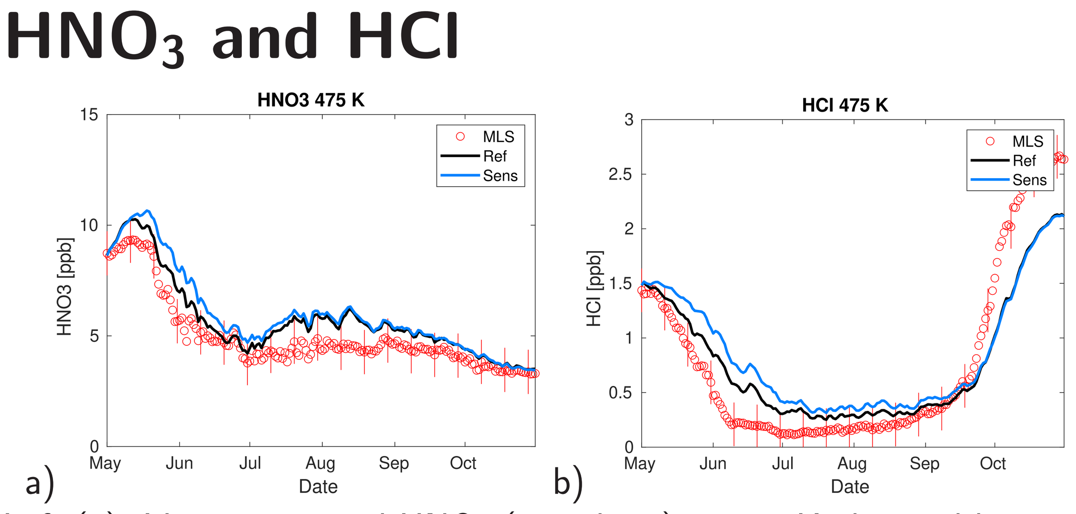
- Wohltmann et al., The Chemical Effect of Increased Water Vapor From the Hunga Tonga-Hunga Ha'apai Eruption on the Antarctic Ozone Hole, Geophys. Res. Lett., doi:10.1029/2023GL106980

PSC microphysical changes

All of the following obviously have no significant effect on ozone loss in ATLAS:

