INFRASOUND IN THE "ZONE OF SILENCE"

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ABSTRACT

Experiments designed to understand the propagation of infrasound signals at distances of less than 200 km were conducted in central Nevada, USA during the week of 11 September 2006. A controlled suite of explosions on the surface, designed to destroy surplus military ordnance, provided the source of the infrasound signals. Three temporary 4-element infrasound arrays were deployed in a line due north of the sources at distances from 76 to 157 km. In addition, seismo-acoustic data was provided by the permanent Nevada Infrasound Array (NVIAR) and collocated seismic array NVAR, located about 36 km east of the source.

The experiment was successful, and detections from all explosions were recorded at all arrays. Therefore, the assumption of the absence of signals in the "zone of silence" is incorrect in this case. At NVIAR the shorter distance and impulsive signals indicated the arrival of direct waves. However, other signals recorded at distances of 76 to 157 km were longer in duration, and initial travel time analysis indicated the rays were turning in the stratosphere. Simultaneous balloon launched rawinsonde weather recordings collected between the sources and the stations through the tropopause showed there were no conditions that would allow turning rays or reflections in the troposphere. Because the travel times were too short for turning rays above the stratosphere, we conclude that the energy was refracted in the stratosphere. Obviously improved atmospheric models through the stratosphere are needed to explain the occurrence of infrasound signals in the "zone of silence".

OBJECTIVES

Classic infrasound propagation theory describes a 'zone of silence' where no energy is predicted to reach sensors near the surface from the limit of the direct arrival out to 200–250 km from the infrasound source. However, recent studies (McKenna, 2005; Golden et. al., 2007) showed that under various wind and temperature conditions infrasound signals can be recorded within these distances. The purpose of this research study is to characterize the conditions under which atmospheric returns are recorded in the zone of silence. A better understanding of these types of signals could be helpful in characterizing the sources at these distances.

RESEARCH ACCOMPLISHED

Experiments were conducted near Hawthorne NV on September 11–13, 2006 (Julian days 254, 255, and 256) designed to collect infrasound and seismic data from well-controlled explosions on the ground surface. Carefully controlled ordnance disposal explosions are conducted by Hawthorne Army Ammunition Depot contractors on a regular basis. These well documented sources provided seismic and infrasound signals for studies of infrasound propagation in the traditional "zone of silence". Figure 1 shows the location of the International Monitoring System (IMS) Primary Seismic array PS-47 (NVAR) with the configuration of the experimental infrasound array (NVIAR) in the middle, as well as the Army Ammunition Depot and disposal pits.

