Preliminary assessments of the global detectability of venusquakes from a balloon platform

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Seismicity on Venus: Prediction & Detection

ISSI TEAM

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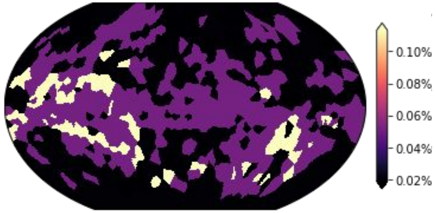
Exploring the Earth

Current goal: Estimating detectability on a global scale

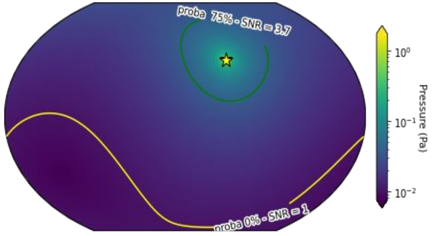
Likelihood of detecting a venusquake of a certain magnitude during a balloon mission

Detection probability model



Probability of an event e to occur at a given location over a given time period

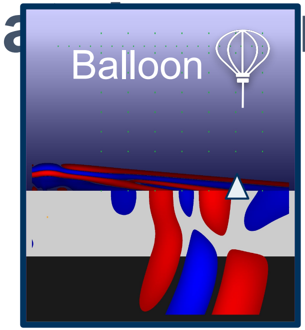
Likelihood of detecting event e for a certain noise level at a given location b



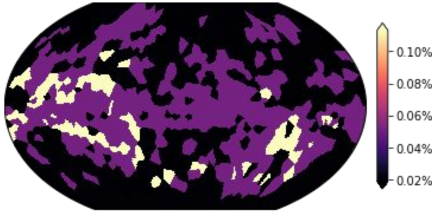
Probability of detecting any type of event equal to or bigger than a certain magnitude from a given balloon location

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

Detection probability model: Wha need?



Wave simulator
Seismo-acoustic simulations with SPECFEM-DG



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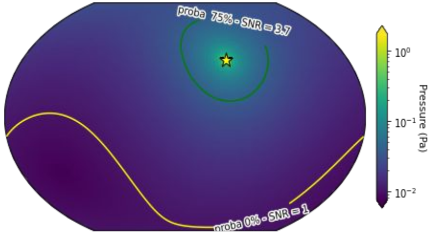
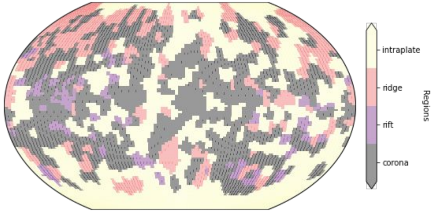




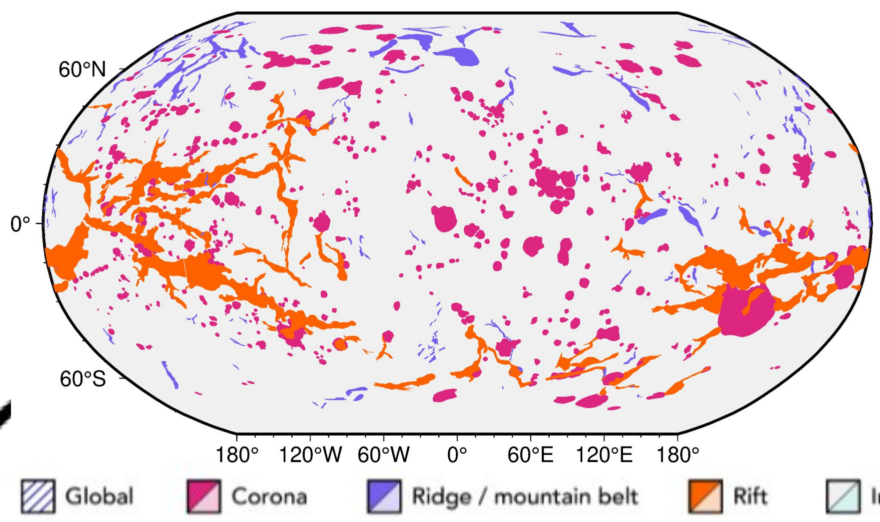
Seismicity estimates
Time and spatial distribution of venusquakes in different tectonic regions

