NORSAR

Funded by The Research Council of Norway

UNIVERSITY OF OSLO

AGU23 San Francisco, CA & Online Everywhere 11-15 December 2023

S11G-0335 The AIR project: Leveraging balloon pressure data for planetary exploration

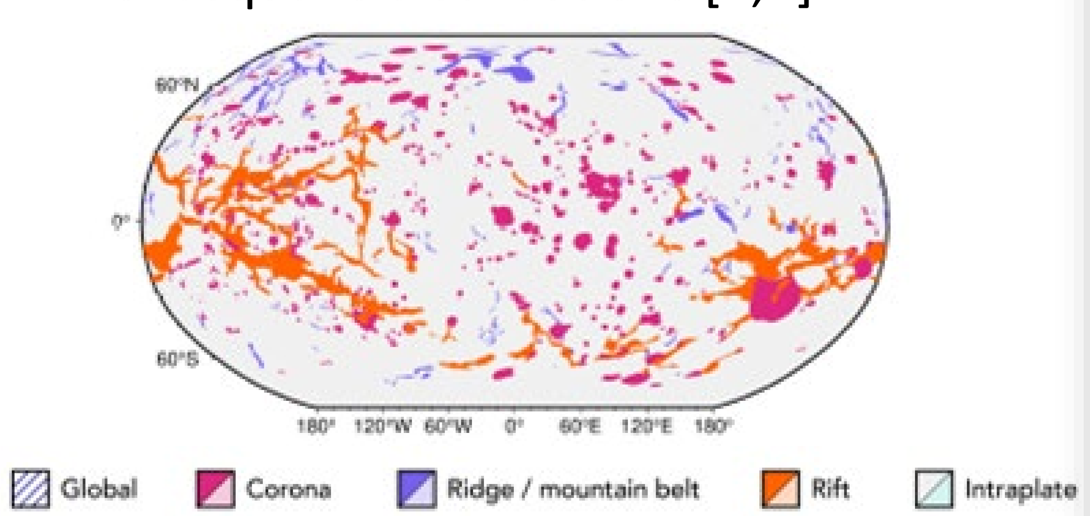
*Q. Brissaud, S.P. Näsholm, A. Turquet, T. Kaschwich and **C.M. Solberg***

Intro

- AIR is a 3.5 years project to assess the feasibility of performing seismic tomography from a balloon platform
- Seismic waves couple to the atmosphere as infrasound which can be recorded from a balloon
- Here we provide the first assessment of the global detectability of seismic infrasound at high altitude

Methods

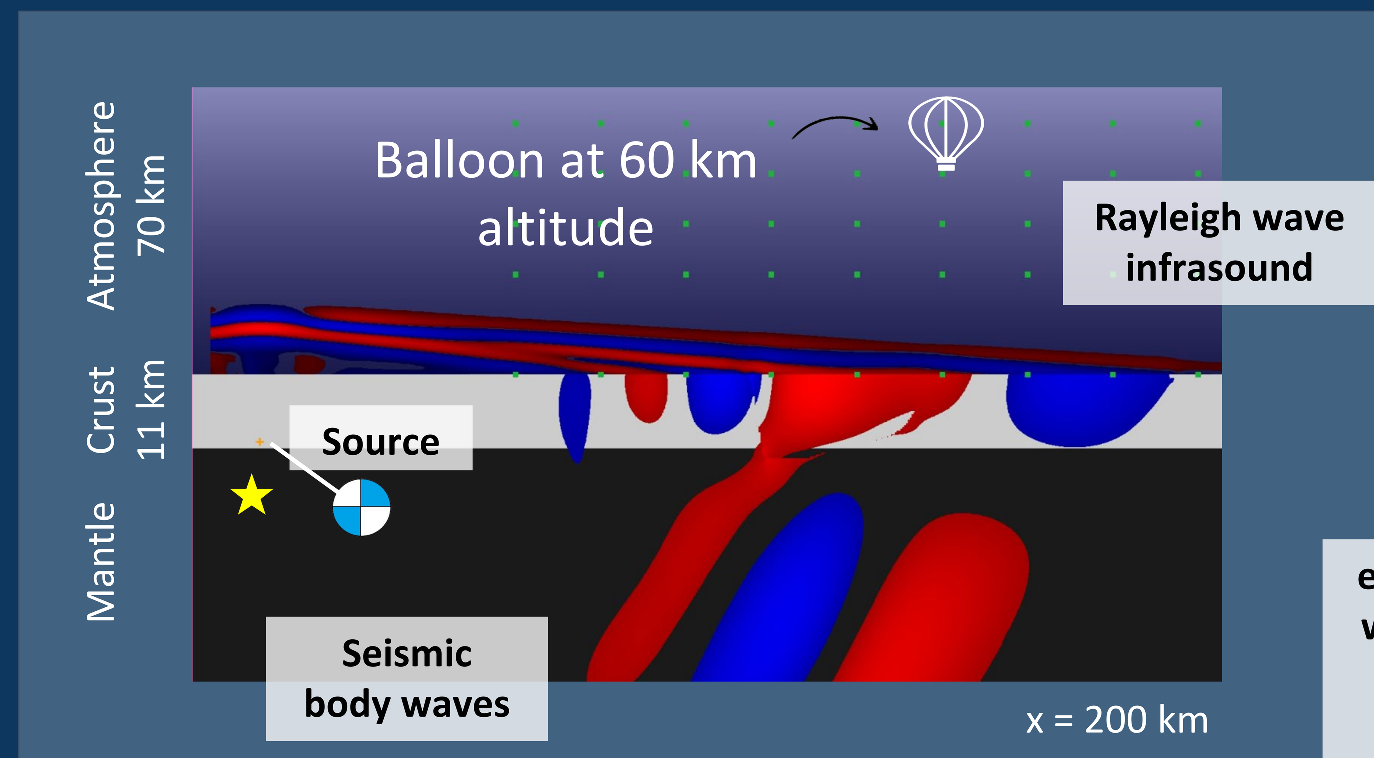
1. We used Earth-to-Venus seismicity estimates to constrain time & spatial venusquake distributions [1,2]



