SAND2019-14617C

A21S-2812: Underground explosion and bolide airburst detection using balloon-borne infrasound sensors

Daniel C. Bowman* (dbowma@sandia.gov) Siddharth Krishnamoorthy** Peter Brown†

*Sandia National Laboratories **Jet Propulsion Laboratory/California Institute of Technology † University of Western Ontario

Introduction

Infrasound sensors on free floating balloons may capture signals that ground based instruments cannot. The negative temperature gradient in the troposphere focuses acoustic energy upward, where it may be intercepted by high altitude sensors even when sound waves are not detectable on the ground. In addition, an acoustic waveguide exists at the tropopause that may efficiently convey signals over vast differences without them ever reaching the ground. Here, we present acoustic waves from a buried chemical explosion and a bolide airburst observed during a recent balloon campaign.

Sensor Deployment

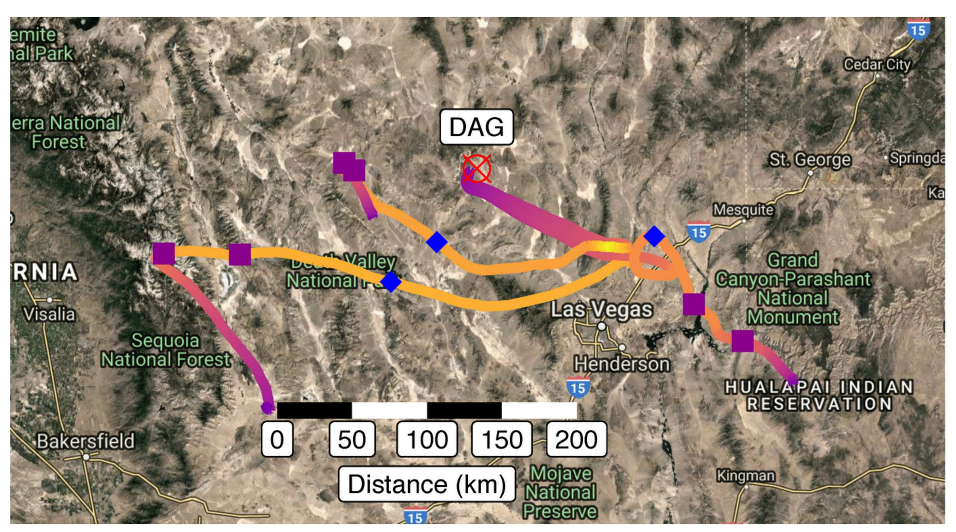

Figure 1: Balloon trajectories on June 22, 2019. Blue diamonds show the position of each balloon when the DAG 4 event occurred. Magenta squares show the starting and ending position of the balloons during the expected acoustic arrival times from the bolide airburst.

Three Heliotrope solar hot air balloons with Gem microbarometer payloads were launched from southern Nevada on June 22, 2019 in order to observe acoustic waves from the fourth Dry Alluvium Geology (DAG) experiment. This DAG event consisted of a 10 ton TNT equivalent nitromethane explosion buried at a depth of 51 m in alluvium. When the event occurred, two balloons were located at ranges of 56 and 95 km to the southwest and one 127 km to the southeast. Just before sunset, acoustic waves from a bolide airburst south of Puerto Rico began crossing the free flying network. As soon as the sun dropped below the horizon, the balloons lost power and began to descend, eventually landing a few hours later.

Acknowledgments

Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. The views expressed here do not necessarily reflect the views of the United States Government, the United States Department of Energy, or Sandia National Laboratories. The contribution of JPL authors was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. Government sponsorship is acknowledged. Report No. SAND2019-XXXX C.