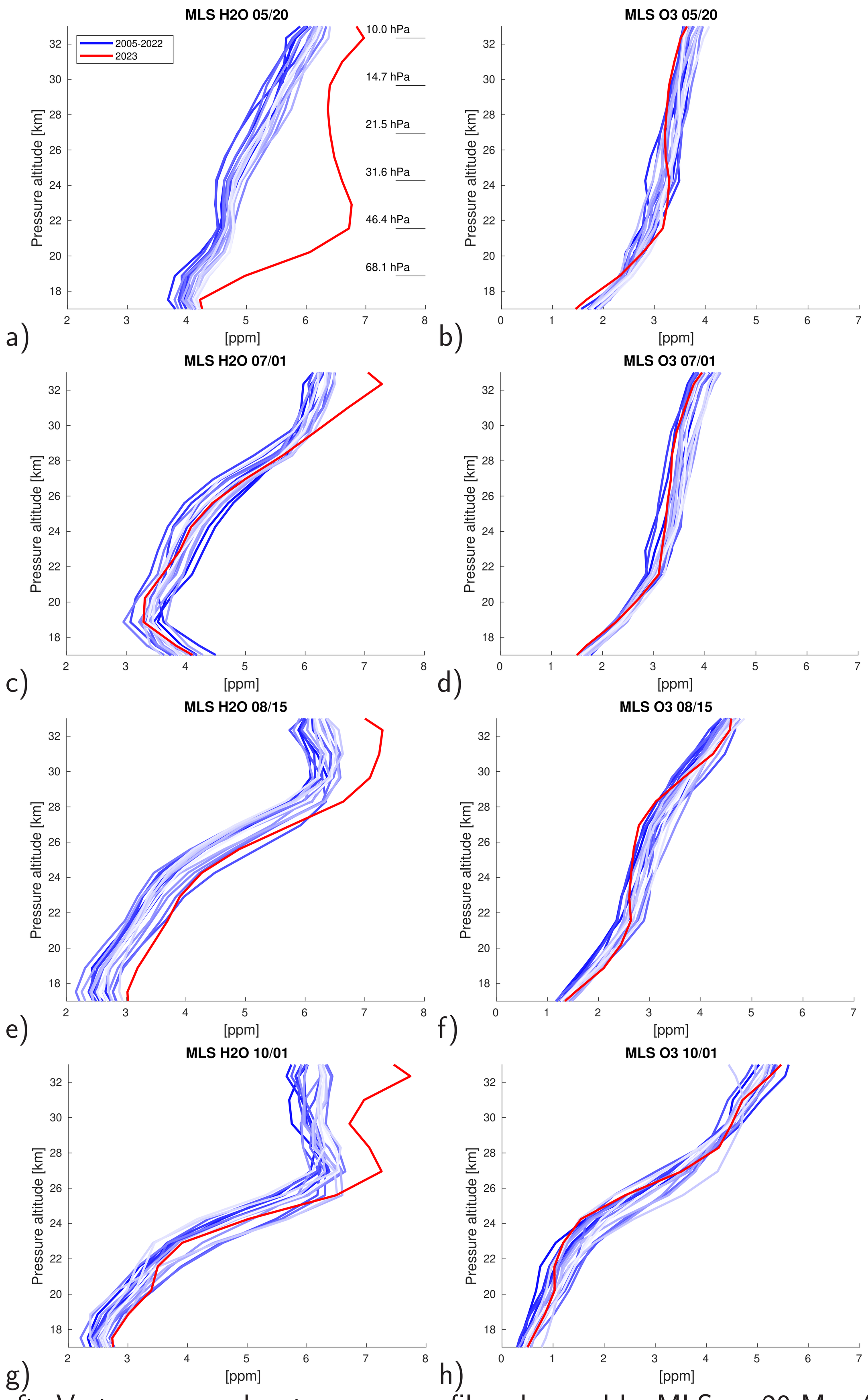
- Threshold temperatures for PSC formation are increased by increased water vapor. A change in water vapor from 5 to 6 ppm increases the threshold temperature for ice by 1.1 K at 50 hPa and for NAT by 0.8 K. STS reactivity is increased by the equivalent of 1 K.
- Changes in water vapor have an effect on the particle size distribution of all cloud types. There is more water vapor available above the saturation limit, and one might expect larger particle sizes and larger surface area densities.
- Denitrification might be affected by differences in the formation of the NAT particles.
- Larger ice particles have a greater fall velocity (not modeled by ATLAS)

