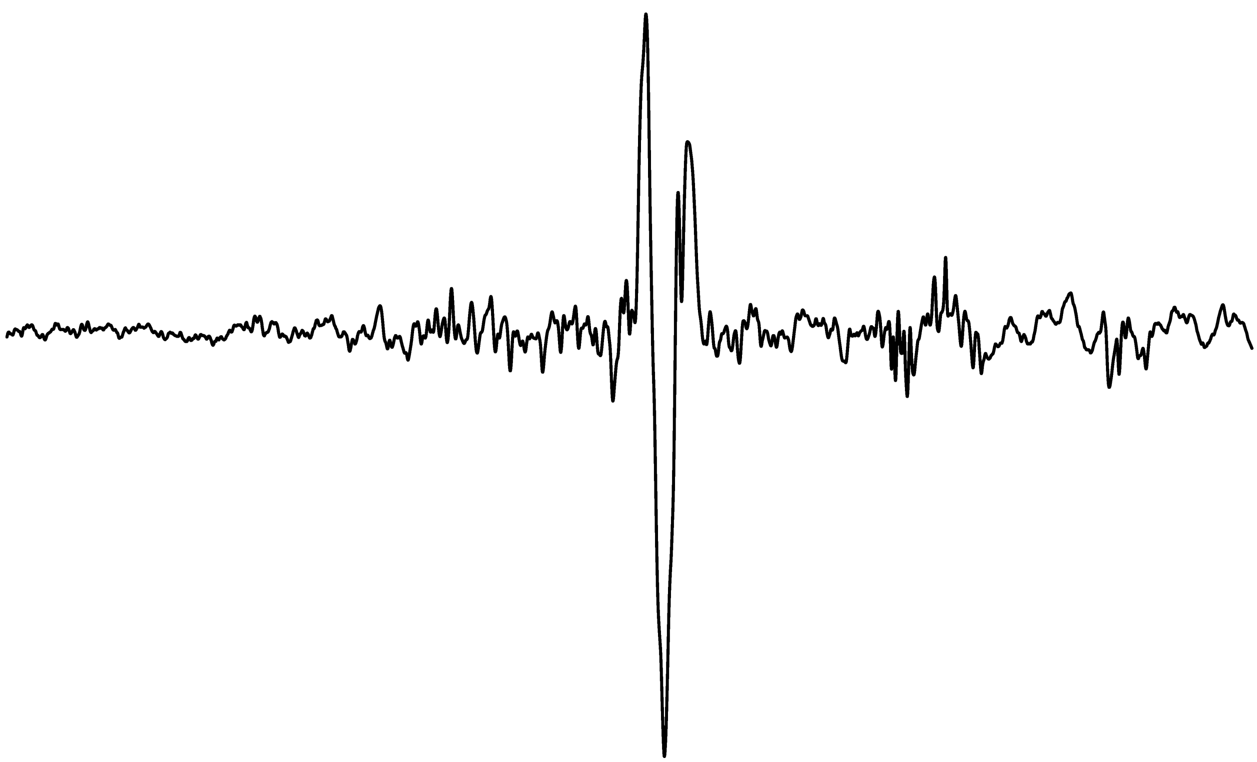
SAND2017-1335R

Ground to Space Geoacoustic Characterization during the DAG Experiment

Daniel Bowman James Cutts Attila Komjathy Micheal Pauken
Rod Whitaker

January 13, 2017



1 Motivation

Infrasound generated from ground motion is likely directional. This has the following consequences:

- Ground-based microphones detect only a fraction of the total acoustic radiation
- Signals launched into the stratospheric duct have unknown amplitudes, complicating attempts to infer source characteristics from regional networks
- Ionospheric response to acoustic forcing is uncertain

It is therefore of paramount importance to quantify the three dimensional propagation characteristics of infrasound from buried sources. Despite initial success with using an octocopter to quantify ground motion with a seismic hammer (Jones et al., 2015), attempts to capture buried explosion sources using this method have proven very difficult. Even when successful, octocopter-borne sensors suffer from high levels of background noise, have limited flight time due to battery life, and require substantial resources to deploy.