Underground Chemical Explosion

10 tons TNT equivalent explosion at 52 m depth

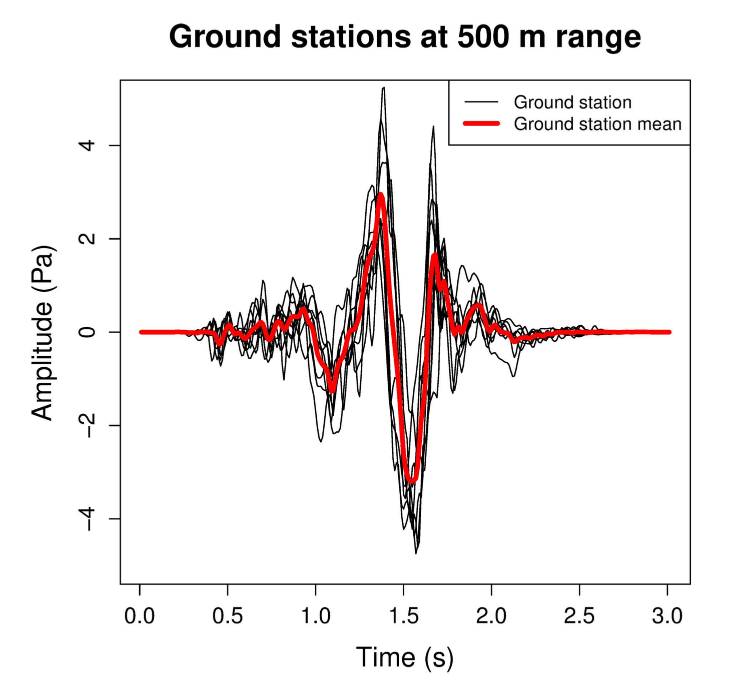

Figure 2: Acoustic signal from the DAG 4 event recorded on ground sensors.

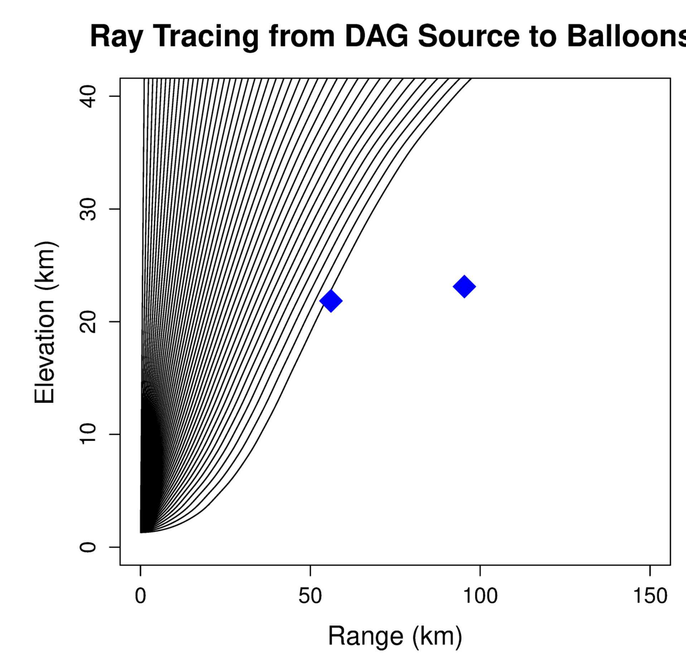

Figure 4: Geometric ray tracing plot of acoustic propagation paths to the southwest, compared with the position of the closest two balloons.

