Atmospheric impacts of the 2022 Hunga Tonga-Honga Ha'apai (HT-HH) eruption

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Summary

The SSiRC-VolRes research community responded to the 2022 Honga Tonga-Honga Ha'apai (HT-HH) through active discussions through a dedicated mailing list (SSiRC Volcano). Over three months, the community discussed the potential impacts of the eruption on climate and stratospheric chemistry. Here we would like to summarize the main discoveries made by the community:

- **HT-HH was the most explosive volcanic event ever recorded by satellites, with injection heights reaching around 55 km.**
- **The amount of SO_2 injected into the stratosphere was relatively small (~0.4 Tg), i.e. 40 times less than for the Mt Pinatubo eruption. As a result, the climate impact is expected to be small and within internal climate variability. The global averaged cooling effect of the eruption is expected to not exceed -0.01°C in 2022, although such prediction should be considered with caution given the unprecedented nature of the eruption.**
- **The plume properties observed by satellites and ground-based instruments suggest the dominance of reflective, non-absorbing, spherical aerosols. However, the composition of the plume remains unknown and subject to further research.**
- **Large enhancements of stratospheric water vapor due to the eruption make it a unique and unprecedented event and may have further implications on stratospheric chemistry**

Introduction and background

VolRes (Volcano Response) is an international climate initiative of the WMO-SPARC-SSiRC working group to be better prepared for the next large volcanic eruption. VolRes is composed of interested scientists across the world aiming to share information and coordinate response plans after a large volcanic eruption using observational and modelling tools. VolRes maintains an e-mail list for fast and direct scientific exchanges in the case of a large volcanic eruption. At present, the mailing list has 245 members. You can either subscribe directly to the list or contact the VolRes coordinators J.-P. Vernier and C. Timmreck. This summary about the 2022 HT-HH eruption was written based on the many contributions from scientists sharing information to the VolRes mailing list and actively participating in those discussions.

The HT-HH volcano located in the Pacific (20.536°S, 175.382°W) erupted in two phases on January 13th and January 15th, 2022. Below are the main findings during the both eruption phases:

The second phase of the eruption injected volcanic materials up to about 55 km.

GEOstationary satellites (Himawari-8, GOES-West, GEO-KOMPSAT-2A) detected two distinct eruptions at 15h30 UTC on January 13th and around 4:00 UTC on January 15th. Using parallax views of these satellites, the second eruption was estimated to inject materials to an altitude of up to 55 km, with the bulk of the plume located near 33-35 km (S. Proud, 01/21). Independent analysis of stereo retrievals from GOES-17 (west) and Himawari-8 image pairs yield similar numbers, 30-35 km for the main umbrella cloud and maximum injection heights of up to 55 km (Carr et al., 2022, under review). Analysis of volcanic plume umbrella shadows also confirm these heights (A. Horvath 01/21). The dispersed plumes following the eruptions have been observed by the OMPS-NPP Limb Profiler (G. Taha, 01/16), SAGE III/ISS (T. Knepp, 3/15; K. Levor 3/16) and CALIOP/CALIPSO satellite-based sensors since the eruptions (B. Legras, 01/18). OMPS-NPP LP detected volcanic aerosol layers at 48 km and 40 km on January16th but with the bulk matter between 18 and 30 km (G. Taha, 02/01). Keying on features of maximum spatial contrast in stereo imagery, MISR further confirms a substantial aerosol plume at around 30 km and higher, and another near the tropopause at 12-18 km, from snapshots acquired between January 17th and January 23rd (R. Kahn, 03/04). In addition, the plumes were also detected by multiple ground-based lidars in Reunion Island (S. Khaykin, 01/23) and Brazil (E. Landulfo, 01/28) between 20-40 km. Trajectory model simulations suggest that the upper plume was transported west by faster easterlies between 30-40 km than the lower plume near 20-30 km (J.-P Vernier, 01/22)

The properties of the plume observed by satellites and ground-based observations suggest the dominance of reflective and non-absorbing, relatively spherical particles.

Light depolarization measurements within the first few days after the eruption by the CALIPSO lidar suggest the presence of a mixture (internal or external) of spherical and aspherical particles that may indicate that SO_2 was rapidly converted into sulfate aerosols (01/28, B. Legras). The upper levels of the plume (at 35-40 km) observed by CALIPSO indicated the presence of aspherical particles such as ash (01/28, B. Legras). The Aerosol Index derived from OMPS-NPP Nadir Mapper measurements suggests that reflective aerosol quickly dominated the composition of the plume (M. Fromm, 01/31). MISR retrievals identify a significant non-spherical aerosol component (ash optical analogs) in the near-source plume at 12-14 km elevation on January 15th. However, retrievals from measurements made of the downwind plume segments over the subsequent week for both the 30+ km and 12-18 km layers show particles that are primarily spherical and non-light-absorbing (sulfate/water optical analogs) (R. Kahn, 03/04).