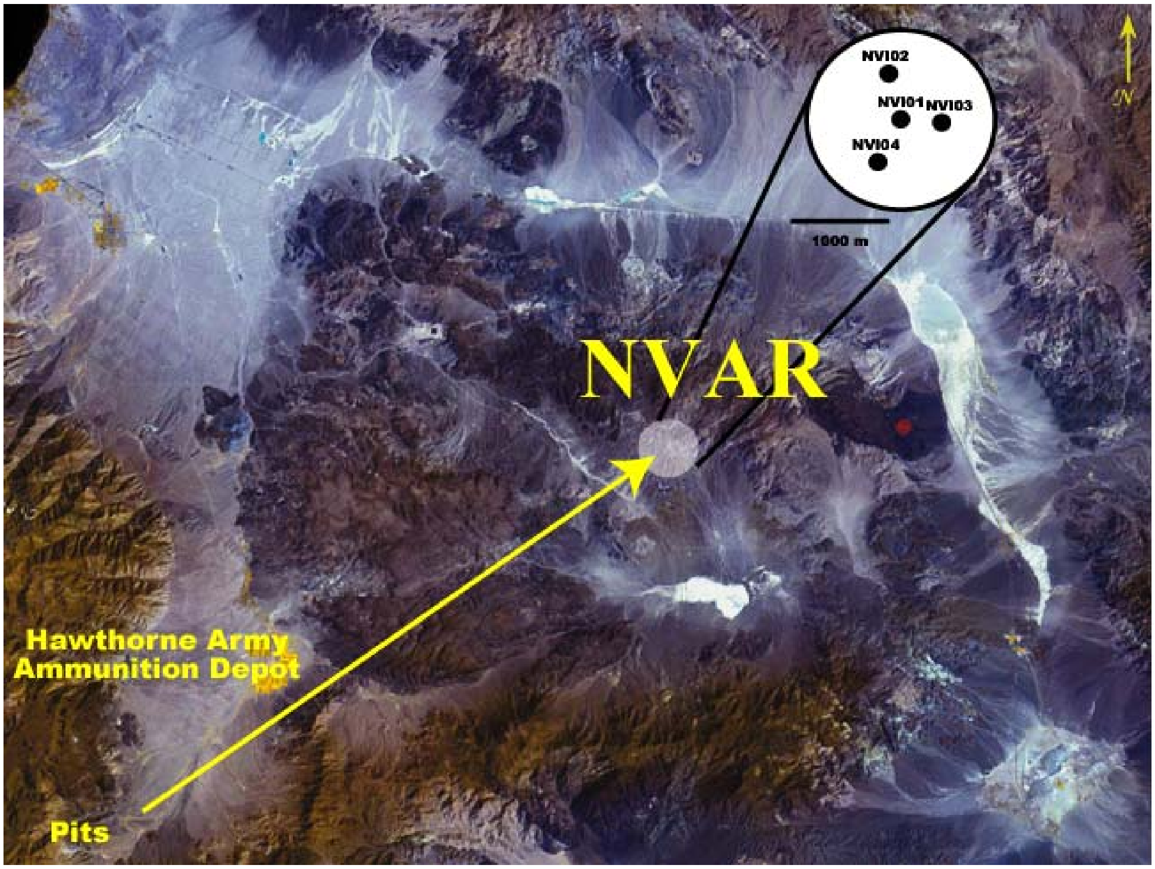

Figure 1. Location of NVAR and the Hawthorne Army Ammunition Depot. The configuration of NVIAR is also shown.

In addition to collecting data at NVIAR during our experiments, we deployed three 4-element portable infrasound arrays at distances of 76, 108, and 157 km north of the demolition location. The array at 76 km was located within the village of Shurz NV (SHURZ), while the other 2 arrays were north and south of the city of Fallon NV, designated Fallon north (FALN) and Fallon south (FALS), along State Highway 95. During the experiment FALS recorded a significant number of infrasound arrivals which were probably associated with activities at the nearby

Fallon Naval Air Station. Each of the three portable arrays consisted of 4 IML infrasound sensors located in line with the direction of propagation of the signals at separation distances of 50, 100, and 150 meters as shown in Figure 2. The linear configuration was chosen to maximize the time delays across the array.

