SAND2013-7629P

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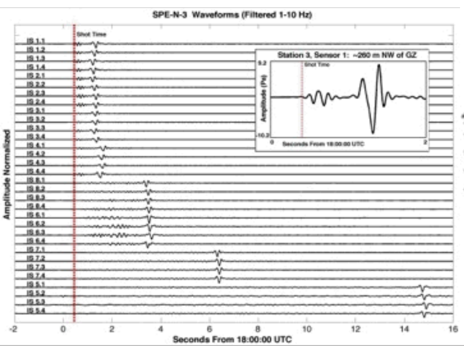
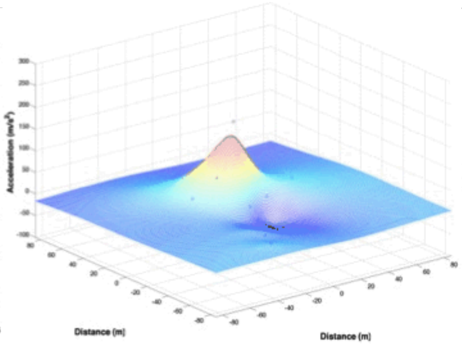
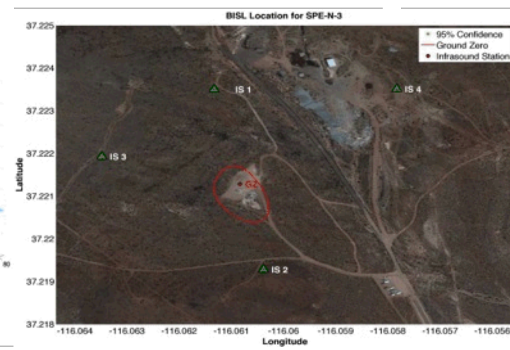
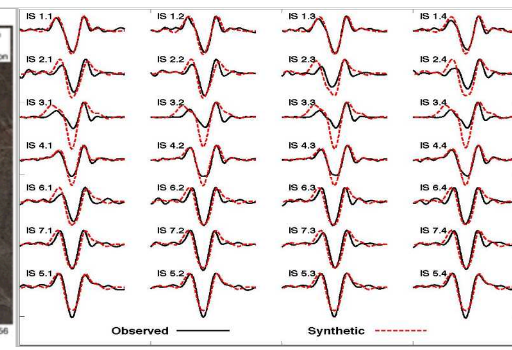
Sandia National Laboratories




# Infrasound Results from the Source Physics Experiment: Nevada National Security Site

Kyle R. Jones – Sandia National Labs
Rodney W. Whitaker – Los Alamos National Labs
Stephen J. Arrowsmith – Los Alamos National Labs

SAND - 2013-XXXX

September 18, 2013

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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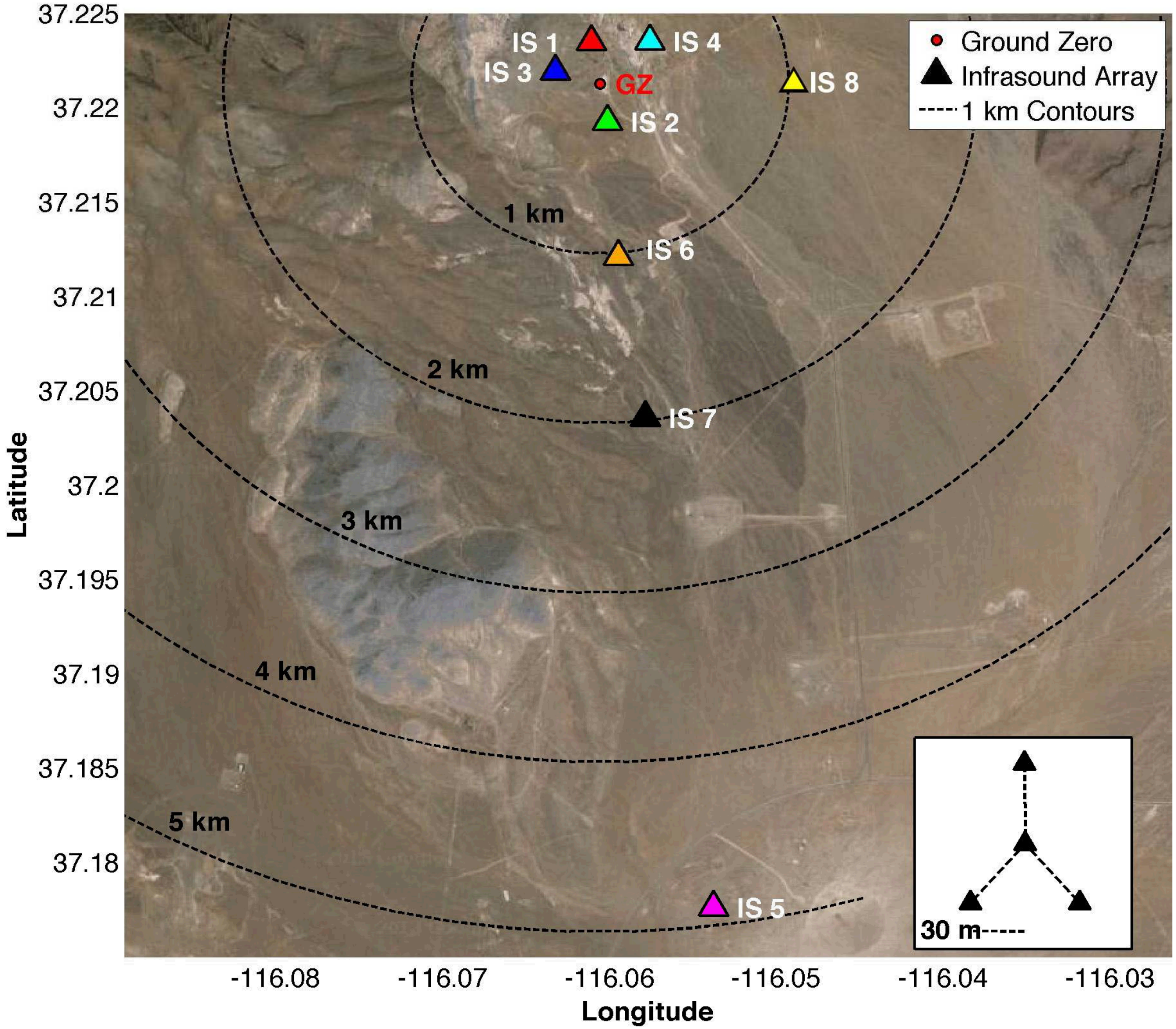
# Introduction

- Collaboration with Rod Whitaker at Los Alamos
- Infrasound data collection and analysis to-date
- Infrasound Source Modeling with the Rayleigh Integral
- Publication
- Comparison with CAVEAT (LANL)
- Future Work
  - Completion of SPE Phase I
  - SPE Phase II

# Map of SPE Infrasound Stations

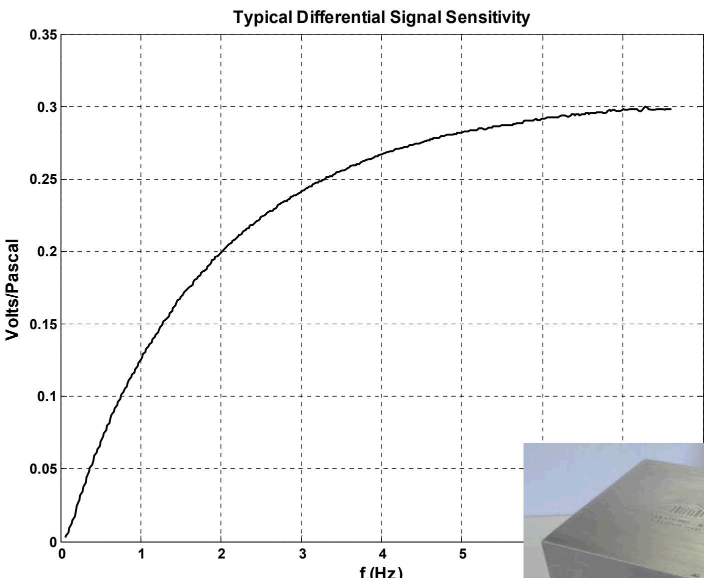
Sandia National Laboratories

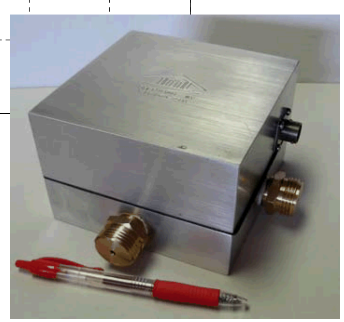


# SPE Infrasound Sensors

**SPE-1 and 2**

- 7 Inter-mountain Labs (ST)
- Flat from ~2+ to ~30 Hz w/porous hoses
- 50 Pa Full Scale Range



**SPE-3+**

- 8 Hyperion Technology Group (IFS-3000 ) Infrasound Stations
- Flat from ~0.1 to ~40 Hz w/porous hoses
  - ~0.1 - 100 Hz without hoses
- 100 Pa Full Scale Range