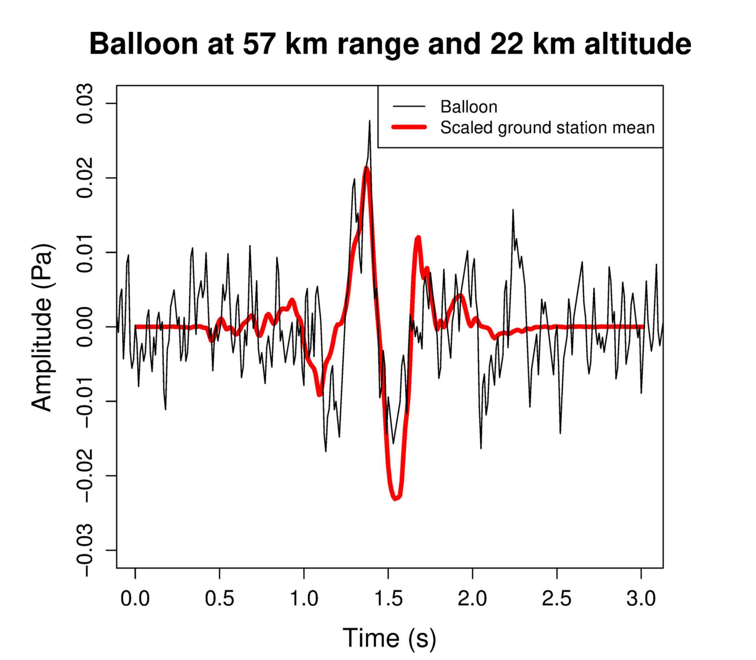

Figure 3: Acoustic signal from the DAG 4 event recorded on the closest balloon.

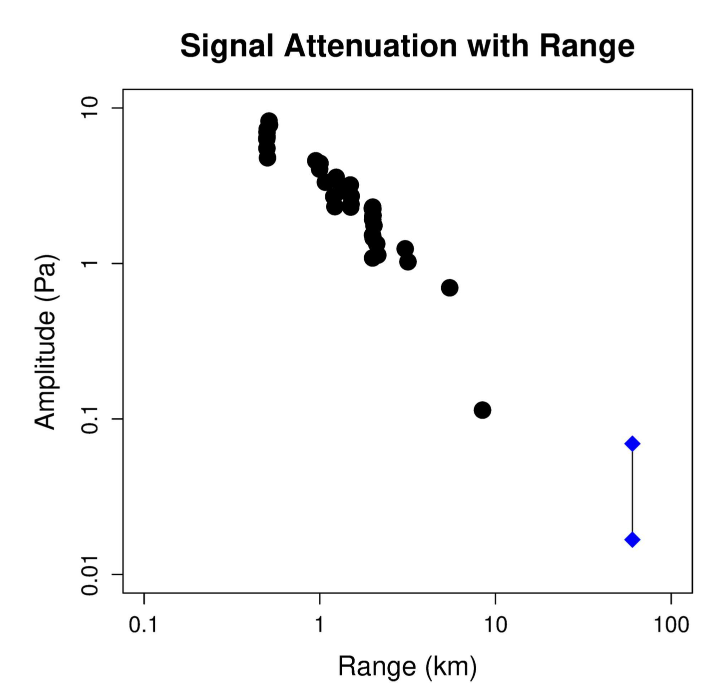

Figure 5: Acoustic amplitude with distance for ground and the closest balloon. Blue diamonds denote balloon amplitudes corrected and uncorrected for acoustic impedance contrasts.

Nearby ground microbarometers recorded a distinct "M" shaped acoustic pulse from the DAG-4 event. Figure 2 shows traces from seven ground stations distributed in a 500 m circle around the epicenter, as well as their average waveform. The DAG 4 acoustic pulse was discovered and confirmed on the closest balloon by predicting the signal arrival time and performing a cross correlation against the average ground waveform. Despite a rather poor signal to noise ratio, the waveform on the balloon is a very close match (Figure 3). Propagation modeling reveals that the balloon was on the very edge of the "shadow zone"; a few kilometers further away could have resulted in a nondetection (Figure 4). The other two balloons were within the shadow zone and thus did not capture any acoustic radiation from DAG 4. Signal amplitude recorded on the nearest balloon is consistent with acoustic attenuation rates measured on the ground microbarometer network once the surface to stratosphere acoustic impedance contrast is accounted for (Figure 5). **This is the first direct (non refracted) impulsive signal recorded on a stratospheric balloon from a known source.** It demonstrates that very little waveform distortion occurs on direct paths; likely most of the signal variance from stratospherically refracted acoustic waves occurs at the ray bending point.