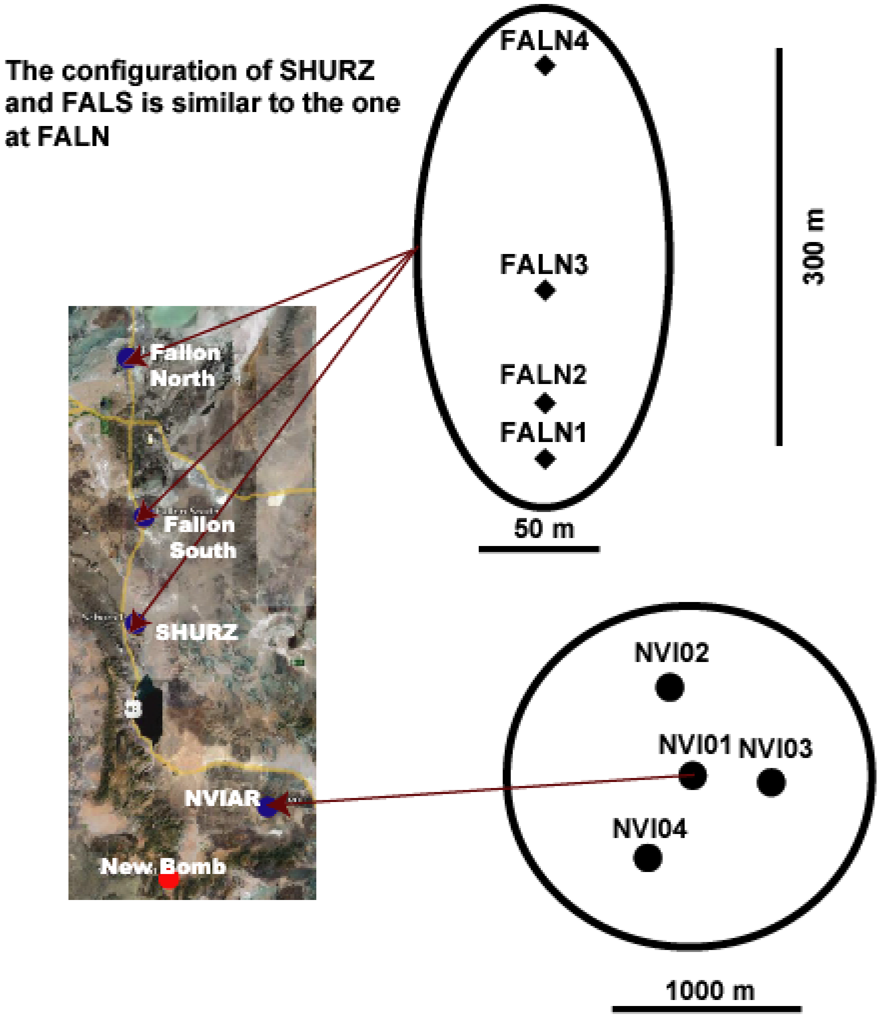

Figure 2. Satellite image of the area of temporary infrasound arrays deployed for the experiments with plan layouts of each array.

Thus, including the permanent array, we have observations at 36, 76, 108, and 157 km from the source. With the exception of NVIAR the stations are all in the traditional "zone of silence". Signals from the explosions recorded at NVIAR are direct arrivals, not turning rays. The presence of the array in the direct arrival distance range provides near source seismic and infrasound waveforms allowing us to calculate very accurate origin times for each explosion. With the exception of FALS, that experienced some cable problems, all the other channels of the arrays recorded data from the munitions explosions. Figures 3, 4, and 5 show the beam (delay and sum) of the arrays for the first day of the experiment.

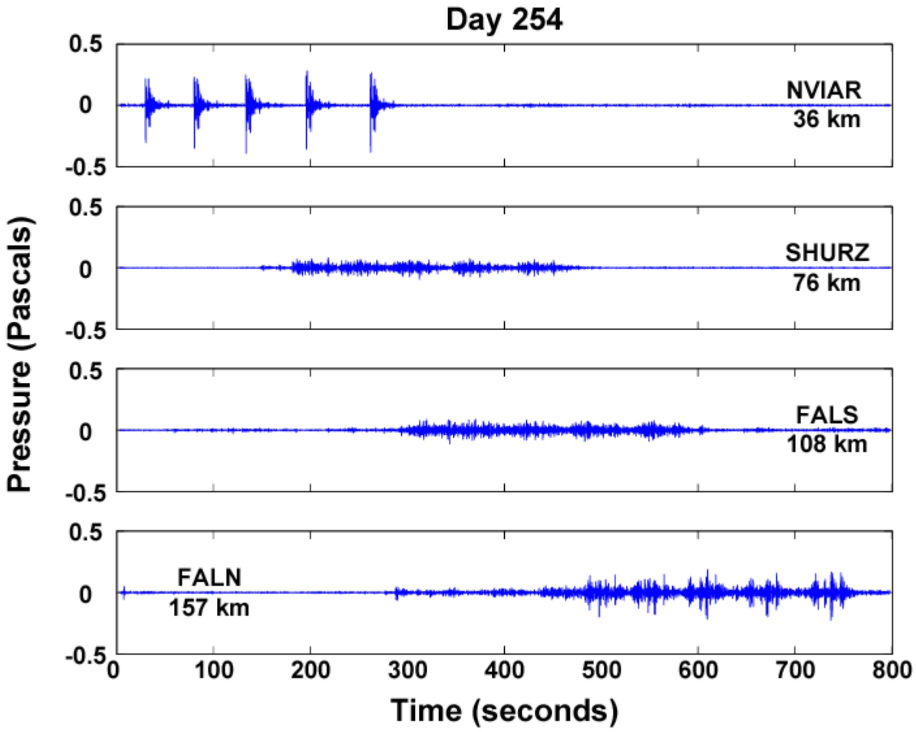

Figure 3. Filtered beam (0.5-3 Hz) for the first day of the experiment.

