# Piezoceramic Sensors and Infrasound Technology

**Carrick L. Talmadge**

**National Center for Physical Acoustics**
**University of Mississippi, Oxford MS**

NCPA
Atmospheric Acoustics

# Potential Applications of Infrasound Sensors

- monitoring potential atmospheric nuclear tests (CTBT applications)
- natural hazard detection of volcanos, tornados, tsunamis
- monitoring natural phenomena such as hurricanes and bolides
- Atmospheric science applications such as studying structure of stratosphere, probing physics of the lower thermosphere.

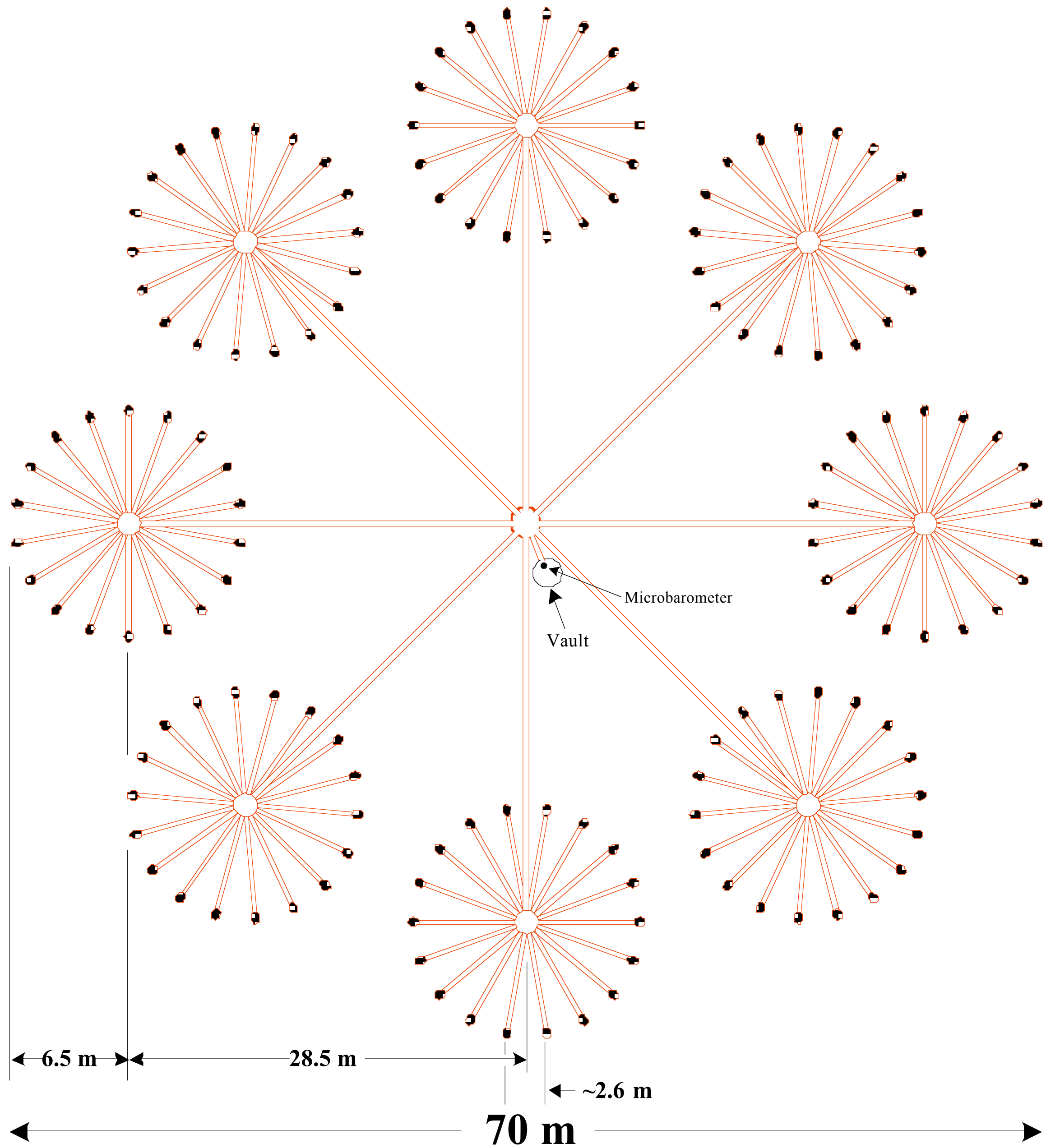
# Challenges of Atmospheric Infrasound

- Noise associated with atmospheric turbulence ("wind noise"), especially at frequencies below 0.1 Hz. Conventionally this is solved by adding large "wind-noise filters" to sensors. The cost of the filters typically far exceeds the cost of the infrasound sensor itself.

- Environmental exposure is a hazard to current, rather delicate microphones, so vaults are constructed to stablize temperature and protect the instrument from environmental exposure.

# Infrasound Pipe Array:

# State of the Art Wind Noise Sensor



# Goals of This Instrument Development

- Replace large pipe arrays with array of infrasound sensors.

- Ruggedize sensors, and construct them to be insensitive to thermal fluctuates:  Removes requirement for instrument vault.