Bolide Airburst

Five kilotons TNT equivalent explosion at 25 km MSL

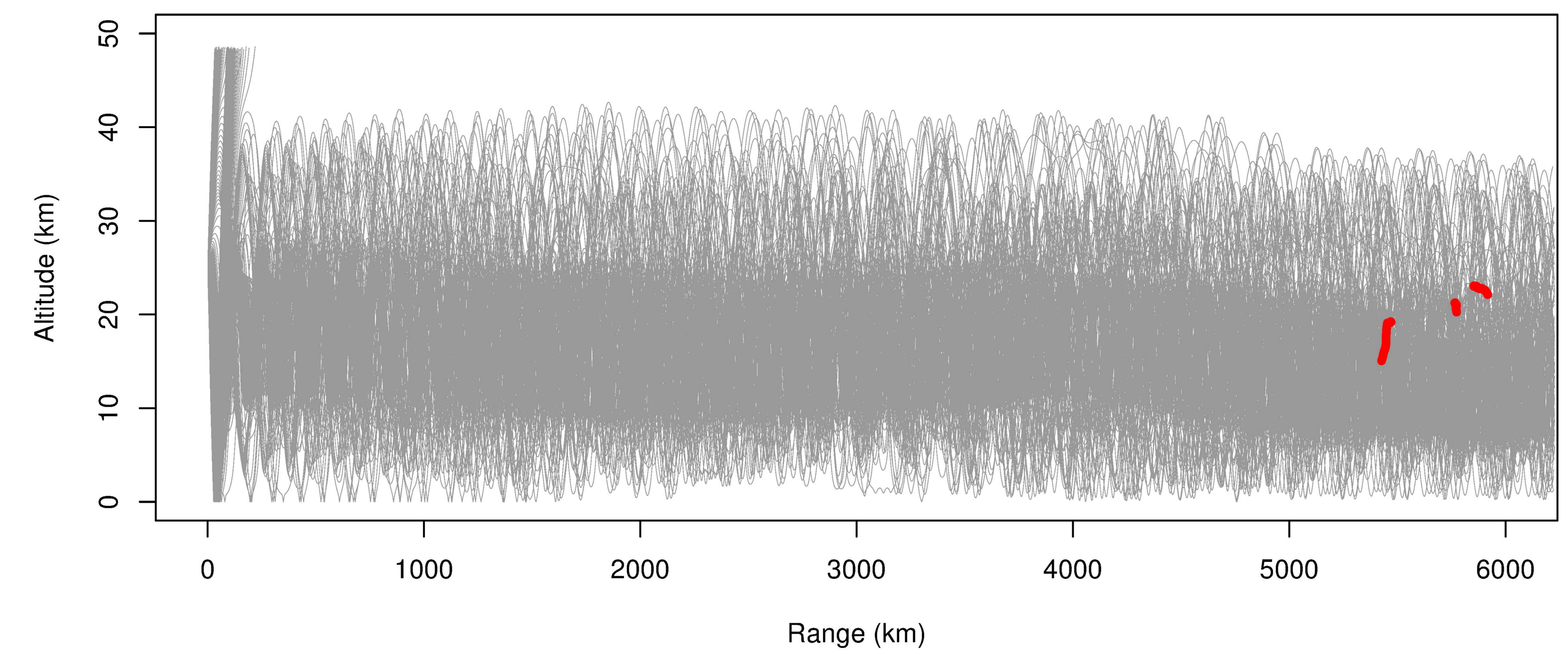

Figure 6: Geometric ray tracing plot of acoustic propagation paths from the bolide airburst location (altitude 25 km) to the balloon borne network. Red lines show the paths of the balloons during the approximately two hour long arrival window.