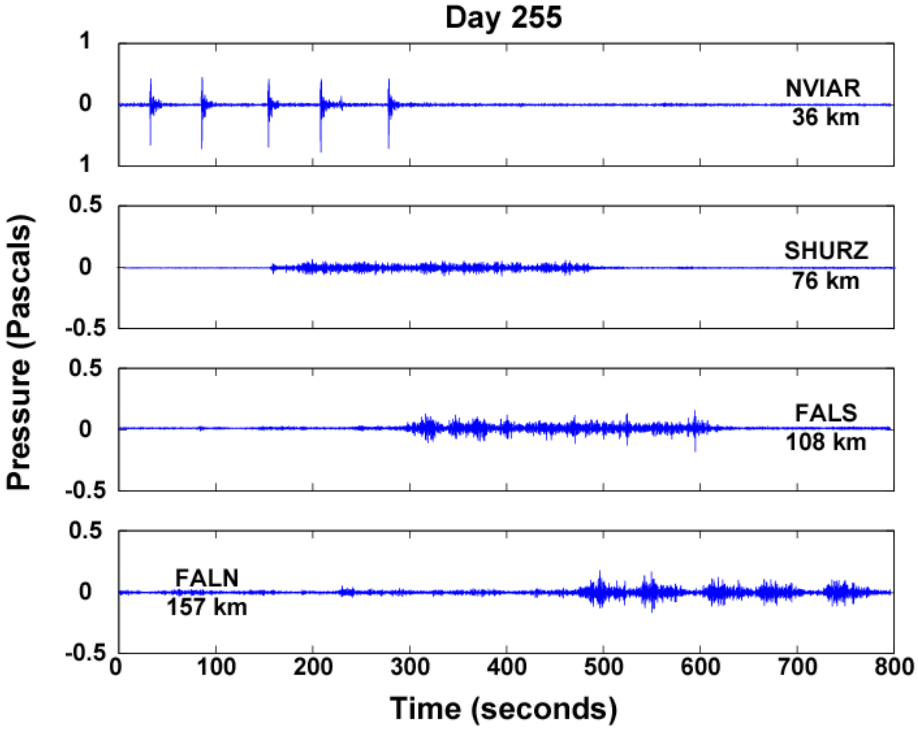

Figure 4. Filtered beam (0.5-3 Hz) for the second day of the experiment

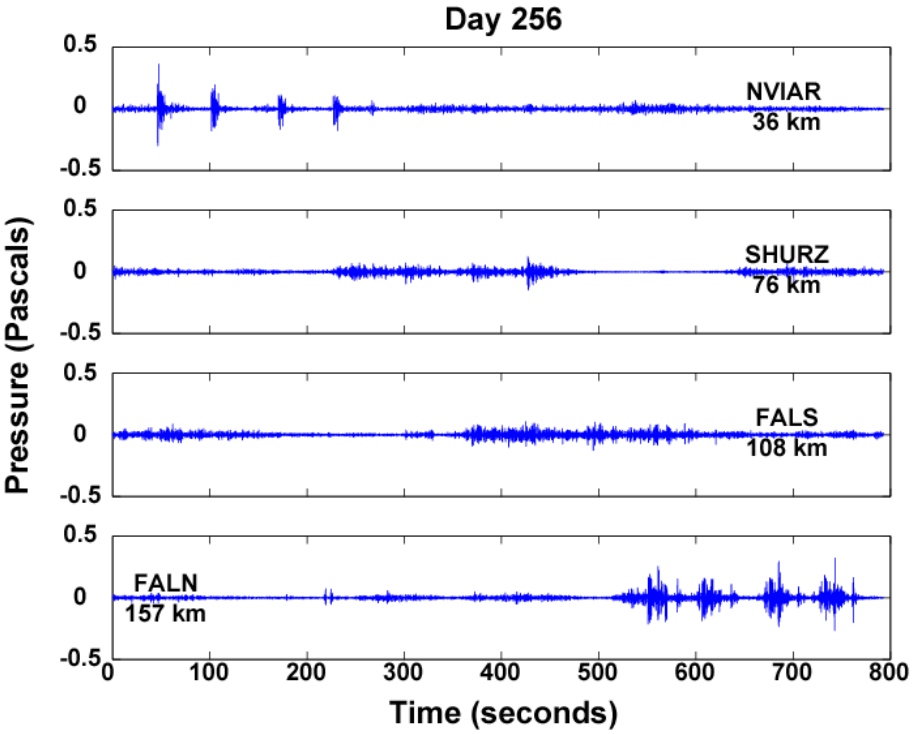

Figure 5. Filtered beam (0.5-3 Hz) for the last day of the experiment

In addition to the infrasound array data we collected meteorological data at the Hawthorne NV airport. We employed the National Severe Storms Laboratory (NSSL) to collect balloon launched rawinsonde meteorological data during our three experiment days. The rawinsondes were used to collect temperature, dewpoint, barometric pressure, GPS latitude, longitude, altitude, and wind speed and direction data.

