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Infrasound Observations from a Seismo-Acoustic Hammer Source at the Nevada National Security Site

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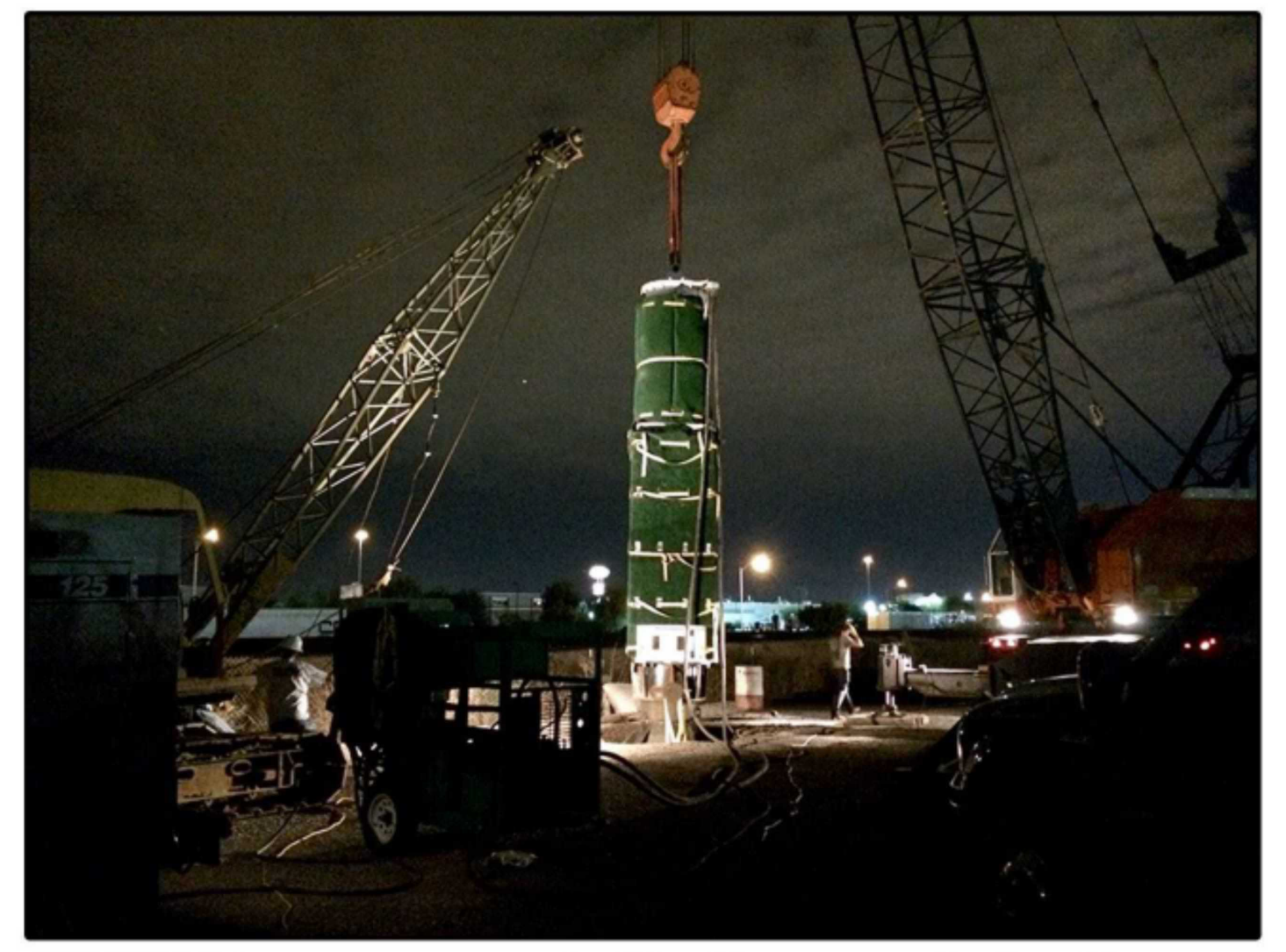
ABSTRACT

As a part of the Source Physics Experiment (SPE) site characterization, Sandia National Laboratories, in conjunction with HK Exploration, deployed a large (13 metric ton) seismo-acoustic hammer source at the Nevada National Security Site (NNSS) in December 2014. This was a small-scale test of a planned larger, active source, seismic survey to be conducted with the seismo-acoustic hammer source in 2015 at the NNSS. During early field-testing of the hammer source we found that, as the mass hit the ground, a significant downward deflection of the surrounding surface imparted an observable infrasound pressure wave into the atmosphere. We present results from the early field-testing as well as the results from the small-scale experiment and airborne sensor data collect at the NNSS. The early field-testing was conducted in a crane yard in North Las Vegas, NV with asphalt at the surface while the test at the NNSS was done on alluvium. The alluvium has a higher flexure rate than the asphalt thus allowing better surface deflection and subsequent atmospheric coupling. For nuclear explosion monitoring, with infrasound, the ground surface is the source of the atmospheric pressure perturbations and by characterizing the source geology we hope to better understand the

BACKGROUND

The HK Exploration Seismic Hammer™ (SH) has been developed to generate large, repeatable seismic impulses for active source seismic experiments. The SH is an impulsive source capable of generating up to .19 mega-joules of energy by hydraulically lifting and then dropping a 13 metric ton mass from a height of 1.5 m. The hammer is capable of up to 3 shots per minute with remarkable consistency. Researchers with the Source Physics Experiment (SPE) are currently using the SH at the Nevada National Security Site for active source characterization experiments to compliment the SPE underground explosions. During these experiments, infrasound sensors were deployed to record any observable acoustic signals being generated by the SH. We have determined that the SH does generate infrasound by its deflection of the ground due to the weight striking the transducer plate, which in turn actuates the ground as an infrasonic loudspeaker. In the Sandia National Laboratories (SNL) studies to date, this system generates a signal that is ~10-12 Hz and observed up to 1.75 km away.