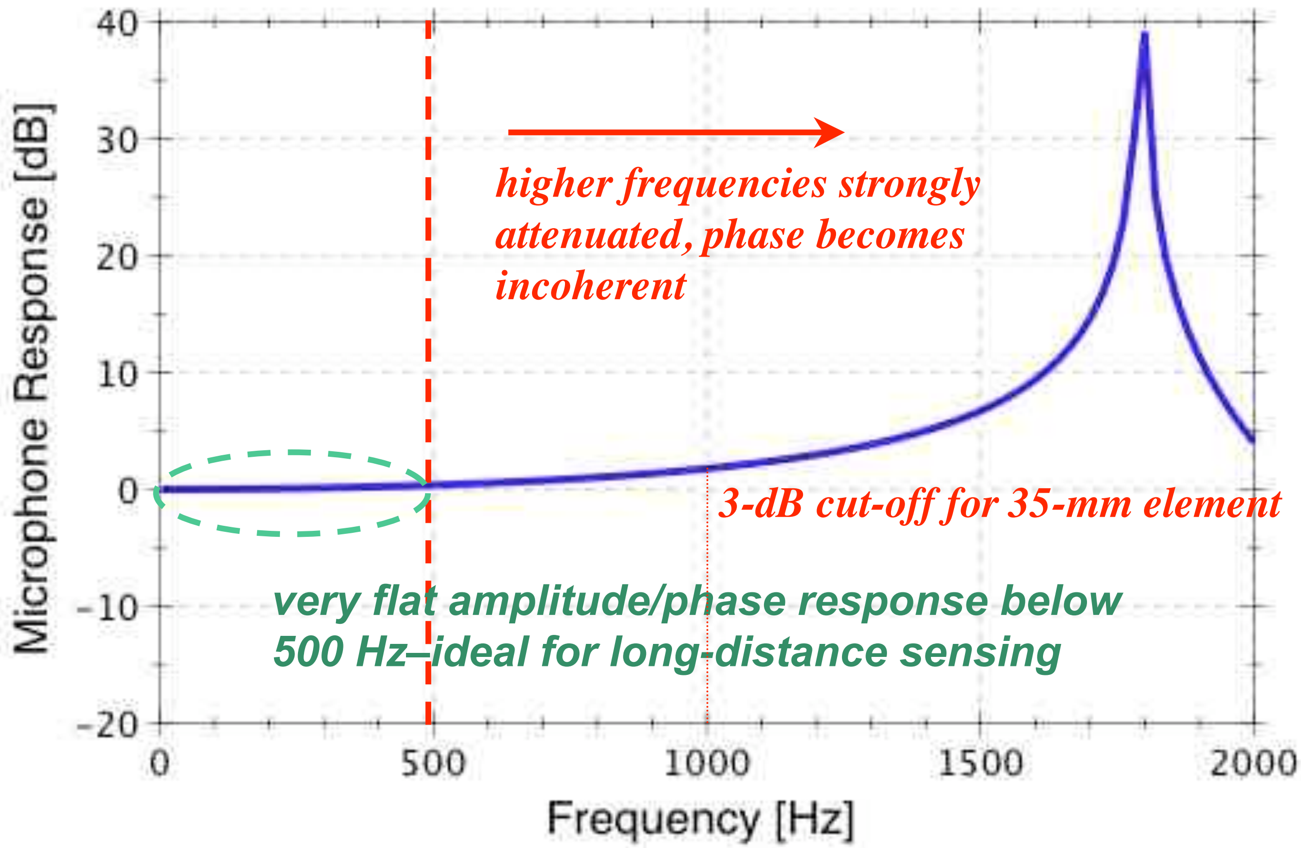
- Make them low-cost enough ($750 vs $5000+) to make practicable multiple arrays of sensors.

- Low replacement cost also reduces risk associated with damaged or destroyed sensors.

# Piezoceramic Sensors

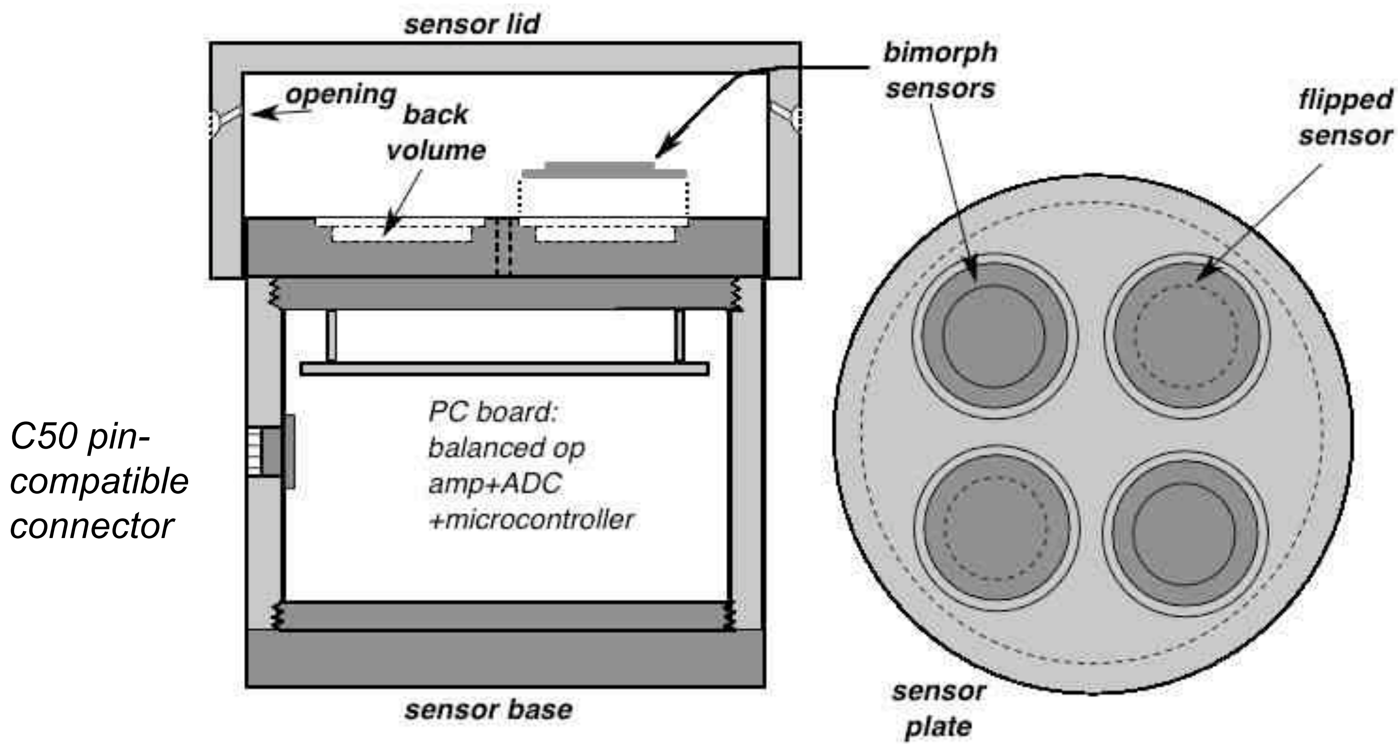
- Resonant Frequency - 1.8 kHz (hinged condition)
- Sensitivity - 3.4 mV/Pa
- Temperature Compensation
  - Reverse bimorphs
  - Insulated enclosures, small openings
- Charge Generating
  - Must operate into a high impendence

# Frequency Response of Piezeoceramic Sensors




Band start frequency depends on design of preamplifier. We can reliably measure pressure signals down to periods of $10^5$s.