detecting any qual to or rtain magnitude from a given balloon location

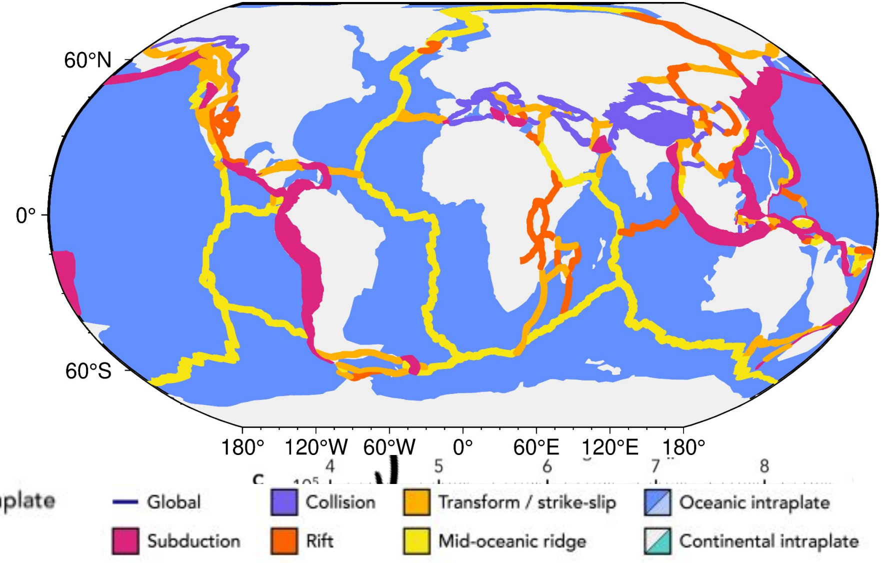
$$\mathbb{P}(x^{obs}_{lat,lon}|M_{w,min}) = 1 - \prod_{\overline{lat},\overline{lon}} \prod_{M_w \geq M_{w,min}} [1 - \mathbb{P}(e_{\overline{lat},\overline{lon},\geq M_w}) \cdot \mathbb{L}(\text{detection}|e_{\overline{lat},\overline{lon},\geq M_w}, \text{noise}, x^{obs}_{lat,lon})]$$

Constraining seismicity (from Van Zelst, 2023)

Venus

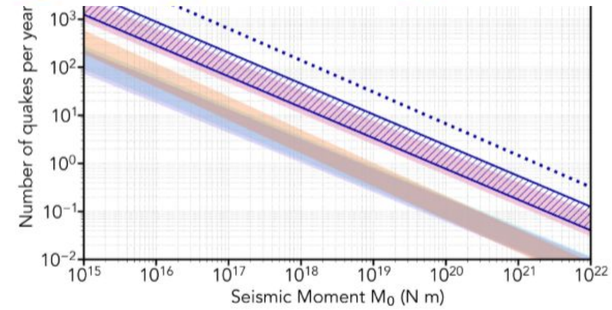


Earth



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.



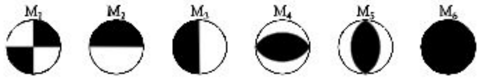
Simulating seismo-acoustic signals: Strategy