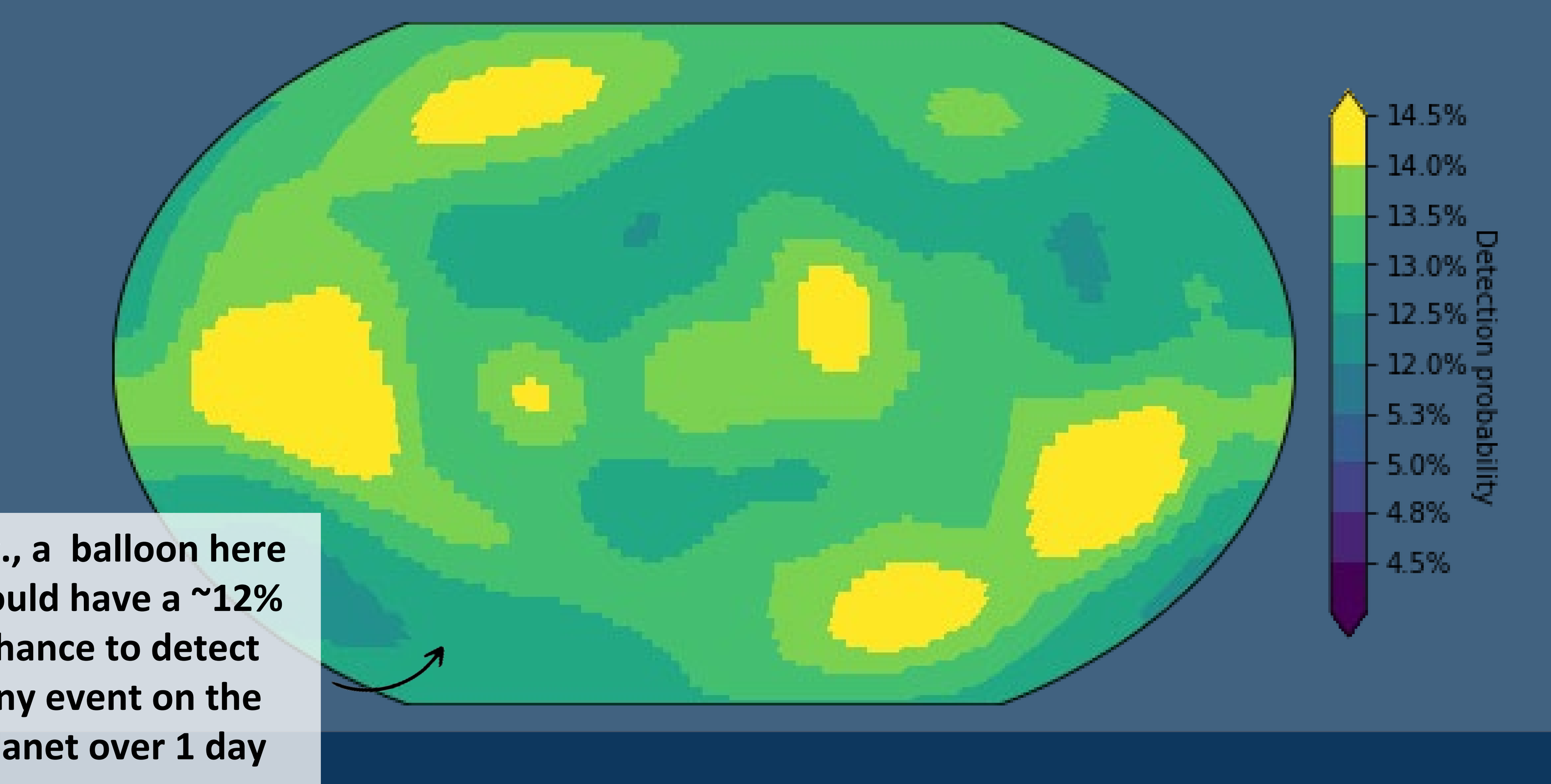
1. We ran waveform simulations < 1 Hz for a normal fault using SPECFEM2d-DG [3] & extracted downwind amplitude vs distance at 60 km altitude. Values >200 km are extrapolated by fitting: a×dist^b
2. We computed the detection probability as a combination of event likelihood and signal detection probability for a given signal-to-noise ratio
3. Balloons are assumed to be free floating with the winds at a constant altitude

We estimated between **15% and 80% probability** of **detecting a venusquake** during a 15 days **balloon mission**