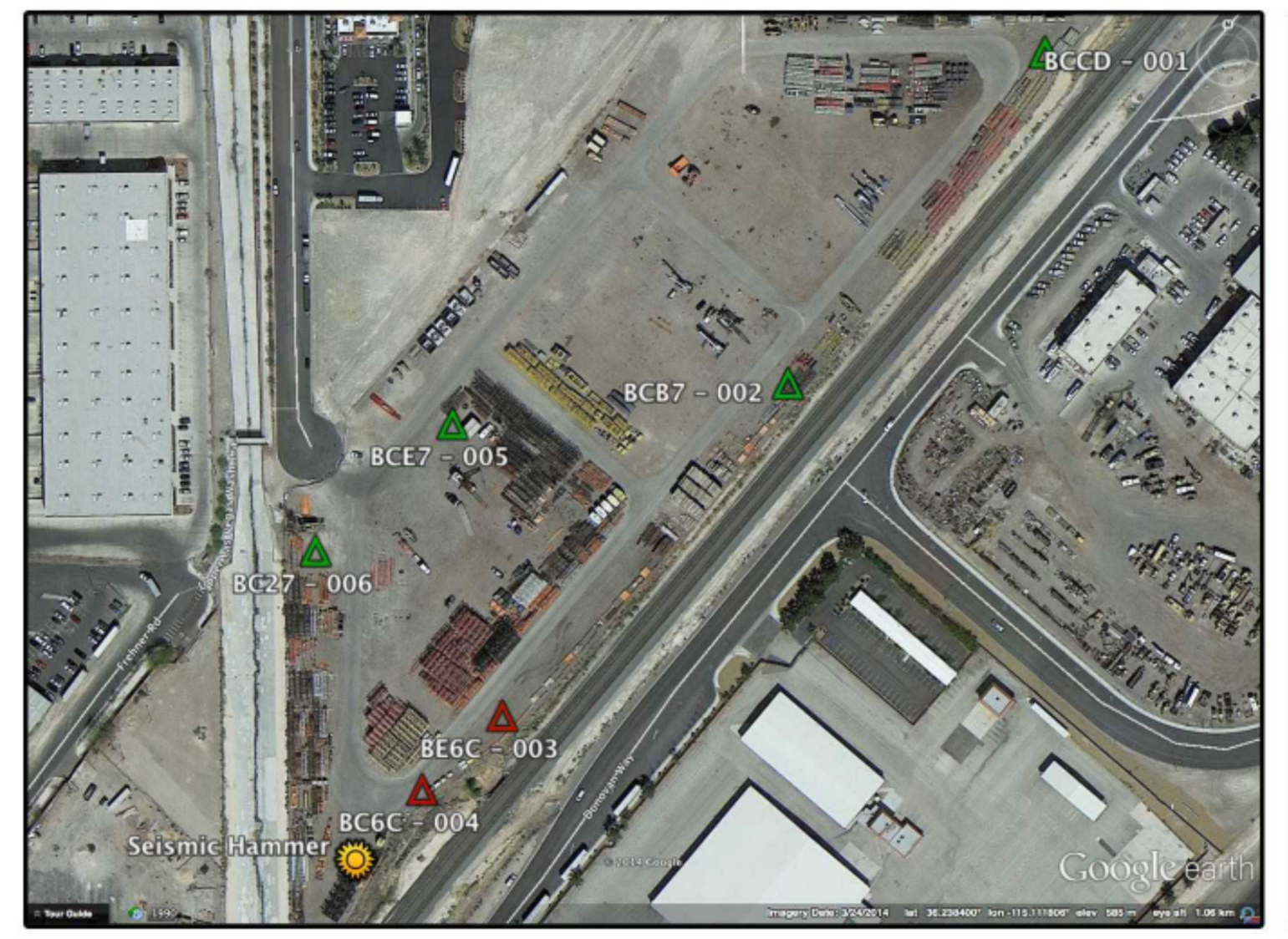


ABOVE: Hammer supported by the crane during the North Las Vegas Test at night.

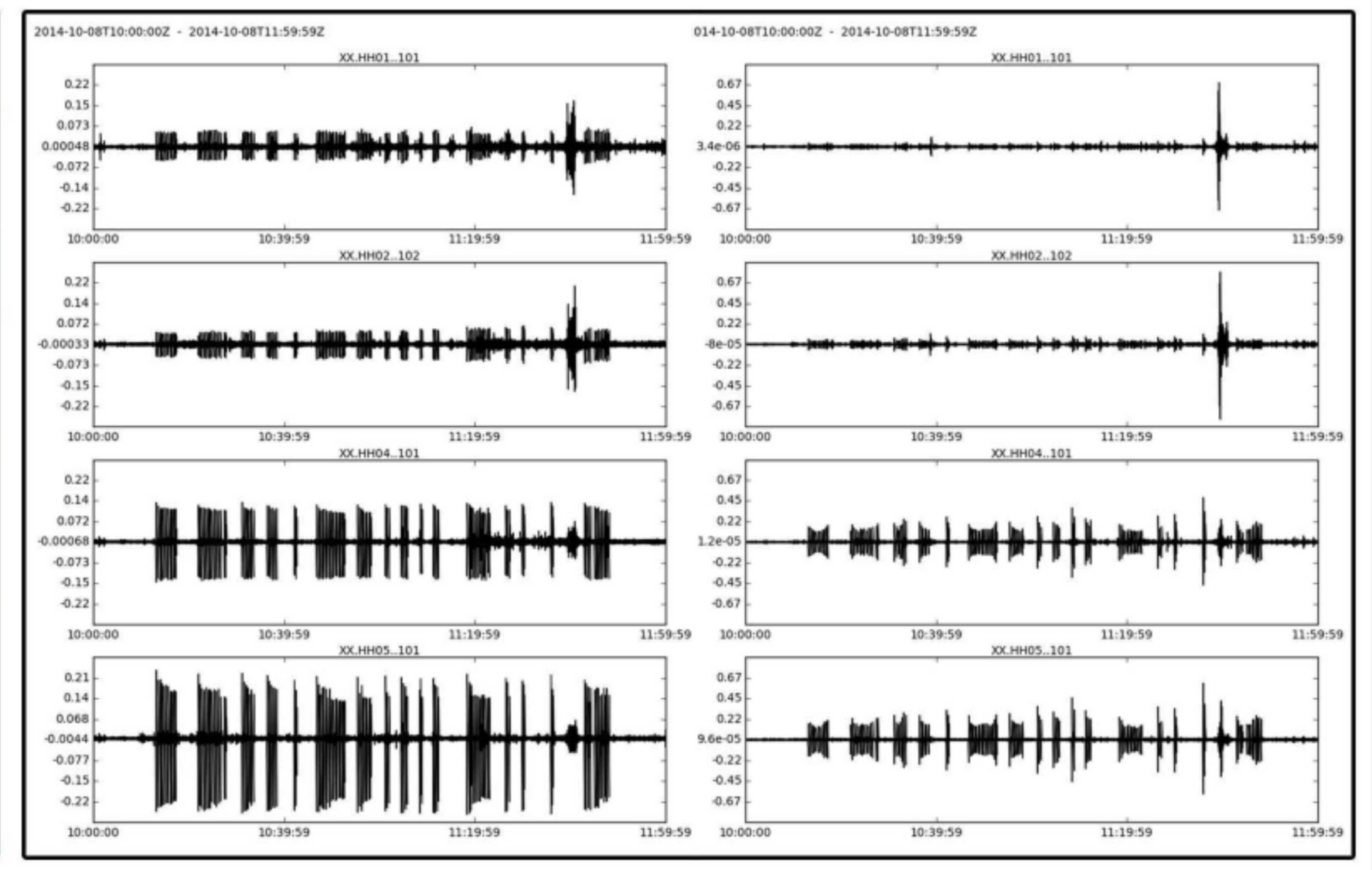
ABOVE: Hammer supported by the crane during the Magni Test. People standing by the hammer for scale.

