Radiative Effects of Hunga Volcanic Eruption in the Middle Atmosphere: A Model and Observation-Based Analysis

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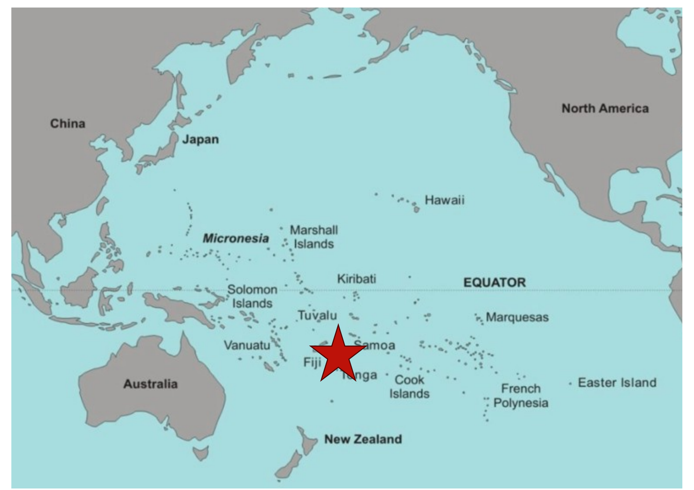
Background

The 2022 Hunga volcanic eruption was an exceptional event: it was the most explosive eruption of the 21st century, but also it was a submarine volcano. This meant that during the eruption vast amounts of ocean water were vapourised and injected into the atmosphere at heights up to 55 km. In the three years following the eruption, the water vapour was able to spread near globally.



Scan Me

Figure 1. Location of the volcano in the South Pacific (left). Scan to see the initial injection of water vapour and the global transport of this with measurments from the microwave limb sounder (MLS) on the Aura satellite (right).

Whole Atmosphere Community Climate Model (WACCM)

SD-WACCM-X couples the troposphere, stratosphere, mesosphere, thermosphere and ionosphere in a single general-circulation–chemistry framework. In specified-dynamics (SD) mode it blends free-running physics above 50 km with re-analysis-constrained meteorology below, giving realistic evolution while retaining internally consistent tides and waves.

Because of computational limits, radiative transfer must be treated with a computationally efficient approach. The long-wave radiation scheme:

- **Two stream**: only two zenith directions are calculated: one upward-looking and one downward-looking
- **Correlated-k scheme** grouping spectral lines into a smaller number of bands and then using a simplified, computationally cheaper approach to calculate the radiative heating rates and fluxes.
- **16 bands** with CO_2, H_2O, O_3, CH_4, N_2O, CFCs, and continuum effects modeled.
- **NLTE module** used above 50km

The water vapour injection from the Hunga eruption was not included in this run of WACCM-X, although strategies to replicate the plume and diffusion of water vapour have been proposed [4, 5].

Observations of Middle-Atmosphere Water Vapour

- **Aura MLS** Satellite in the process of being decommissioned; water vapour observations on eight consecutive days each month.
- **MIAWARA** Ground-based radiometer in Bern, Switzerland. High spectral resolution allows retrieval of water-vapour profiles up to 75 km with continuous sounding.

MIAWARA radiometer on the roof of the at the Zimmerwald Observatory, Canton Bern, CH.

