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Infrasound from DAG-4 recorded on a stratospheric balloon

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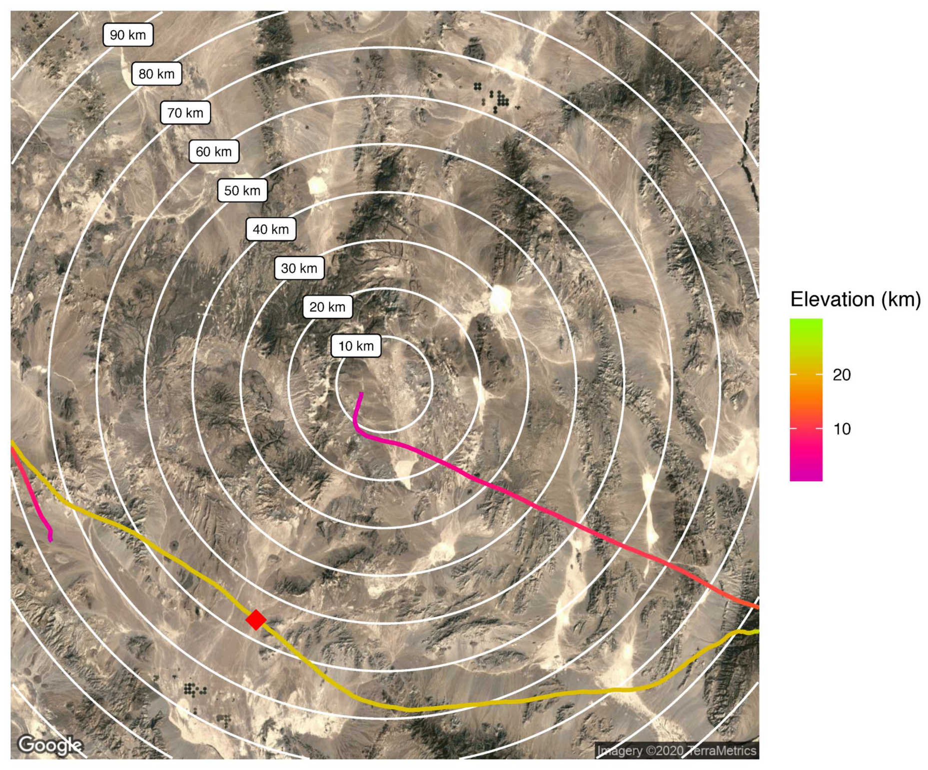
Introduction

Balloon-borne microbarometers can record acoustic waves from ground and airborne sources at great distances. Ground motion generated sound waves are particularly interesting since theory suggests that they should have much greater amplitude at high elevation angles. Also, airborne acoustic recordings at very short ranges have shown that the far-field sound pulse faithfully preserves the characteristics of the source. Here, I present results from a balloon-borne sensor that captured an acoustic pulse from the DAG-4 buried chemical explosion at an elevation of 21.8 km and a range of 56 km. The waveform matches those recorded at ground stations 500 m from the source. No evidence of vertical directionality was observed because the sound wave takeoff angle was nearly horizontal. Signal amplitude closely follows predictions from ray tracing when the impedance contrast between the ground and the stratosphere is taken into account. This study demonstrates that 1) ground motion generated sound waves can be captured and characterized using distant airborne microbarometers 2) path effects have little impact on the signal provided no refraction occurs and 3) amplitudes predicted by geometric acoustics are a close match for those actually observed in the stratosphere.