NORTH LAS VEGAS HAMMER TEST

The North Las Vegas (NLV) hammer test was the initial proof-of-concept test to determine if the seismic hammer produced infrasound. HH Seismic deployed the hammer at a crane yard in North Las Vegas, NV. We installed 6 Hyperion, seismically decoupled infrasound sensors from a few 10s of meters out to 0.5 km (see map below left). The data were recorded at 1000 Hz on REFTEK digitizers. Unfortunately, during the test the closest REFTEK did not record the data correctly (red triangles below left). The remaining 4 sensor - digitizer systems recorded data correctly. Since this was a proof-of-concept test, we were still able to verify that the Seismic Hammer does produce infrasound. This test was conducted in the middle of the night to reduce excess anthropogenic noise and the winds are typically reduced at this time as well. During this test the hammer was placed on asphalt and eventually broke through to the underlying soil. The Seismic Hammer generates remarkably consistent signals as shown in the waveforms (below right). The left panel shows the waveforms filtered between 0.5 and 20 Hz while the right panel is filtered between 80 and 110 Hz to emphasize the train signal (large spike) compared to the hammer signals. In the spectrograms (right) we found two main areas of energy around 10 Hz and 95 Hz.



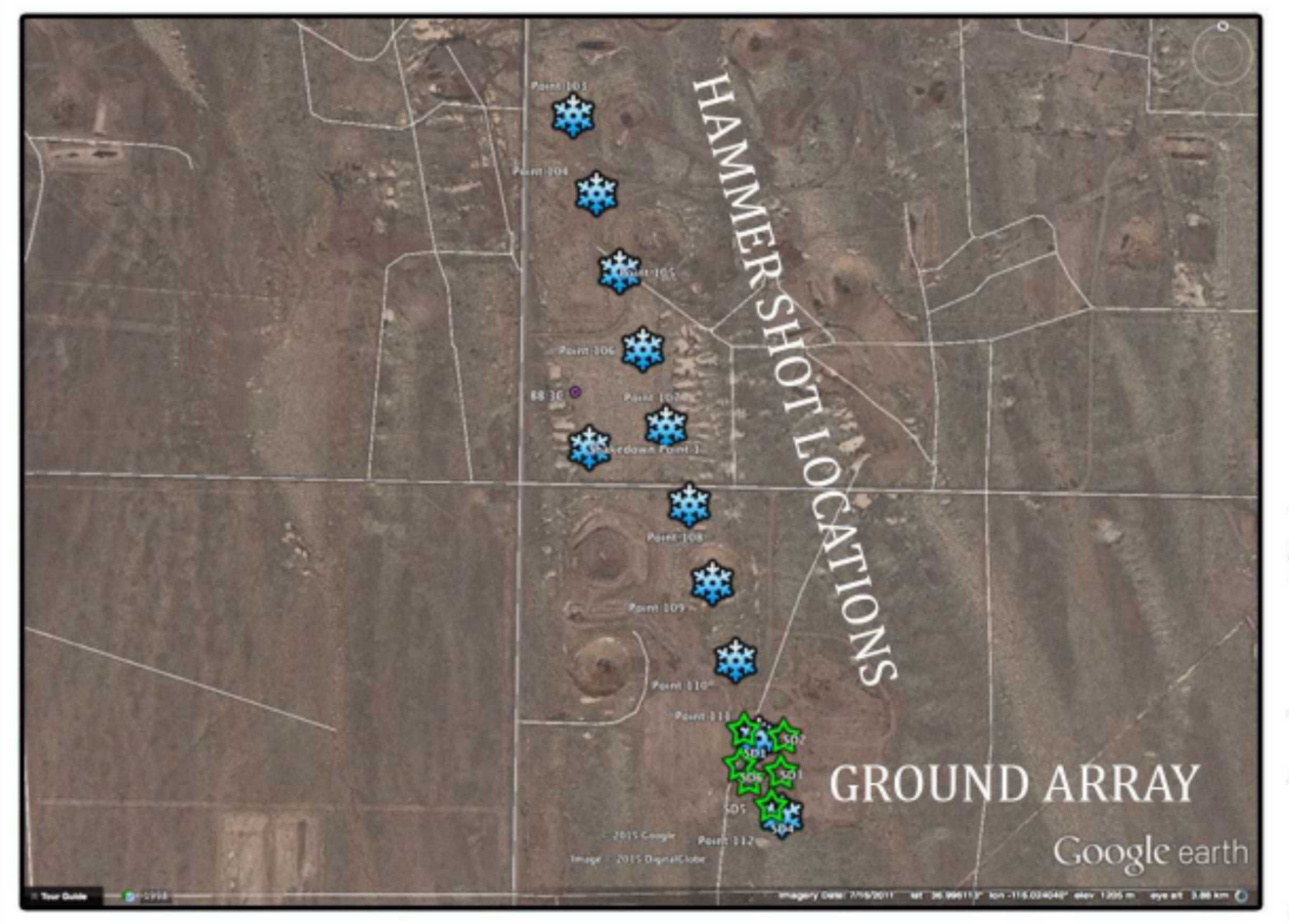
ABOVE: Map of deployed infrasound stations for NLV Test. Green stations were operational, while red stations were not. Largest source-to-receiver distance was 0.5 km.



ABOVE: Plot showing filtered traces of hammer shots. Left panel is filtered 0.5 - 20 Hz and right is filtered 80 - 110 Hz. Large spike in the right panel is a passing train. Hammer shots are very consistent.

