National Aeronautics and Space Administration

Infrasound Detection as a Geophysical Probe Using Earth as a Venus Analog

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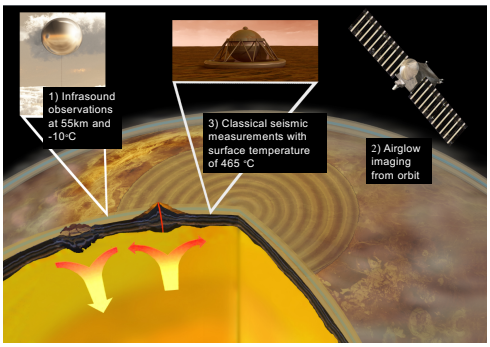
Program: Strategic

Summary

The planetary evolution and structure of Venus remain uncertain more than half a century after the first visit by a robotic spacecraft. It is necessary to detect the signs of seismic activity to understand how Venus has evolved,. Due to the adverse surface conditions on Venus, with extremely high temperature and pressure, it is infeasible to place seismometers on the surface for an extended period of time. Due to *dynamic coupling between the solid planet and the atmosphere*, the waves generated by quakes propagate upward and can be detected in the atmosphere itself. Our goals are:

- Detect seismicity using infrasound measurements and characterize seismic wave propagation in order to determine crustal structure.
- Conduct complementary investigation of airglow phenomenology, atmospheric gravity waves and ionospheric disturbances



Three techniques defined at Keck Institute for Space Studies KISS) workshop at Caltech to detect seismicity on Venus in June 2014 – 1) Infrasound measurements; 2) Airglow imaging and 3) Seismometer on ground (currently infeasible).

Project Objective

JPL in collaboration with ISAE and Caltech Campus is in the process of developing an instrument to measure seismic activity on Venus by detecting infrasonic waves in the atmosphere.

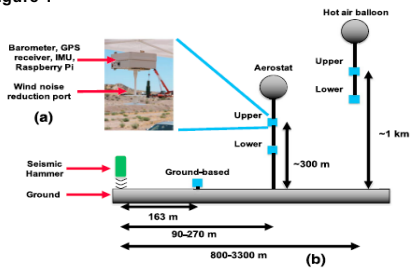
The **overall objective** of this research is to demonstrate the feasibility of using sensitive barometers to detect infrasonic signals from seismic and explosive activity on Venus from a balloon platform. Because of Venus' dense atmosphere, seismic signatures from even small quakes (magnitude ~3) are effectively coupled into the atmosphere. The seismic signals are known to couple about 60 times more efficiently into the atmosphere on Venus than on Earth.

Our **specific objective** for FY18 was to investigate the capability of balloon-borne barometers to perform airborne seismology using artificial seismic events as infrasound sources.

Short-range seismic infrasound detection using weak seismic sources

Pahrump, Nevada Experiment

Figure 1



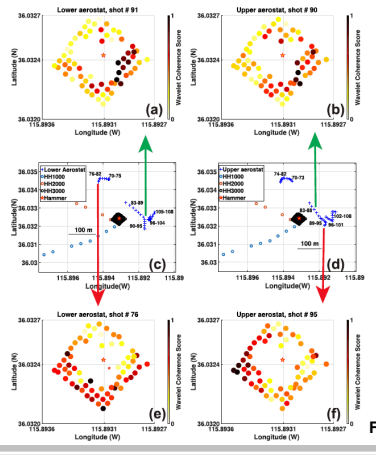


Figure 2

- **Figure 1 (left)** Barometer configuration utilized in the Pahrump experiment. (a) Description of each barometer package containing a barometer, GPS receiver, inertial measurement unit (IMU), a noise reduction port, and a Raspberry Pi computer (b)
- **Figure 2 (right)**. The maps in (c) and (d) show the estimated location of the airborne barometers at the shot time obtained from their GPS location tags (denoted by blue crosses), with the shot number indicated in black text next to the barometer position. In the successful cases [shown in (a) and (b)], the geophones in the direction of the barometer have a higher score than those in the opposite direction. However, wind noise also causes cases where this technique fails to produce an accurate wavelet coherence map [shown in (e) and (f)].

Long-range seismic infrasound detection and characterization using natural quakes

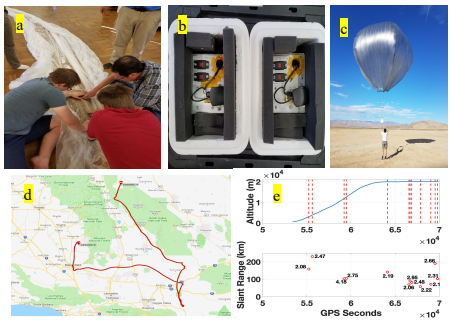


Figure 3. (a) Fabricating the 6-meter balloon envelope; (b) Readying the instrument box for launch; (c) Balloon launch on July 22; (d) Flight trajectories on July 22; (e) Balloon altitude and intercepted aftershocks events.

Benefits to NASA, JPL and Significance of Results

- The results above demonstrate that seismic signals can be detected, characterized, and geolocated from the air.
- This has major implications for detecting seismic activity on Venus, where landing and surviving for long periods poses a significant challenge.
- The balloon-based *in situ* infrasound detection capability developed here will also augment JPL's existing capabilities for the remote sensing of infrasonic waves originating from *earthquakes, tsunamis, meteor impacts and other natural hazards* and has potential application to infrasonic networks operated under the Comprehensive Test Ban Treaty Organization (CTBTO).

Publications and Presentations

Krishnamoorthy, S., V.H. Lai, A Komjathy, M. T. Pauken, J. A. Cutts, R. F. Garcia, D. Mimoun, J. M. Jackson, D. C. Bowman, E. Kassarian, L. Martire, A. Sournac, and A. Cadu "Aerial Seismology Using Balloon-Based Barometers," in *IEEE Transactions on Geoscience and Remote Sensing*. doi: 10.1109/TGRS.2019.2931831

[B] Krishnamoorthy, S., V.H. Lai, L. Martire, Ervan Kassarian, Attila Komjathy, James A. Cutts, Michael T. Pauken, Raphael F. Garcia, David Mimoun, Jennifer M. Jackson, Daniel C. Bowman (2018). "Balloon-Borne Infrasound as a Remote Sensing Tool for Venus – Progress in 2017." Presented at the 15th International Planetary Probe Workshop Boulder, CO June 11, 2018

[C] Krishnamoorthy, S., E. Kassarian, V. H. Lai, L. Martire, A. Komjathy, J. A Cutts, M. Pauken, D. Bowman, R. Garcia, D. Mimoun and J. M. Jackson (2018). "Progress towards Venus Seismology through Balloon-based Infrasound Remote Sensing." Presented at the AGU Fall Meeting, Washington DC, Dec 16-20, 2018.

[E] Daniel C Bowman, Siddharth Krishnamoorthy, Jonathan M Lees, Eliot F Young, Oliver D Lamb, Sarah Albert, Attila Komjathy and James A Cutts (2018). Infrasound Observations Using High Altitude Balloons." Presented at the AGU Fall Meeting, Washington DC, Dec 16-20, 2018.

[F] Krishnamoorthy, S., D. C. Bowman, L. Martire, A. Komjathy, J.A. Cutts, M.T. Pauken, R. F. Garcia, D. Mimoun, V.H. Lai, and J. M. Jackson (2018). "The Road to Venus Seismology via Oklahoma." Presented at the VEXAG Meeting November 8, 2018.

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