Assumptions and uncertainties when simulating seismo-acoustic wave propagation on Venus

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https://teams.issibern.ch/seismicityonvenus/

NORSAR
Exploring the Earth

AIR – Airborne Inversion of Rayleigh waves

Using sound balloon-records to probe the subsurface

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- 3 years – just started
- Project owner: NORSAR
    - PI Quentin Brissaud
    - Postdoc Marouchka Froment (from next week)
    - Peter Näsholm (me – also at University of Oslo)
    - MSc student Celine Solberg
    - Antoine Turquet (researcher)
    - Tina Kaschwich (deputy department manager)

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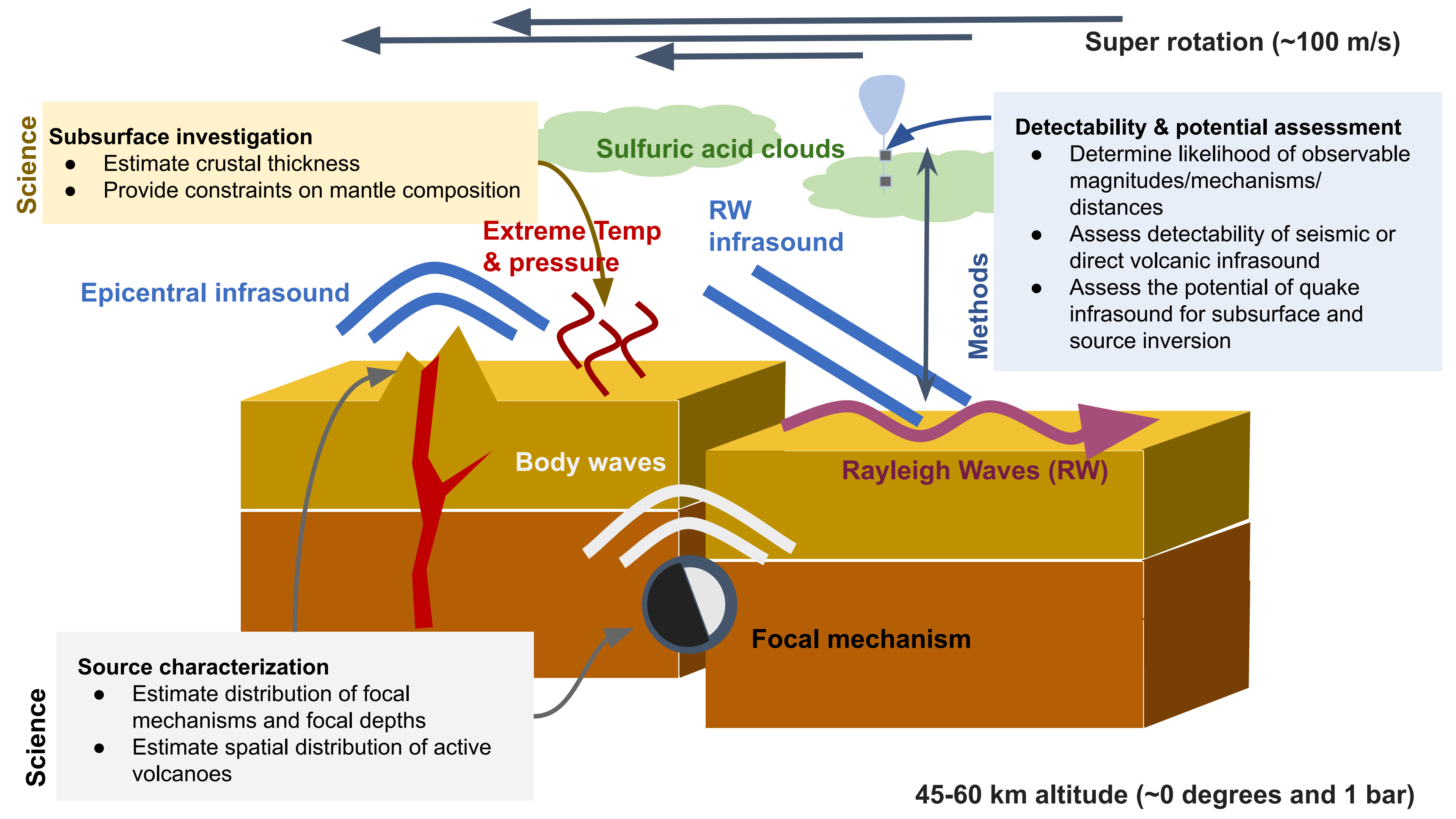
Using sound balloon-records to probe the subsurface

Main objective:
Novel algorithms to invert for subsurface velocities and for characteristics of seismic events using acoustic waveforms recorded at the balloon

Secondary objectives:

1) Determining the detectability-range of earthquakes from a balloon through the characterization of seismically-induced infrasound
2) Differentiating between source & path effects controlling the wave characteristics observed at the balloon
3) Implementing & validating an inversion method to retrieve subsurface and source properties from infrasound data along with a measure of their uncertainty.



