Remote Localisation and Characterisation of Venus’ Seismic and Volcanic Events through a Network of Balloon-Based Instruments

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Overview

1. Geophysics of Venus
   - Seismic and Volcanic Activity
   - Monitoring the Ground from the Atmosphere?
   - Atmospheric Conditions

2. Balloon-Based Instrumentation

3. Example Use of a Balloon Network

4. Take-Home Messages

5. Technical and Scientific Challenges
Venus Balloon-Based Science
Léo Martire

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Seismic and Volcanic Activity

- **Quakes**
  - Observational data: little to no evidence of clear subduction zones. But: *extensive rift system* and *several fault lines*.
  - No evidence of those structures being still active.
  ⇒ *Significant tectonic activity might still take place*, but most probably limited in magnitude.

- **Volcanoes**
  - Young looking basaltic surface, few craters ⇒ *volcanic activity*?
  - Recent evidence suggests active volcanic features [8].
  ⇒ *Volcanic activity* most probable, but rate remains unknown.

Localisation of events (plains, ridges, mountains, coronae, etc.) can help constrain whether or not Venus is still active, and how.
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  can help constrain whether or not Venus is still active, and how.
Monitoring the Ground from the Atmosphere?

- **Key point:** any surface event (quake, volcanic tremor, etc.) will generate acoustic atmospheric waves, **infrasound**, due to the **mechanical coupling** between the ground and the air.

Figure: Numerical simulation of a quake under flat topography, generating **infrasound**. Red/blue is amplitude saturated at ±1 %: in air (top light grey shade), pressure perturbation is represented; in the layered ground (bottom 3 darker grey shades), vertical velocity is represented. Yellow cross: hypocentre (source). Green dots: recording stations.
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- Propagation of such **infrasound** to **high altitudes** is efficient [2, 6].

  \[ \delta v \propto \rho^{-1/2} \]  
  \[ \Rightarrow \delta v \text{ increases with altitude} \]

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• [9] reviews ways to study Venus’ interior, including \textbf{balloon-based} concepts

**Why from the atmosphere?**

1. Conditions at the surface are \textit{harsh}.
   \begin{align*}
   (\approx 735 \text{ K}, \approx 92 \text{ bar})
   \end{align*}

2. Between altitudes 55 to 65 km,
   \begin{itemize}
   \item temperature range from $+27$ to $-30$ $^\circ$C,
   \item pressure range from 0.50 to 0.10 bar.
   \end{itemize}
   ✓ Technology usable there: \textit{already exists}, and \textit{will survive long enough}.

⇒ What type of instruments?
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Balloon-Based Instrumentation I

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Figure: Instrumented helium balloon, field test.
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  ① **Infrasound Sensors**
  • used hanged below balloon
  • records atmospheric pressure

Figure: Infrasound sensor (top box) with noise reduction port (below). ≃ 7 kg, ≃ 40 cm high.
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1. **Infrasound Sensors**
   - used hanged below balloon
   - records atmospheric pressure

2. **Inertial Measurement Units (IMUs)**
   - used attached to balloon envelope
   - records balloon envelope deformations
Balloon-Based Instrumentation II

- For any signal - acoustic wave -
  (seismic/volcanic/atmospheric source),
  a single balloon can acquire both
  1. **scalar** data from **pressure records** and
  2. **vector** data from **envelope deformations**.
Balloon-Based Instrumentation II

• For any signal - acoustic wave - (seismic/volcanic/atmospheric source), a single balloon can acquire both
  1 scalar data from pressure records and
  2 vector data from envelope deformations.

⇒ A single balloon can estimate both the signal’s
  1 amplitude and
  2 direction.

• With 2 infrasound sensors (hanged on a ladder):
⇒ annulus of possible localisation [4] of a ground event.

• With IMUs (balloon envelope, vector data)
⇒ constrain azimuth.

• Such setup is ≃ ready to go. One balloon on Venus: feasible by 2035.

• What to gain by using more than one balloon? Horizon 2061.
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![Diagram showing balloon, infrasound sensors, incident wave, and possible localisation](image)
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Networking with Free-Floating Balloons

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- For each balloon, **angle of arrival** $\Rightarrow$ annulus of possible localisation.

*Figure:* Localisation estimation using angle of arrival, for 1 balloon.
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**Figure:** Localisation estimation using angle of arrival, for 2 balloons.
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Figure: Localisation estimation using angle of arrival, comparison with "real" localisation.
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  - A better understanding of Venus’ geophysics and interior.
  1. detection/localisation of events (expected to be seismic or volcanic),
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- Operating a **network** of science balloons ⇒ **new possibilities**:
  - enhanced source localisation (this presentation),
  - continuous and **global** (≠ local with 1 balloon) monitoring.
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    - Materials? Resistance to sulfuric acid in clouds, to shear wind gusts?
    - Manoeuvrability? Free-floating, controllable?
  - Earth communication: bring back data. Antenna, band? Orbiter relay?

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    - Atmospheric dynamics' effects? Gravity waves, bow waves [5], etc.
  - Noise-reducing inlets for pressure sensors? E.g. against wind gusts.
  - Spacecraft effects:
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Thank you for your attention.

Questions?

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References I


