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Infrasound direction-of-arrival determination using a balloon-borne aeroseismometer

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Introduction

Figure 1: A solar hot air balloon with an infrasound payload moments after launch.

Over the last decade, stratospheric balloons have emerged as important platforms for infrasound studies: they can cross large regions over land and over oceans, they are very low-noise platforms since they travel with the wind, and they could even detect seismic activity on Venus. However, existing infrasound direction of arrival determination methods are not well adapted for balloons. We have developed a technique called *aeroseismometry* that utilizes the motion of the balloon in response to acoustic loading to derive the direction of arrival of the signal.

Aeroseismometer Concept

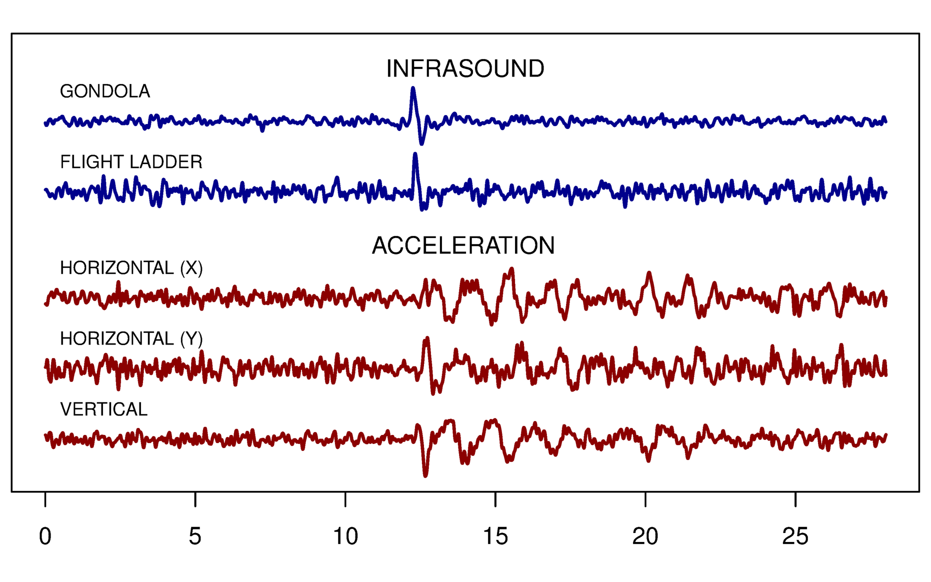

Figure 2: A weak (0.03 Pa) acoustic pulse inducing a measurable acceleration on a large zero-pressure balloon.

Acoustic waves involve longitudinal displacement of the medium through which they travel. Objects embedded in this fluid – such as balloons – shift in concert with this displacement. Onboard motion sensors with properly georeferenced axes can therefore determine the direction of arrival of the signal.