# Schematic of NCPA Sensors

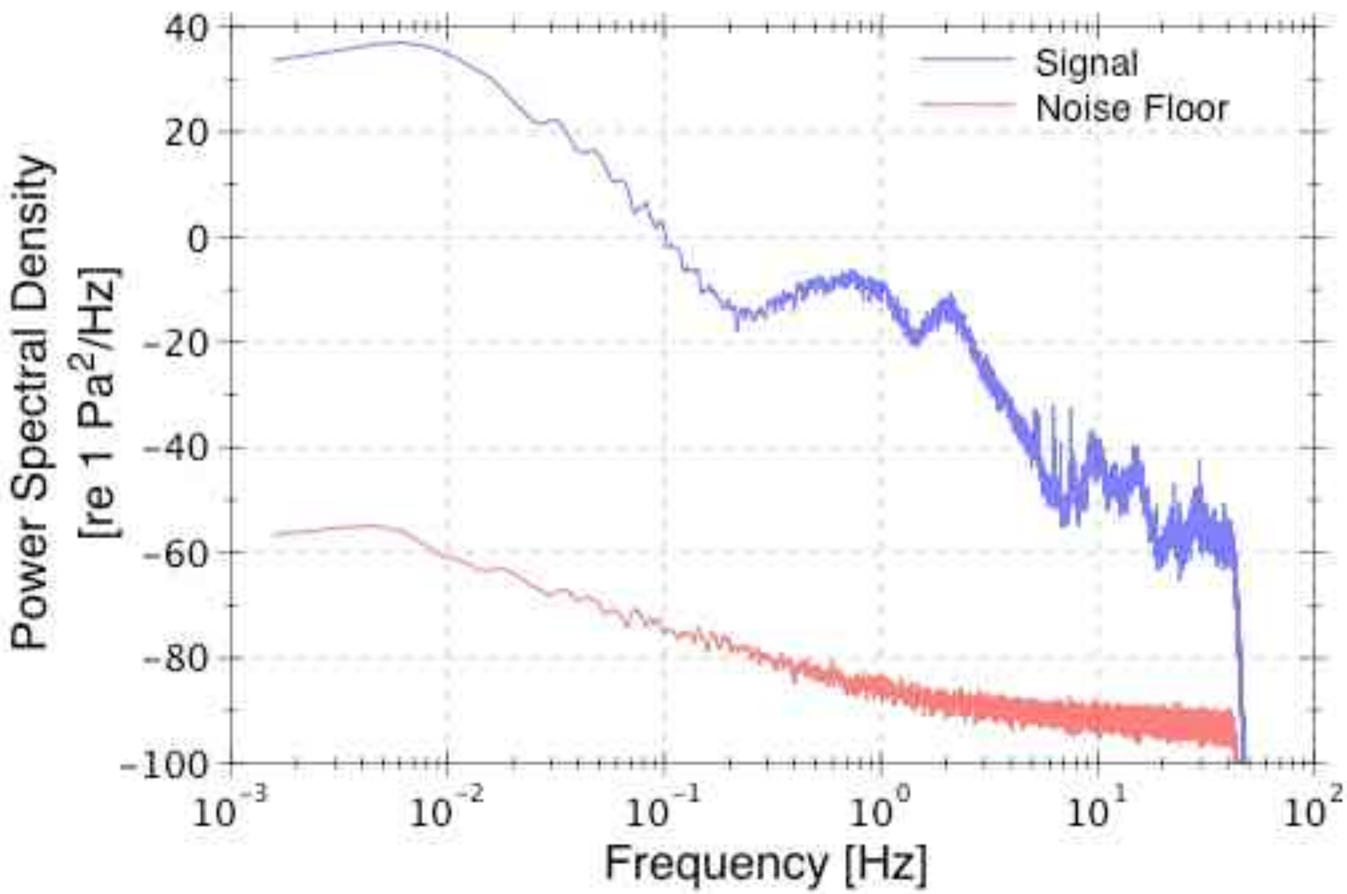



This 4-element design reduces effects of temperature gradients across sensors. Current design has different base plate, sensor lid. Still Chaparral 50 compatible.