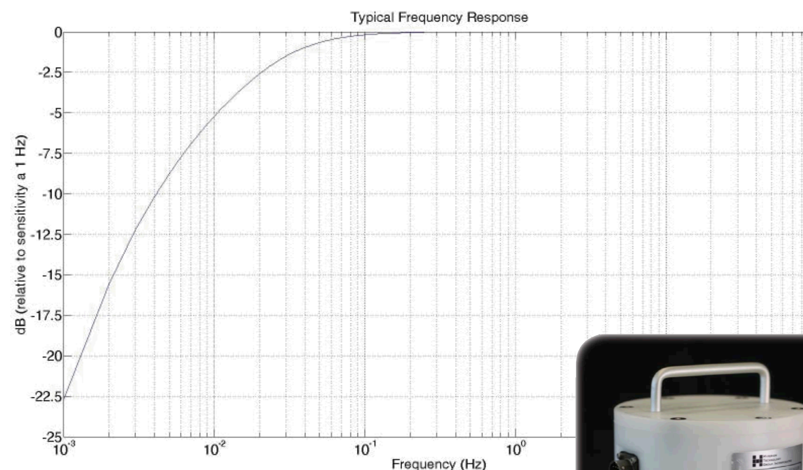
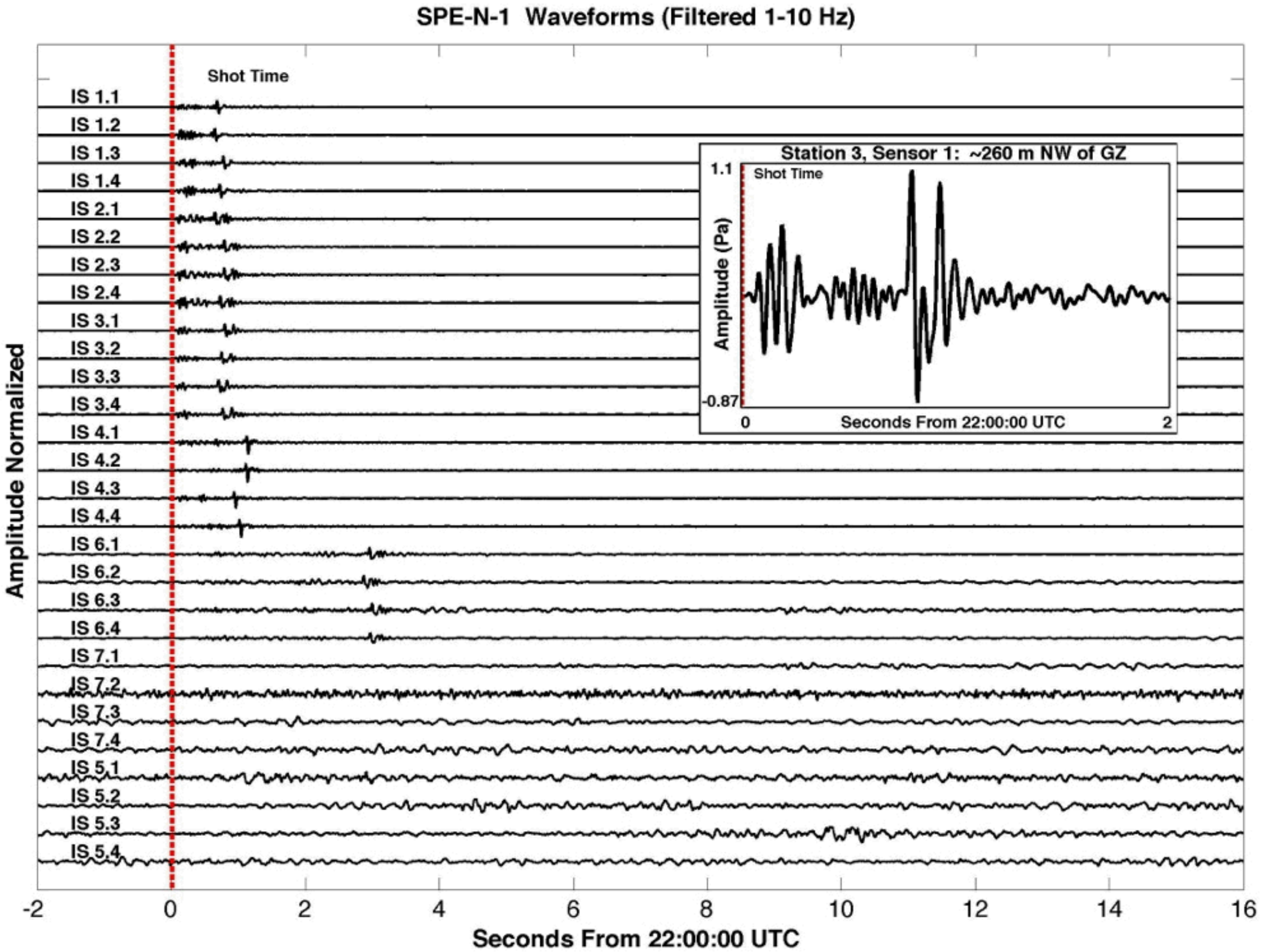



**Figure 3.** IFS-3000 Typical frequency response.

Inter-mountain Labs. 555 Abraska, Sheridan, WY 82801
(307) 674-7506 http://www.intermountainlabs.com/

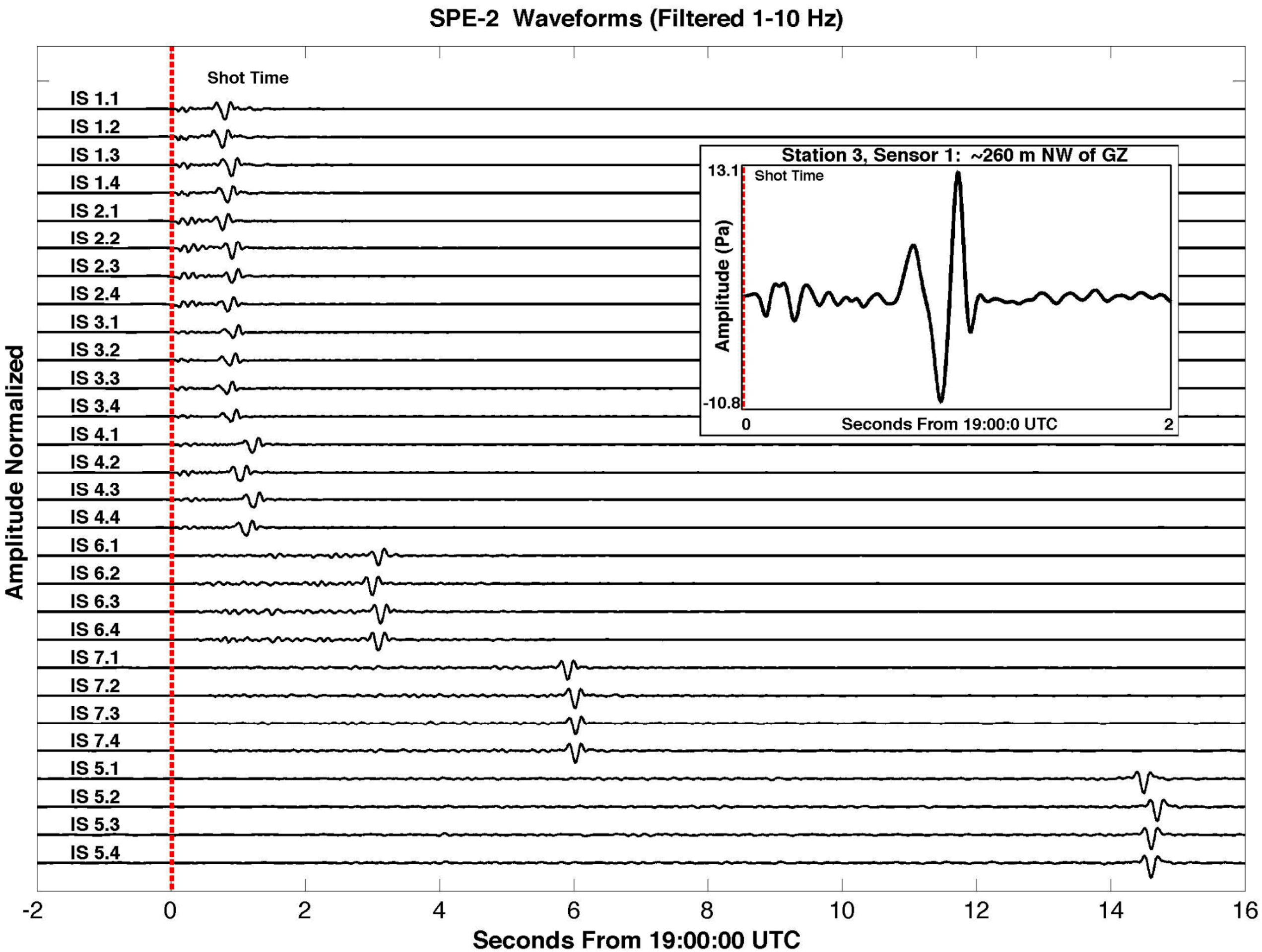
Hyperion Technology Group, Inc., 3248 West Jackson Street, Tupelo, Mississippi 38801
662.823.0600 http://www.hyperiontechgroup.com