HNO_3 and HCl



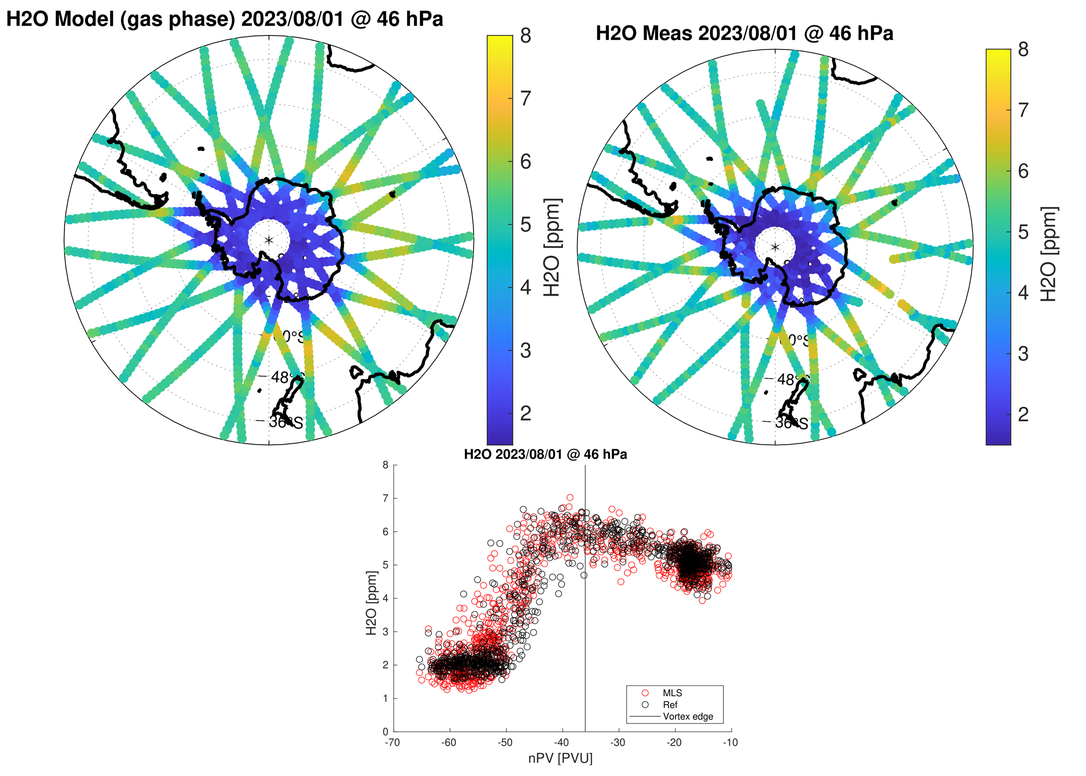
Left (a): Vortex-averaged HNO_3 (gas phase) at 475 K observed by MLS in 2023 (red dots) and modeled by ATLAS. Black line: Reference run. Blue line: Sensitivity run without the effect of Hunga Tonga on water vapor. Right (b): Same for HCl (gas phase).

MLS water vapor and ozone observations



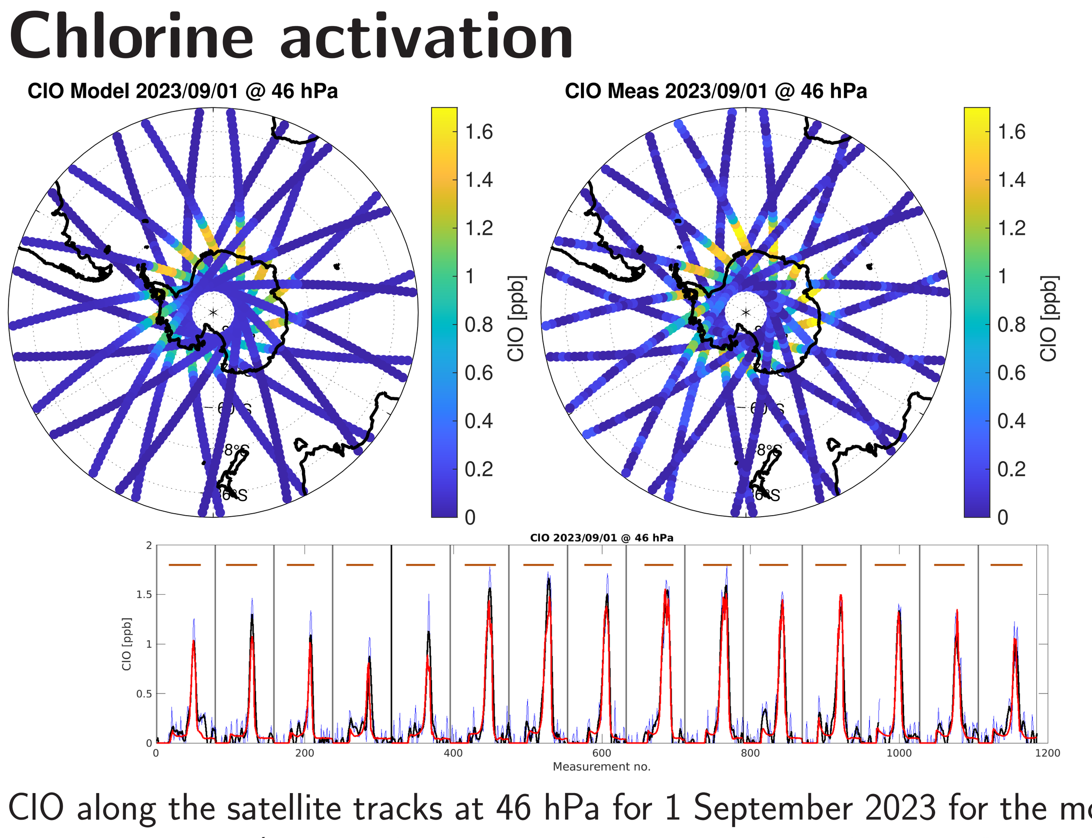
Left: Vortex-averaged water vapor profiles observed by MLS on 20 May (a), 1 July (c), 15 August (e) and 1 October (g) for all years of the MLS data record. 2005–2022 in shades of blue, 2023 highlighted in red. Right: Same for ozone (b, d, f, h). Average over all MLS measurements of the given day inside the -36 PVU contour of modified potential vorticity. Every other MLS pressure level is indicated in panel (a).