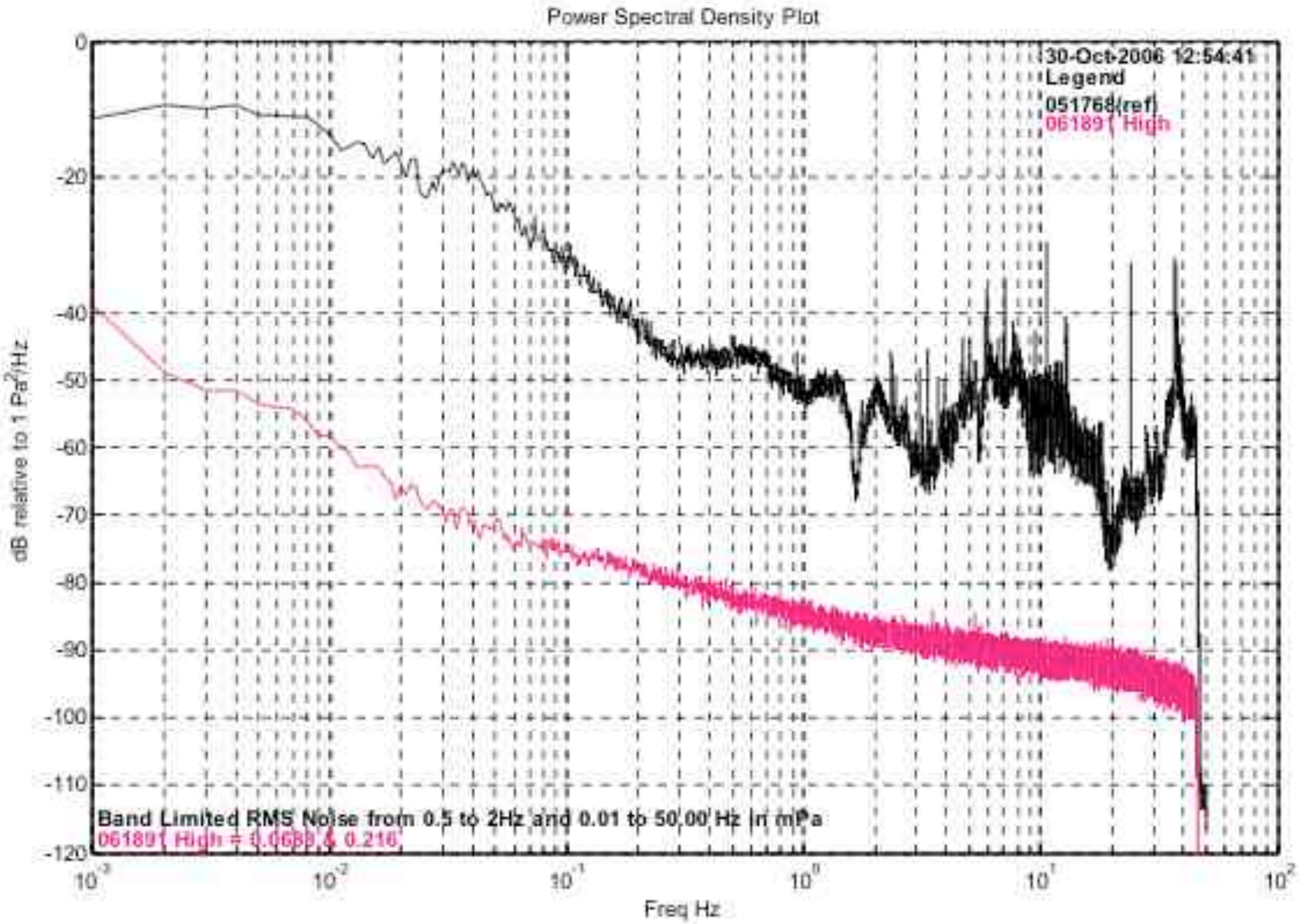
# Characteristics of Sensor

- highly ruggedized
- 0.0005 Hz- 100 Hz operating range (3-dB). Can be calibrated to 500-Hz.
- plug compatible with Chaparral 50
- self-calibration using reciprocal calibration method has been demonstrated from 0.1–100 Hz, calibration chamber with calibrated volume source.
- Sensor can be configured as accelerometer (or dual pressure/acceleration sensor with same sensing elements).