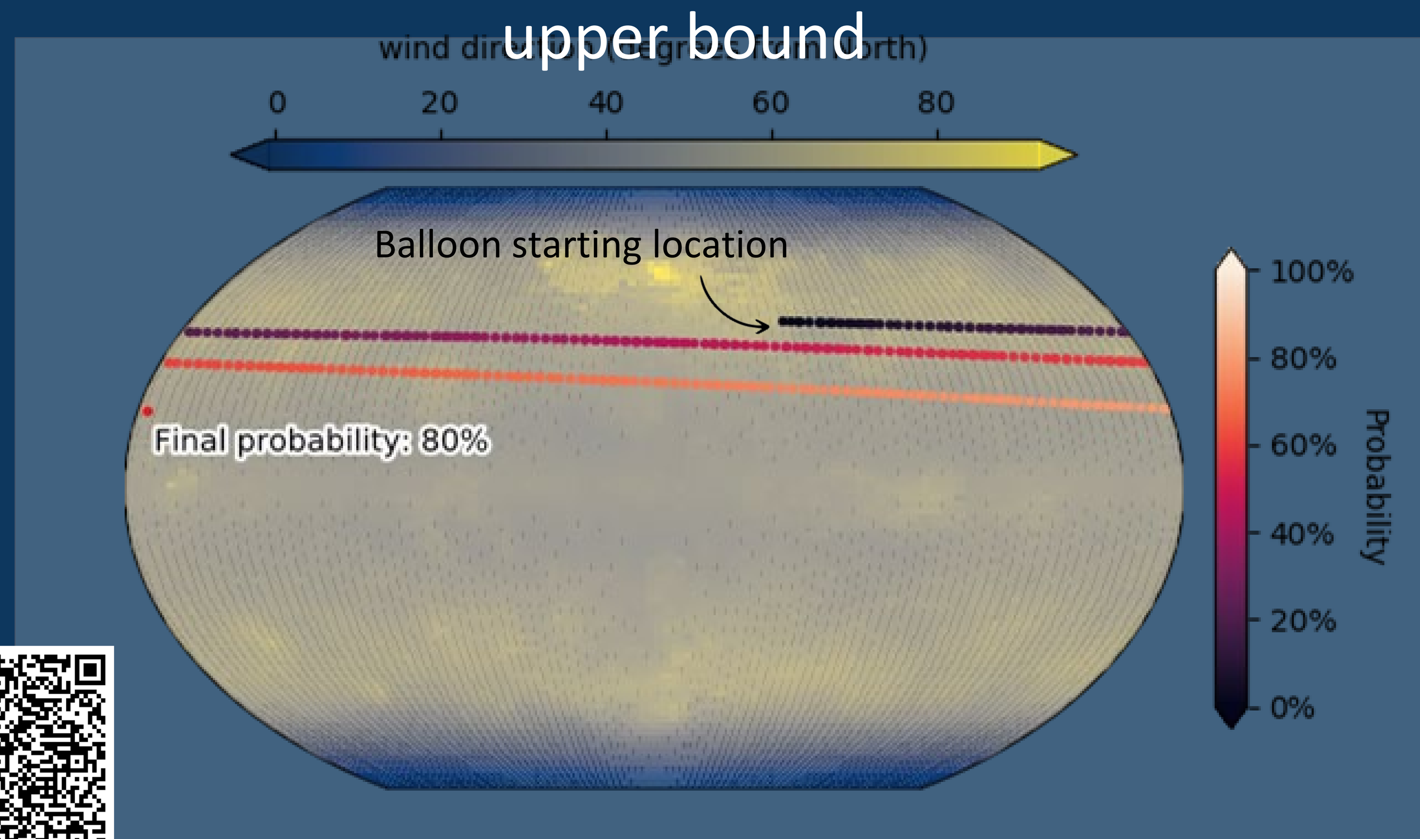
Simulation of seismic infrasound from a strike-slip mechanism at 10 km depth