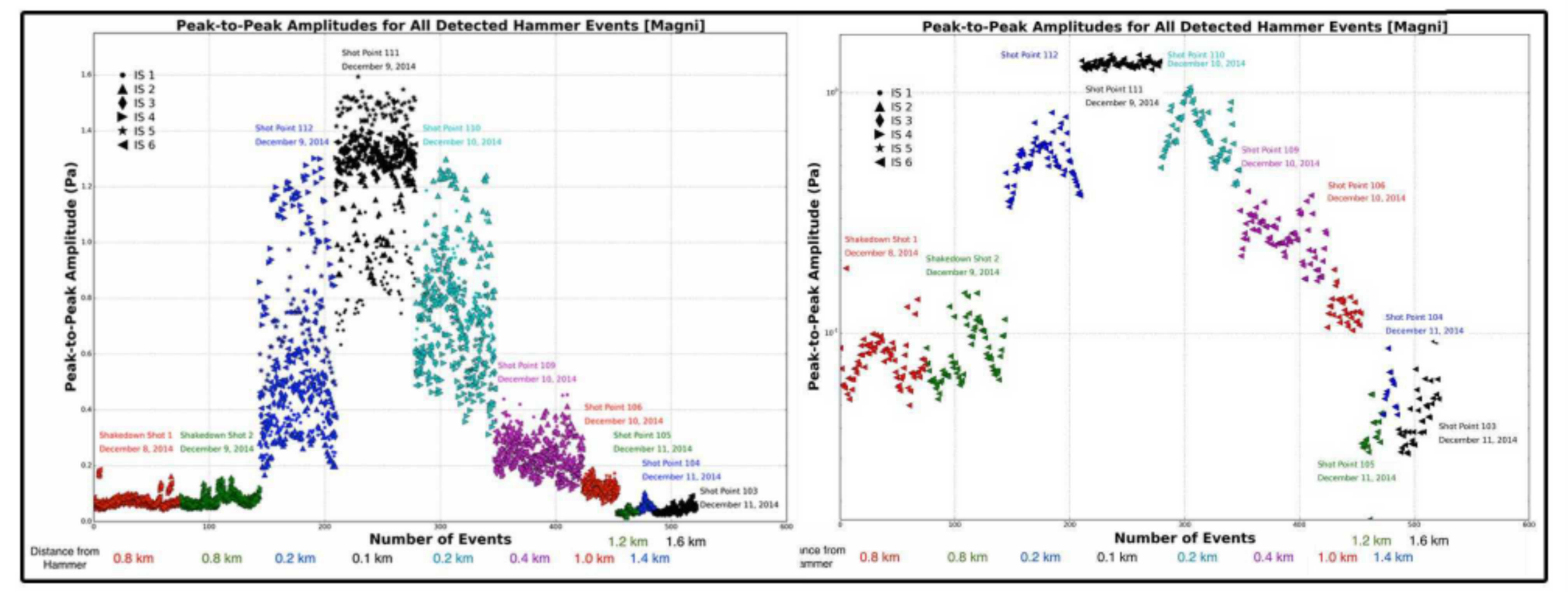
MAGNI TEST

The Magni test was conducted in December 2014 at the NNSS as a small-scale shakedown test prior to the larger survey (Thor). We deployed 6 Hyperion, seismically decoupled infrasound sensors with REFTEK digitizers. The 6 sensors were deployed roughly 100 m azimuthally around one of the hammer shot points along the Southeast line (left). After the hammer test shot location near the center of the line, the hammer shots moved from the Southeast to Northwest. The sensor network remained stationary while the hammer was relocated.



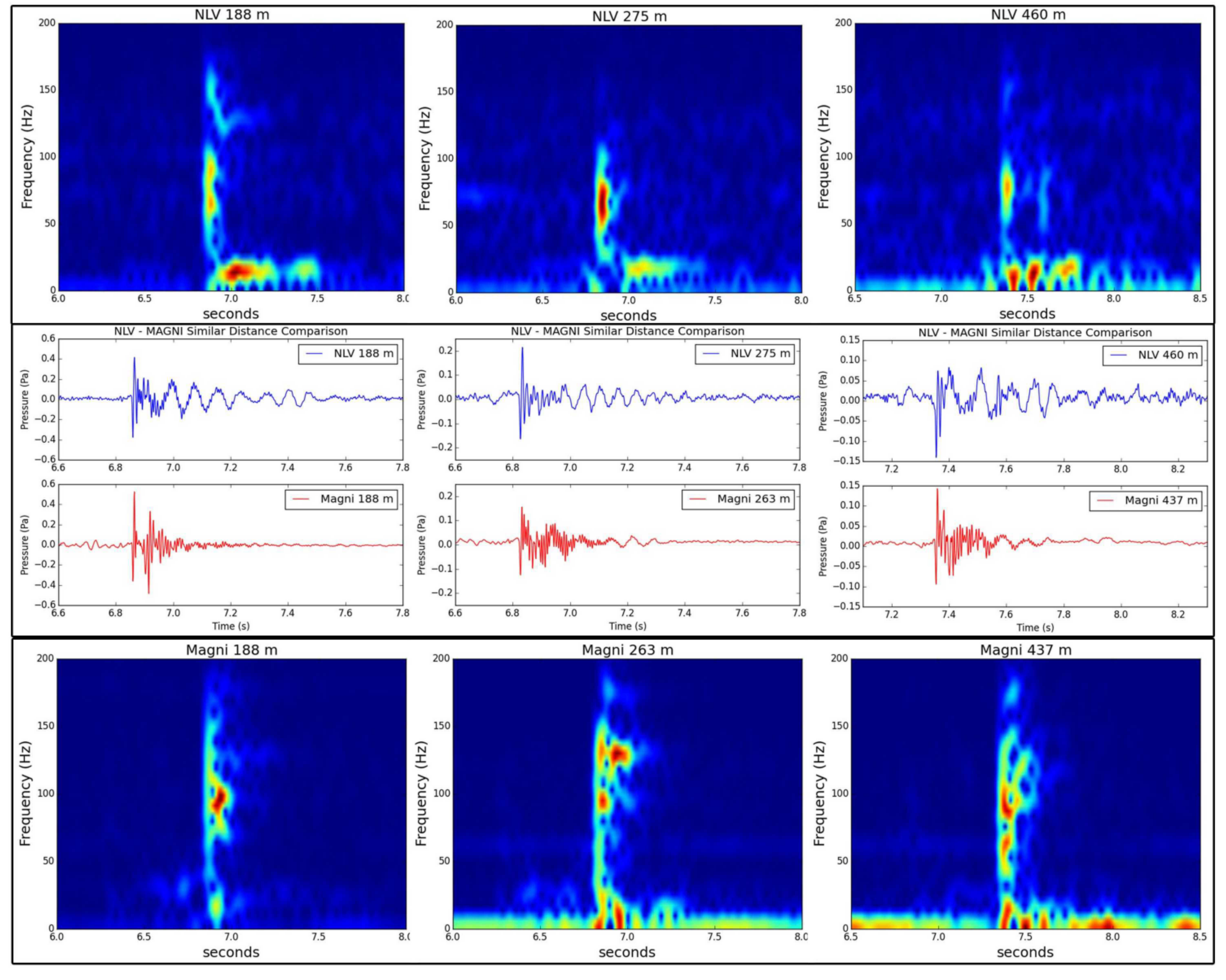
ABOVE: Map showing the 6 Hyperion, seismically decoupled infrasound sensor locations and the hammer shots for the Magni test. The shot point at center left was the "shakedown" shot. The shot series continued from Southeast to Northwest along 200 m increments.