Sensor and Balloon

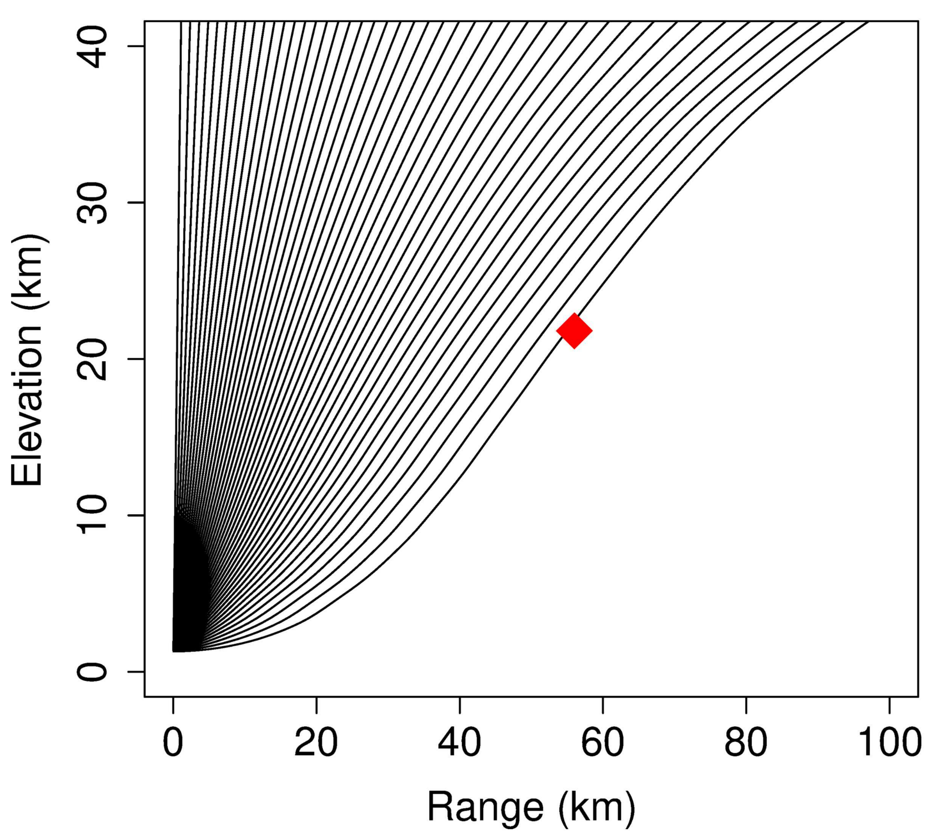
Acoustic waves were recorded on a Gem microbarometer on board a Heliotrope solar hot air balloon similar to the one shown above.

Flight Path



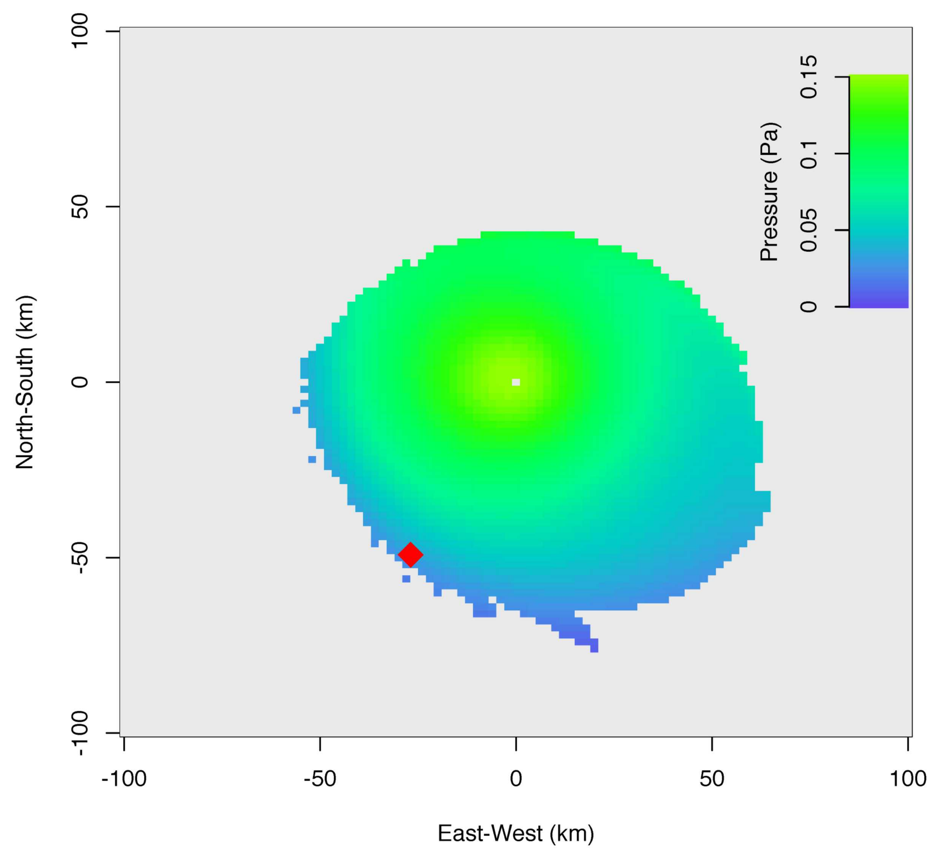
The trajectory of the balloon-borne microbarometer from its launch point 5 km west of the DAG site to its landing point in the Amargosa Valley. The red diamond shows the balloon's position when the DAG-4 signal was detected.