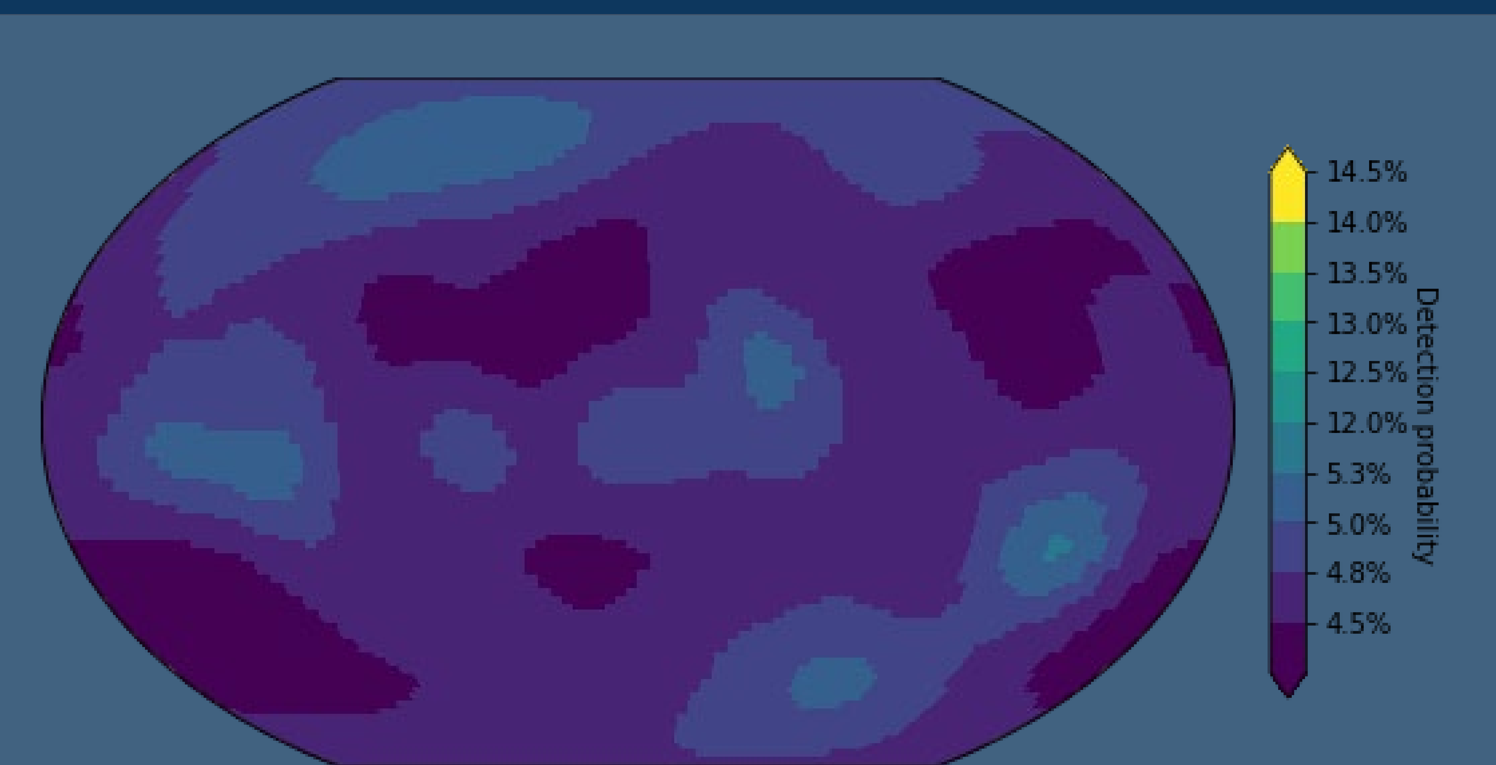
Probability $\mathbb{P}(x^{obs}_{lat,lon}|M_{w,min})$ of detecting ANY $M_{w,min} \geq 5$ over one day assuming a seismically active Venus - upper bound



Probability of detecting ANY $M_{w,min} \geq 5$ integrated along a 15 days balloon trajectory - upper bound



Same probability as above but with assuming a seismically active Venus - lower bound



SCAN ME

Contact information
Quentin Brissaud, AIR PI,
Quentin.Brissaud@norsar.no
Celine Marie Solberg, MSc student
celinems@uio.no

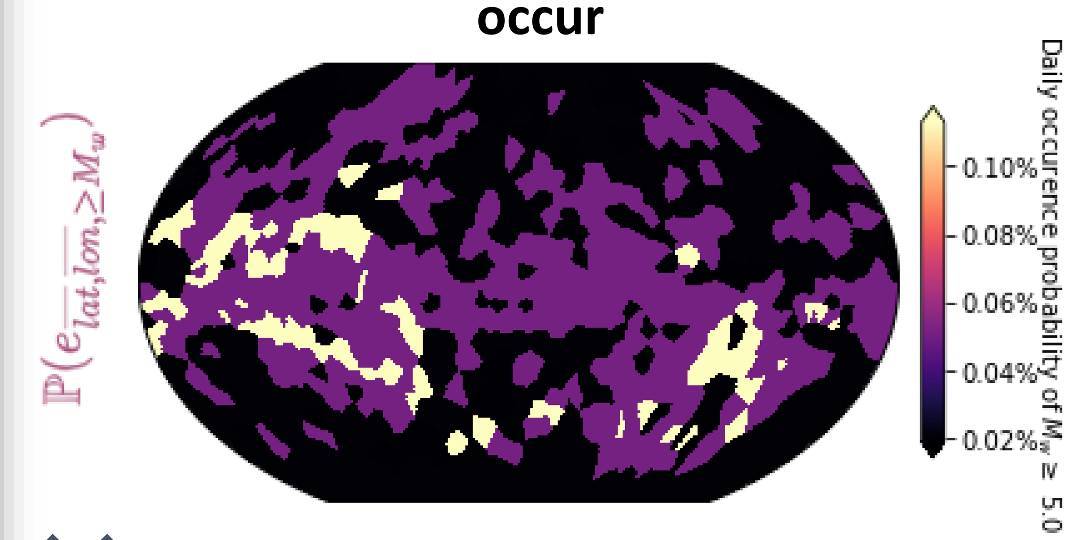
[1] van Zelst, Iris, et al. "Estimates on the possible annual seismicity of Venus." (2023) 10.31223/X5DQ0C
[2] Sabbeth, L., et al. "Estimated seismicity of Venusian wrinkle ridges based on fault scaling relationships." (2023) 10.1016/j.epsl.2023.118308
[3] Martire, Léo, et al. "SPECFEM2D-DG, an open-source software modelling mechanical waves in coupled solid–fluid systems: the linearized Navier–Stokes approach." (2022) 10.1093/gji/ggab308

Description of detection model

$$\mathbb{P}(x^{obs}_{lat,lon}|M_{w,min}) = 1 - \prod_{lat,lon} \prod_{M_w \geq M_{w,min}} \left[1 - \mathbb{P}(e_{\overline{lat},\overline{lon},\geq M_w})\, \mathbb{L}(\text{detection}|e_{\overline{lat},\overline{lon},M_w}, \text{noise}, x^{obs}_{lat,lon})\right]$$

