National Aeronautics and Space Administration

Feasibility of Detecting Venus Seismically-Induced Atmospheric Waves Via Cubesat Occultations

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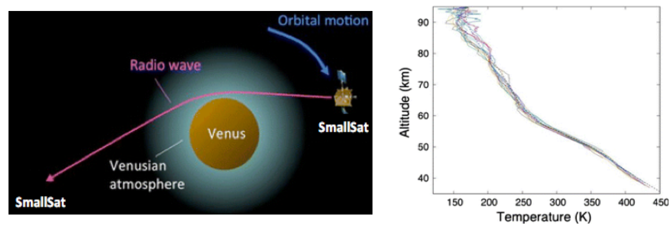
Program: Innovative Spontaneous Concepts

Introduction:

Background: Occultation sounding is a remote sensing technique that vertically scans a planetary atmosphere to retrieve its properties in a fine vertical resolution by measuring the amount of bending of propagating signals between a pair of occulting spacecraft over a planet's limb. Radio Occultations (RO) between an orbiting spacecraft around Venus and a ground-based antenna on Earth have been used to probe the vertical thermal structure and circulation activity of Venus's atmosphere with measurements conducted by the Pioneer Venus Orbiter (PVO), Magellan, Venus Express (VEX), and Akatsuki missions (cf, Figure 1).

Our **overarching goal** is to determine if orbiter-to-orbiter radio occultation measurements could detect Venus seismic events. Proposed measurements would be collected by placing two orbiting cubesats around Venus such that they provide a nearly continuous radio link through the atmosphere. The **primary objective** of the proposed work is to use simulations to determine the nature and uniqueness of the expected seismically-induced atmospheric perturbations, their variation with altitude and distance from the event, and their detectability within the background of natural atmospheric activity.

Innovation: We propose, for the first time, to deploy a constellation of small satellites (smallsats: 2 - 3 spacecraft) to perform RO observations of Venus's atmosphere via dual-frequency cross-link communication at radio frequencies to extract highly accurate (< 1 K) vertical temperature profiles of the upper Venusian atmosphere globally. We will use the observations to remote sense quake-induced acoustic waves [epicentral infrasound (**EI**) and Rayleigh-wave-induced infrasound (**RI**)] and geophysically-induced gravity waves and determine their characteristics. Single orbiters with radio links only to Earth do not provide frequent enough atmospheric profiles at varied geographic locations to unveil detailed atmospheric dynamics (like wave phenomena), while a small group of smallsats with radio links between them can provide high density spatial-temporal coverage.



Imamura et al. Earth, Planets and Space (2017) 69:137

Figure 1: **(*Left*)** *Sample schematic of occultation sounding geometry between two SmallSats in crosslinks communication.* **(*Right*)** Radio occultation vertical temperature profiles obtain from Akatsuki radio occultations.

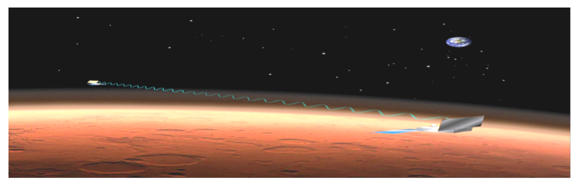


Figure 2: *Schematic of occultation geometry between two SmallSats..*

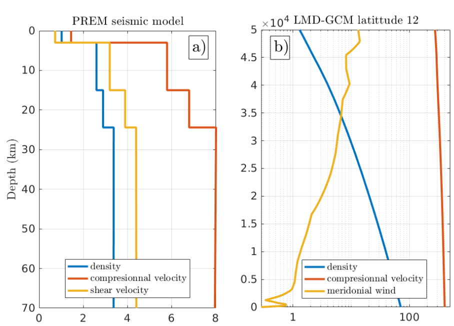


Figure 3: Panel a) PREM seismic model. Panel b) Atmospheric model extracted from the LMD GCM.