Atmospheric model
Extracted from Venus Climate Database

Seismic model
Candidates for seismic models based on Earth scaling

Wave simulator
Seismo-acoustic simulations with SPECFEM-DG

Focal mechanism model
Compute waveforms for fundamental moment tensors

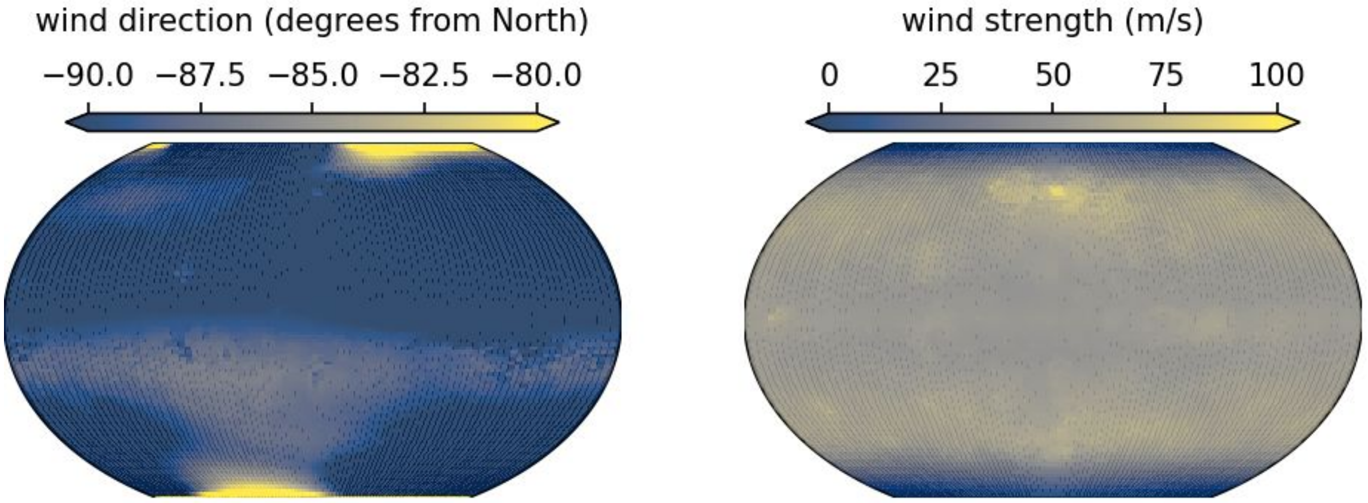


Convolution with source time function
Accounting for source time function dependence on magnitude

Extrapolation amplitudes to large distances
Curve fitting of amplitudes assuming asymptotic behaviour

Atmospheric model

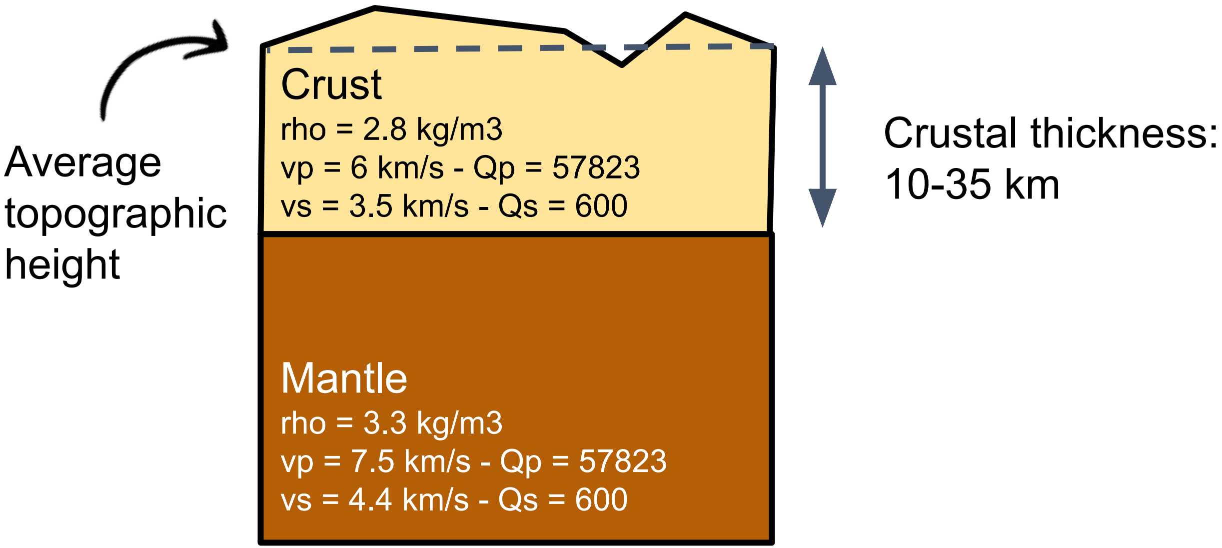
The Venus Climate Database (VCD) provides hourly predictions of winds, temperatures, and atmospheric compositions with altitude