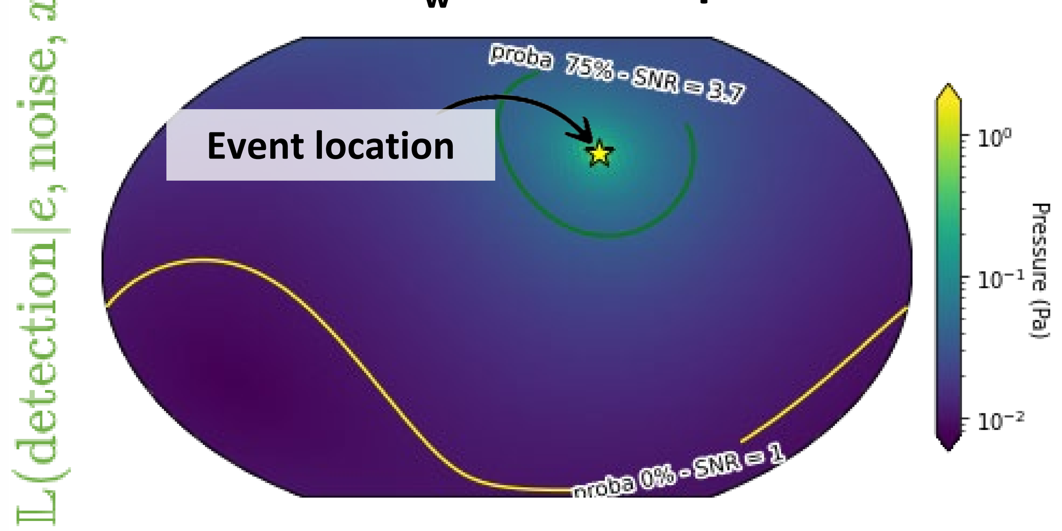
- $\mathbb{P}(x^{obs}_{lat,lon}|M_{w,min})$: Detection probability of events with magnitude ≥ $M_{w,min}$ from a balloon location **lat,lon**
- $\prod\prod$: Product over all possible source locations and magnitudes
- $\mathbb{P}(e_{\overline{lat},\overline{lon},\geq M_w})$: Probability of an event **e** with magnitude M_w to occur at location $\overline{lat},\overline{lon}$
- $\mathbb{L}(\text{detection}|\ldots)$: Detection likelihood of event **e** at location $\overline{lat},\overline{lon}$ with noise level **noise** from a balloon location at **lat,lon**

Daily probability of M_w = 5 venusquake to occur



×

Max. amplitude at 60 km altitude from a M_w = 5 venusquake



Future work

1. Determine amplitude vs distance curves for sources with different focal mechanisms, at various depths, and for different crustal thicknesses
2. Validate extrapolation against global full waveform simulations
3. Investigate potential for inversion of simulated infrasound data to retrieve seismic parameters

The AIR project: Leveraging balloon pressure data for planetary exploration

*Q. Brissaud, S.P. Näsholm, A. Turquet, T. Kaschwich and **C.M. Solberg***

Seismicity results from **van Zelst, Iris, et al. "Estimates on the possible annual seismicity of Venus." (2023)** [10.31223/X5DQ0C](https://doi.org/10.31223/X5DQ0C)

Estimate	$M_w \geq 3.0$	$M_w \geq 4.0$	$M_w \geq 5.0$	$M_w \geq 6.0$	$M_w \geq 7.0$
Inactive Venus	826 - 2568	95 – 296	11 – 34	1 – 4	0 – 0
Active Venus - lower bound	10760 - 33460	1161 – 3609	126 – 391	14 – 42	2 – 5
Active Venus - upper bound	84263 - 262023	5715 – 17773	465 – 1446	44 – 136	4 – 15

Table 1. Number of venusquakes per year equal to or larger than a certain moment magnitude for our three possible Venus scenarios. A range is provided based on the uncertainties in the chosen scaling factor for the seismogenic thickness.