Infrasound-Induced Motion

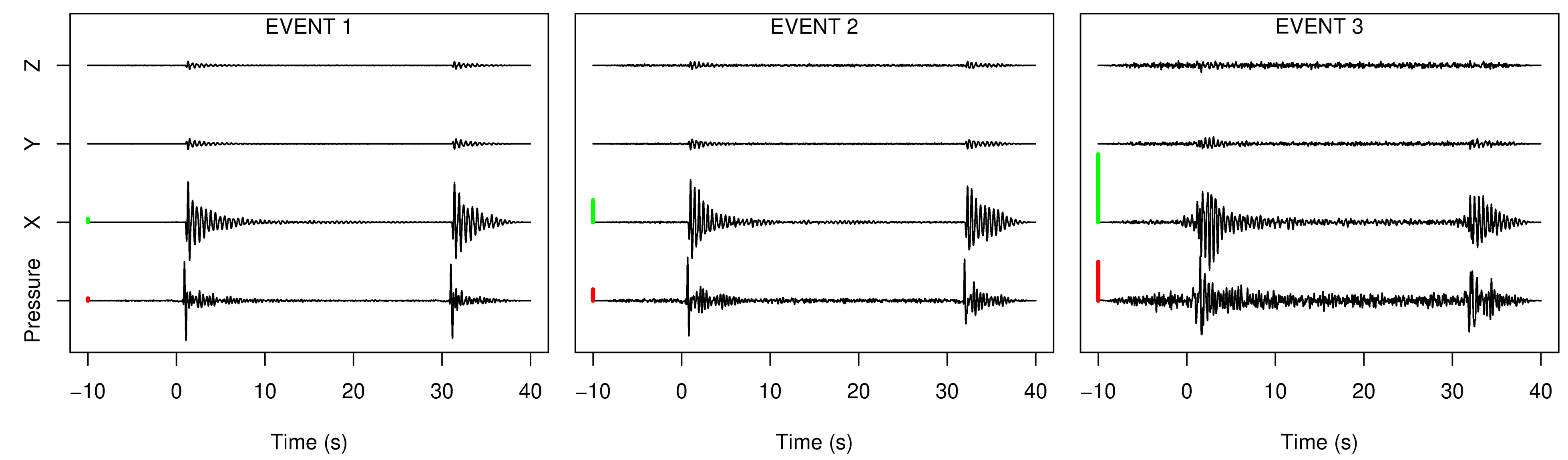

Figure 3: Pressure and body frame acceleration recorded on a high altitude balloon in response to acoustic signals. The X axis is approximately vertical, the Y and Z axes are approximately horizontal. The red scale bar represents 0.25 Pa, and the green scale bar represents 0.4 ms^{-2}.

A balloon carrying an infrasound sensor and an inertial measurement unit (IMU) was deployed in acoustic range of three sets of two 1 ton TNT equivalent explosions. The resulting motion recorded on the IMU (above) was georeferenced based on the orientation of the sensor package at the time the signal was received, and the direction of vibration derived.