Ray Paths



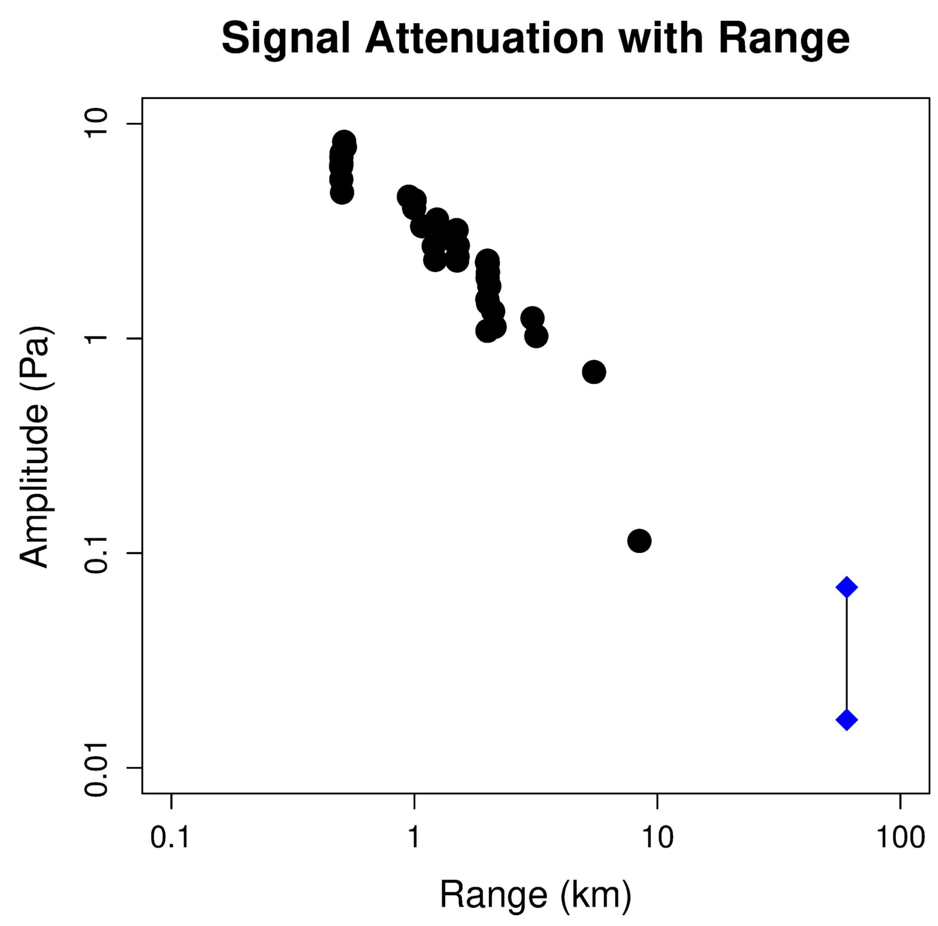
Acoustic ray paths from the DAG site towards the balloon-borne microbarometer. The red diamond shows the balloon's position when the acoustic signal was detected. The microbarometer was very nearly in the "acoustic shadow", a region in which no arrivals are expected. This effect is due to the upward-refracting characteristics of the lower atmosphere.