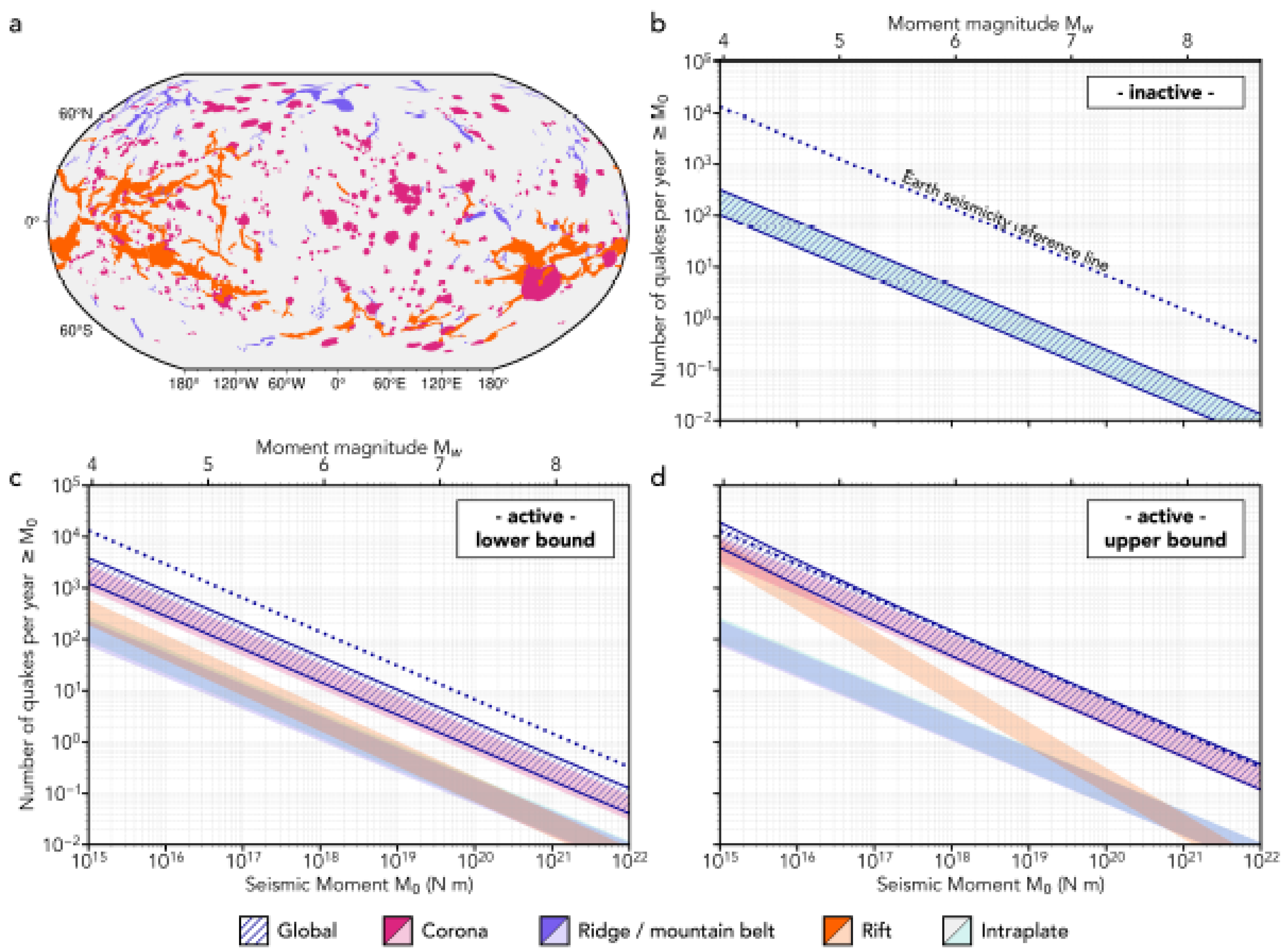
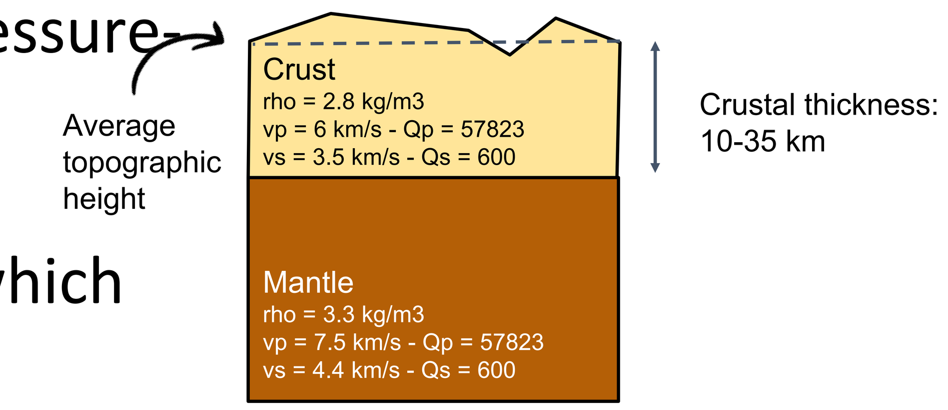


Figure 2. (a) Map of Venus (Robinson projection) showing the areas of mapped coronae, ridges and mountain belts, and rifts (Price & Suppe, 1995; Price et al., 1996). (b-d) Ranges of potential quake size-frequency distributions on Venus for (b) an inactive Venus with background seismicity analogous to Earth's continental intraplate seismicity; (c) a lower bound on an active Venus; and (d) an upper bound on an active Venus. The hatched area shows the global, accumulated annual seismicity that combines the seismicity of the different individual tectonic settings. Note that because of the log-log scale, the global estimate and the seismicity range of the highest individual tectonic setting are closely-spaced. Dotted dark blue line indicates the reference Earth seismicity line, which corresponds with the slope of the size-frequency distribution of global seismicity on Earth (Figure 1c).

Details about methodology

<u>Seismic model</u>

- We choose mantle velocities from a pressure-rescaled version of PREM
- Crustal thickness is selected as 15 km which is in a realistic range derived from topography and gravity data