Direction of Arrival Estimation

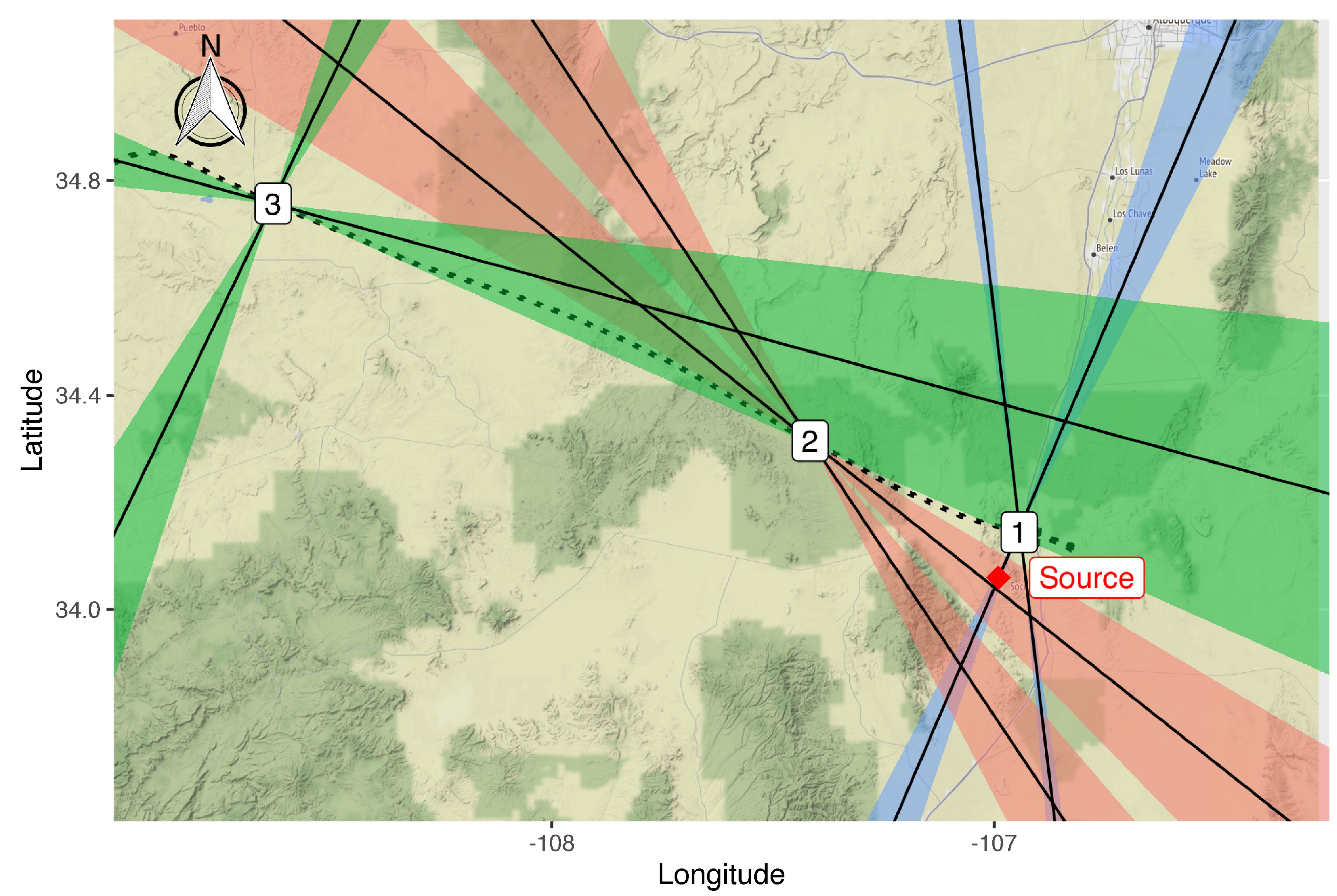

Figure 4: Direction of arrival estimates for three sets of two 1 ton TNT equivalent explosions carried out at a common location. The dashed line shows the path of the balloon, and the shaded regions represent 2σ uncertainty around each estimate.

Five of the six estimates correctly identify the direction of arrival of the signal (above), while the sixth is likely due to the weaker signal recorded at greater range. The direction estimates are 180° aliased since the impulse response of the balloon is not taken into account. Current research is focused on utilizing the pressure waveform and balloon response to remove this aliasing effect.

Geolocation

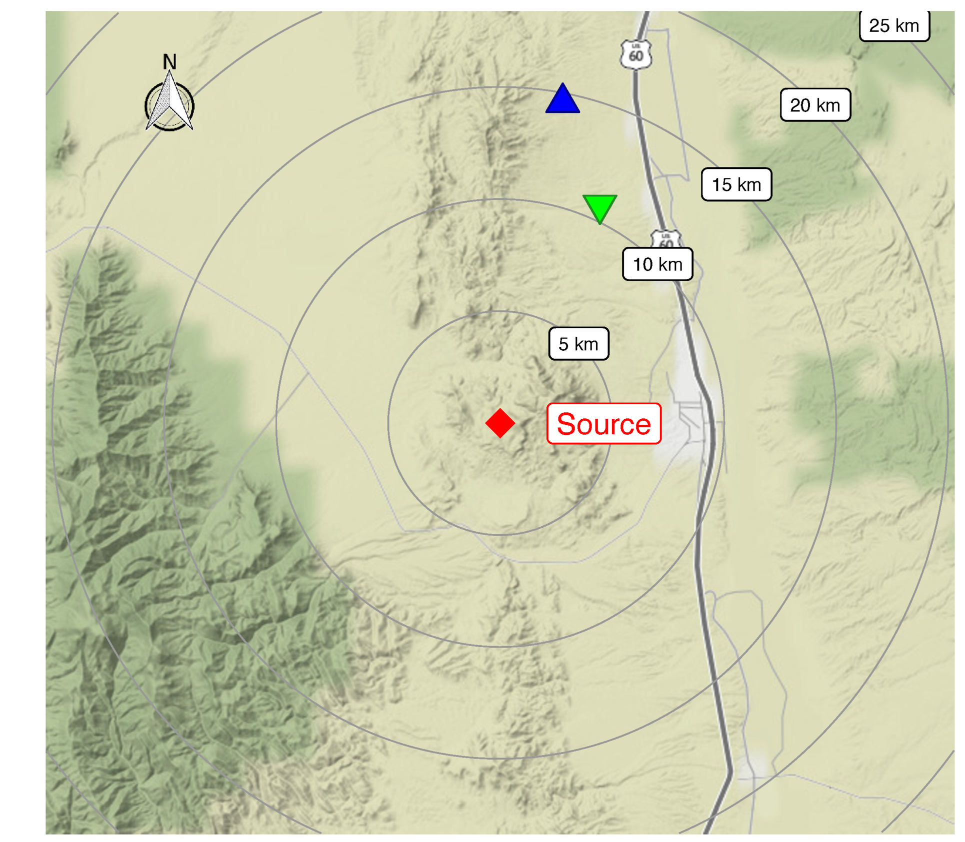

Figure 5: Source locations derived using 5 of the 6 direction of arrivals recorded during the experiment. The blue upward triangle denotes the first trial location, and the green downward trial indicates the new location after adjusting for distance.

In addition to providing direction of arrival, aeroseismometers can be used to geolocate signal sources. A vector sensor geolocation technique used in hydroacoustics was adapted to calculate the site of the explosions recorded on the aeroseismometer during the field test. The technique first identifies a trial location, then reweights the observations based on source-receiver distance. This is done because a given azimuth error has a greater impact further from the receiver. For this demonstration, 5 of the 6 directions were included in the location calculation. The first trial location is about 15 km from the site, but the distance reweighting reduces this error to about 11 km. These results show that geolocation is possible as long as at least two balloons record a common signal and/or if the signal repeats itself at least once with sufficient time delay for the balloon(s) to change position.

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