Infrasound also can be detected using balloon-borne sensors (see Bowman and Lees (2015)) and ionospheric soundings using GPS (see Otsuka et al. (2006)). Recent balloon experiments in 2016 have demonstrated exceptionally high signal to noise ratios (see Figure 1), and ionospheric methods represent a long range, passive detection capability that is less sensitive to atmospheric conditions than direct infrasound measurements. Since the DAG series will be exceptionally well characterized using ground infrasound networks, seismometers, and accelerometers, the experiment is an excellent opportunity to evaluate ground to space detection thresholds as well.

These objectives align with a Venus mission concept being studied by the Jet Propulsion Laboratory (JPL) (Stevenson et al., 2015; Arrowsmith et al., 2015; Garcia et al., 2016; Cutts et al., 2016). The goals are to ascertain the interior structure of the planet by detecting air-coupled seismic activity. This is desirable both because the impedance contrast is lower on Venus and because surface conditions are very hostile. The infrasound sensors will be deployed on balloons floating in a region of the atmosphere with similar temperatures and pressures as the surface of the Earth (see Figure 2). Orbiters may also investigate the acoustic perturbation of Venus airglow. Although balloons have been deployed on Venus before (Sagdeev et al., 1986), a detailed study of ground-motion induced infrasound captured in the atmosphere on Earth is necessary to insure mission success.

2 Proposed Collaboration with JPL

During a recent workshop devoted to the emerging field of airborne geoacoustics, JPL and the SPE Geoacoustics team agreed that the DAG series was an excellent opportunity to collaborate. JPL brings invaluable experience in instrumentation, scientific ballooning, and ionospheric sounding. The SPE Geoacoustics team will be operating a high quality ground microphone network; furthermore they have pioneered infrasound deployments on both octocopters and free flying balloons. Both groups have strong acoustic analysis and modeling capabilities.

Three activities are proposed:

- Deploy a passive GPS receiver array near the DAG site to scan the total electron content of the ionosphere.
- Overfly at least one shot with a superpressure balloon at an altitude $> 20km$
- Overfly one to several shots at low altitudes (0.5 - 3 km) using sensors on a remote controlled hot air balloon.

Items 2 and 3 are currently included in JPL's mission plan, although the team had not yet decided on a venue when the DAG was brought to their attention. Item 2 is the most logistically difficult and might be best described as a stretch goal, but Item 3 may be relatively low impact depending on altitude and launch location. Item 1 is a potentially disruptive example of "low hanging fruit" that would both increase monitoring capabilities on Earth and seismic detection capabilities from orbit above Venus. The DAG geoacoustic team would serve in a facilitative role for these tasks.