Table 1 gives the arrival times, travel times and velocities for the first arrivals at each array for all three days while Figure 6 shows the velocities for each day at each of the four arrays.

Table 1. Arrival times, travel times and velocities of first arrivals at each array for all three days of the experiment.

Acoustic Arrival Times			
	DAY 254	DAY 255	DAY 256
NVAR	17:41:28.102	17:54:10.35	20:50:48.590
SHURZ	17:43:58.74	17:56:39.8	20:53:07.3
FALS	17:45:49.78	17:58:30.0	20:55:19.0
FALN	17:48:54.17	18:01:33.34	20:58:20.24
Acoustic Travel Times (seconds)			
NVAR	105	105	105
SHURZ	256	255	244
FALS	367	365	376
FALN	551.5	548.5	557
Average Travel Velocities (m/s)			
NVAR	343	343	343.8
SHURZ	296	297	310
FALS	294	295	286
FALN	284	285	281

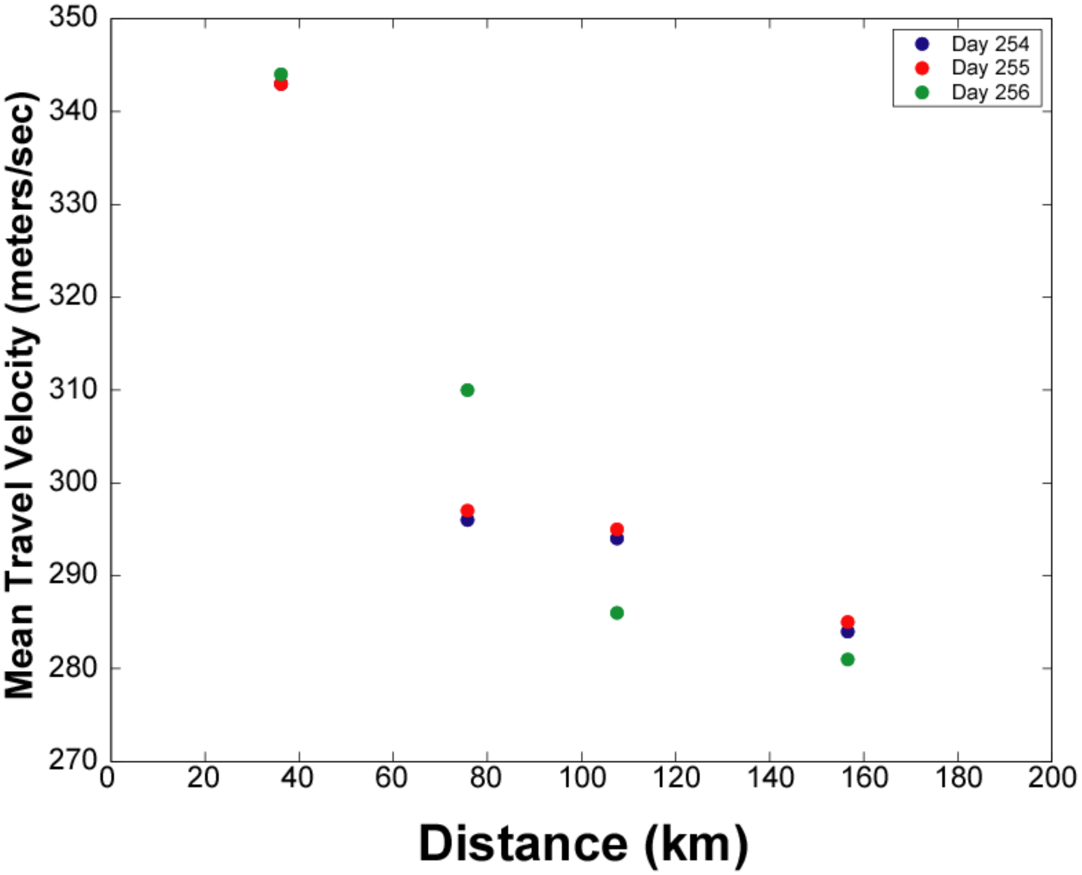

Figure 6. Infrasound travel velocity at each array for all three days of experiments.

At NVIAR travel velocities for all arrivals were about 343 m/s. At the other arrays velocities between 263 m/s and 297 m/s were determined. These velocities indicate that except for NVIAR all of the arrays recorded stratospheric returns. We would expect travel velocities between 200 and 240 m/s for thermospheric returns. There were no arrivals with velocities below about 263 m/s indicating that none of the arrivals were from thermospheric returns (Mutschlecner and Whitaker, 1999).