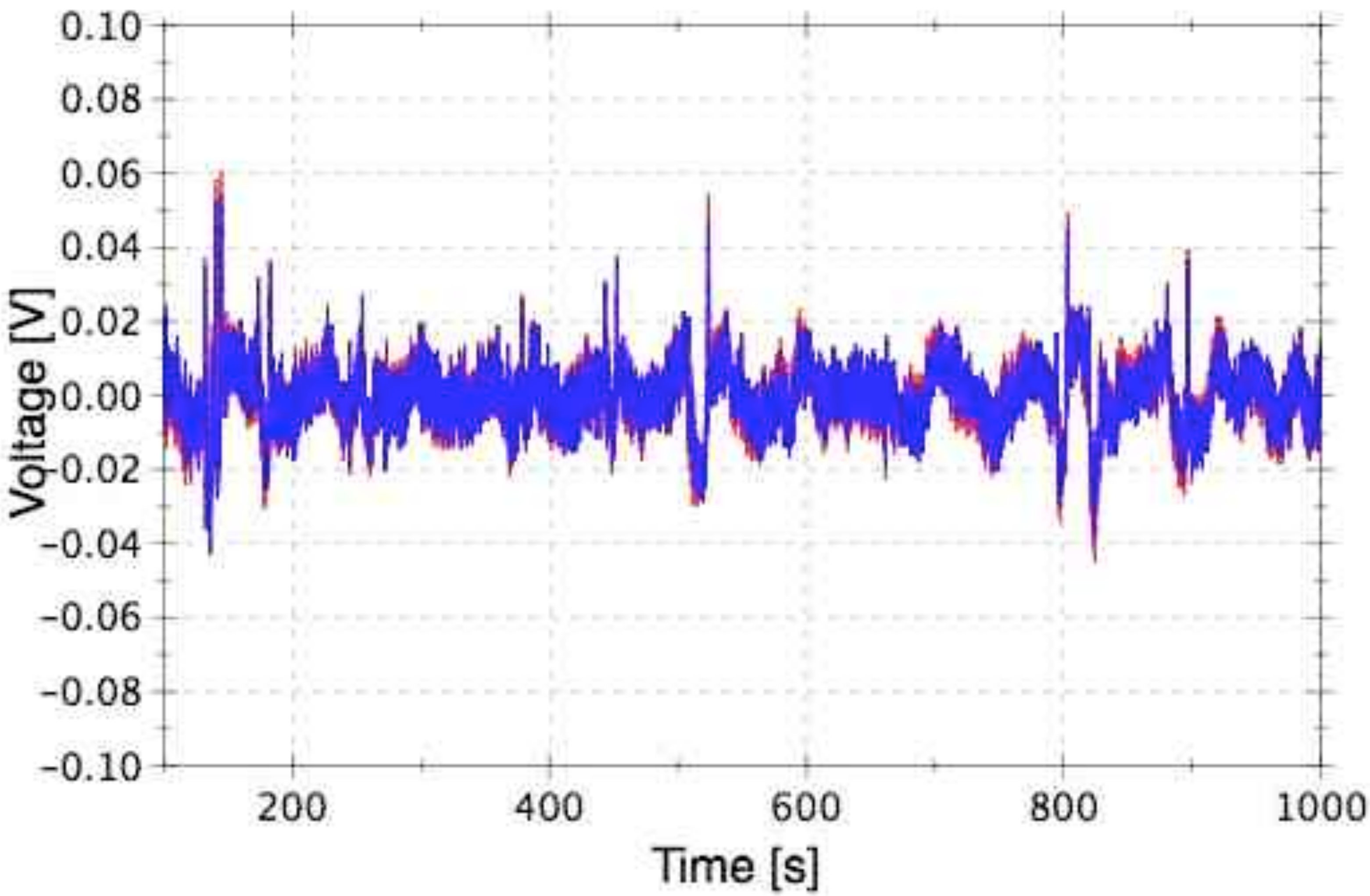
# Microphone Noise Floor



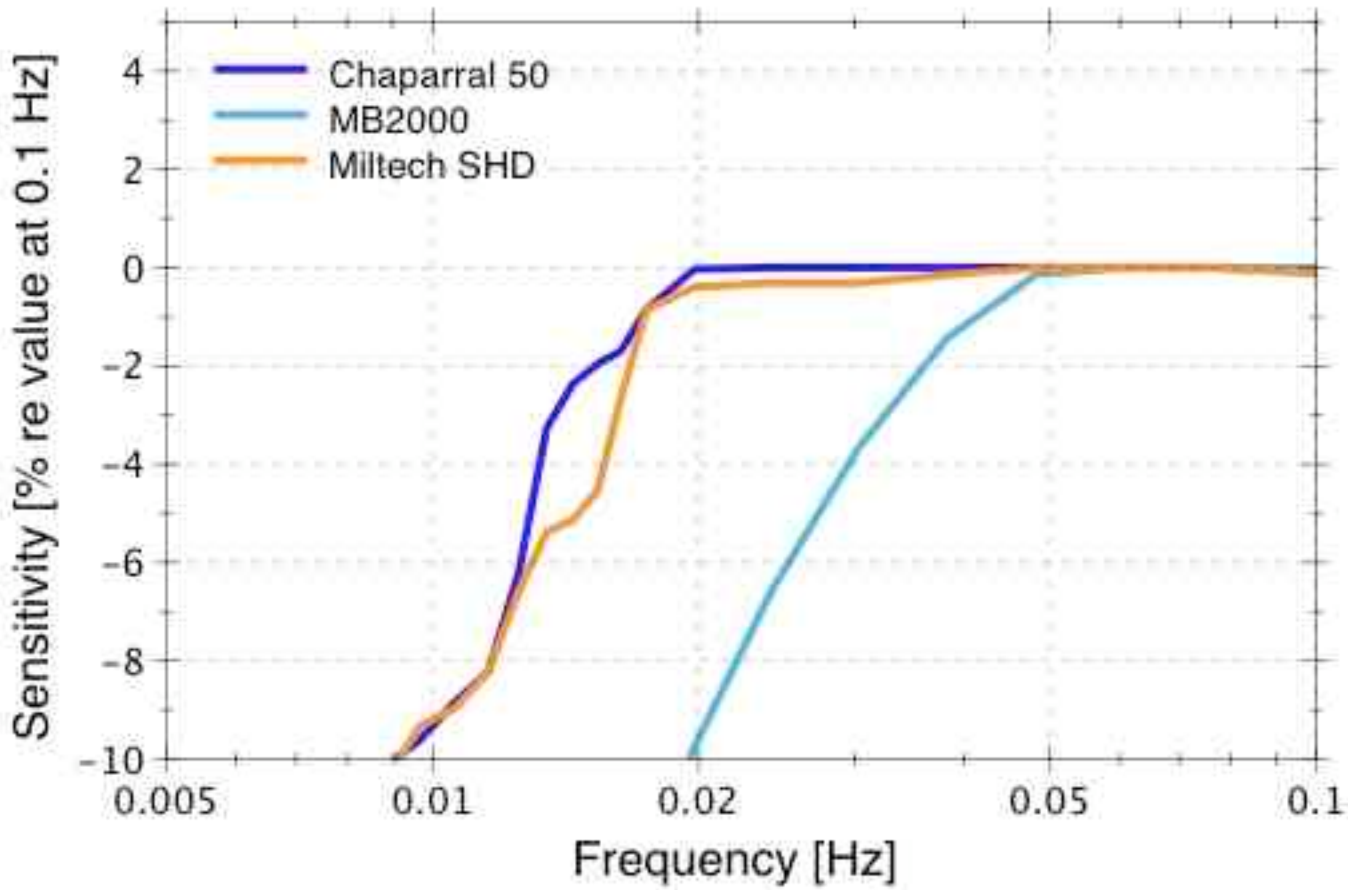
# Comparison with C50 Microphone



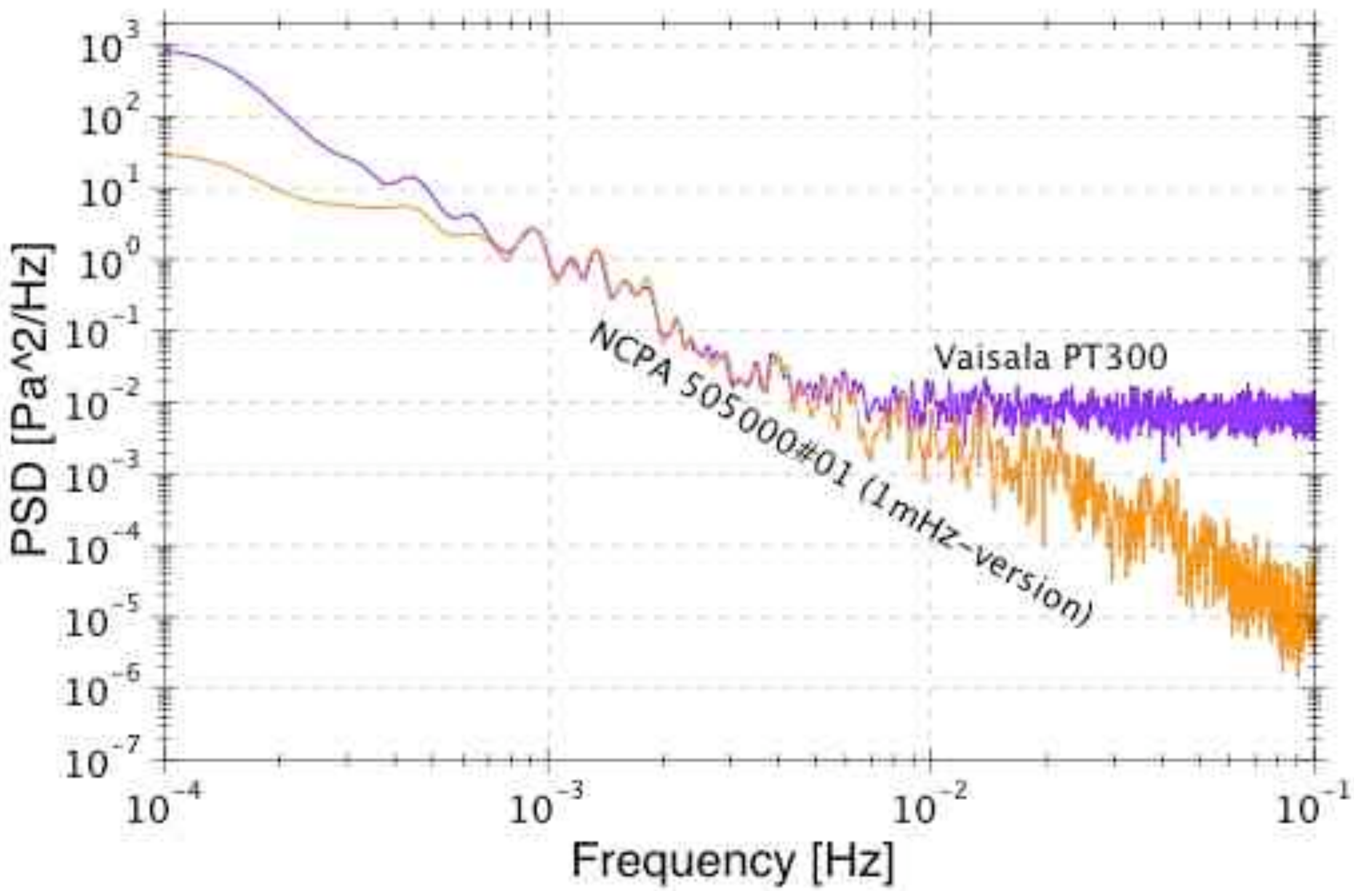
# Single Sensor Comparison with C50



# Single Sensor Comparison



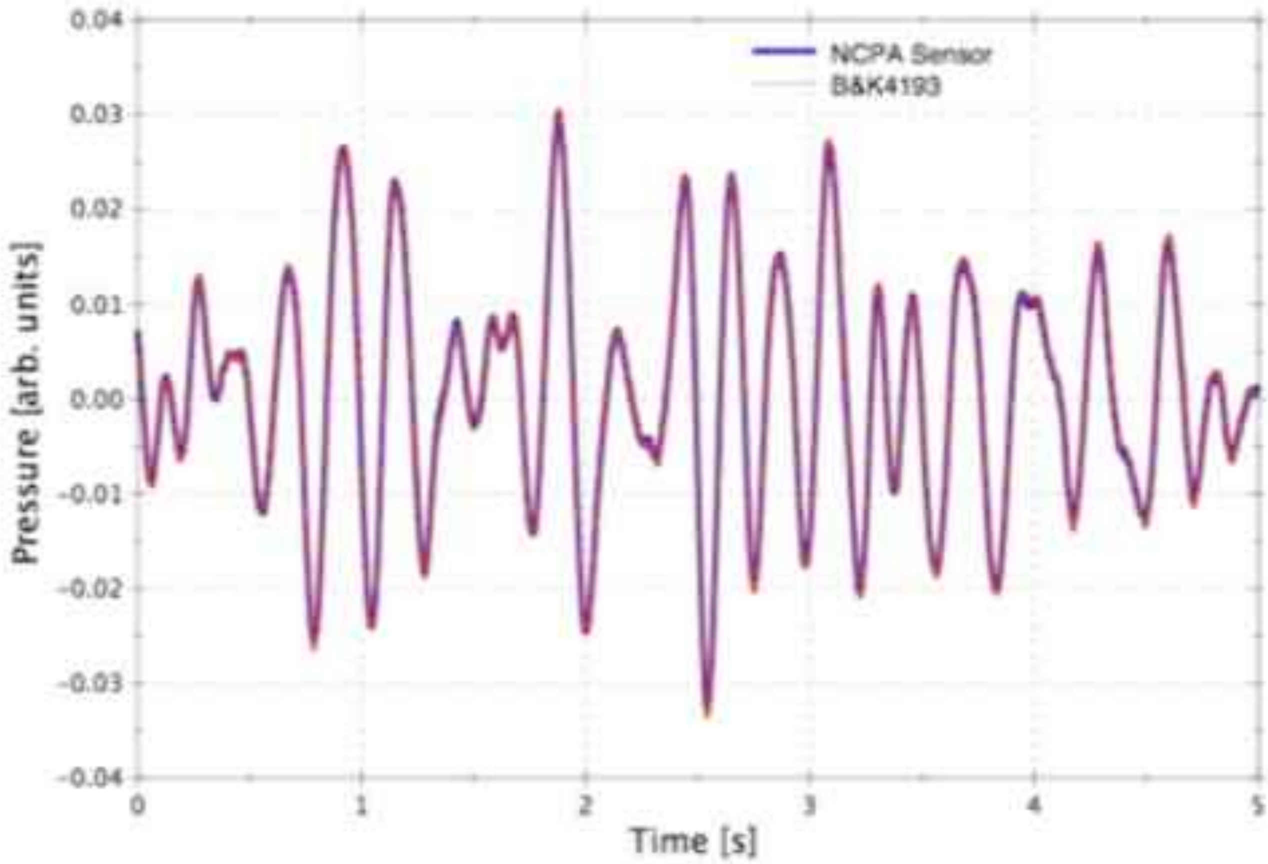
# Comparison with Vaisala Pressure Sensor



# “High Frequency” Sensor

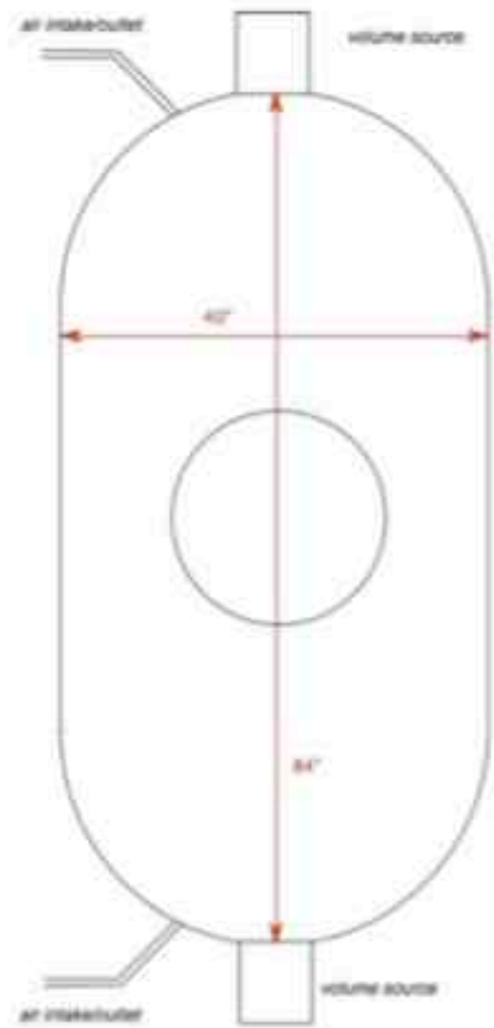
- Allow use of microphone for low-frequency sound, long-range propagation experiments.
- 0.1 Hz- 1000 Hz operating range, configurable gain
- Improved vibrational isolation (elevated sensor applications).
- More compact sensor packaging.
- Vertical (4-m, 8-element) portable towers are in development at the NCPA.