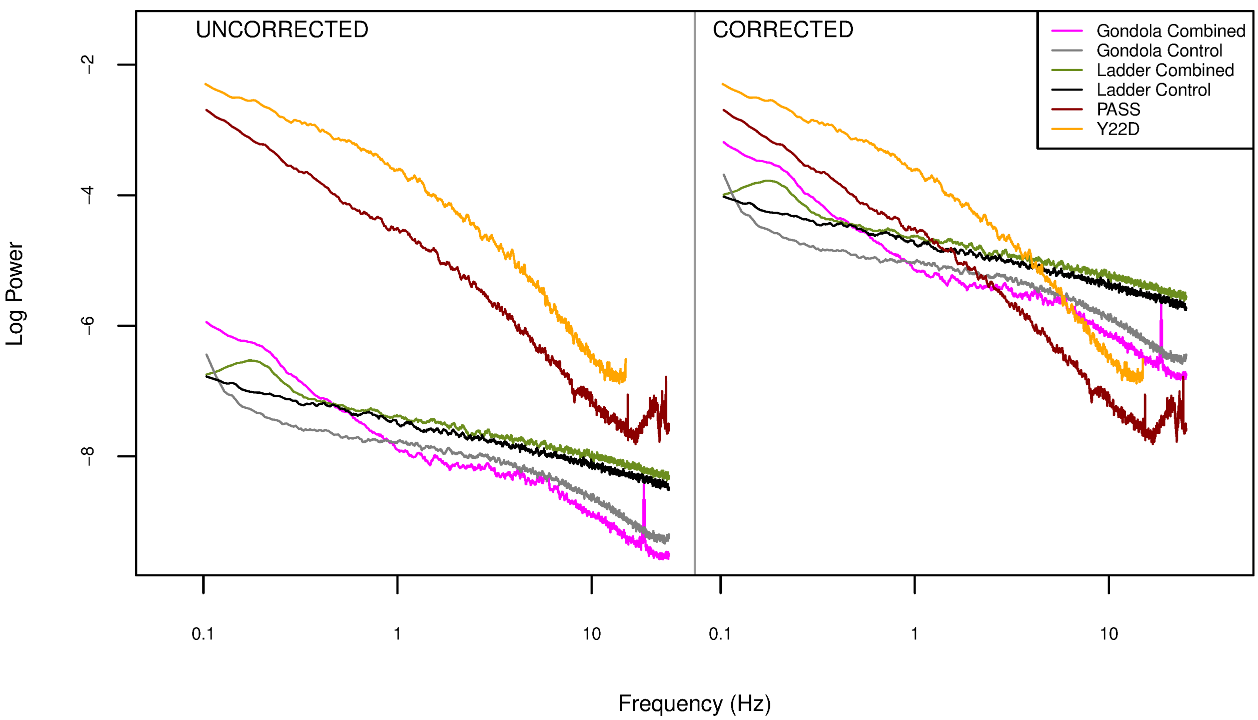


Figure 1: Infrasound in the stratosphere recorded on the HASP 2016 balloon ("LADDER" and "GONDOLA") and on co located ground stations with wind mitigation ("PASS") and without ("Y22D"). The left panel shows infrasound amplitudes as recorded, and the right panel applies a naive pressure/density correction. Stratospheric stations have augmented detection ability below 5 Hz, and perhaps higher depending on atmospheric focusing.

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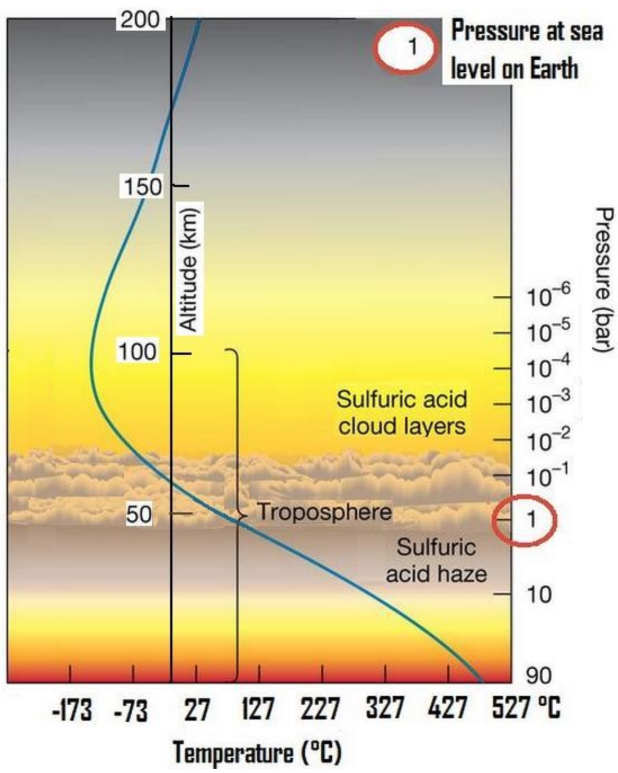

Figure 2: The atmosphere of Venus, including the proposed infrasound balloon flight region.

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