There is also an interesting observation at SHURZ for the first two days. An infrasound arrival is recorded approximately 30 seconds before the arrival of the main wavetrain. This arrival, shown in Figure 7 has the same back-azimuth as the main arrivals and a travel velocity of 341 m/s. We interpret this as being a direct arrival and 30 seconds later an arrival with a travel velocity of 296 m/s was recorded indicating a stratospheric return. Any other potential direct arrivals of the later shots are masked by the much larger amplitudes of the stratospheric returns. Therefore at a distance of 76 km from the source both direct and stratospheric arrivals are recorded. However on day 256 we could not observe the direct arrival due to higher local noise conditions. In addition, the yields of the explosions were all smaller than the previous two days.

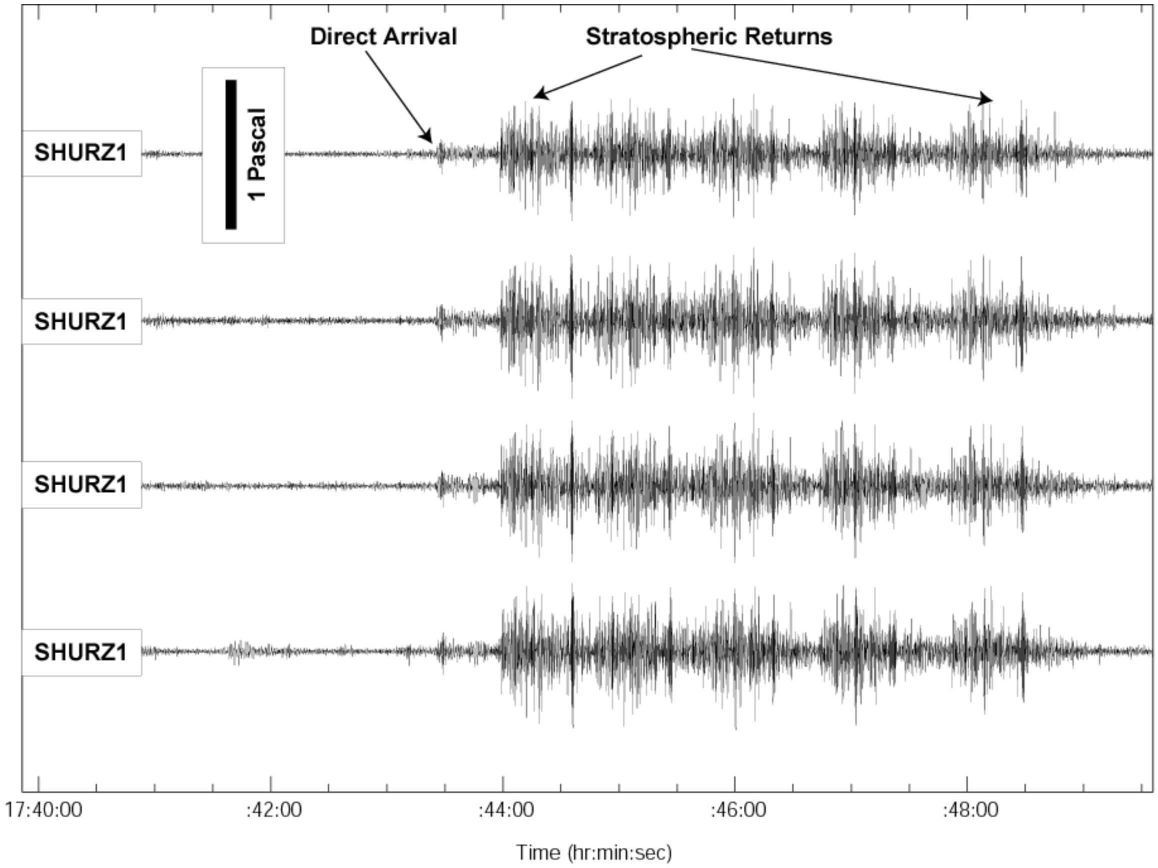

Figure 7. Infrasound data from day 254 recorded at SHURZ, showing both direct arrivals and stratospheric returns.