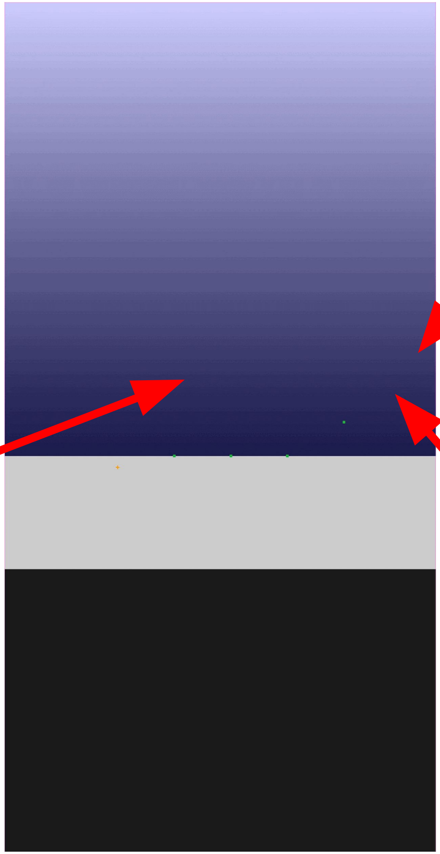
Winds at 50 km altitude

Seismic model

- Very little constraints of the crust and mantle
- We use a pressure rescaled version of the **Preliminary Reference Earth Model (PREM)**



Simulating seismo-acoustic signals



Scattered body waves

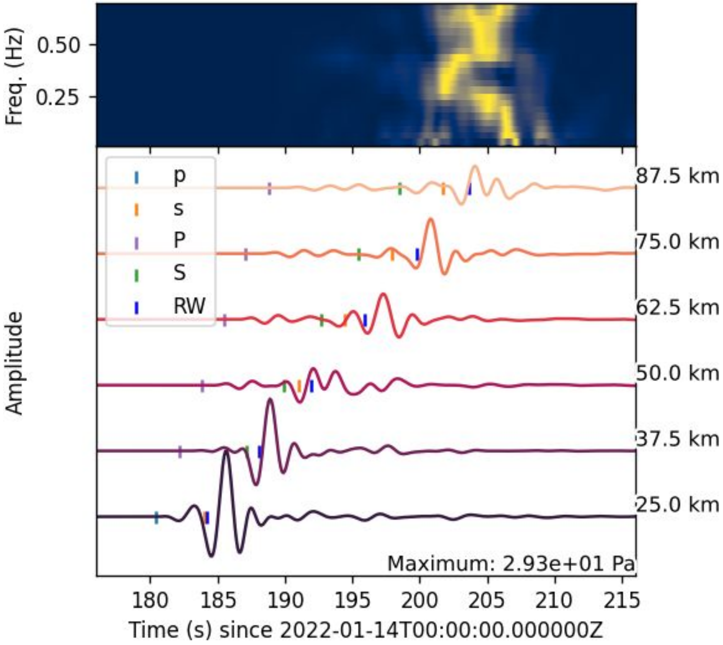
Epicentral Infrasound generated just above the epicenter