Super rotation (~100 m/s)
Science
Subsurface investigation
Estimate crustal thickness
Provide constraints on mantle composition
Sulfuric acid clouds
Detectability & potential assessment
Determine likelihood of observable magnitudes/mechanisms/ distances
Assess detectability of seismic or direct volcanic infrasound
Assess the potential of quake infrasound for subsurface and source inversion
Methods
RW infrasound
Extreme Temp & pressure
Epicentral infrasound
Body waves
Rayleigh Waves (RW)
Focal mechanism
Source characterization
Estimate distribution of focal mechanisms and focal depths
Estimate spatial distribution of active volcanoes
Science
45-60 km altitude (~0 degrees and 1 bar)

The new paradigm of seismo-acoustic inversion

- **Ultimate goal**: Getting ready for ballon-bourne seismology and seismic-based velocity inversion on Venus → several unique aspects compared to traditional seismology:

    - Balloon-borne seismic inversions require an **accurate forward model connecting source characteristics to infrasound pressure signals**

    - **Uncertainties must be properly accounted for** during the inversion process to capture the true range of possible seismic models

    - Seismic-based velocity inversions generally rely on **three-components seismic sensors and/or accurate source models which are not available from a network of balloon sensors**

- What are the best-suited inversion techniques and key modeling parameters to incorporate to resolve the uncertainties associated with an (mostly) unknown Venus interior?

Assessing inversion potential from Earth balloon data

➔ Two questions: (1) what phases can we identify, and (2) can we extract surface-wave dispersion characteristics from infrasound data?

Mw 7.2

Balloon data

Scaled seismometer data

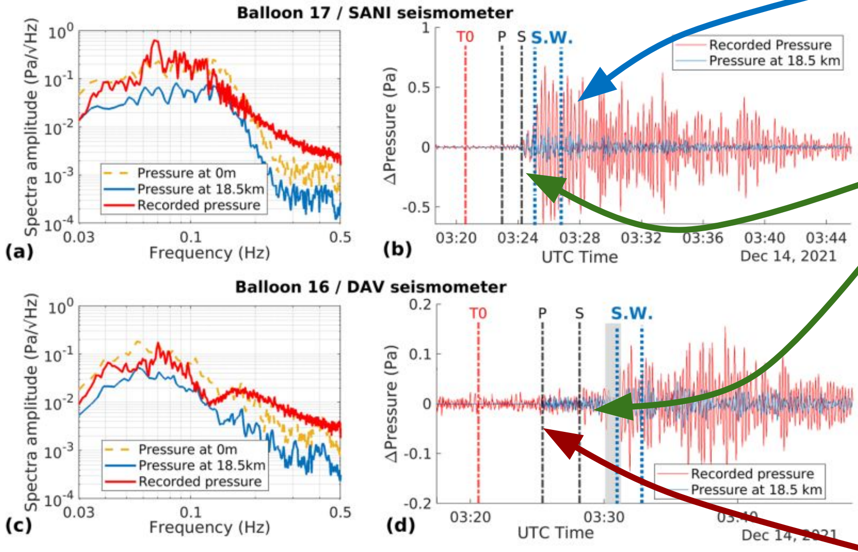


Figure 3. Comparison between pressure records and upward propagation of pressure perturbations induced by the ground vertical velocity. Spectra (a and c) and time domain pressure perturbations (b and d) are provided for Balloon 17 compared to SANI seismometer records (a and b), and for Balloon 16 compared to DAV seismometer records (c and d). The waveforms presented in this figure are band pass filtered in the 0.03–0.5 Hz frequency range. Origin time of the quake, and theoretical arrival times of pressure perturbations generated by P, S and Rayleigh Surface Waves (S.W.) at balloon altitude are provided as vertical dashed lines. A 1 min data gap is present on balloon 16 starting at 03:30:08 UTC. It is indicated by the gray shading area.