CONCLUSIONS AND RECOMMENDATIONS

This unique dataset provides us the opportunity to try to gain a better understanding of the dynamics of the atmosphere allowing infrasound propagation in the “zone of silence”. Initially it was believed that infrasound propagation in the classic “zone of silence” is controlled by short lived temperature inversions in the troposphere (Mckenna, 2005), and that the infrasound signals are propagating through those ephemeral ducts. Local meteorological data recorded in the source/receiver path during the time of the explosions show no inversions in the troposphere, yet signals are recorded at all arrays. In the case of NVIAR, these are direct arrivals and the other arrays are all located within the so called "zone of silence". With the exception of a direct arrival on one day of our experiment at SHURZ, all the recorded signals at stations SHURZ, FALS and FALN are stratospheric returns, based on average travel velocities. Clearly troposphere inversions are not the only mechanism that controls the “zone of silence”.

Preliminary modeling with InfraMap software using the Naval Research Laboratory Ground to Surface (NRL-G2S) coefficients for day 256 is not able to predict the stratospheric returns recorded at the temporary arrays. The atmospheric temperature profile derived from InfraMap is shown in Figure 8. The model agrees with our rawinsonde data up to balloon burst in the lower stratosphere around 24 km.

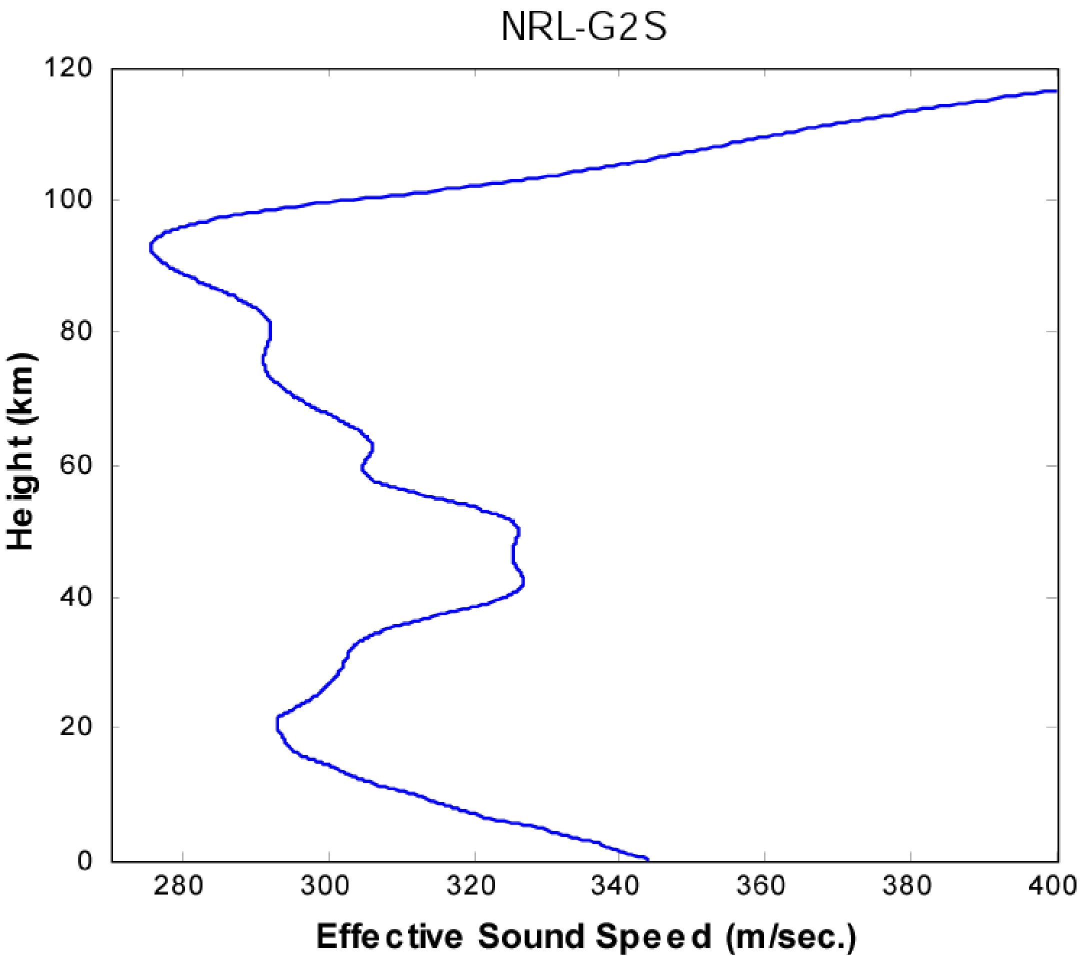

Figure 8. Temperature profile from InfraMap modeling.