Water Vapour Anomaly

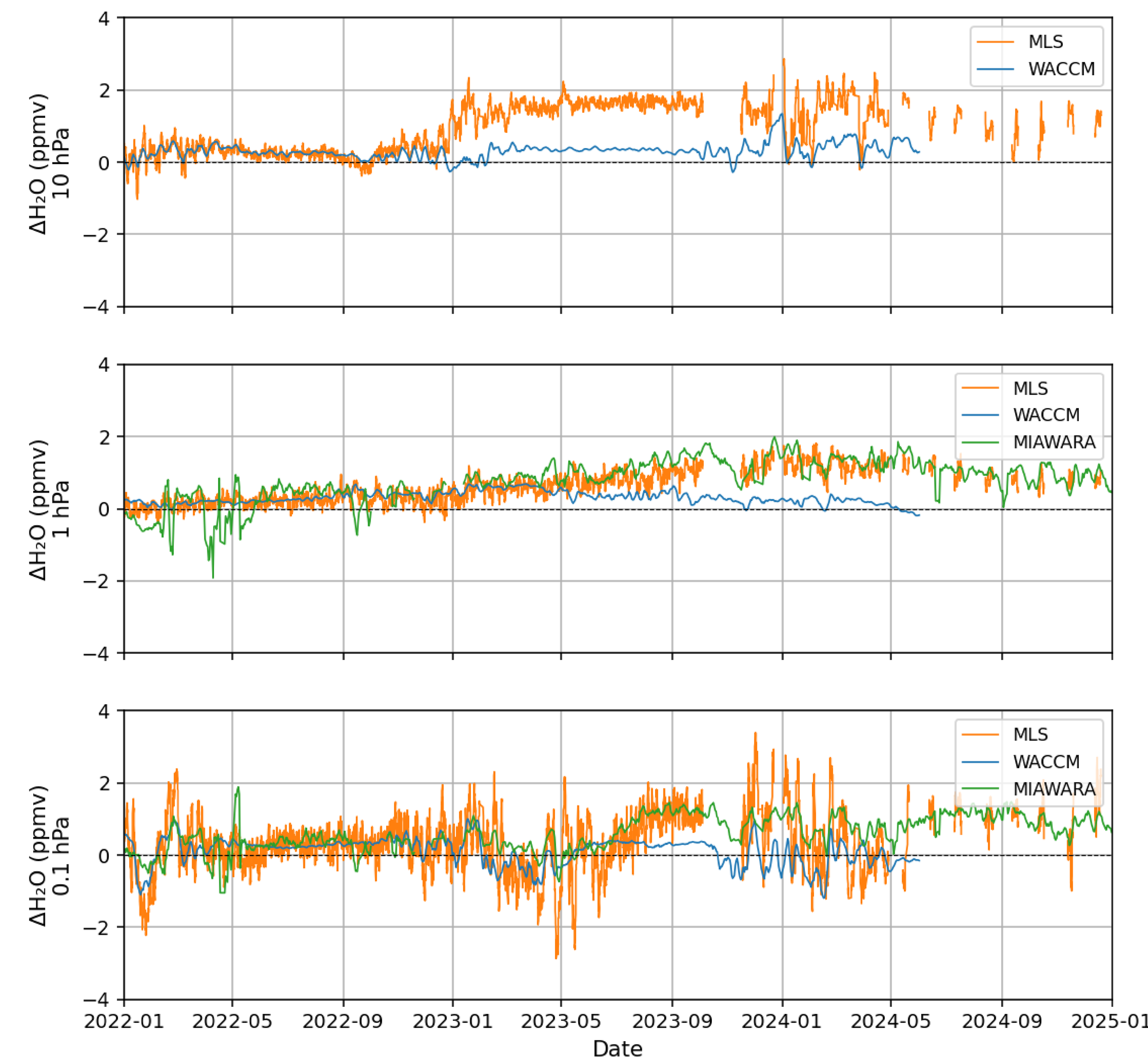


Figure 2. Water vapour anomalies at various pressure levels above Bern, Switzerland, after 2022 compared to the mean mixing ratios between 2016 - 2021.

Atmospheric Radiative Transfer Simulator (ARTS)

ARTS is an open-source codebase for Earth-observation, energy-budget studies and interplanetary remote sensing. It supports line-by-line computations at wavelengths ranging from microwave to the visible.

Pyarts Fluxes is a thin Python wrapper that turns the full-featured ARTS workspace into a one-call radiative-flux calculator [1]. This was used with the following settings:

- **Physics:** Full line-by-line optics for species species: H_2O, CO_2, O_2, O_3, N_2, CH_4 and continuum contributions.
- **A lookup table** is generated once to store absorption coefficients for each species at a range of pressure-temperature combinations.
- **Spectral Resolution** of 4000 points between 2.5 µm and 10 000 µm.
- **10 Streams** are calculated in total: 5 downward and 5 upward

Heating Rate Model Differences

Absorbing species were extracted from the WACCM model, alongside temperate profiles. Long wave heating rates were calculated with the ARTS model. The two sets of heating rate profiles could then be compared. Non-LTE estmated from [3, 2].