# SPE-1 Waveforms



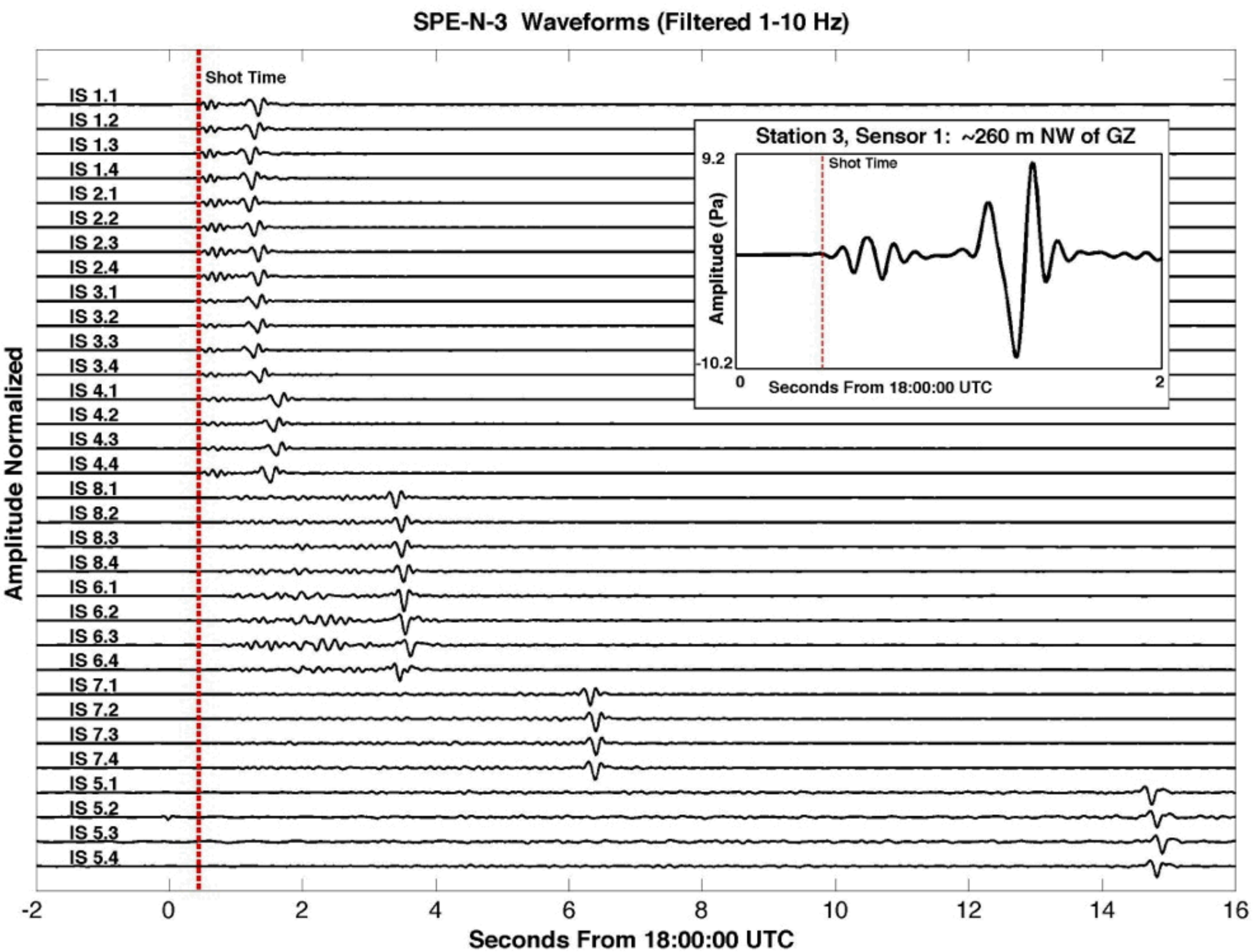

- Waveforms from 7 infrasound arrays
- Band pass filtered between 1 and 10 Hz
- Seismic arrival precedes acoustic
- Red line indicates shot time
- No arrivals can be seen past 1 km

# SPE-2 Waveforms



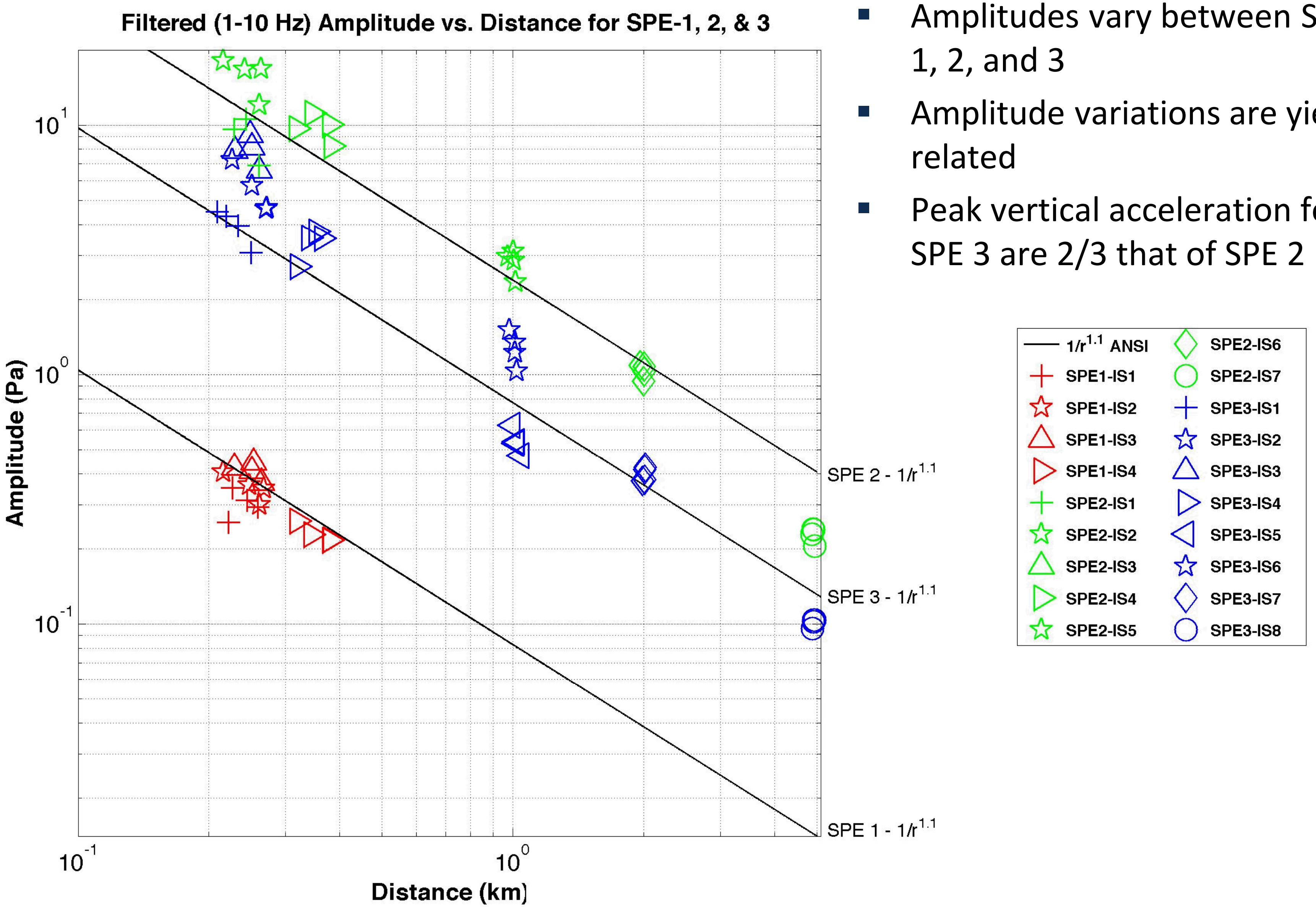

- Waveforms from all 7 infrasound arrays
- Band pass filtered between 1 and 10 Hz
- Seismic arrival precedes acoustic
- Red line indicates shot time
- Arrivals can be seen at all stations at all distances

# SPE-3 Waveforms



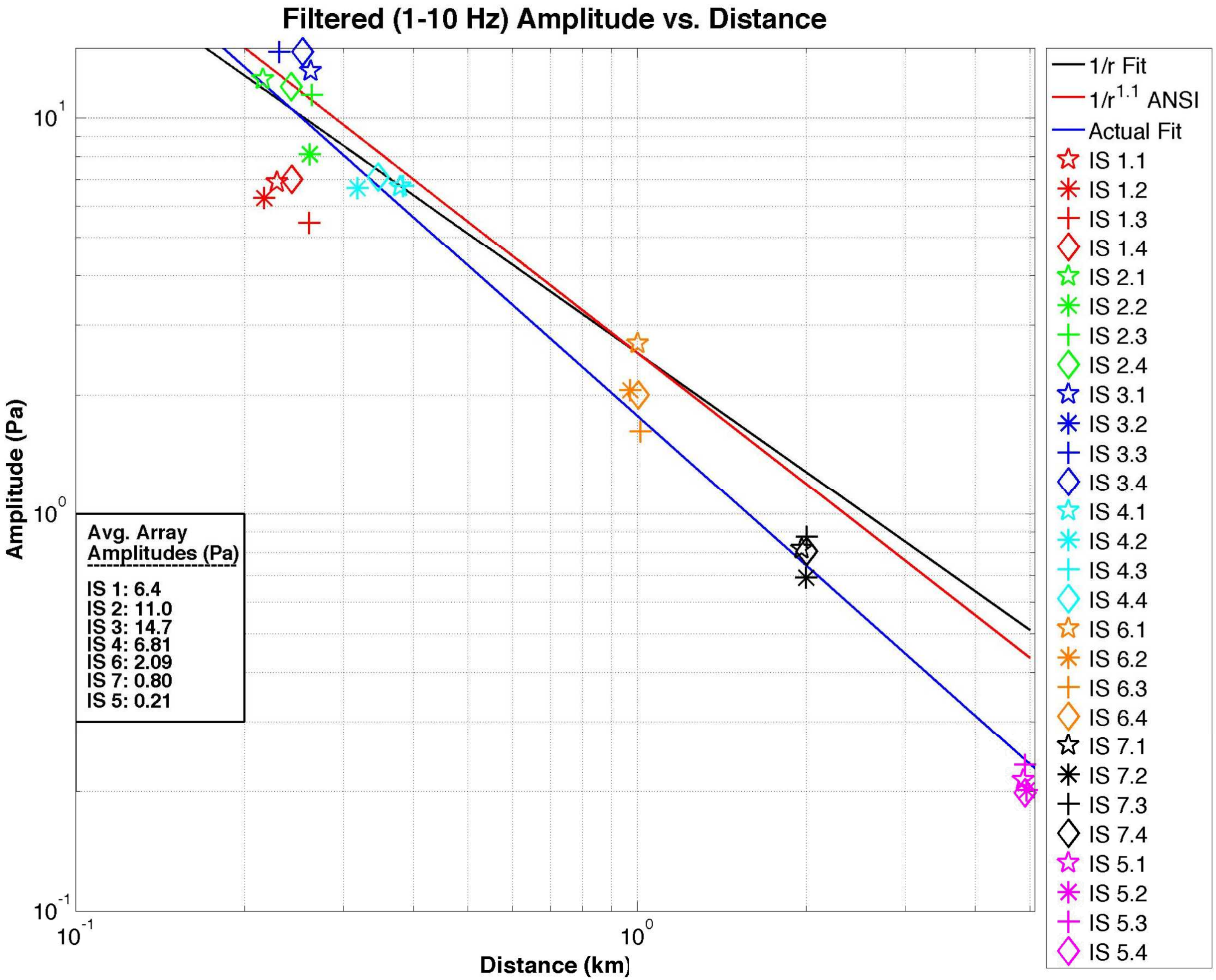

- Waveforms from all 8 infrasound arrays
- Band pass filtered between 1 and 10 Hz
- Seismic arrival precedes acoustic
- Red line indicates shot time
- Arrivals can be seen at all stations at all distances
- **Very** similar to SPE-N-2