BELOW: Two peak-to-peak amplitude plots from all of the hammer shots recorded by each of the infrasound sensors on a linear scale (below left) and log amplitude (below right) for sensor 6. The amplitudes increase as the hammer is moved from the test shot location and then from Southeast to Northwest. The amplitude variation (below left plot) shows the range variation in sensor location. The log plot (below right) shows the amplitude increasing and then decreasing over the course of the hammer shot sequence. This may be related to when the hammer is repositioned and the soil has to be recompacted.



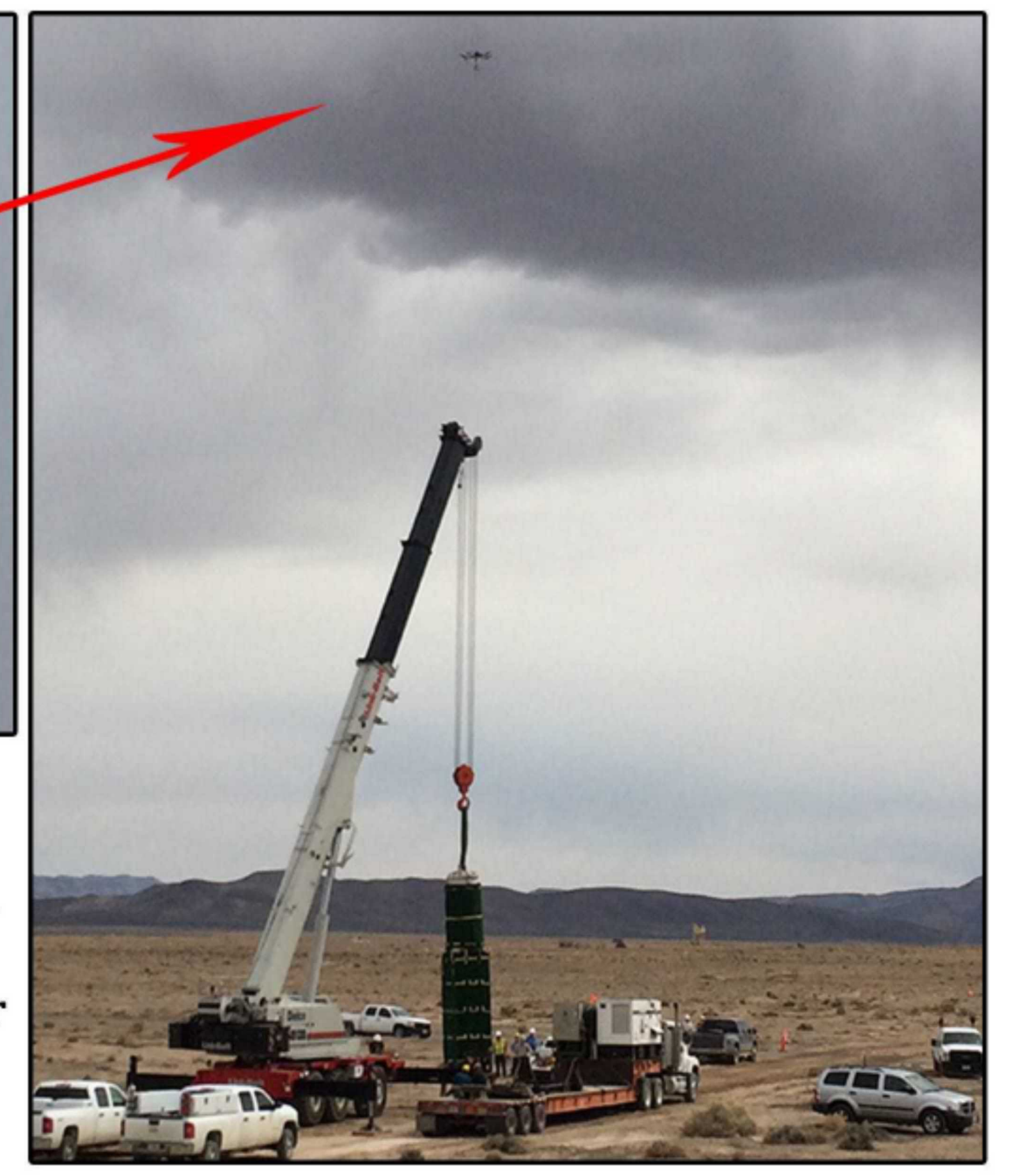
NLV vs. MAGNI COMPARISON

Since the infrasound component of the Seismic Hammer is generated by the deflection of the ground surface we wanted to look at the comparison of signals between the North Las Vegas (NLV) and Magni tests. The NLV test was conducted on asphalt with compacted ground beneath (composition unknown) and the Magni test was conducted on uncompacted alluvium. The plots below show waveforms at similar distances between the two tests (blue is NLV and red is Magni). The spectrograms on top are from NLV and below from Magni. The peak frequency content shifted from ~10 Hz at NLV to ~12 Hz at Magni.