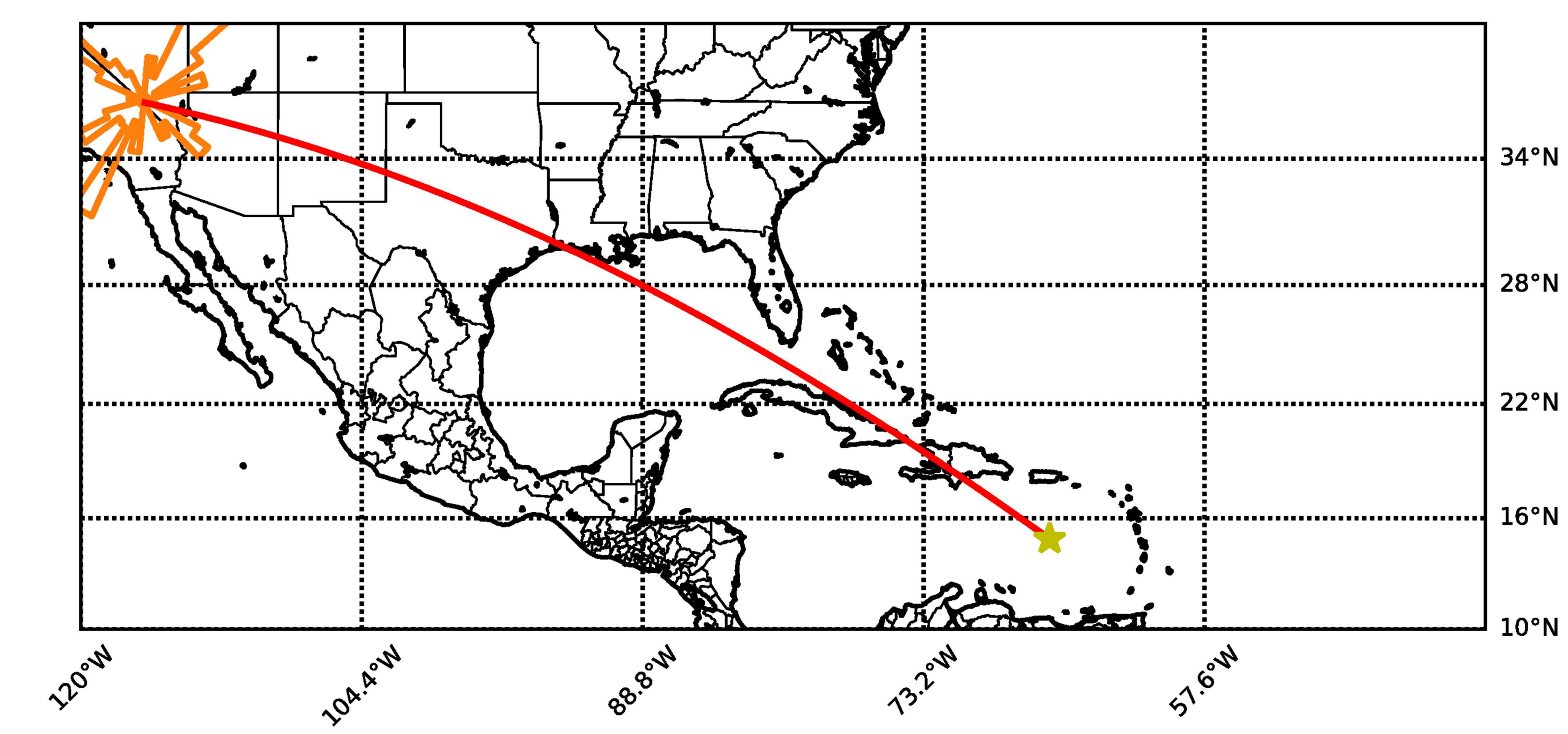

Figure 7: Arrival azimuths during the expected bolide infrasound recording period on the balloon-borne network. Figure is courtesy of Sarah Albert, Sandia National Laboratories.

A 3-meter asteroid entered Earth's atmosphere south of Puerto Rico at about 21:25 UTC, June 22, 2019. The resulting airburst had a yield of approximately 5 kilotons TNT equivalent, depositing most of its energy at about 25 km MSL. Range-dependent geometric ray tracing indicates that acoustic waves from the event were trapped near the tropopause (Figure 6). The signals would have begun crossing the balloon network about 5 hours after the event, just before local sunset. Fortunately, the balloons were still aloft. A frequency-wavenumber analysis reveals signals crossing the balloon array from two different dominant azimuths during this time period, one of which roughly corresponds to the expected direction of arrival from the bolide (Figure 7). The other azimuth probably corresponds to the ocean microbarom, which was present on all three balloons and occupies the same frequency band as the airburst signal. Two events were detected during this time period, both of which have the appropriate azimuth. No other events were formed during the hour before and after the expected bolide arrival time, suggesting that the two detections are indeed from the airburst. **We conclude that sparse microbarometer networks floating in the lower stratosphere can detect kiloton-scale airbursts from thousands of kilometers away.** However, we plan to run synthetic tests to confirm the results presented above.