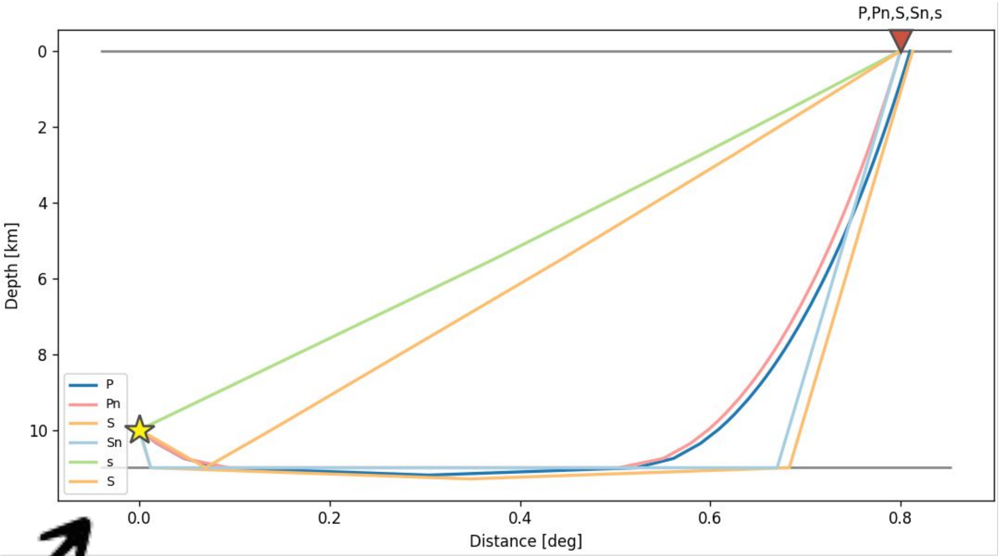
Surface waves

Simulating seismo-acoustic signals

Example of simulation outputs for a source with Mw 5 at 10 km depth and half duration 2 s