RW waves above noise level

S wave arrivals above noise level

P wave arrivals below noise level

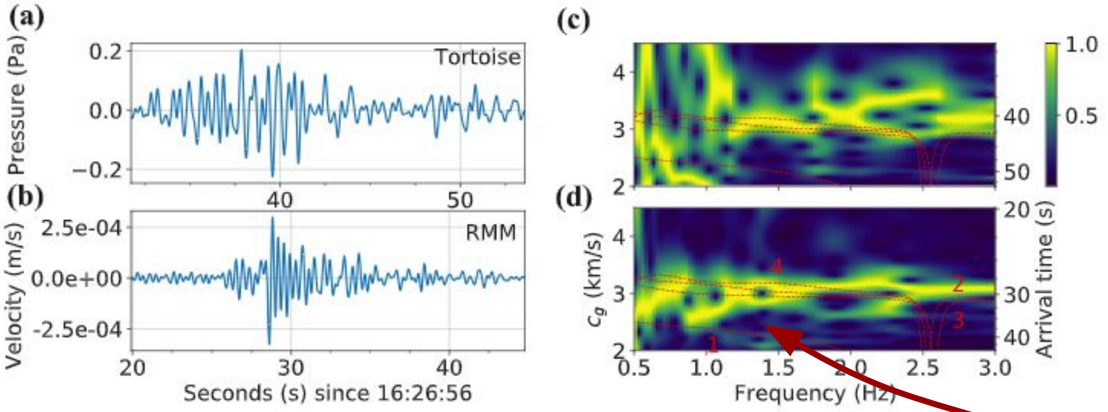
Assessing inversion potential from Earth balloon data

➔ Some of the Rayleigh-wave dispersion characteristics can be extracted from small earthquakes but **balloon noise might lead to a misinterpretation of group velocity curves**

Mw 4.2

Balloon

Closest seismometer



Lg wave

Figure 4. Frequency-Time ANalysis (FTAN) analysis of seismic and acoustic records. (a) Pressure time-series after event R1b at Tortoise, and (b) seismic vertical velocities at station RMM. (c), Corresponding FTAN group velocity between 0.2–3 Hz and 2–4.5 km/s of raw pressure data at Tortoise, and (d) of the seismic record for event R1b at station RMM. Arrival times corresponding to each group velocity value are shown on the right axis of plots (c) and (d). Theoretical group velocity curves computed at the epicenter using the CVMH model, which provides the best fit to data, are plotted in red over each panel for comparison. The red number over each curve indicates the mode number, with "1" corresponding to the fundamental mode.

What is needed to retrieve seismic velocities?

➔ We need to **select what physical quantities to use as inputs for the inversion** to identify the key modeling uncertainties

➔ Existing seismic velocity inversion methods might not all be appropriate for "single-component" infrasound-based inversions:

Rayleigh-wave dispersion based inversions

- Source location (at least one body wave observation + RW or multiple balloons)
- converted Rayleigh wave individual mode observations
- converted Rayleigh wave group velocity simulator

Full-waveform based inversions

- Source location
- Focal mechanism
- Source time function
- Full-waveform simulator

Body wave arrival time based inversions

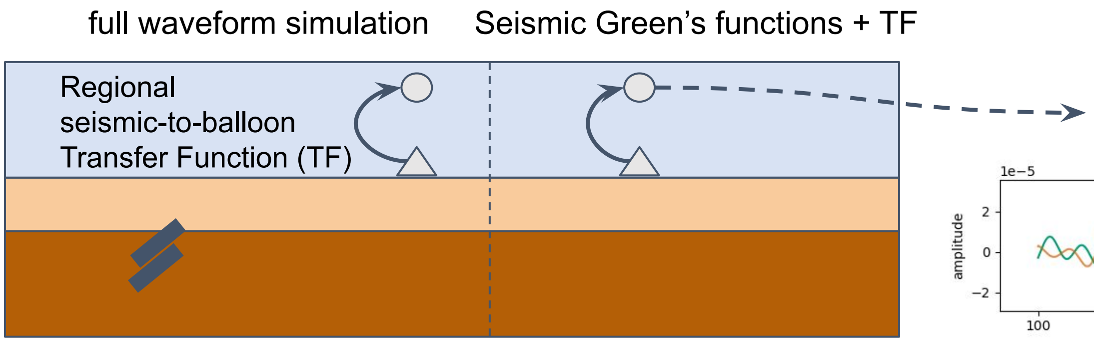
- Source location
- converted seismic body wave observations (and reflections)
- Body phase arrival time simulator