Water vapor map comparison



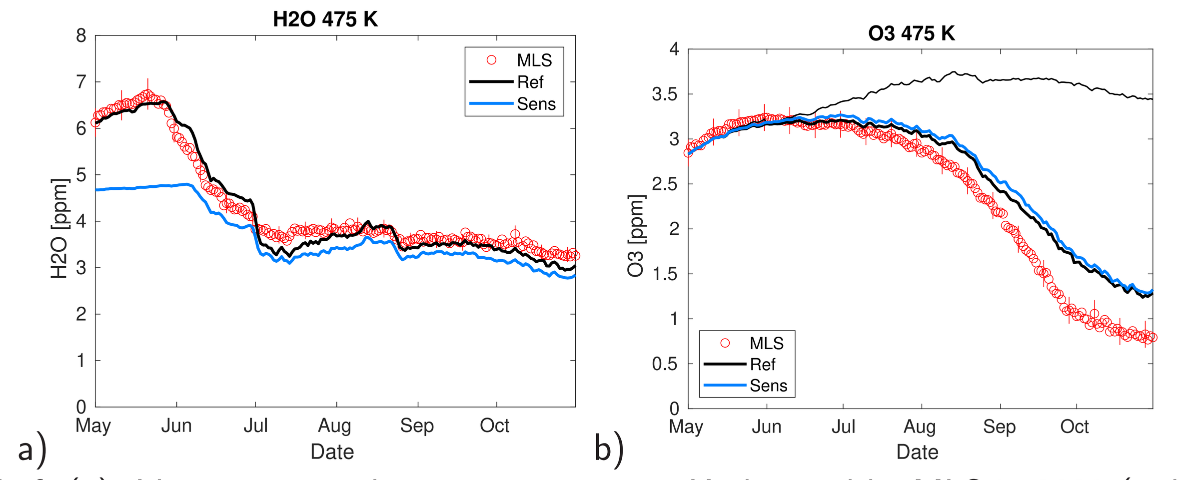
Water vapor along the satellite tracks at 46 hPa for 1 August 2023 for the model as polar projection (upper left), for MLS (upper right), and as function of PV (bottom, red dots MLS, black dots ATLAS).