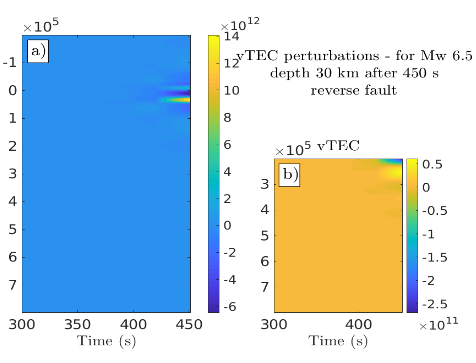


Figure 6: Panel a) corresponds to the absolute VTEC perturbations after 450 s for a seismic event of magnitude 6.5 at location x = 0 km depth 30 km. Panel b) is similar to panel a) but focuses on the Rayleigh-wave contribution from 250 km from the source.

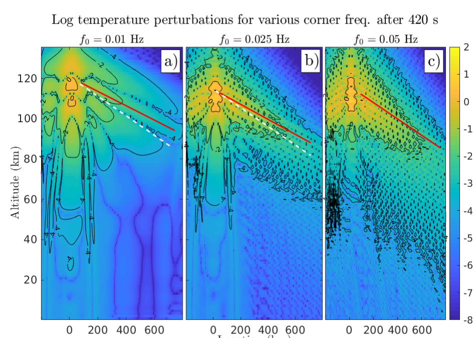


Figure 4: Log of temperature perturbations (K) after 420 s for a seismic event of magnitude 6.5 at location x = 0 km depth 30 km and for various source corner. Red lines denote the planar Rayleigh-wave induced acoustic wavefront. The white dashed line corresponds to the planar front of panel c).

Results:

- Below 0.05 Hz, horizontal winds do not seem to significantly reduce the energy above 40 km altitude for a PREM-like subsurface model,
- RI amplitudes are significantly smaller (roughly 10 times smaller) than EI amplitudes. RI vertical wavelengths are similar to EI ones,
- There are significant differences between source mechanisms, in terms of amplitude, for both EI and RI and, in terms of wavelengths, for the EI. However, there seems to be no difference in terms of wavelengths for the RI. Finally, reverse faults seem to be the most efficient at transferring energy in the atmosphere,
- Shallow event above 20 km depth, produce large temperature fluctuations (> 20 K) for a magnitude 6.5. Therefore, events with magnitudes around 4/4.5 could potentially be detected,
- Higher frequency events produce larger variations in the atmosphere for F0 < 0.05 Hz and
- VTEC perturbations are significantly smaller than on Earth but the background electron density amplitude being roughly 2 orders of magnitude smaller, the relative perturbations are similar to Earth shallow earthquakes for similar magnitudes

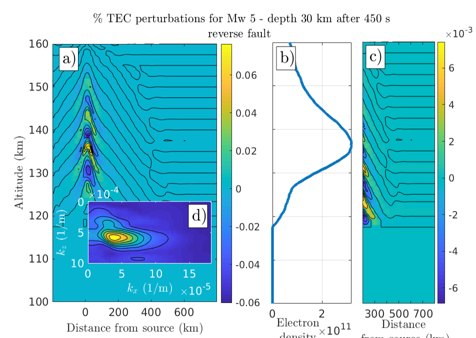


Figure 5: Panel a) corresponds to TEC perturbations (%) after 450 s for a seismic event of magnitude 5 at location x = 0 km depth 30 km. Panel b) shows the background electron density used for this simulation.

Benefits to NASA, JPL and Significance of Results:

There are three main conclusions:

- EI temperature, neutral density and electron density fluctuations produced by reverse-fault Venus quakes of magnitude 5.5 and over can be theoretically detected within 200 km from the epicenter,
- RI temperature and electron density fluctuations produced by reverse-fault Venus quakes of magnitude 5.5 and over can be theoretically detected. Given these conclusions, it seems that the appropriate path forward should be to continue the development of cubesat occultations as a unique opportunity to monitor the seismic wave activity on Venus and
- Low-frequency events with magnitudes < 6.5 at depth > 30 km might be hard to detect.

Presentation:

Vergados, P, Q. Brissaud, R. Preston, A. Komjathy, T. Bocanegra, S. Krishnamoorthy, Chi Ao, D. Atkinson, S. Asmar, J. Lazio (2019) "Understanding Venus's Seismicity Using SmallSat Radio Occultation Observations," Presented at the EPSC-DPS Joint Meeting 2019, Geneva, Switzerland, Sept 15-20.

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