Global wave modeling

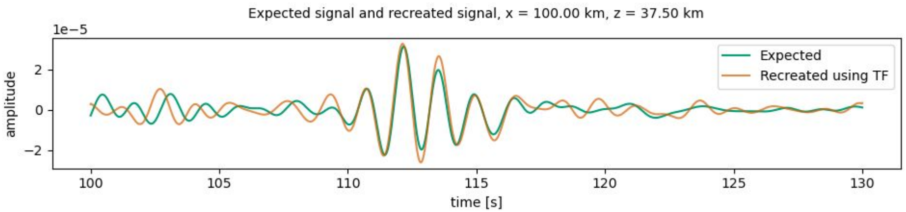
➔ Full seismo-acoustic coupling at global scale is numerically very expensive due to the **small acoustic wavelengths in the atmosphere**

➔ Seismo-acoustic Green's functions not directly accessible but **empirical ones could be built assuming laterally homogeneous seismic and atmospheric media** and quasi-plane wave acoustic propagation

➔ Atmospheric process relaxation frequencies can be altered to only model the low-frequency end of the spectrum



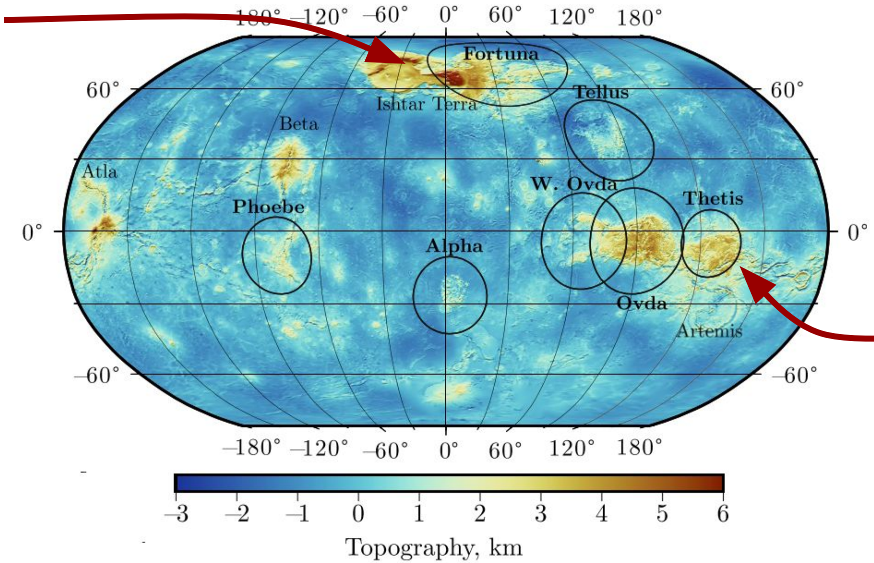
Balloon pressure simulated using seismic + TF



Topography

- **Topography can scatter acoustic energy** when the wavelengths of surface waves on the same order than topographic wavelength
- **Ignoring steep topography** in the frequency range of interest **will lead to overly optimistic amplitude estimates + loss of information about crustal seismic velocities**