# Comparison of HF Sensor to B&K 4193



# NCPA Calibration Chamber:
# Goals

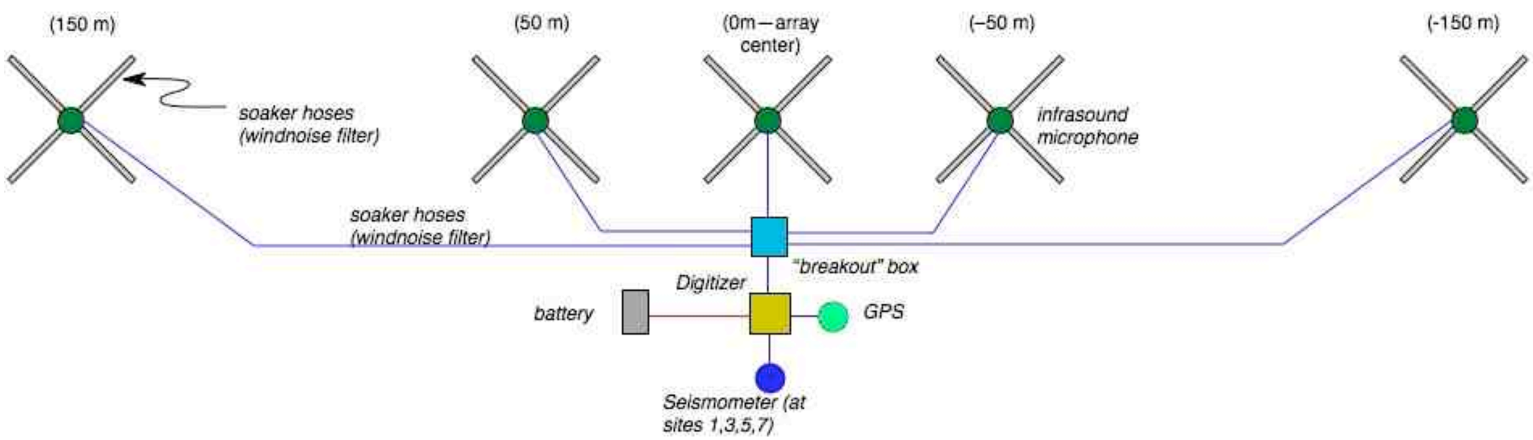
- Allow accurate (0.05 dB) calibration from 0.01—20Hz.
- System will be enclosed within concrete outer shell & will be mounted on active vibrational isolation system.
- Allow variation of pressure, temperature, humidity & even gas content (e.g., replace atmospheric air with helium).
- Thermally stabilized volume. Calibration volume will be instrumented for air temperature, humidity, pressure, vibration.



# 2009 Nevada Field Deployment of Array


Nominal array locations were at 180–250 km, in 10 km steps

# Array Geometry



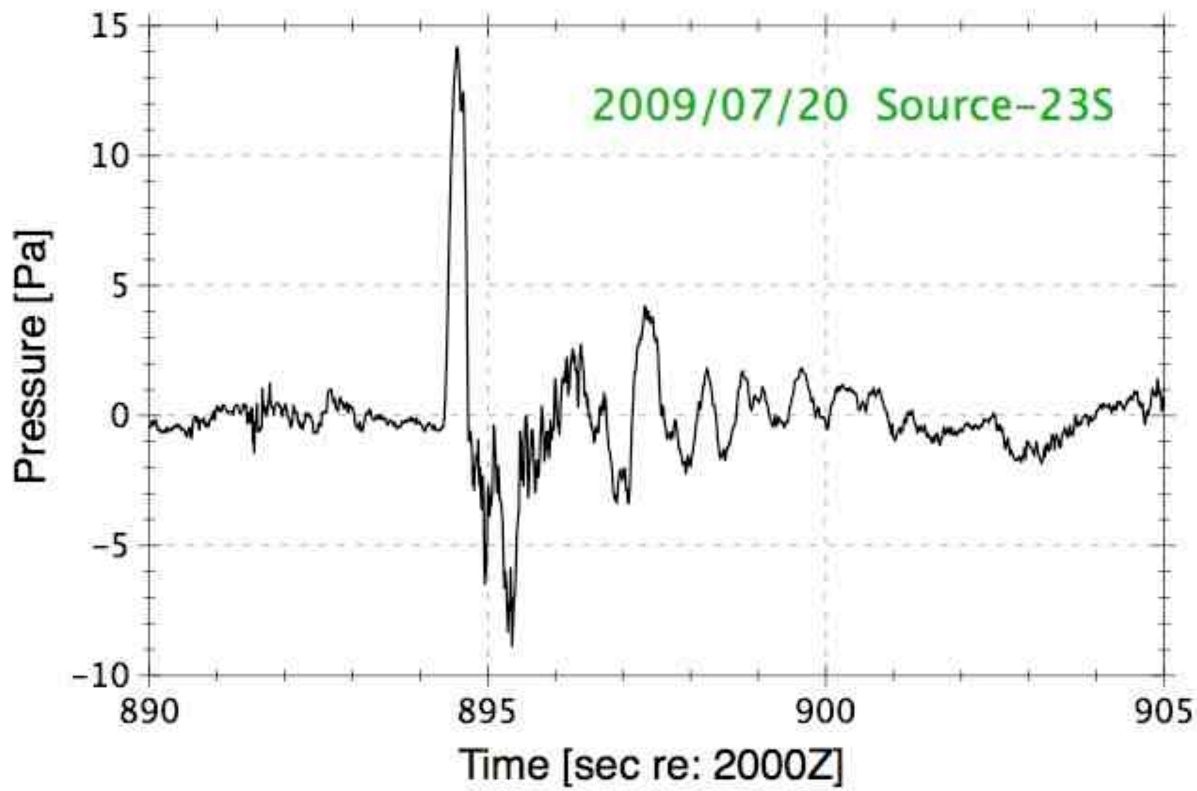

- All infrasound microphones were NCPA sensors.
- Outer sensors characteristics: 10 mHz–100 Hz, 0.13 V/Pa; center mike 1 mHz–100 Hz, 0.025V/Pa
- Digitizers used were Geotech SMART 24 (“even” numbered array”) or Miltech Fence Posts (“odd numbered arrays”).