# Amplitude vs. Distance



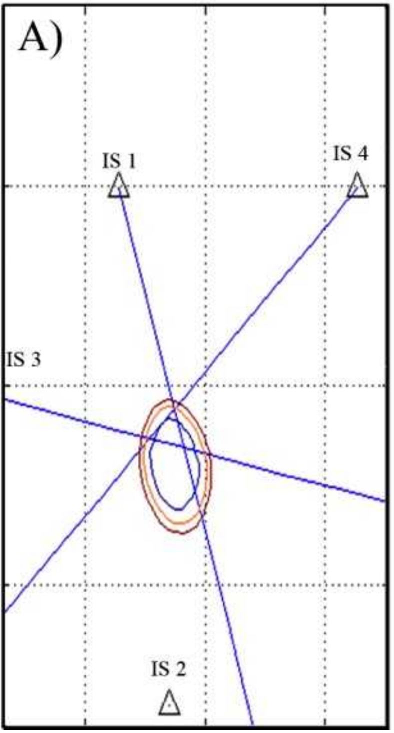

- Amplitudes vary between SPE 1, 2, and 3
- Amplitude variations are yield related
- Peak vertical acceleration for SPE 3 are 2/3 that of SPE 2

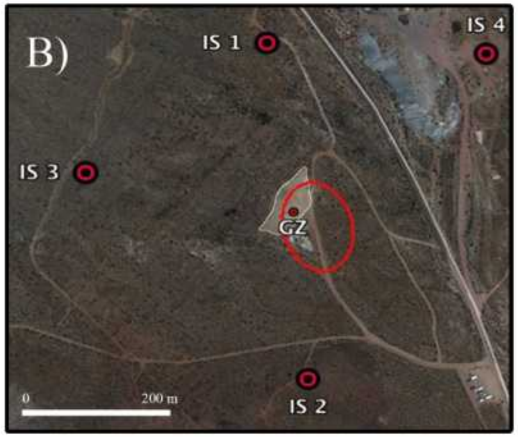
# Amplitude vs. Distance

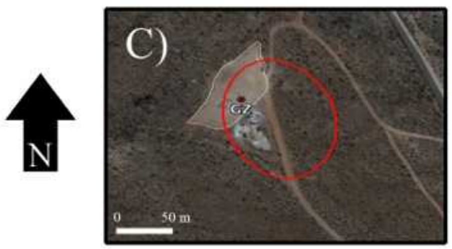



- Amplitude decays linearly
- Reasons for amplitude differences:
  - Off-axis vs. On-axis pressures observations
  - Line of sight
  - Wind reduction issues

# SPE-N-1 Source Localization

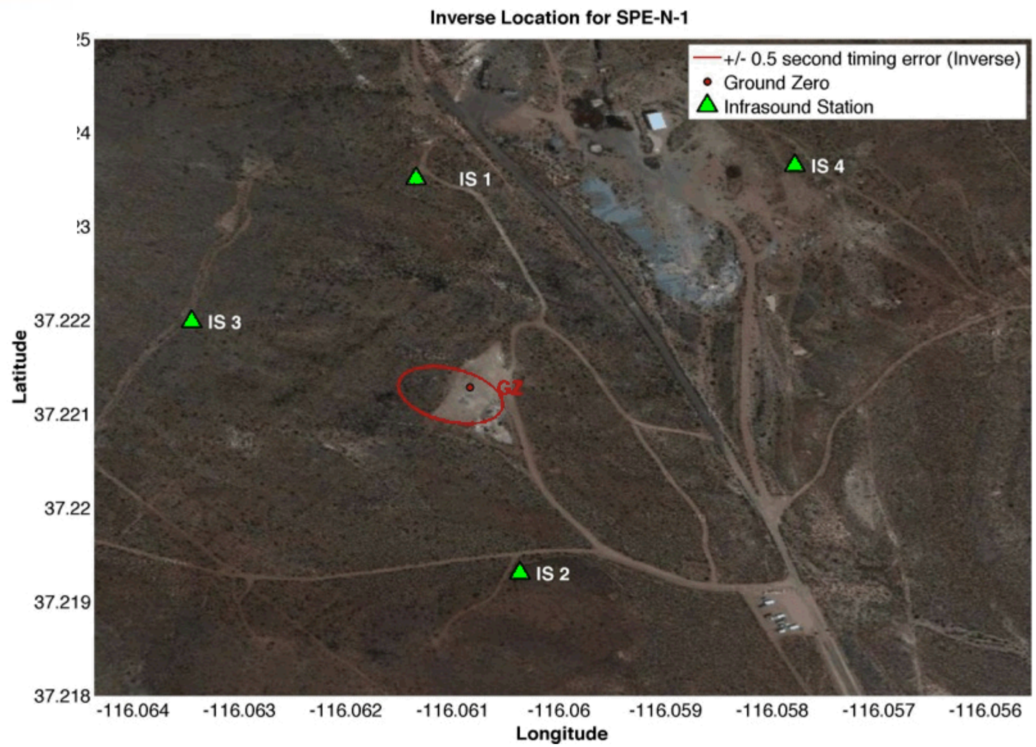



LEFT:

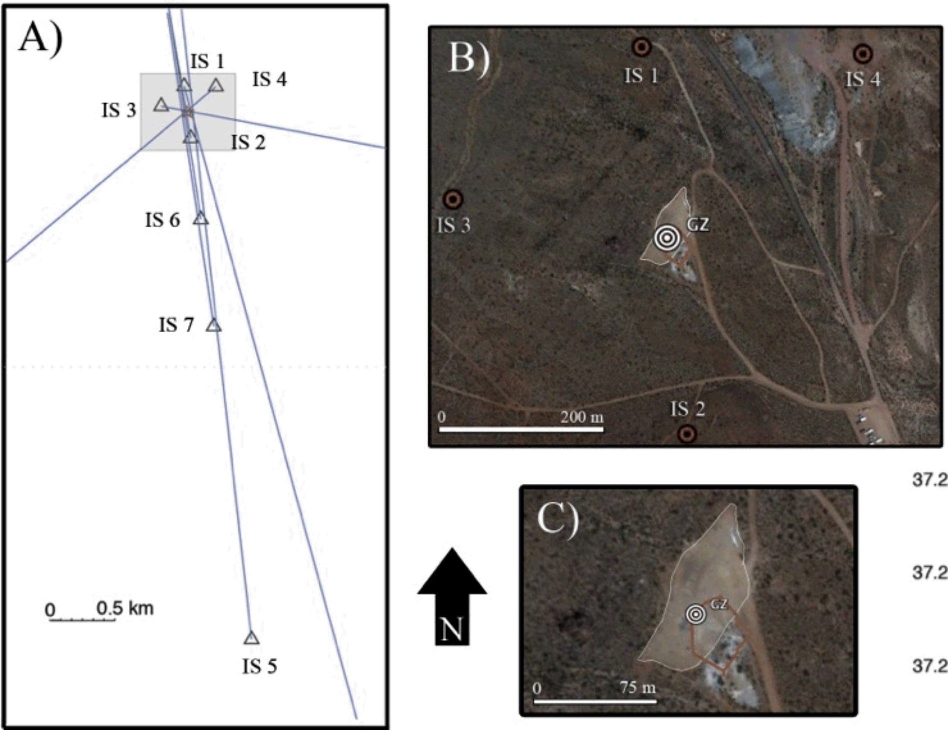
- Bayesian Infrasound Source Location for SPE-N-1
- Solution is the red boundary representing 95% confidence (90 m x 131 m)




RIGHT:

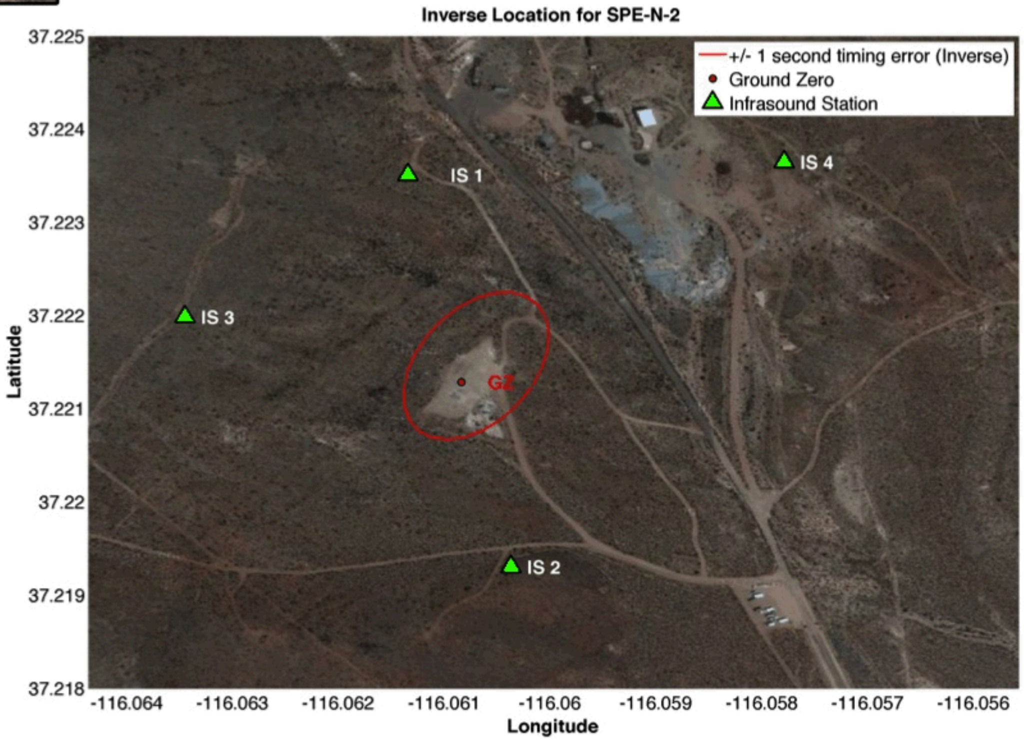
- Arrival Time Inverse Location Solution
- Solution is the red boundary representing a timing error of +/- 0.5 seconds (60 m x 90 m)