A very low altitude inversion is common for desert environments due to ground heating from sunlight. This inversion was observed each day during our experiments and is seen in the actual rawinsonde temperature profile in Figure 10. Though hard to see in the model profile the inversion generates a rolling wave that attenuates at distances less than 100 km as is shown in Figure 9. This could explain the direct arrival recorded at SHURZ at a distance of 76 km from the source, while at FALS at a distance of 108 km it was attenuated. However, modeling indicates no energy should return to the surface at any of our stations. Obviously atmospheric models in the stratosphere need to be refined to successfully predict arrivals within the "zone of silence".

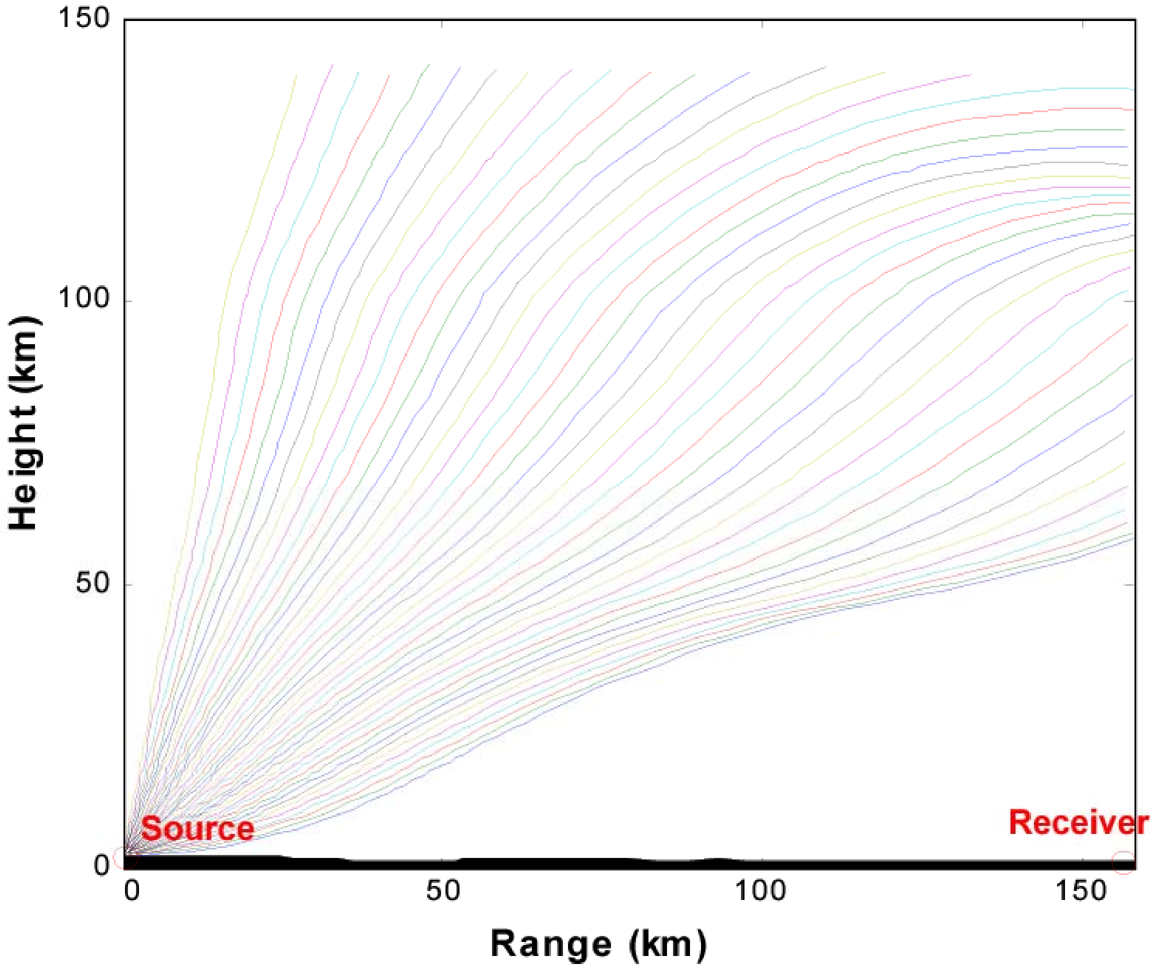

Figure 9. Rays traced through the atmospheric model, indicating that there should be no energy returned to the surface at distances of 76 to 157 km. A direct arrival could be recorded at distances up to 100 km.

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