SnT 2025 8 SEPTEMBER ONLINE DAY 9 TO 12 SEPTEMBER AT HOFBURG PALACE, VIENNA & ONLINE
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

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Modelling the characteristics of infrasound signals as detected from a balloon platform: Earth and Venus applications

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INTRODUCTION AND MAIN RESULTS

We use IMS and atmospheric balloon data from the Strateole-2 campaign to benchmark propagation modelling of long-range infrasound signals from the Hunga Tonga-Hunga Ha'apai eruption. In addition, we show the global morphology of infrasound waveguides at balloon altitudes. Applying the framework on Venus indicates that its atmosphere support ducting of similar eruptions to balloon altitudes despite the high sound speed regions on the surface.

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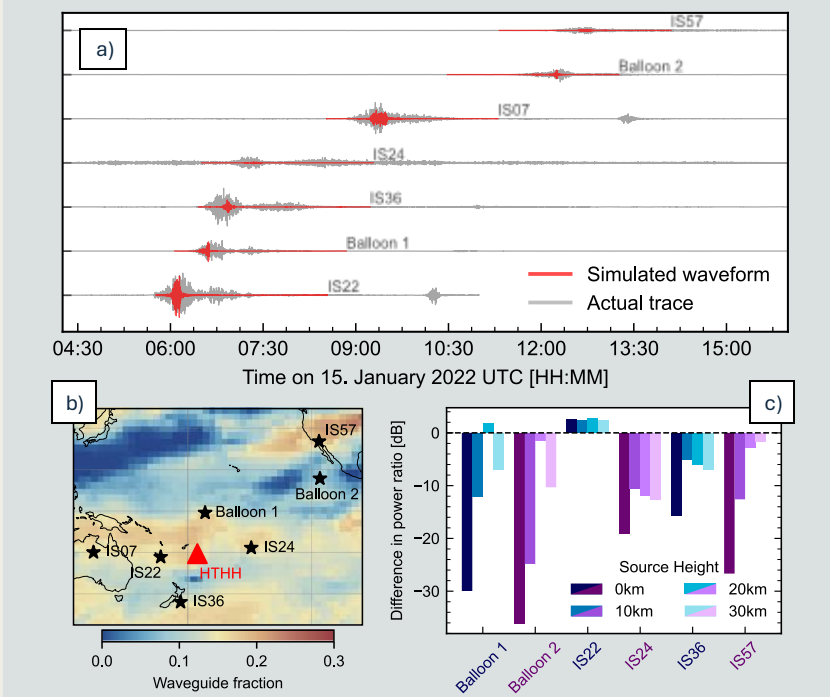
Introduction & Objectives

- **Hunga Tonga-Hunga Ha'apai** (HTHH) infrasound, 15 January 2022, recorded by two Strateole-2 balloons (~20 km altitude) [1, 2]. Together with IMS infrasound ⇒ Earth-based benchmarking, gaining confidence in **Venus volcano sound** modeling
- **Venus**: Surface sensors not viable due to harsh climate. Earth-like pressure at ~60 km altitude ⇒ Balloons can measure infrasound
- Are there **infrasound waveguides on Venus** that allow volcanoes to be heard at balloons? **Global ducting morphology**?