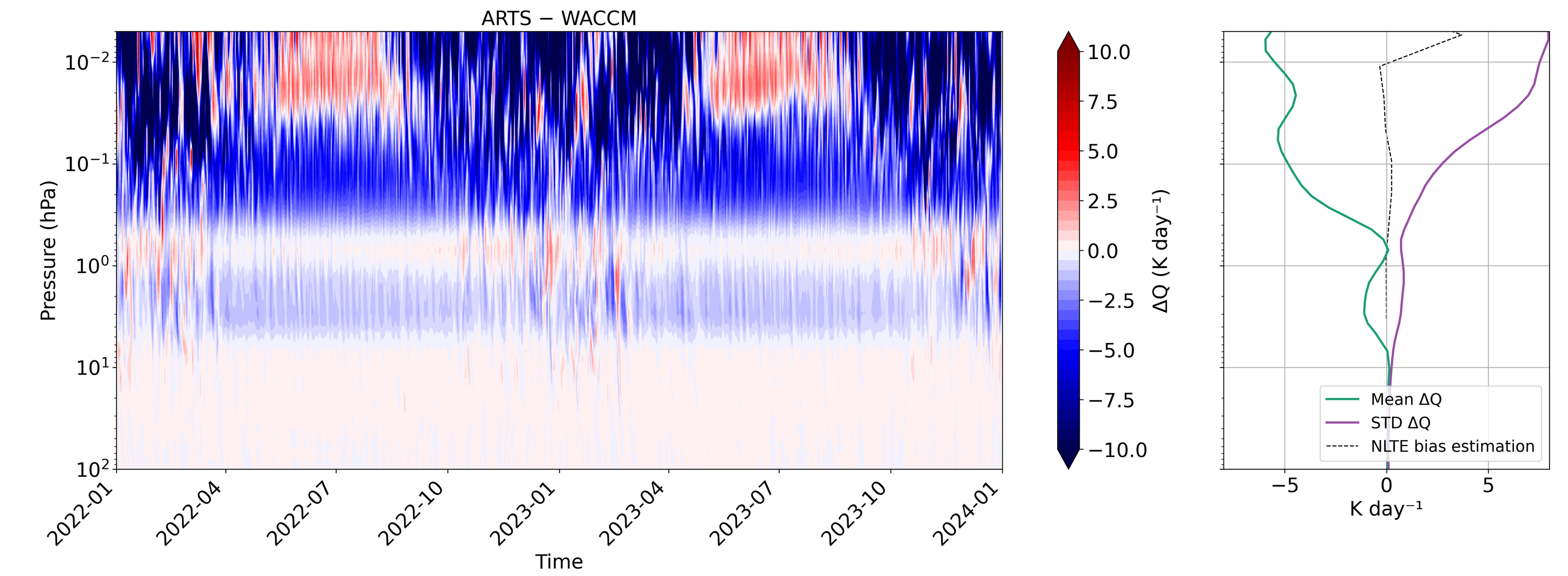


Figure 3. Comparison of heating-rate differences derived natively in WACCM and after using the same fields in ARTS. Left: time series of the difference in the two years following the eruption; right: mean difference and the standard deviation of differences across this time period. An attempt has been made to quantify the NLTE effects which are modelled in WACCM but not in the ARTS simulations.

Impact of water vapour on heating rates

The water vapour measurements from the MIAWARA instrument were put into atmspheric profiles containing climatological values for all other atmospheric variables. Heating rates were simulated with ARTS, allowing a heating rate anomaly from the excess water vapour to be calculated.

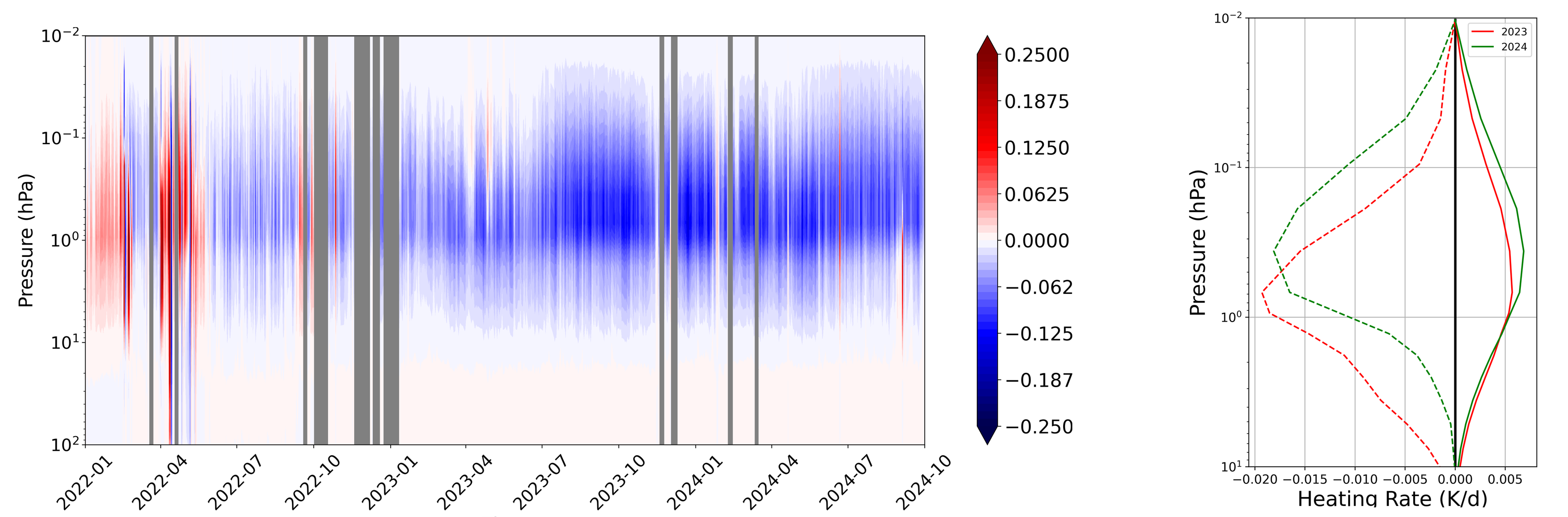


Figure 4. Left: heating-rate anomaly caused solely by changes in the water-vapour mixing ratio after the Hunga 2022 eruption; right: statistics of the heating rate anomolies by year, in dashed lines are the longwave and in solid lines are the shortwave heating rate anomolies.

References

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