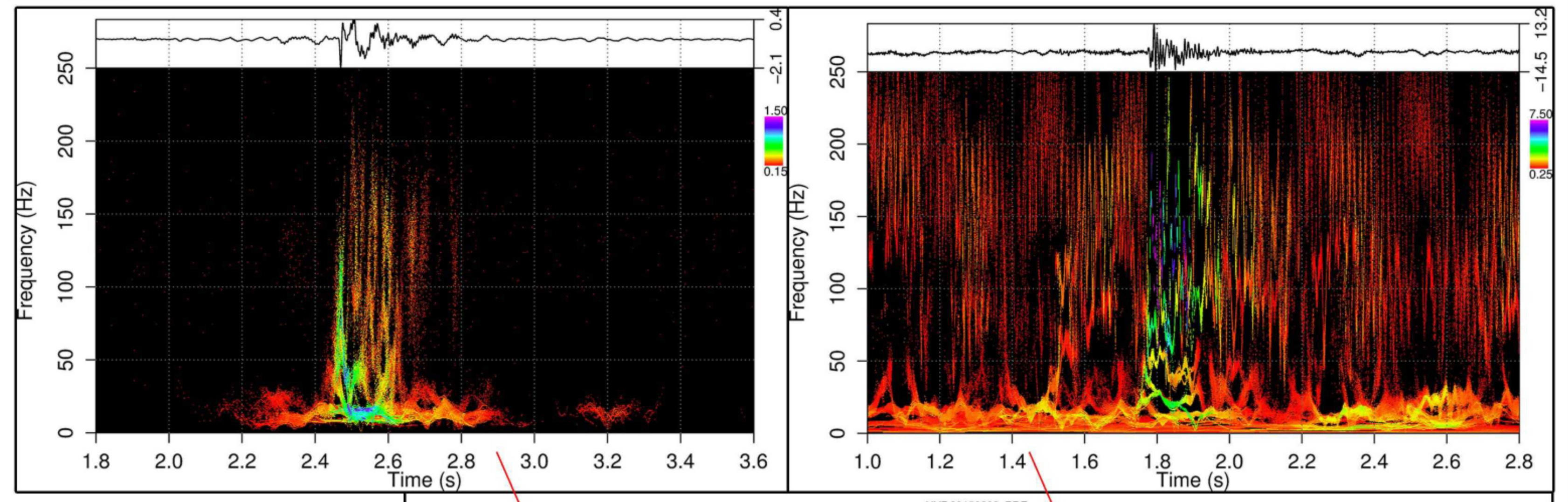
THOR TEST

The Thor test was conducted in March 2015 at the NNSS. This is a continuation of the Magni test and was conducted in Yucca Flat alluvium. For this test our primary objective was to fly a digital, seismically decoupled Hyperion infrasound sensor above the Seismic Hammer. After several test flights we successfully collected three flights of airborne infrasound data above the hammer. In addition to collecting infrasound data on the airborne platform we installed four ground-based infrasound sensors around the hammer to observe the 3-D wave-field (discussed on right panel). The photos below show one configuration of mounting (below left), the vehicle in flight with sling-load mounting (below middle) and hovering above the hammer (below right), also with slingload mounting.



ENSEMBLE HILBERT SPECTROGRAMS

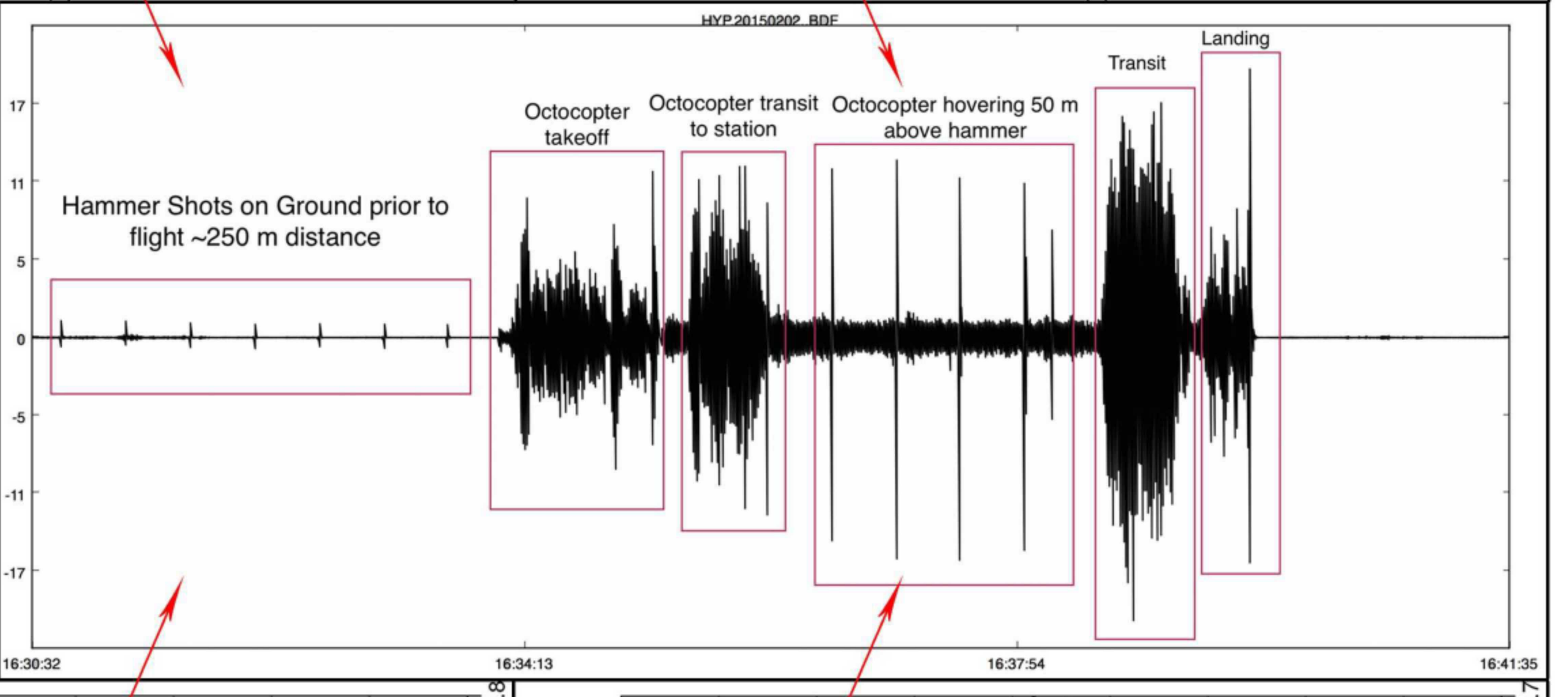
The plots below are a combination of the Hilbert-Huang Transform (HHT) and Empirical Mode Decomposition EMD) that defines the instantaneous frequency as the time derivative of phase (Bowman and Lees 2015). This method allows us to highlight both the rotor noise as well as the actual signal of the hammer. The two EHS plots above are from the octocopter while the two below are from a nearby ground station. Color scale is amplitude in Pa.

