A BALLOON-BORNE AEROSEISMOMETER FOR LOCATING SEISMIC ACTIVITY ON VENUS.

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Introduction: Events on planetary surfaces and atmospheres can generate low frequency sound waves capable of traveling across regional to global scales. These waves carry information not only on the phenomenon that generated them but also the medium through which they passed. Sensitive microbarometers are used to capture these signals on Earth (e. g. the globe-spanning International Monitoring System) and Mars (the InSight lander). However, temperature and pressure conditions on the surface of Venus are inimical to long term sensor deployment, and oceans cover large regions of the Earth.

In the last half decade, microbarometers on free flying balloons have emerged as an alternative to surface-based deployments[1]. This has led to the possibility of monitoring seismic activity on Venus using acoustic waves induced by ground motion captured on balloons floating in the relatively clement cloud deck[2]. However, microbarometers deployed on a single balloon cannot determine signal direction-of-arrival; in particular, there is no practical way to ascertain the azimuth without multiple stations. We are developing the *aeroseismometer*, a sensor that measures the balloon acceleration induced by impinging sound waves, as an answer to this problem.

The Aeroseismometer: A serendipitous signal recorded on a balloon-borne accelerometer in concert with a small acoustic pulse suggested that even weak sound waves produce a measurable response on large balloons (**Fig. 1).** Subsequent experiments on tethered balloons validated this concept [3,4]. This inspired a campaign involving free flying balloons in the lower stratosphere and a set of ground chemical explosions to produce powerful acoustic waves. Inertial measurement units and accelerometers recorded the flight system's response to these waves. This motion encoded the direction of arrival of the signals with sufficient fidelity to produce a rough location for the explosions.

Following this successful proof of concept, we are currently modeling the response of free flying balloons to acoustic waves as a means of improving the direction of arrival capability. This modeling will inform further iterations of the aeroseismometer prototype and determine optimal placement (e. g. on the balloon envelope, hanging below on a tether, etc.)

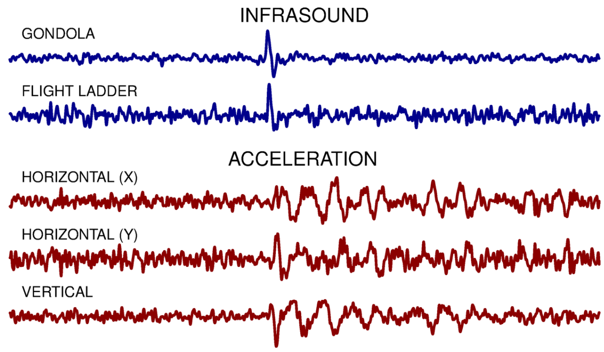

Figure 1: A balloon-borne accelerometer responds to an incident acoustic wave during the Fall 2016 High Altitude Student Platform flight.

Presentation Content: We will introduce the aeroseismometer, describe the initial proof of concept, and discuss the results of the first active-source geolocation experiment. We will show that acceleration seems polarized with direction, and that the arrival vectors pointed back to the source for some (but not all) of the events. Then, we will outline efforts to model the flight system's impulse response in order to further improve the aeroseismometer's direction of arrival capability. Finally, we will describe how a balloon-borne aeroseismometer could detect and locate seismic activity on Venus. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

[1] Bowman, D. C. *et al.* (2019), *Geoacoustic observations on drifting balloon-borne sensors*, In Le Pichon, A., E. Blanc, and A. Hauchecorne, eds. Infrasound Monitoring for Atmospheric Studies : Challenges in Middle-atmosphere Dynamics and Societal Benefits, Springer Nature.
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[3] S. Krishnamoorthy *et al.* (2019). Advances towards balloon-based seismology on Venus. 50th Lunar and Planetary Science Conference, The Woodlands, TX.
[4] Garcia, R. F *et al.* (2020), An active source seismo-acoustic experiment using tethered balloons to validate instrument concepts and modelling tools for atmospheric seismology. *Geophysical Journal International*. DOI: 10.1093/gji/ggaa589.