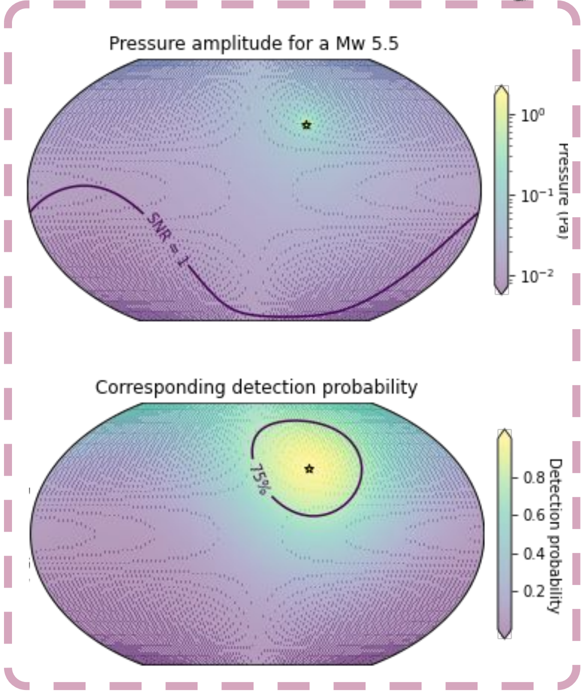
Balloon sensors at 60 km altitude

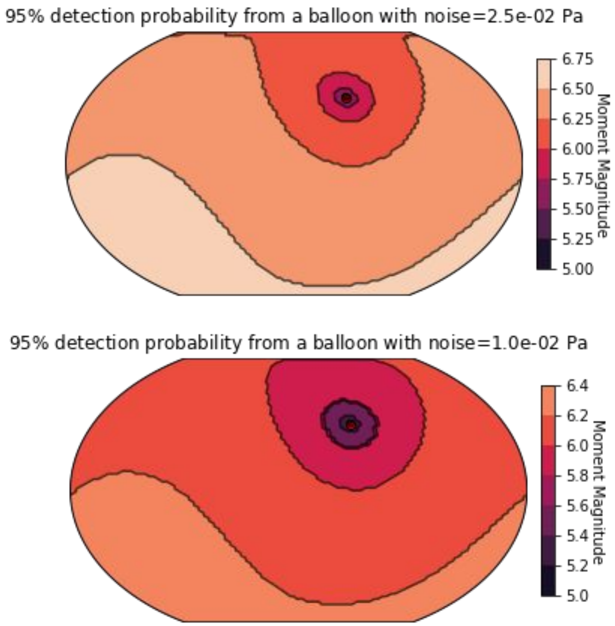




A global view of detectability

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

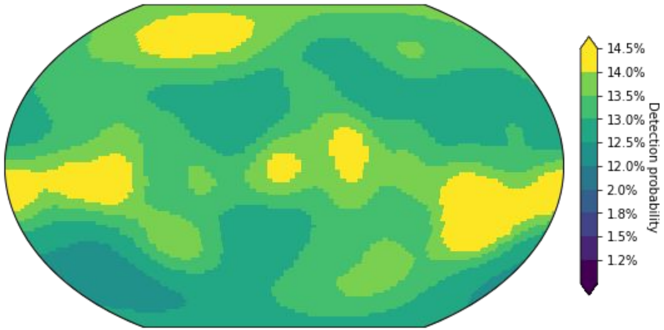




Lower noise level

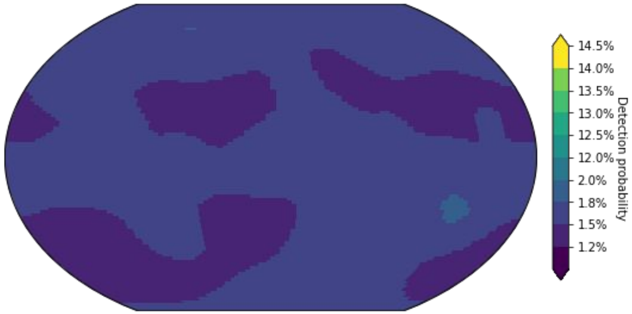
A global view of detectability in an active Venus setting

High activity Venus



Switching to different scenario

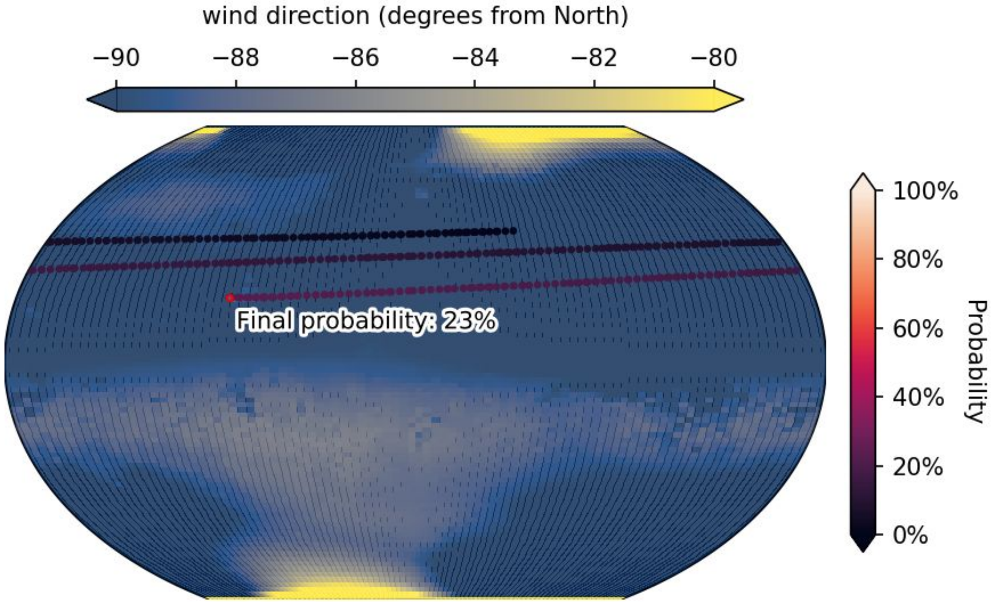
Low activity Venus



Little variations of detectability with location due to **strong coupling between the ground and the atmosphere** (~100 times stronger than Earth)

Detection probability during balloon mission

We simulate balloon trajectory by assuming a constant flight altitude of 50 km and a balloon drifting freely with the wind