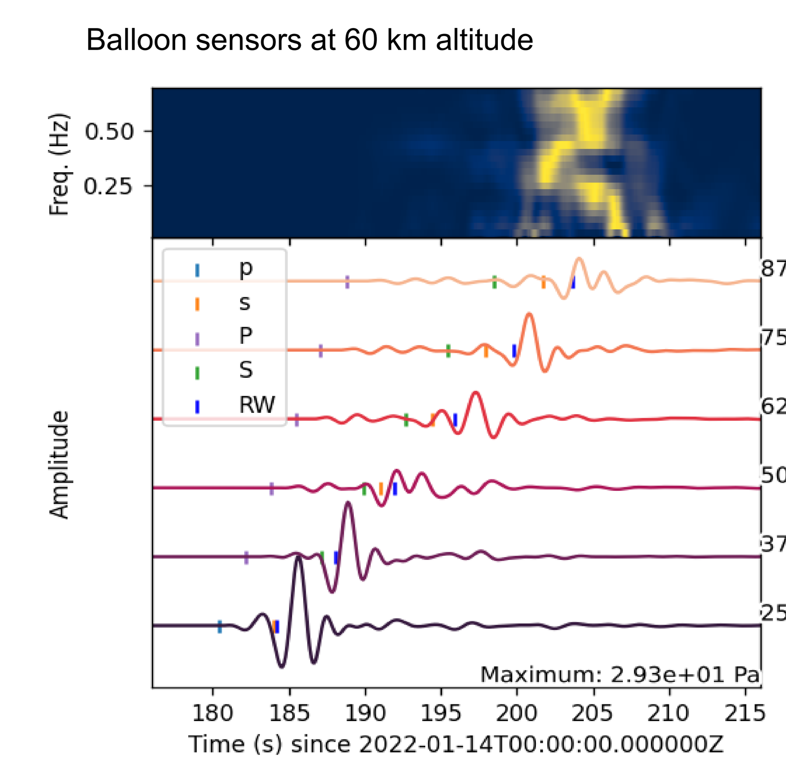


<u>Atmospheric model</u>

- Winds, pressure, temperature, density, and attenuation parameters are extracted from the [Venus Climate Database (VCD)]()
- Atmospheric parameters show small variations with latitude and longitude. We therefore use a profile extracted at latitude 0 and longitude 0 for the simulations.

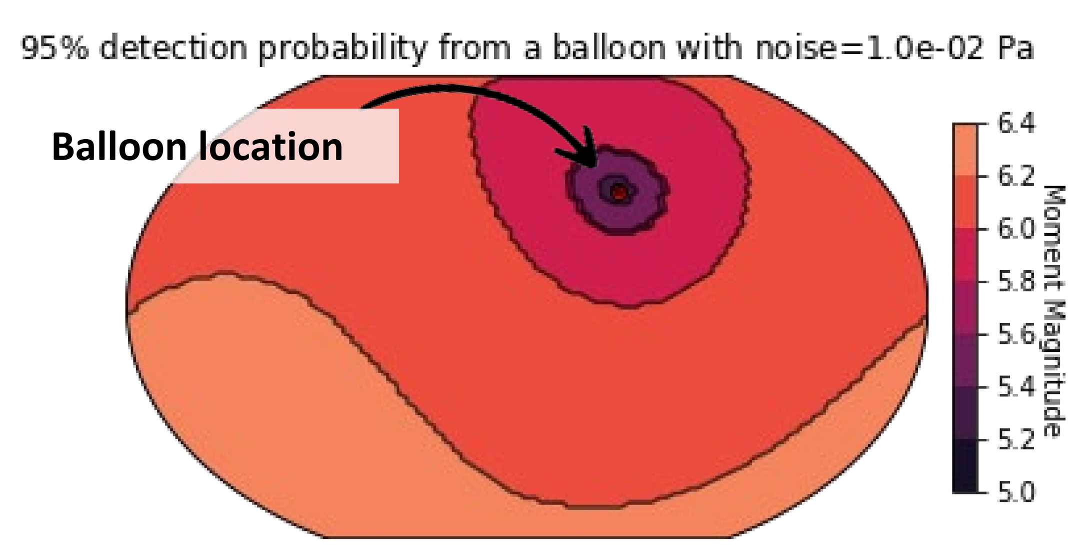
<u>Seismic sources and simulations</u>

- For our preliminary investigation, we considered only one source depth at 10 km depth and a pure normal (see Figure) or strike-slip fault.
- We simulate signals only along one azimuth that maximizes the ground vertical velocity