# SPE-N-2 Source Localization




LEFT:

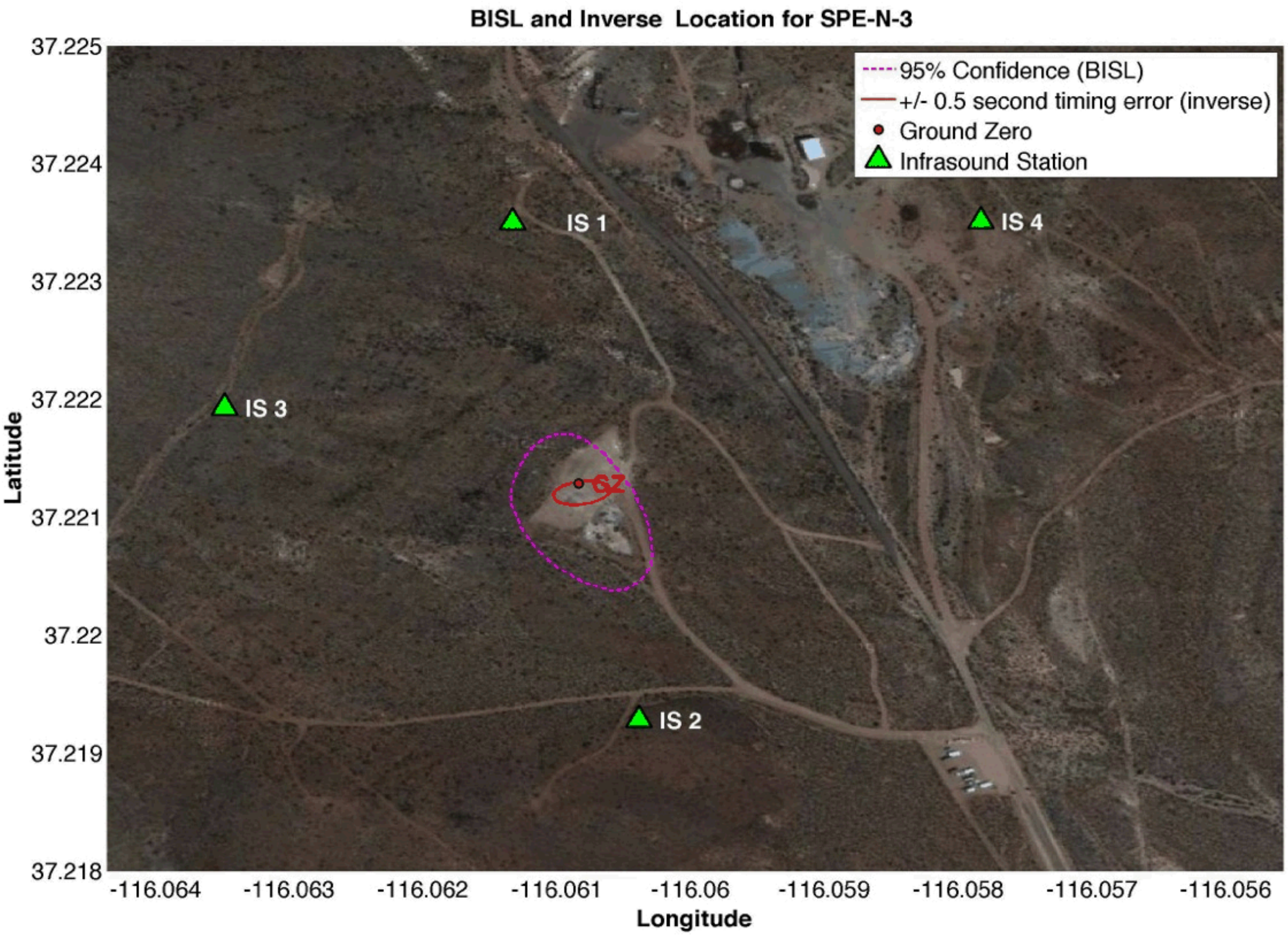
- Bayesian Infrasound Source Location for SPE-N-2
- Solution is the red boundary representing 95% confidence (30 m x 33 m)




RIGHT:

- Arrival Time Inverse Location Solution
- Solution is the red boundary representing a +/- 1 second timing error (100 m x 180 m)

# SPE-N-3 Source Localization




**Bayesian Infrasound Source Location for SPE-N-3**

- Solution is the magenta boundary representing 95% confidence (80 m x 150 m)

**Arrival Time Inverse Location Solution**

- Solution is the red boundary representing a timing error of +/- 0.5 seconds (20m x 38 m)

# Rayleigh Integral Source Modeling

- 1) Use data from surface accelerometers to get ground motion
- 2) Set up a grid and interpolate/extrapolate the accelerometer data
- 3) Calculate pressure for each grid point using:
  - P = Pressure
  - $\rho$ = density of air
  - Acc = ground motion (m/s$^2$) – retarded time (i.e. not time aligned)
  - r = distance from grid point to observation point
  - dS = Area of each grid point

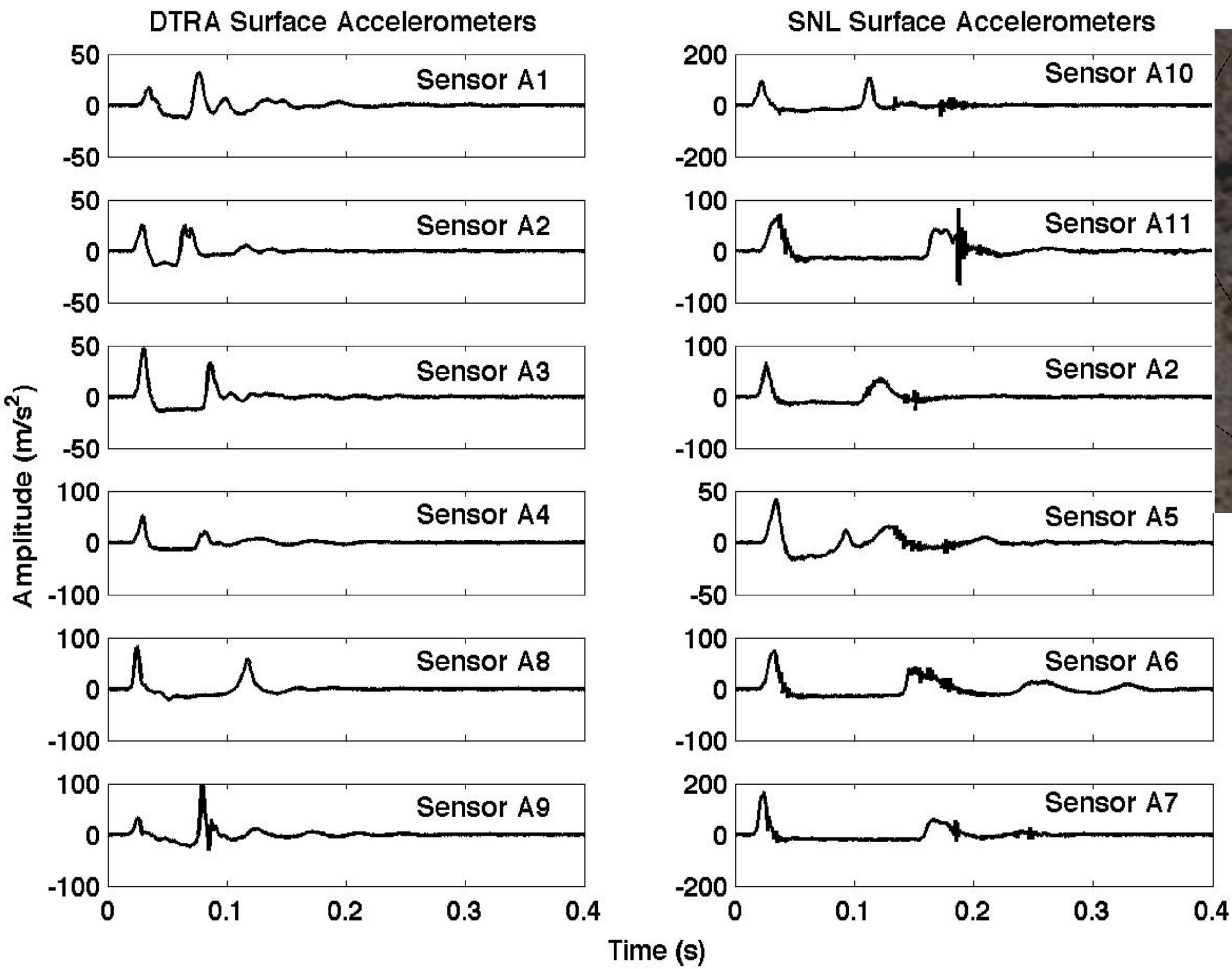
$$p = \rho \frac{Acc}{2\pi r} dS$$

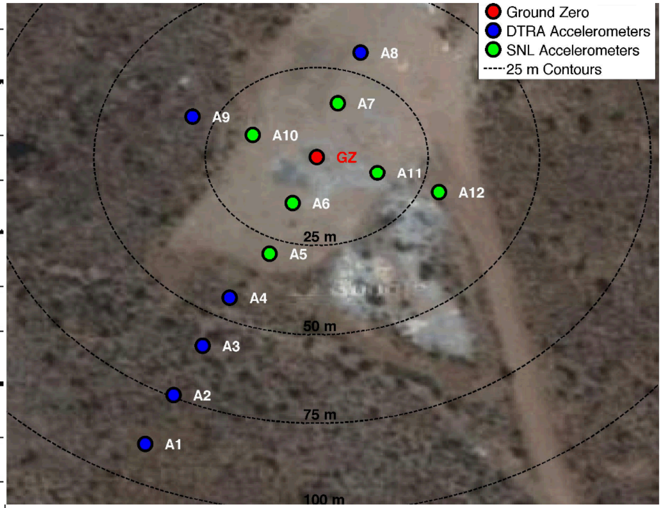
$$p(x, y, z; t) = \rho_0 \int_S \frac{\dot{u}\left(x', y'; t - \frac{R}{c_0}\right)}{2\pi R} dS,$$

- 4) Integrate the pressures at each grid point over both area and time to produce a synthetic waveform
  - The final summation step takes into account the constructive and destructive interference inherent in such a large source area.