In complement, AERONET ground-based observations indicate that the volcanic plume passing over Eastern Australia on January 16th was rich in poorly-absorbing (Single Scattering Albedo of 0.98 at 440 nm) fine particles (effective radius about 0.22 µm on 16 Jan 2022), reaching an Aerosol Optical Depth (AOD) up to 1.9. Two days later, the plume observed over Western Australia resulted in an AOD reduced by a factor 2. The plume remained rich in poorly absorbing fine particles on 19 Jan 2022. (M. Boichu, 02/08).

Total SO_2 mass estimates of 0.4 Tg yield a small impact on climate.

The first eruption on January 13 injected 0.05 Tg of SO_2 (S. Carn, 01/15). IASI SO_2 retrievals (Metop-B) suggest the total SO_2 mass on January 15th to be around 0.4 Tg, and near 0.3 Tg on the 16th. (L. Clarisse 01/17). Based on the mass of SO_2 injected, simple emulators suggest a global annual-mean Stratospheric Depth (SAOD) at 550 nm of around 0.0055 and a global annual-mean temperature response of less than -0.01°C in 2022 (01/27, T. Aubry/A. Schmidt, using EVA_H to calculate SAOD and FaIR to calculate temperature). However, this might be an underestimate of the climate impact due to rapid sulfur chemistry which may have quickly converted SO_2 into sulfate, as well as due to the unprecedented injection altitude. In addition, there might be other types of aerosols than sulfate that could contribute to additional climate effects.

Increased BrO and HCl observed by satellite

After the second phase of the eruption, two distinct BrO clouds were observed by GOME-2 (01/23, J. Burrow), one co-existing with the upper SO_2 level cloud while the lower cloud remained in the troposphere and got dispersed across the Western Pacific. Preliminary calculations suggest that the interaction between magma and sea water created significant HCl in the troposphere which catalyzes HOBr reactive uptake on sea salt aerosols, leading to large amount of BrO released in the troposphere. (02/01, T. Roberts).

10-fold increase of stratospheric water vapor in the vicinity of the plume.

MLS data show remarkable and persistent H_2O enhancements as high as 1 hPa (01/18, S. Khaykin). This agrees with the enhancement observed in the SAGE III/ISS record (03/15. T. Knepp) showing a positive anomaly of about 20 ppmv three weeks after the eruption between 20-25 km, 4-5 times higher than the background levels (K. Levor, 3/16).

Atmospheric waves/Lamb waves

Atmospheric waves were observed in IASI temperature retrievals by combining data from 2 IASI instruments on January 15th and 16th (01/18 C. Clarbeaux). Stratospheric gravity waves caused by the eruption are also detected in AIRS satellite data (01/20 Lars Hoffmann). Infrasound wave trains were recorded in the tropical lower stratosphere by Strateole 2 long-duration balloons flying over the Pacific. The data show 3 distinct wave packets corresponding to the major and following stratospheric injections of volcanic material (A. Podglajen/P. Selitto, 01/18).

Rapid deployment to make in situ balloon measurements in the volcanic plume

A team of researchers from CNRS/LPC2E collaborated with the University of Reunion Island to make balloon-borne in situ measurements with OPC sensors (3 LOAC flights) in coincident with lidar observations (01/28, C. Kloss). Other teams from NASA/NIA and the University of Colorado expressed interest to coordinate in situ measurements of the plume (01/28, T. Deshler, J.P. Vernier).

Reference:

Carr, J. L., Á. Horváth, D. L. Wu, and M. D. Friberg (2022), Stereo plume height and motion retrievals for the record-setting Hunga Tonga-Hunga Ha'apai eruption of 15 January 2022, Geophys. Res. Lett., doi:10.1002/essoar.10510365.1, under review.

Acronyms:

WMO: World Meteorological Organisation

SPARC: Stratosphere-troposphere Processes And their Role in Climate

SSiRC: Stratospheric Sulfur and its Role in Climate

VolRes: Volcano Response Plan after the next major eruption

HT-HH: Honga Tonga-Honga Ha’apai

OMPS-NPP: Ozone Mapping and Profiler Suite – Suomi National Polar-orbiting Partnership

CALIOP/CALIPSO: Cloud-Aerosol Lidar with Orthogonal Polarization /Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations

MISR: Multi-angle Imaging Spectro Radiometer

IASI: Infrared Atmospheric Sounding Interferometer

AIRS: Atmospheric Infrared Sounder

NOAA: National Oceanic and Atmospheric Administration

CNRS: Centre national de la recherche scientifique

GOME-2: Global Ozone Monitoring Experiment

CNRS/LPC2E: Centre national de la recherche scientifique/ Le Laboratoire de Physique et de Chimie de l'Environnement et de l'Espace

LOAC: Light Optical Aerosols Counter

NIA: National Institute of Aerospace

NASA: National Aeronautics and Space Administration