PROGRESS TOWARDS BALLOON-BASED SEISMOLOGY ON VENUS IN 2021-2022.

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Introduction: Adverse conditions on the surface of Venus have thus far prevented long-duration seismic studies. Traditional seismology on the surface of Venus using a long-lived lander is decades away. Since 2016, we have been developing remote sensing technology that would enable the detection and characterization of putative Venusian seismic activity from balloons in its upper atmosphere. In this presentation, we will discuss the progress our group has made in the last year.

Infrasound Remote Sensing: Infrasound has been recorded from a variety of events on Earth. Of particular interest to Venus exploration are infrasound signals from quakes, volcanic eruptions, thunderstorms, and meteors. Venus offers a unique opportunity for the use of infrasound as an investigative tool for surface ground motion– due to its dense atmosphere, energy from seismic activity couples with the Venusian atmosphere up to 60 times more efficiently than Earth [1], [2]. Infrasound is also known to propagate long distances from generating events with relatively little attenuation, thereby making it an effective alternative to placing sensors on the surface of Venus. Acoustic sensors used to capture infrasound may also be used to investigate low-frequency, large-scale planetary atmospheric features such as planetary-scale gravity waves.

The main advantage of performing balloon-based infrasound science on Venus is the extension of mission lifetimes by virtue of being in a more benign environment. Compared to 460 C temperature and 90 atmospheres pressure on the surface [3], atmospheric conditions are more Earth-like at 55-60 km altitude on Venus. Further, acoustic sensors greatly benefit from being on a platform that floats with the wind, leading to higher coverage and lower wind noise.

Recent Significant Results: In this presentation, we will discuss several significant recent advances made towards balloon-based seismology on Venus. Notably, these include:

1. **Detection of surface waves from several earthquakes:** In 2021, we demonstrated the detection of the first natural earthquake from a high-altitude balloon with the detection of a magnitude 4.2 earthquake from a balloon at 4.8 km altitude in Southern California [4]. In addition, pressure sensors on board Strateole-2 balloons demonstrated balloon-based detection of Rayleigh waves generated by large earthquakes (Magnitude 7.3) from continental distances (~3000 km). These detections show the feasibility of balloon-based seismic monitoring using balloons on Venus, where similar quakes would generate signals that are nearly 60 times stronger.

2. **BASS flight campaigns:** The Balloon-based Acoustic Seismology Study (BASS) is funded through the NASA Planetary Science and Technology through Analog Research (PSTAR) program. In September 2021, we completed the first summer of flights in Oklahoma in search of infrasound signals from fracking-generated earthquakes. Oklahoma State University students launched and recovered over 30 flights of "heliotrope" solar-heated balloons in a period of 2 months from July to September 2021. In the second year of the flight campaign from July to September 2022, we will aim to fly targeted campaigns over known earthquake swarms in the continental US (target sites include West Texas, Owens Valley in California and Central Idaho). We will share details of our flight campaigns in the final presentation.

3. **Development of infrasound modeling tools for Venus:** The discrimination of signals of interest from the noise background and their proper classification is essential for event identification on Venus. In the absence of any measurements, forward modeling of signals can provide a comprehensive database for studying signal properties, detection limits, and inversion algorithms. We are developing simulation tools to generate a catalog of infrasound signals from seismic events on Venus by expanding the Earth based simulation tool SPECFEM-DG[5], [6] to include acoustic effects unique to CO_2 at high temperature and pressure, which can influence infrasound propagation.

4. **Aeroseismometer Demonstration:** The aeroseismometer or vector infrasound technique enables the determination of the direction of arrival of an infrasound signal using a single station, by monitoring the dynamic response of the balloon to the incoming wave. Using a highly accurate inertial measurement unit in conjunction with a barometer on board a stratospheric balloon, we detected infrasound signals from surface chemical explosions in Socorro, New Mexico and inverted their direction of arrival from a single station [7]. The ability to determine direction of arrival of signal from a single station will eliminate the need for deployable structures and reduce the mass, power and data budget for infrasound monitoring on Venus.

Presentation Content: In this presentation, we will provide an overview of advances made in the last year towards making balloon-based seismic monitoring on Venus a reality. We will discuss significant recent results and present a plan to address challenges that may be encountered on Venus.

References:

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