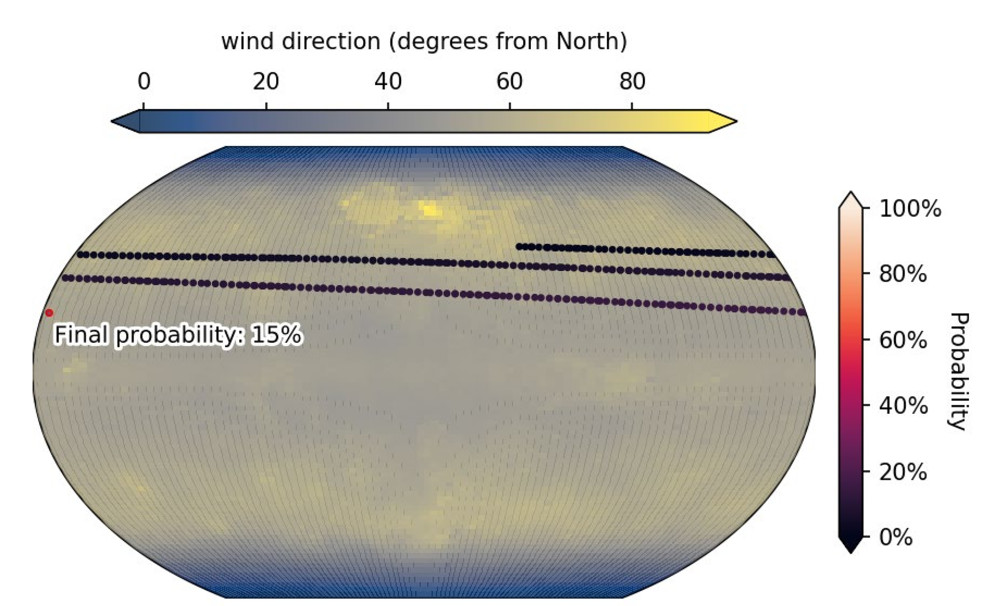


Extra Figures about detection model

Magnitude detection threshold from a specific balloon location

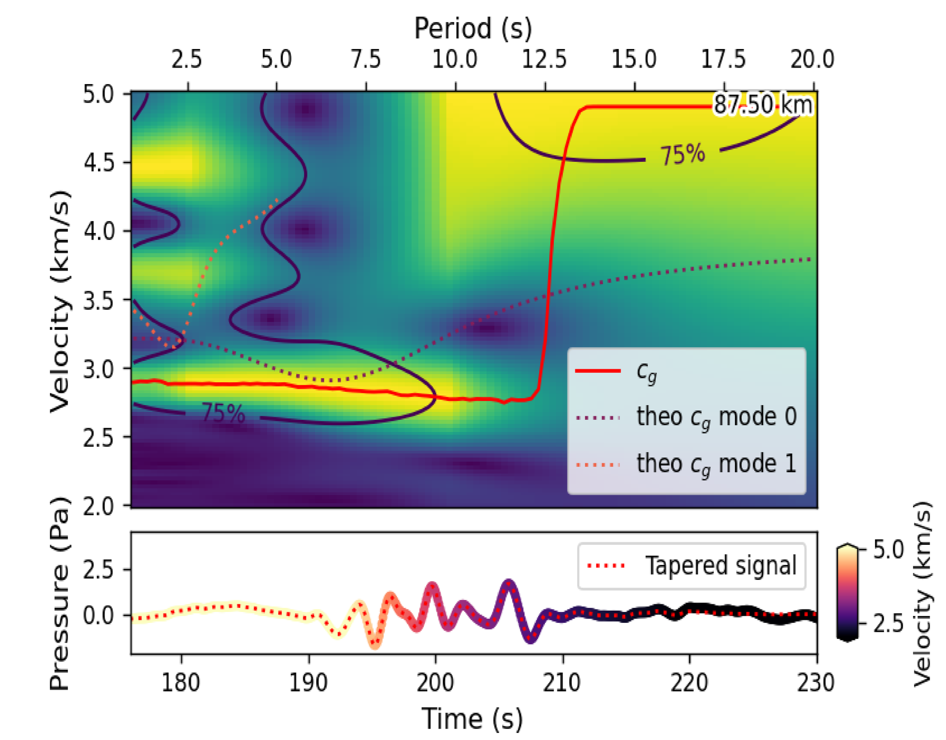


Probability of detecting ANY Mw,min ≥ 5 integrated along a 15 days balloon trajectory - lower bound

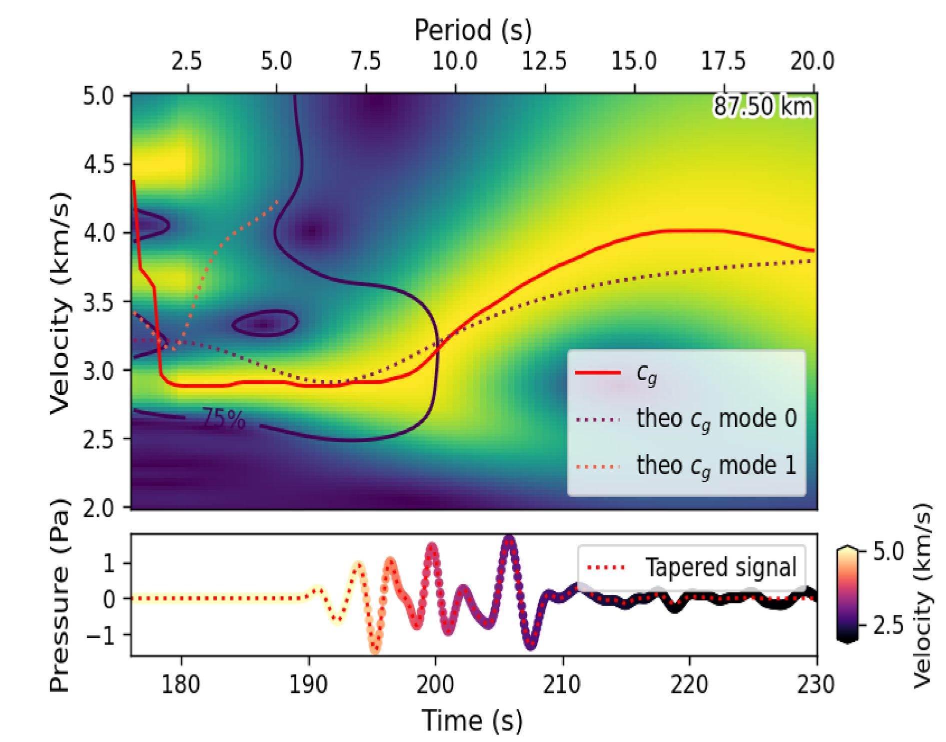


Inversion results: Waveforms contain information about the subsurface

- We performed a frequency Time ANalysis (**FTAN**) on seismic and infrasound signals
- Seismic and Acoustic group velocity vs frequency curves show strong correlations



With realistic noise



Ground to balloon