# Rayleigh Integral Source Modeling

- 1) Use data from surface accelerometers to get ground motion




**DTRA Accelerometers**
A1, A2, A3, A4, A8, A9

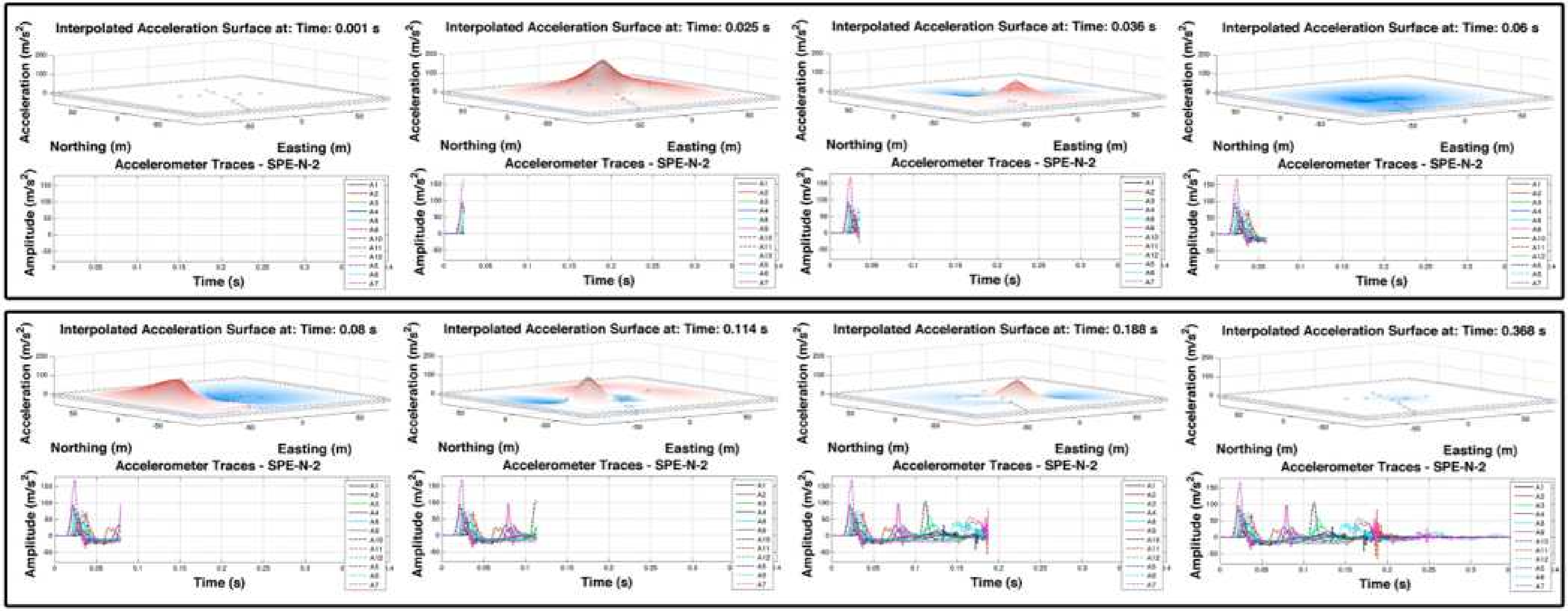
Endevco 500g

**SNL Accelerometers**
A5, A6, A7, A10, A11, A12

Endevco 500g

# Rayleigh Integral Source Modeling

- 2) Set up a grid and interpolate/extrapolate the accelerometer data



# Rayleigh Integral Source Modeling

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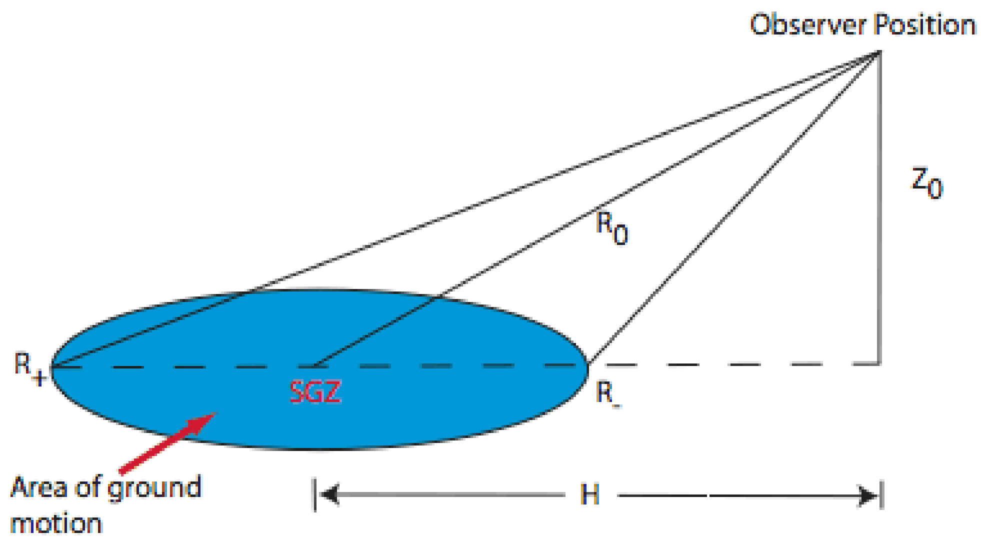
- 3) Calculate pressure for each grid point using: $p = \rho \frac{Acc}{2\pi r} dS$
  - P = Pressure
  - ρ = density of air
  - Acc = ground motion (m/s$^2$) – retarded time (i.e. not time aligned)
  - r = distance from grid point to observation point
  - dS = Area

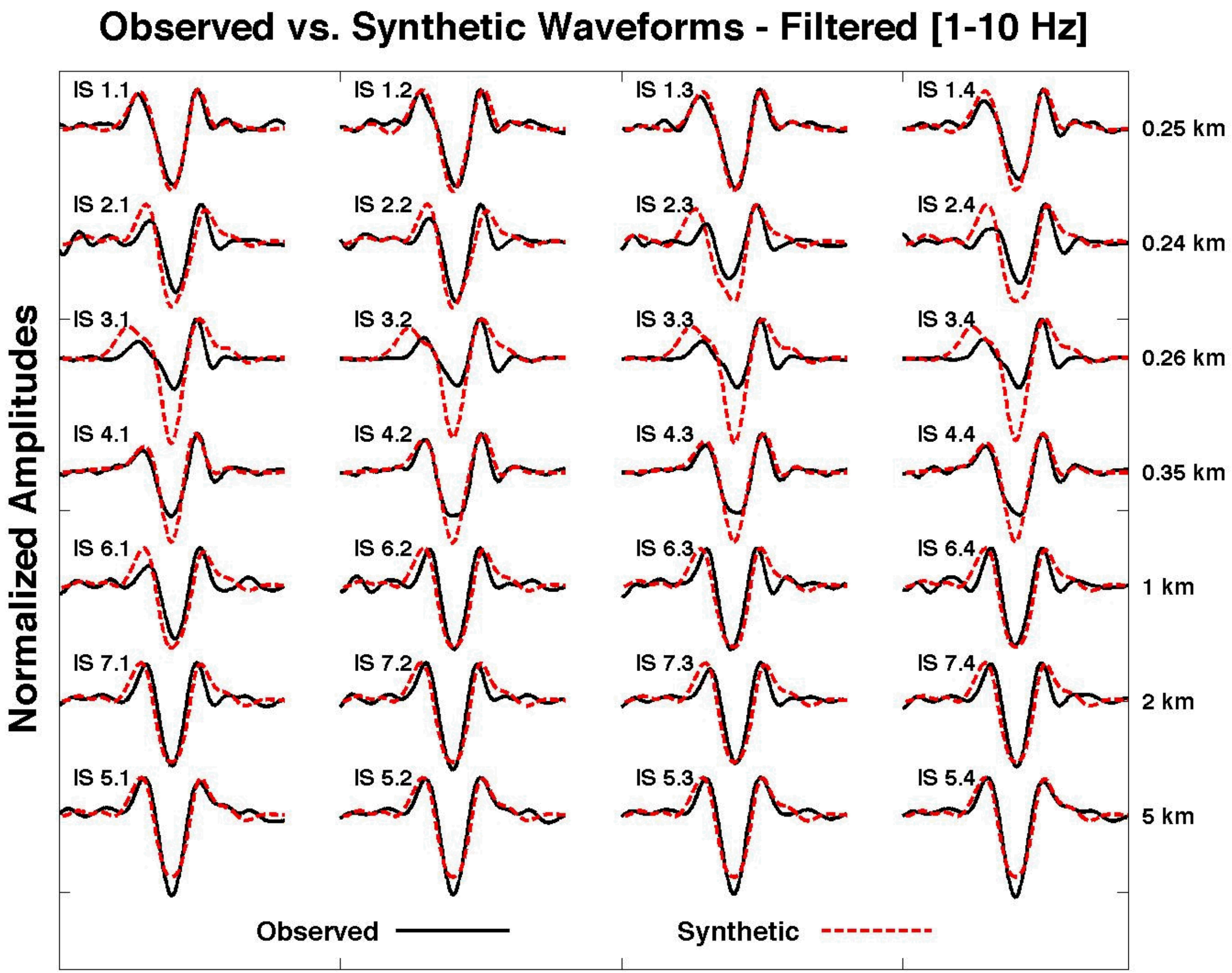
$$p(x,y,z;t) = \rho_0 \int_S \frac{\dot{u}\left(x',y';t-\frac{R}{c_0}\right)}{2\pi R}\, dS,$$