Conclusion and future work

We estimated between 23% and 80% probability of detecting a venusquake during a 15 days balloon mission

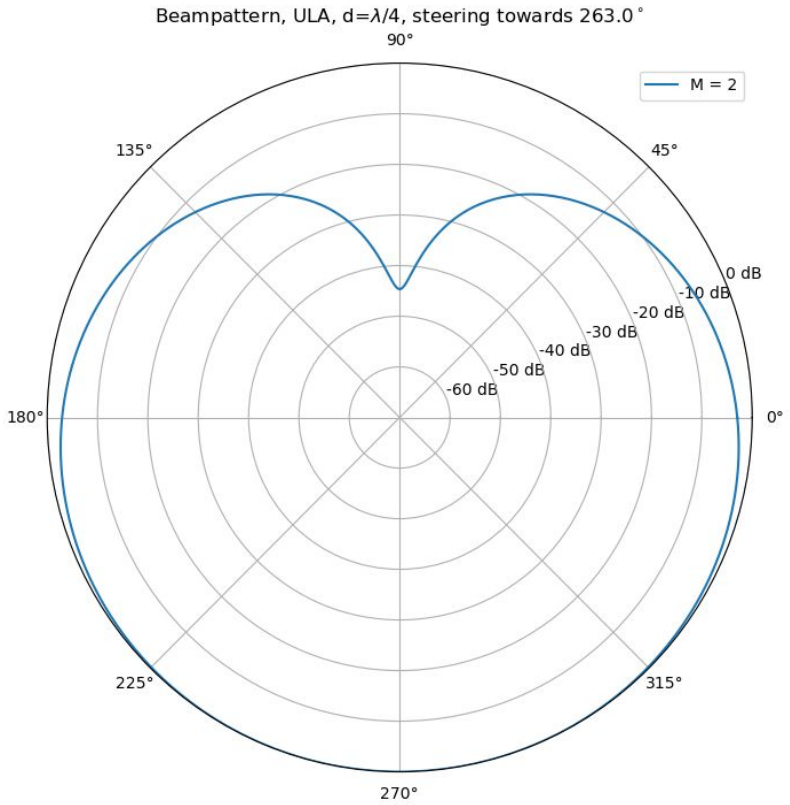
- We explored a very small source and velocity parameter space
  - Need to vary focal depths and subsurface velocities
  - Investigate influence of topography on the seismo-acoustic wavefield

- We only modeled seismo-acoustic waves up to 200 km
  - Need to find efficient modeling or extrapolation techniques to model over global scales

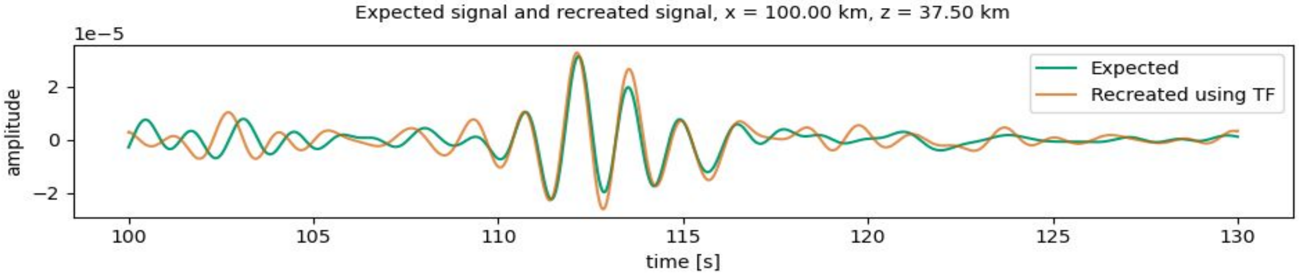
- For crustal and source inversion purposes, we need to pick at least S and RW arrival times. We therefore need to have maps for both the detectability of S and RWs.

- We need to look in more details at beamforming capabilities at the balloon to increase SNR (when multiple sensors are on the balloon tether)

Beamforming



Transfer function



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SPECFEM2d-DG simulations