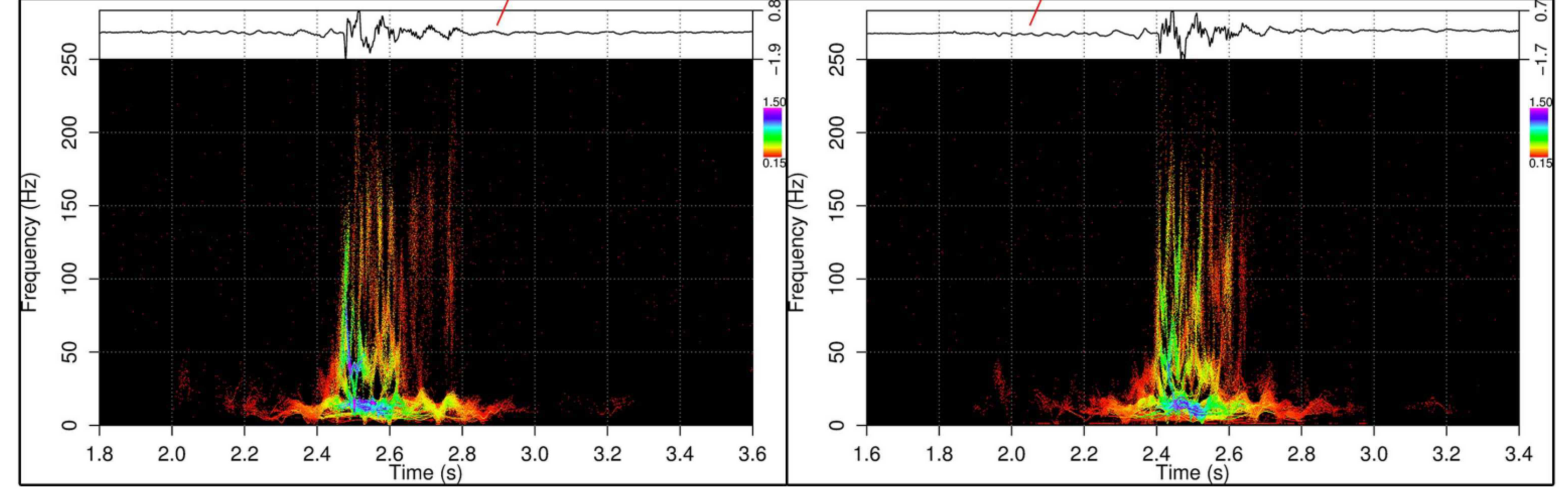


ABOVE: EHS spectrograms from the sensor on the octocopter observing a hammer hit while on the ground (left) and in the air (right).

RIGHT: Waveform trace from the octocopter sensor showing the different stages of the collect (ground, take-off, transit, stable hover, transit, and landing.

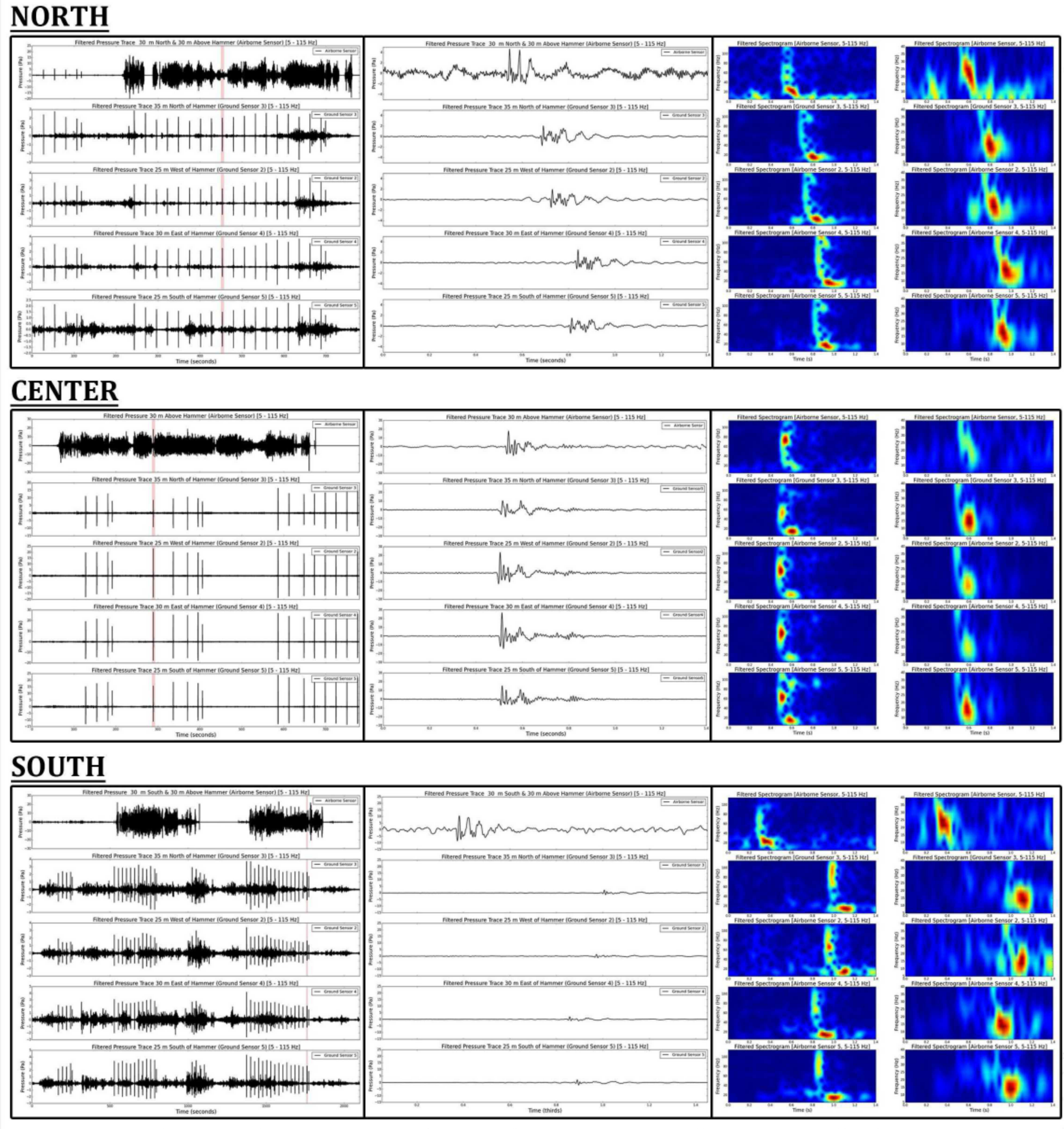
BELOW: EHS spectrograms from a ground sensor located ~250 m from the hammer.