Expected Amplitude



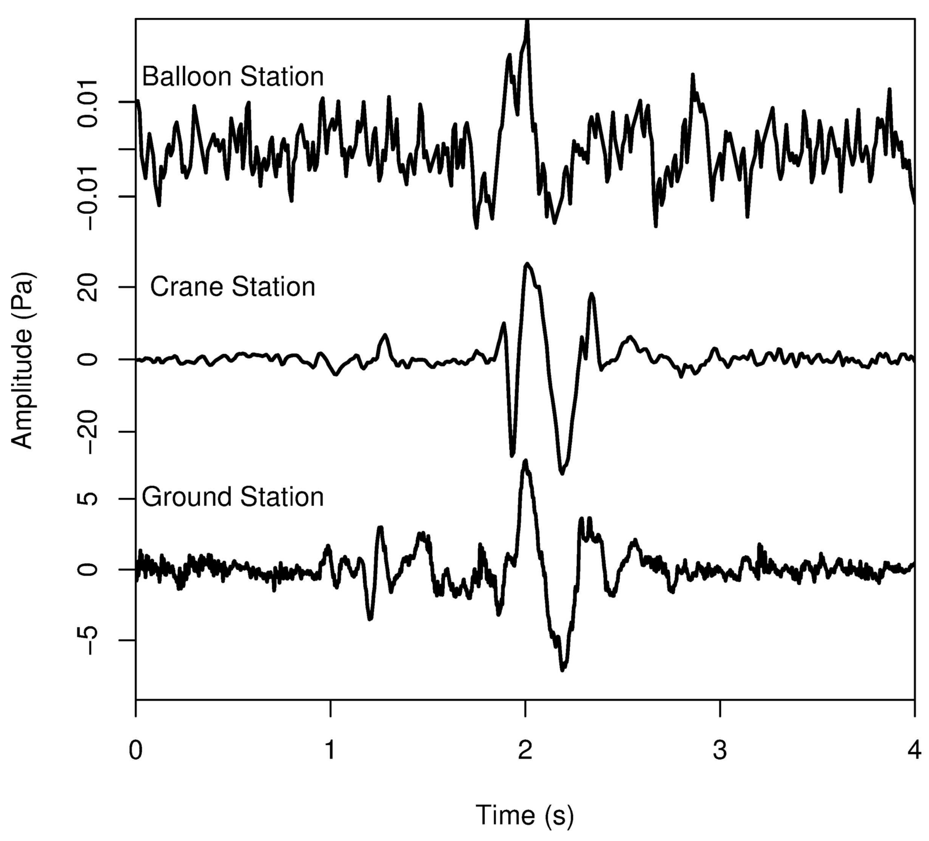
Expected pressure amplitudes at the balloon's elevation assuming an isotropically radiating source with similar overpressures as those recorded on the DAG-4 ground microbarometers (4 Pa at a range of 1 km). The plot takes both geometric and intrinsic attenuation into account, as well as amplitude reduction due to impedance contrast (approximately a factor of 4).

Attenuation



Signal amplitude compared to range for ground stations (black dots) and the balloon (blue diamond). The two balloon symbols show amplitudes adjusted and not adjusted for impedance contrasts.

Waveforms



Waveforms recorded on the balloon (top) compared with those recorded atop a crane 34 m above the ground and 150 m from ground zero (middle) and a ground station 500 m from ground zero (bottom).

Conclusions

This experiment is the first ground motion generated acoustic signal recorded from the stratosphere, and the first time a direct wave from a known point source on the surface has been captured. Furthermore, it showed that balloon flight paths can be predicted sufficiently well to allow transits of specific regions of interest. Signals that travel along direct (non-refracted) ray paths are faithful representations of those that are launched from similar elevation angles very close to the acoustic source. Propagation and attenuation modeling is able to accurately predict both the likelihood of signal capture as well as the expected pressure amplitudes. This has implications for constraining the directional radiation pattern from future planned chemical explosion experiments, monitoring for clandestine nuclear explosions, observing signals from volcanoes and earthquakes, and performing geophysics on solar system bodies such as Venus and Titan.

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