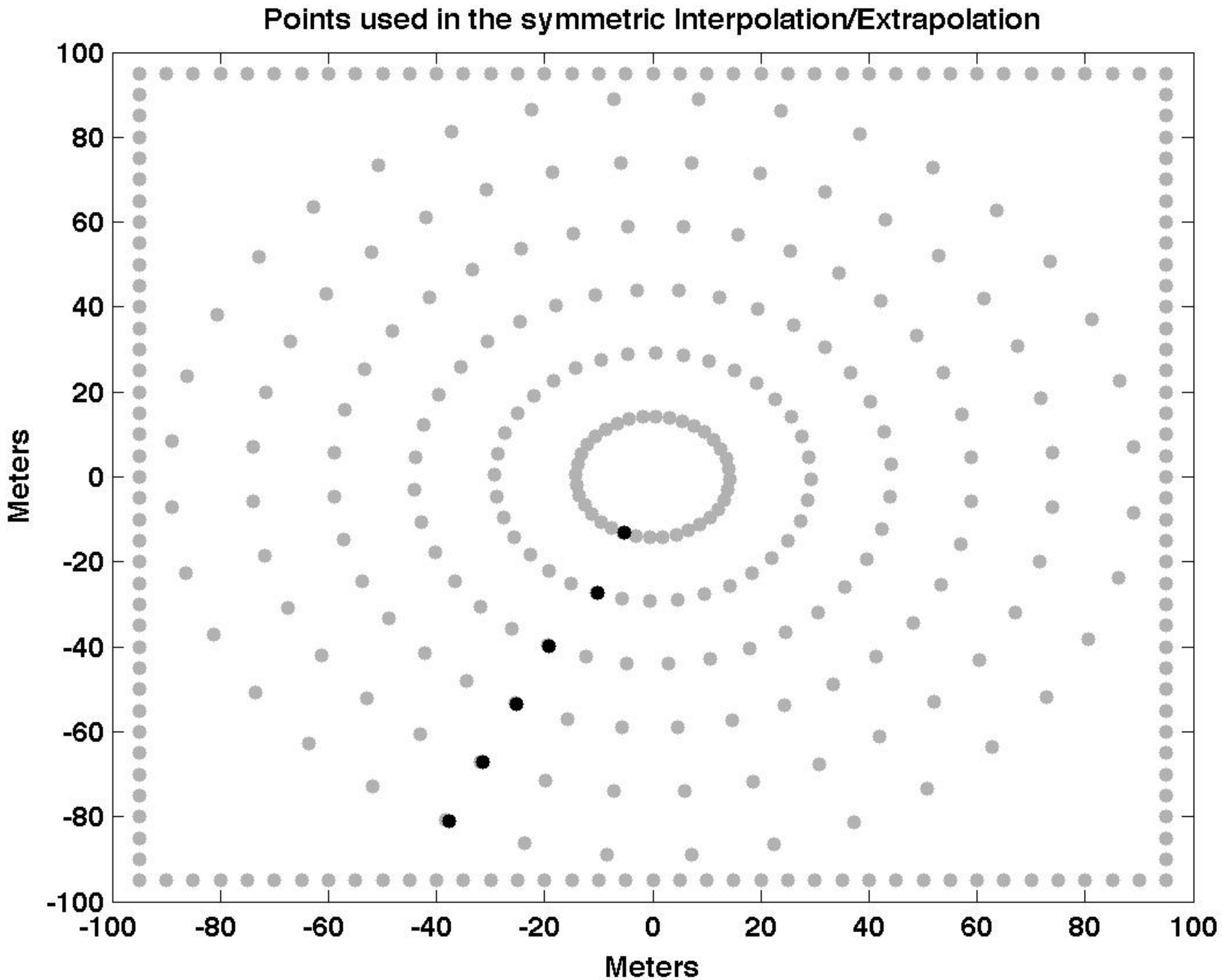

Whitaker 2007 – Infrasound Signals as Basis for Event Discriminants

# Rayleigh Integral Source Modeling

- 4) Integrate the pressures at each grid point over both area and time to produce synthetic waveform
  - The final summation step takes into account the constructive and destructive interference inherent in such a large source area.
  - Can be thought of a baffled piston in an infinite plane

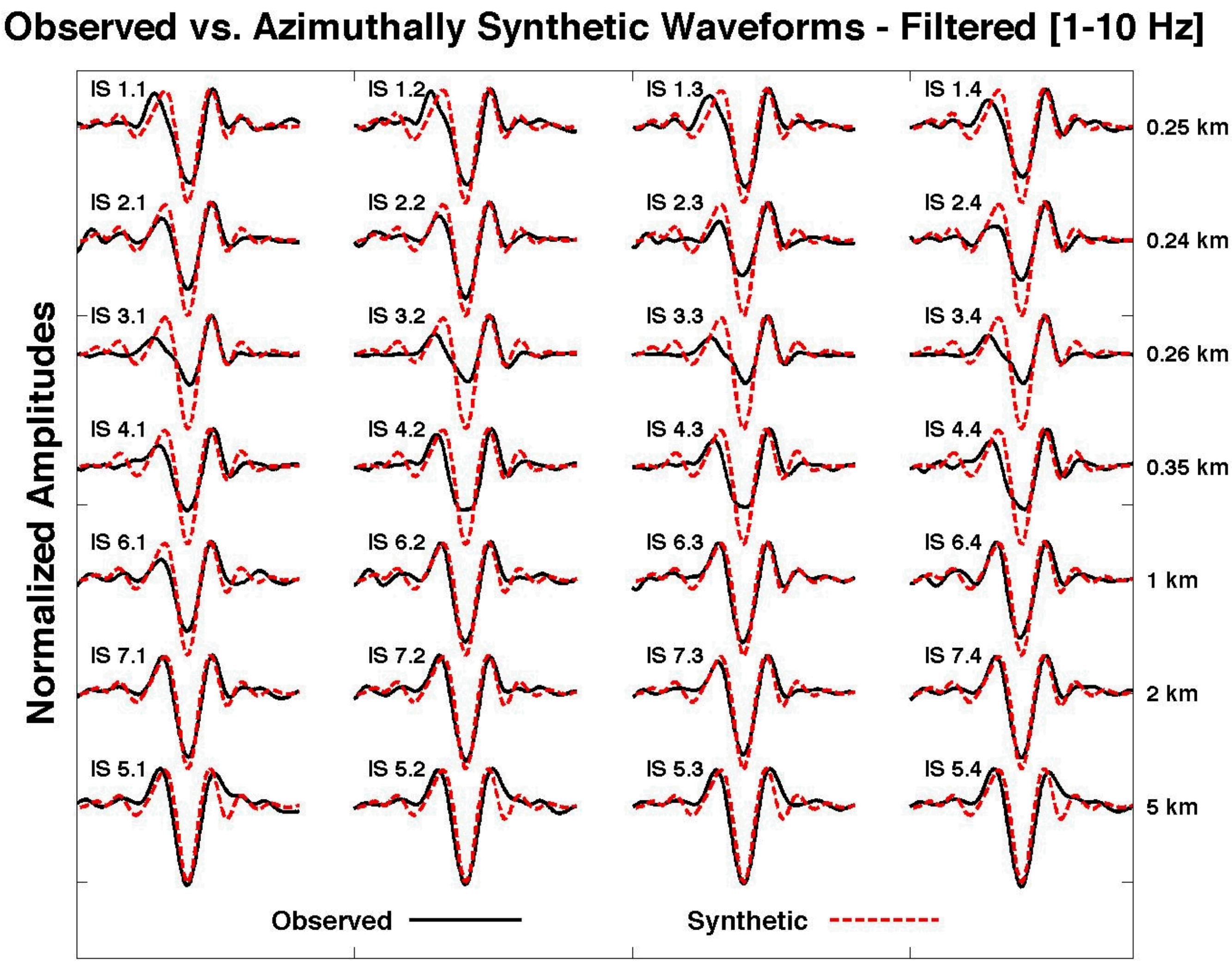


# Rayleigh Integral Verification



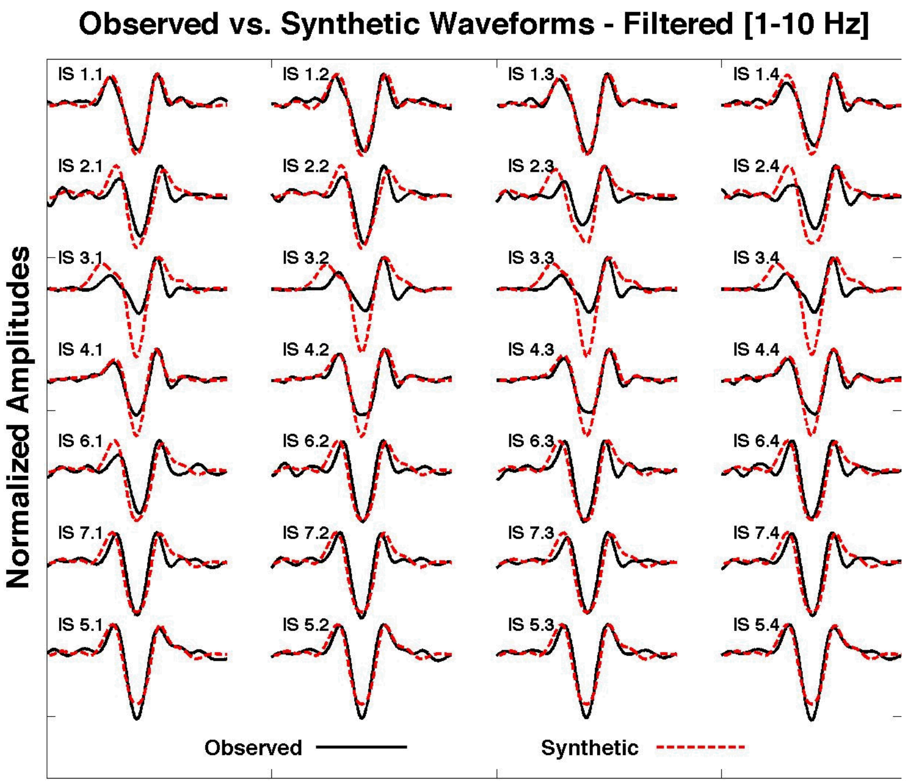
# Rayleigh Integral Verification

- While close, the waveforms are more “symmetric” than the observed data.