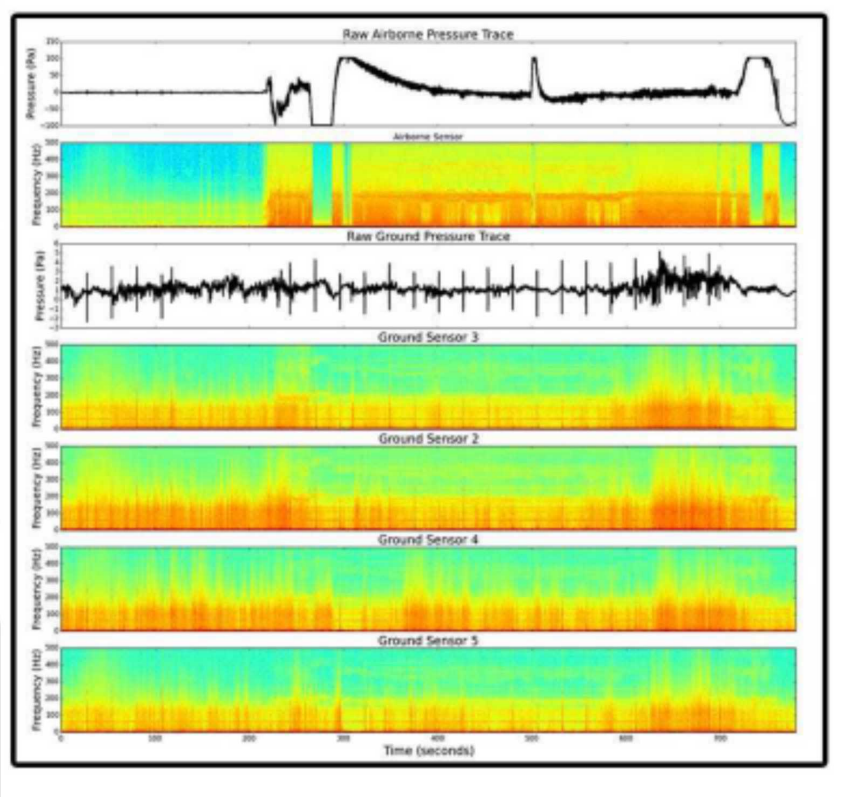


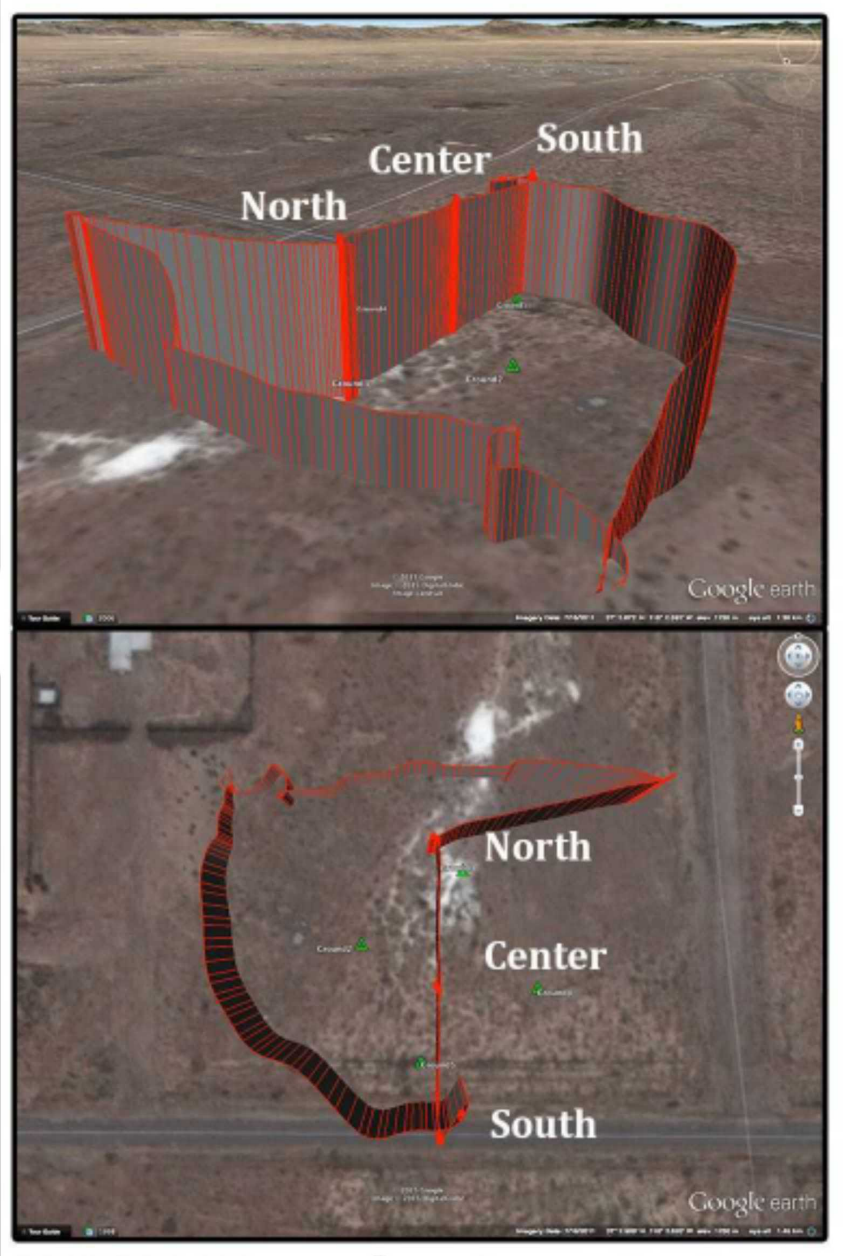
THOR AIRBORNE & GROUND STATIONS

After it was verified that the airborne sensor could detect the hammer shots above the rotor and vibration noise we proceeded to deploy the airborne sensor at various locations above and around the hammer. In addition to the airborne sensor we deployed four ground stations roughly 30 m North, South, East, and West of the hammer. The airborne sensor then hovered 30 m above ground level (AGL) and 30 m North, directly above and finally, 30 m South of the Hammer. Winds during the test were from South to North.



BELOW: Raw Spectrograms from the airborne sensor and four ground stations





ABOVE: Maps showing octocopter flight path and hover locations in 2D and 3D. Green triangles are infrasound ground stations.

ABOVE: Waveforms and spectrograms from airborne and ground stations while the octocopter hovered 30 m AGL and 30 m North of the hammer, directly above the hammer and 30 m South of the Hammer.

CONCLUSIONS

Through the three seismo-acoustic hammer tests (NLV, Magni, and Thor) we have shown that the HK Exploration Seismic Hammer™ produces infrasound signals that can be detected out to nearly 2 km. The signals have a downward first motion indicating that the source of the infrasound is from the downward deflection of the ground and resulting rebound. Not only did we observe a slight shift in frequency (low to high) when moving from the asphalt ground surface to the alluvium but also that the asphalt tends to "ring" a little more than the alluvium. Like any surface to air coupling of infrasound energy it is important to understand the surface source. With the observed differences between the two observed surface types there may be potential for the hammer to be used as a "surface source" calibration system.

Finally, mounting and flying an infrasound sensor over an active seismo-acoustic source using a drone octocopter had never been attempted prior to our work at NNSS for the Thor experiment. We successfully demonstrated that not only is it possible to mount and fly the sensor but that during low wind conditions the signal-to-noise is such that the hammer signals can be easily observed above background and vehicle noise resulting in 3-D wave-field observations of the source.

FUTURE WORK

With the successful completion of the proof-of-concept airborne vehicle infrasound system we plan to develop a smaller, lighter infrasound package for subsequent deployments. Reducing the payload size and weight will increase flight time and should allow us to mount the smaller sensor on a vibration reducing 3-axis gimbal for better noise reduction. Future deployments will include more data collects on the Seismic Hammer as well as deployment over the Source Physics Experiment (SPE) test 5 planned for Fall 2015. If all goes well we would like to potentially fly multiple airborne sensing systems on and around the Seismic Hammer as well as future SPE shots for 3-D wave-field mapping in real-time.

ACKNOWLEDGMENTS

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