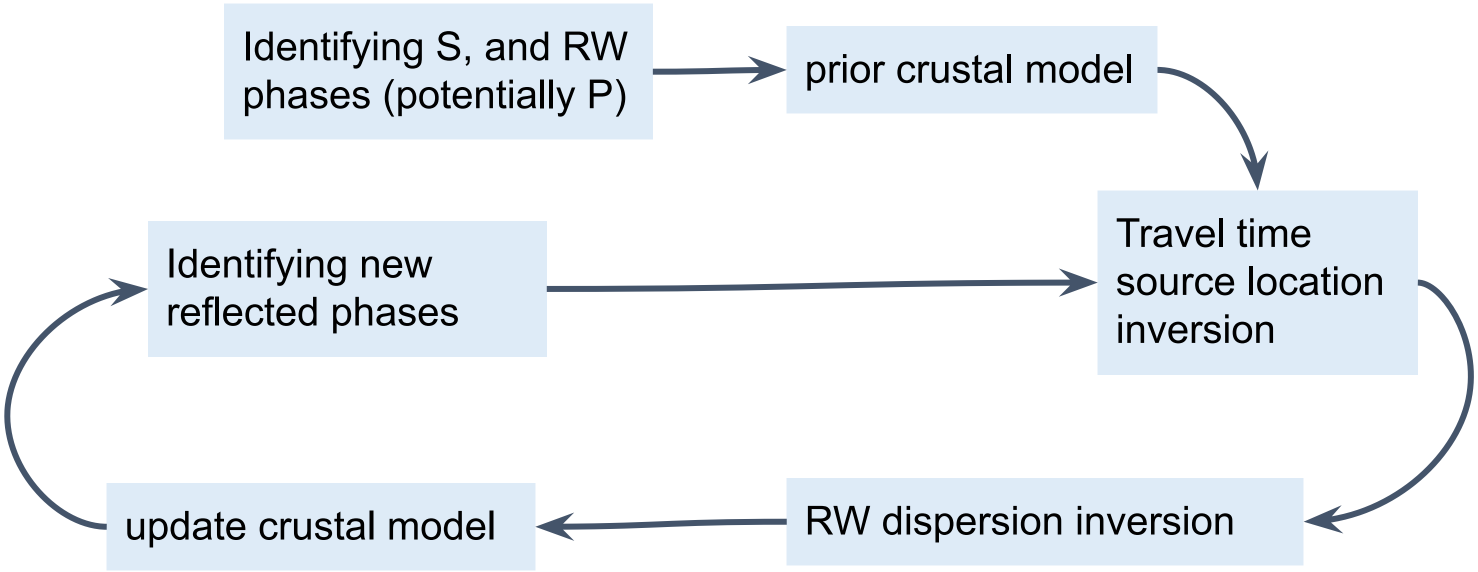
Steepest topographic slopes but near the pole where balloon flights should be avoided



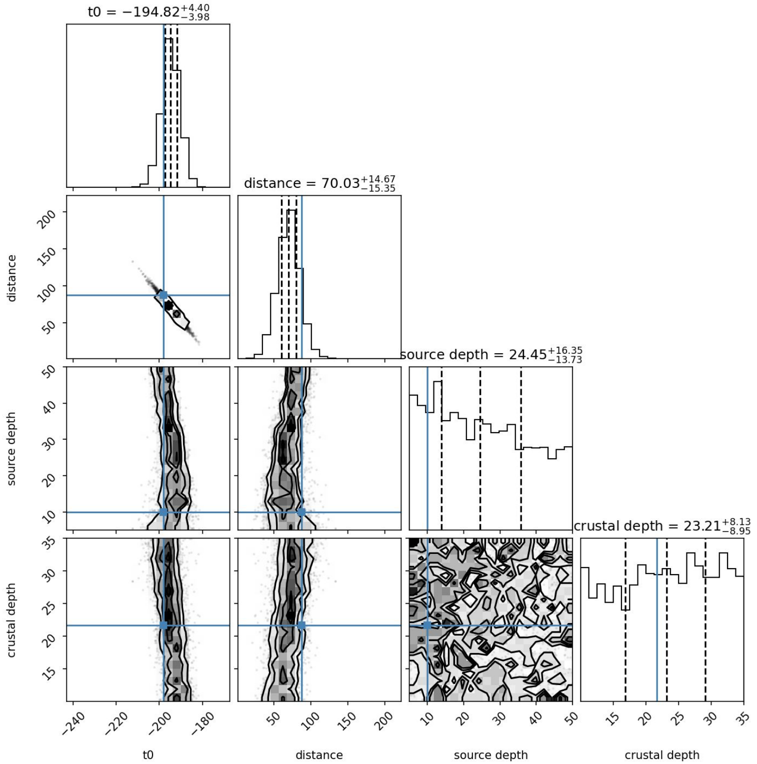
Shorter topographic wavelengths in Ovda/Thetis region could significantly scatter the low frequency seismo-acoustic signals

Incorporating uncertainties in source and velocities

➔ Focal mechanism, location, depth, and origin times need to be inverted for simultaneously with seismic velocity parameters



Retrieving source characteristics



Variations of atmospheric wind and temperature

- Wind and temperature models we have applied so far:
- Uncertainties:
- Enhancement potential:
-

Discussions and future steps

- How do the different uncertainties interplay?
- What model uncertainties might be the the greatest showstoppers to balloon-bourne Venus seismology?
- XXX