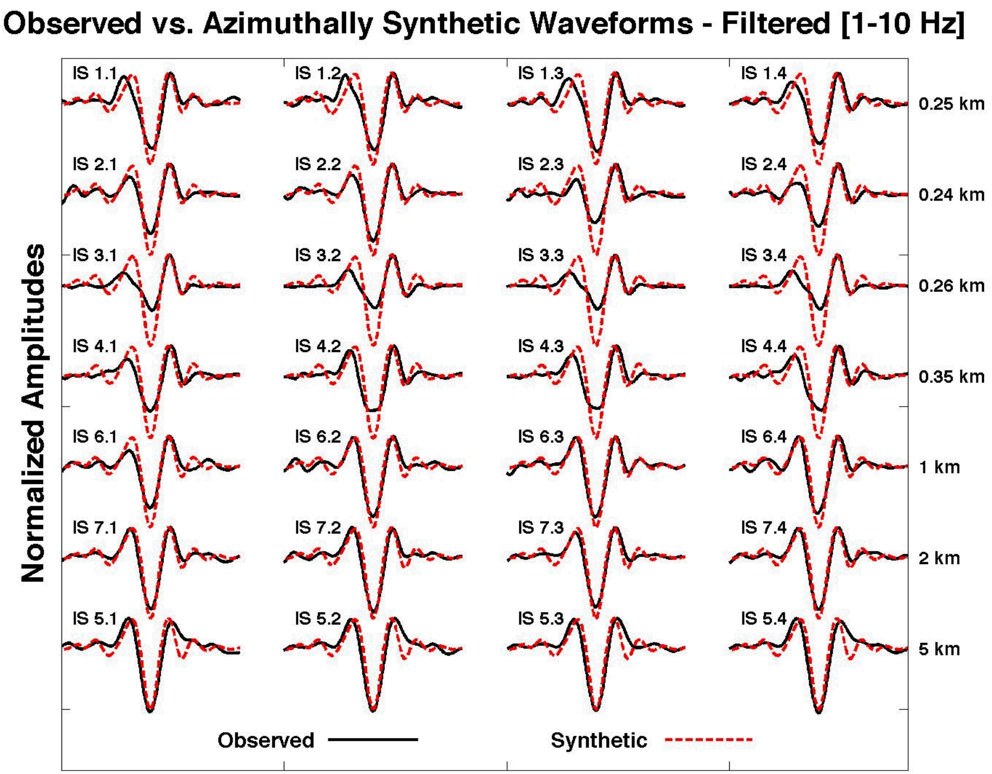


# Rayleigh Integral Comparison

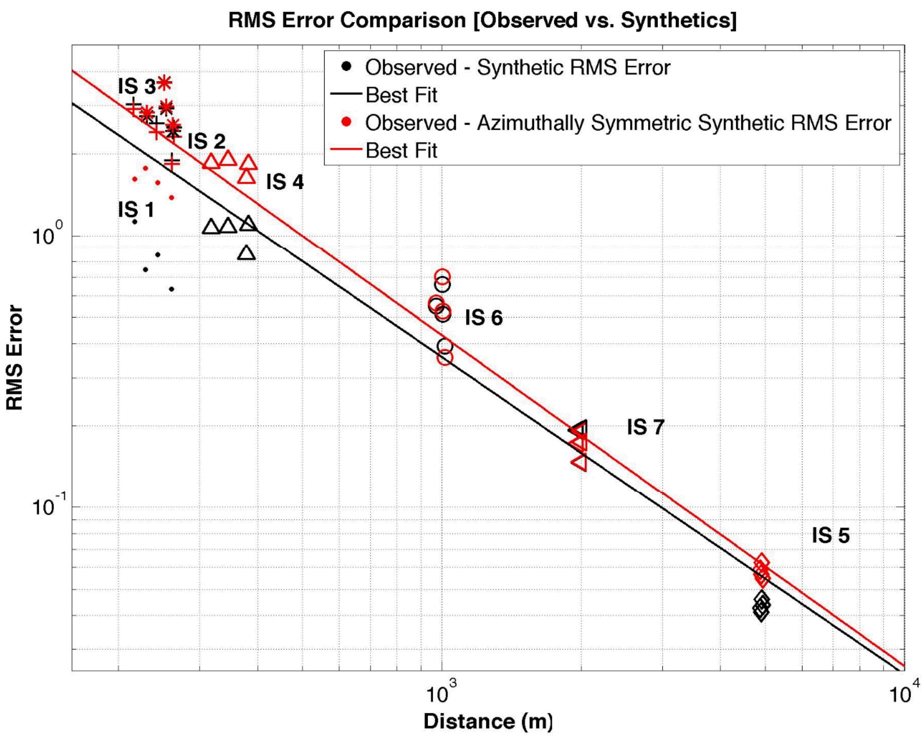
Original Synthetics

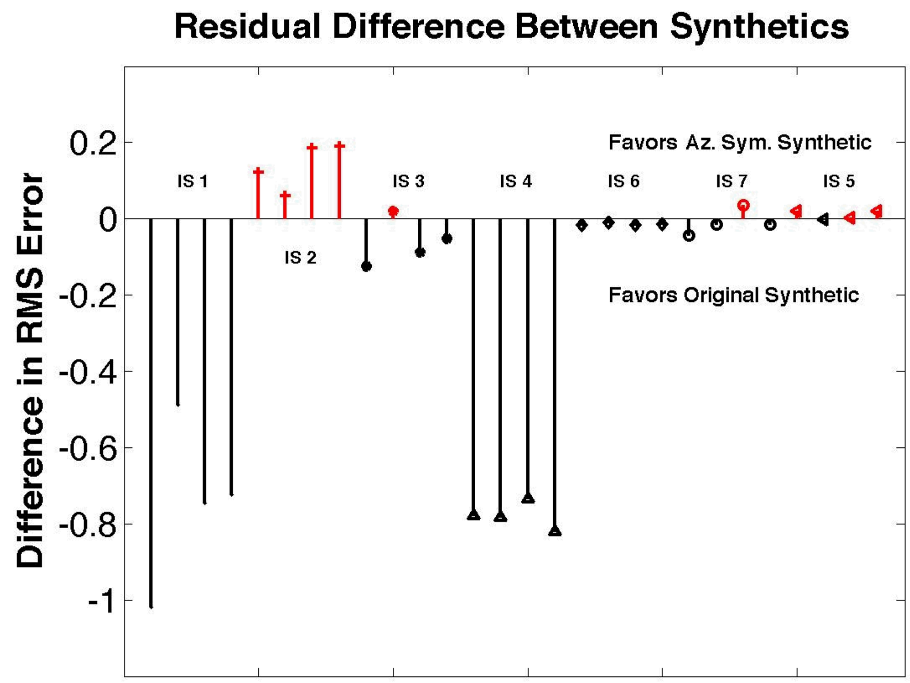



Azimuthal Synthetics



# Rayleigh Integral Error Analysis



# Publication

- The collaborative work on the Rayleigh Integral will be submitted for publication this FY to the Geophysics Journal International (GJI)

**Modeling the infrasound acoustic signal generation of underground explosions at the Source Physics Experiment using the Rayleigh integral**

Kyle R. Jones[1], Rodney W. Whitaker[2], and Stephen J. Arrowsmith[2]
[1] Sandia National Laboratories, NM, USA. E-mail: krjones@sandia.gov
[2] Los Alamos National Laboratory, NM, USA.

Accepted date. Received date; in original form date

Abbreviated Title: Infrasound modeling with the Rayleigh integral

Kyle R. Jones

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Albuquerque, NM 87185-0404, USA

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Fax: 505-844-5321

Email: krjones@sandia.gov

**SUMMARY [500 Word Limit]**
The overall mission of the National Center for Nuclear Security Source Physics Experiment (SPE) at the Nevada National Security Site (NCNS) near Las Vegas, Nevada is to improve upon and develop new physics based models for underground nuclear explosions using scaled, underground chemical explosions as proxies. To this end, we use the Rayleigh integral as an approximation to the Helmholtz-Kirchoff integral to model infrasound generation and propagation in the far-field. Infrasound generated by single-point explosive sources above ground can typically be treated as monopole point sources. While the source is relatively simple, the research needed to model infrasound from above ground point

2

# Path Forward

- Continued collaboration with LANL and LLNL
- Continue to advance RI and apply to SPE-3+
  - Effort to use completely synthetic source terms
  - Evaluate the role of damage and acoustic source generation
  - Compare select UGTs with current SPE infrasound data
  - Incorporate more physical effects (i.e. wind, micro-topography)
- SPE Phase II with a new deployment plan aimed at furthering current and new research goals

# Questions?