Chlorine activation



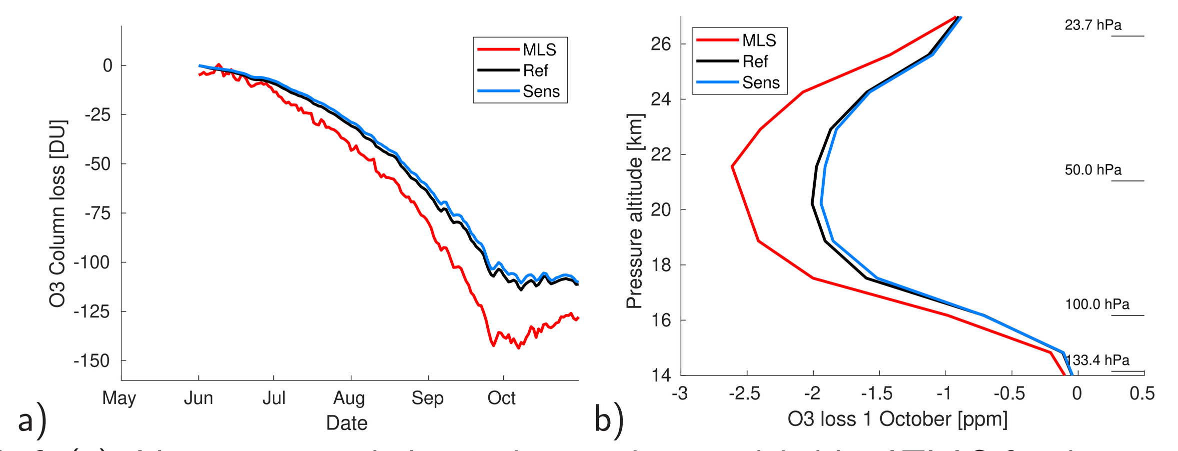
ClO along the satellite tracks at 46 hPa for 1 September 2023 for the model as polar projection (upper left, at the correct local times of the MLS measurement, since ClO is short-lived), for MLS (upper right), and as a line plot (bottom, black line MLS, red line ATLAS).

Modeled and observed water vapor and ozone



Left (a): Vortex-averaged water vapor at 475 K observed by MLS in 2023 (red dots) and modeled by ATLAS. Black line: Reference run. Blue line: Sensitivity run without the effect of Hunga Tonga on water vapor. Right (b): Same for ozone. Thin black line: Passive ozone tracer initialized on 1 June. Difference between passive ozone tracer and other lines quantifies amount of ozone loss.

Ozone loss in model and observations



Left (a): Vortex-averaged chemical ozone loss modeled by ATLAS for the partial column 133.4–23.7 hPa. Ozone loss determined by subtracting a passive ozone tracer initialized on 1 June from the modeled ozone. Black line: Reference run. Blue line: Sensitivity run without the effect of Hunga Tonga on water vapor. Red line: Ozone loss determined by subtracting the passive ozone tracer from ozone observed by MLS. Right (b): Corresponding vortex-averaged chemical ozone loss profiles on 1 October.

Conclusions

Water vapor

- The Hunga Tonga-Hunga Ha'apai eruption increased water vapor in the emerging Antarctic vortex in 2023 by 20–40% compared to earlier years
- Observed water vapor in 2023 was back to the range of earlier years in July

Ozone and temperature

- Ozone in 2023 was in the range of earlier years from May to October
- Vortex temperatures in 2023 were close to the long-term mean and not exceptionally low (not shown)

Ozone loss and dehydration

- The increased water vapor from Hunga Tonga had a minor effect on Antarctic ozone depletion through the end of October in ATLAS (less than 4 DU)
- This minor effect is due to the low temperatures in the vortex, as they occur every year in the Antarctic. This limits water vapor to the saturation pressure and thus resets any anomalies through the process of dehydration before they can affect ozone loss
- ATLAS runs underestimate observed ozone loss in 2023 by about 30% (in contrast to good agreement with observations for other winters). Some processes not captured by ATLAS are: HTHH water vapor radiative effects in ERA5 and changes in aerosols.
- MLS ClO mixing ratios typically align within 10% margin with ClO mixing ratios modeled by ATLAS, suggesting that the discrepancy is not caused by an underestimation of chlorine activation

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