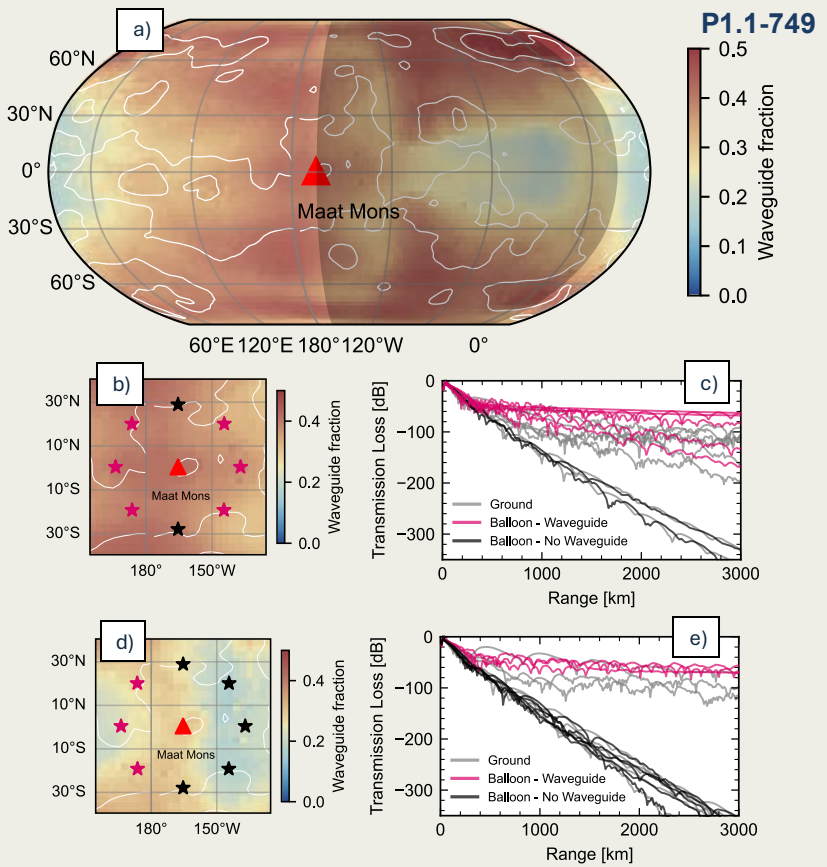
Methods & Data

- **HTHH**: Atmospheric model G2S (MERRA2 to ~80 km) [3, 4] + Gravity wave perturbations [5]. Recorded signals are from the IMS network and Stratéole-2 campaign.
- **Venus Climate Database**, with attenuation [6, 7].
- **Pulse propagation: Fourier reconstruction** of Transmission Loss (TL). Delta pulse $[0.02, 0.1]$ Hz, each freq. calculated by Parabolic-equation ePape [8]
- **Ray-theory waveguide fraction:** Ratio of rays ducted from an isotropic source at balloon [4] + apply reciprocity ⇒ **Global ducting assessment**



HTHH (a) Modelled & recorded, [0.02, 0.1] Hz, source at 20 km altitude. (b) Waveguide fraction for 1-70 km relative to balloon. (c) Difference between modelled and recorded power ratio relative to the IMS station IS07.

- **Taking HTHH plume height into account** ⇒ Predict relative amplitudes (but source characteristics are uncertain)
- **Estimate global volcanic sound waveguiding on Venus** using ray-theory based waveguide fractions. Parabolic-equation based TL shows additional ducting.



Venus (a) Waveguide fractions at dawn (06:00) for Maat Mons. Balloons 60 km altitude. Waveguides below 130 km. (b-c) From Maat Mons at dawn. Point sources propagated to balloons, $f = 0.05$ Hz. Pink: trapped in waveguide. (d-e) Same as (b-c), at dusk (18:00)

[1] A. Podglajen et al., (2022), "Stratospheric balloon infrasound from the 15 Jan 2022 Hunga eruption," GRL, 49(19). [2] J. S. Haase et al., (2018), "Stratéole-2: Around the world in 84 days." [3] C. H. Hetzer, (2024), "The NCPAG2S client," GitHub: chetzer-ncpa/ncpag2s-clc. [4] D. P. Drob, J. M. Picone, and M. Garcés, (2003), "Global morphology of infrasound propagation," JGR, 108(D21). [5] C. S. Gardner et al., (1993), "Gravity wave spectra of atmospheric fluctuations," JGR, 98. [6] A. Martinez, (2023), "Variability of the Venusian thermosphere with the IPSL Venus GCM," PSS, 389. [7] R. F. Garcia et al., (2024), "Seismic wave detectability on Venus with balloons and airglow imagers," ESS, 11(11). [8] R. Waxler et al., (2021), "NCPAprop v2.1.0," Zenodo.

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Searching for waveguides on Venus

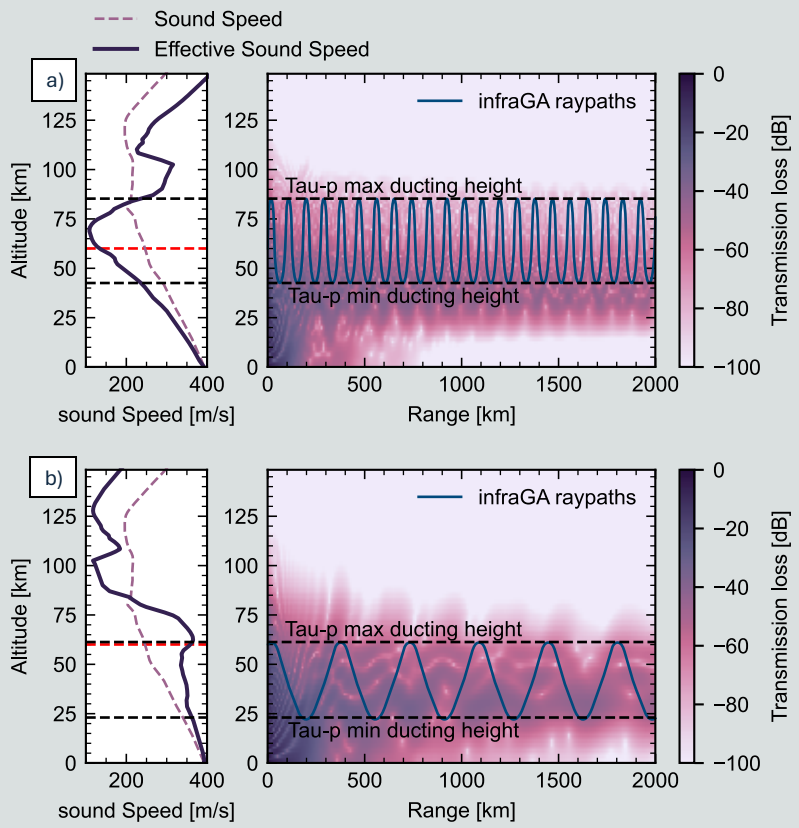
- Westwards super-rotational winds in the middle atmosphere of Venus can create large waveguides. But due to high sound speeds at the surface, it is uncertain whether sound gets ducted from the ground
- We have identified two possible waveguides going in opposite zonal directions. The calculated TLs indicate that it is possible for infrasound to get ducted

Definition of the waveguide fractions

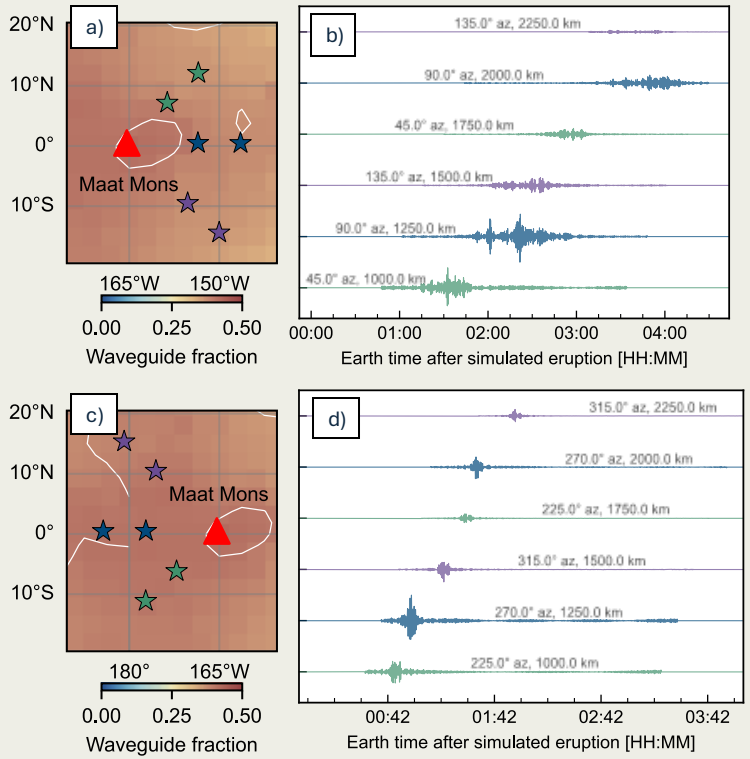
The waveguide fractions are calculated using the formulation of vertical slowness from the Tau-p method [1, 2]. Given a balloon at altitude $z_0 = 60$ km, sound speed $c(z)$, inclination θ from the vertical and along track wind $\mathrm{u}(z)$, the vertical slowness is:

$$q(p,z) = \sqrt{\left(\frac{1}{c(z)}\right)^2 - \frac{p^2}{(1-u(z)p)^2}}.$$

The ray turns when $q(p,z) = 0$. Thus, we can find the extent of a waveguide by searching for roots of $q(p,z)$ relative to the balloon for rays launched evenly across all directions.



Waveguides on Venus. This figure shows predicted ducting heights together with the PE based TLs for waves launched at 60 km altitude above Maat Mons during dawn, *f* = 0.05 Hz. The rays shown on top are simulated using infraGA [3] without attenuation. (a) In the eastward direction against the strong winds. (b) In the westward direction along the strong winds. Note that shallower inclination angles (10 vs 45) is needed for ducting towards the west.



Waveforms on Venus. Example waveforms calculated from the surface of Maat Mons to balloons at 60 km altitude located towards the east (a, b) and west (c, d). The propagated pulse is a delta function with *f* = [0.02, 0.1] Hz. The waveforms are normalized across stations.

[1] D. P. Drob, J. M. Picone, and M. Garcés, (2003), "Global morphology of infrasound propagation," JGR, 108(D21). **[2]** M. A. Garcés et al., (1998), "Traveltimes for infrasonic waves in a stratified atmosphere," GJI, 135(1). **[3]** P. Blom, (2019), "Modeling infrasonic propagation through a spherical atmospheric layer: The stratospheric pair," JASA, 145(4).