# Field-Deployed Microphone

# Sources for Nevada Deployment

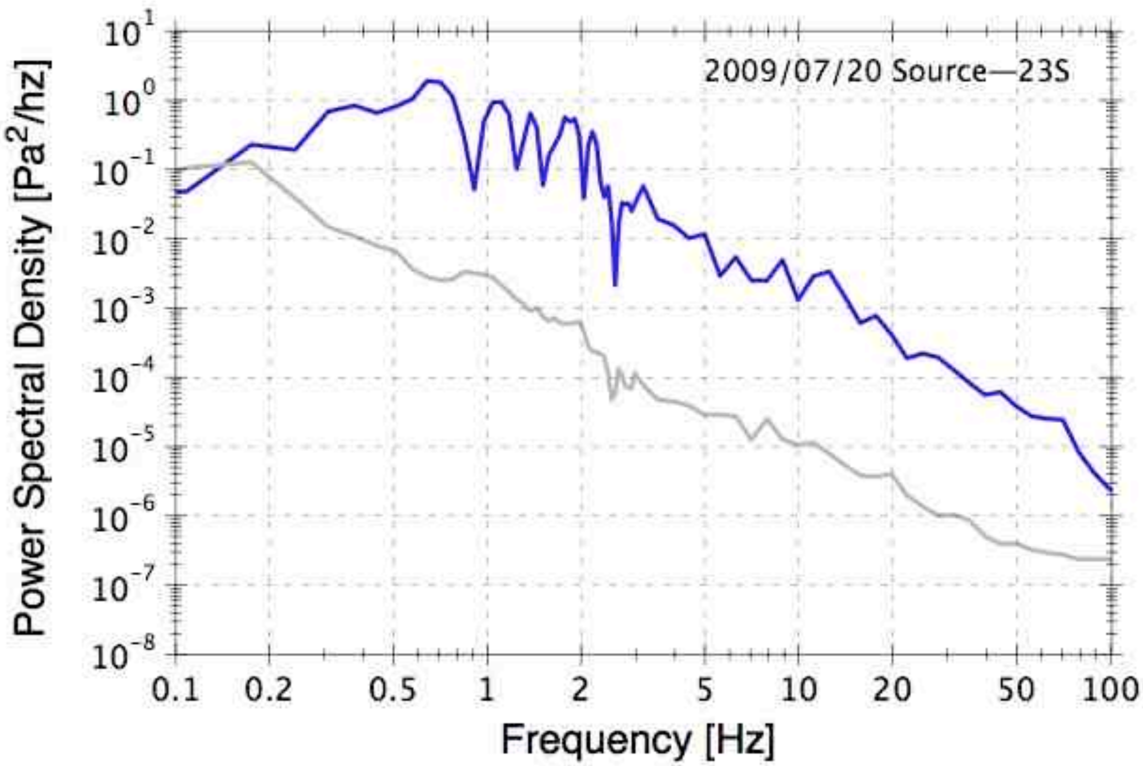

4, 20 and 80 tons-TNT equivalent explosions at the Utah Testing and Training Range (UTTR), as part of the Trident missile disposal program.

# Source Capture–23 km South



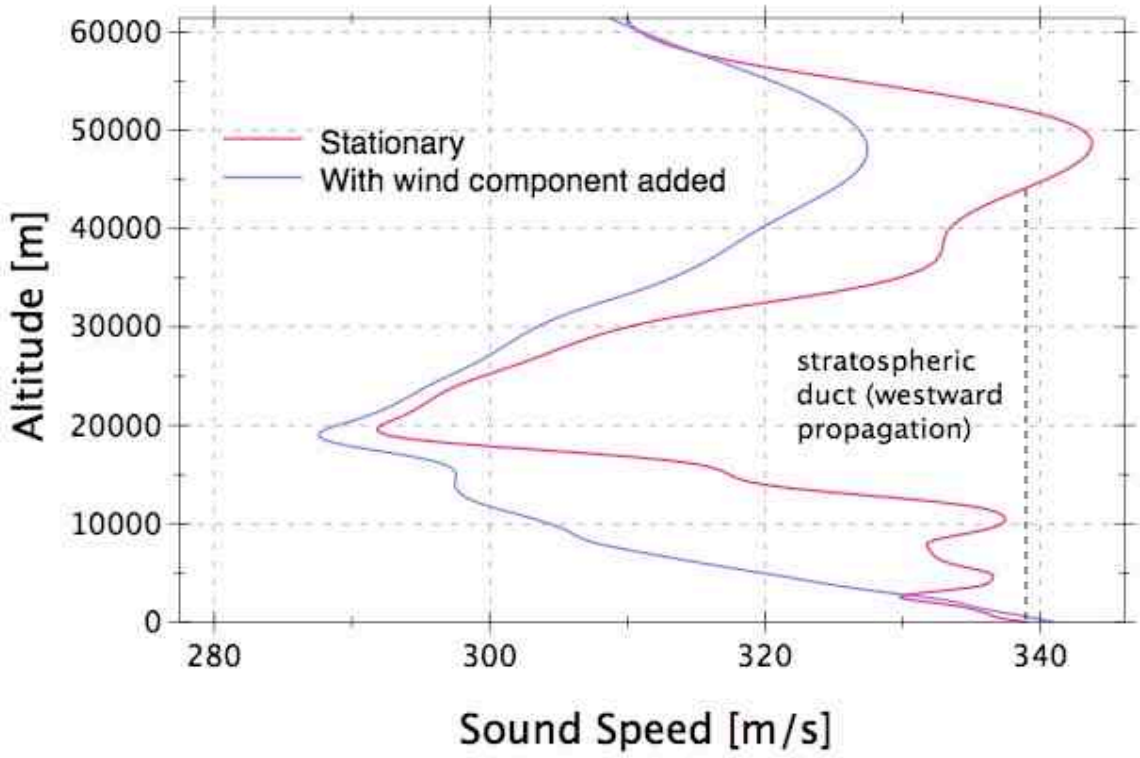

Source capture used 2 co-located microphones 23-km south of source. Assuming spherical spreading, source strength was about 70-Pa at 1 kilometer. Source capture used a Chaparral USB Digitizer.

# Source Spectral Content

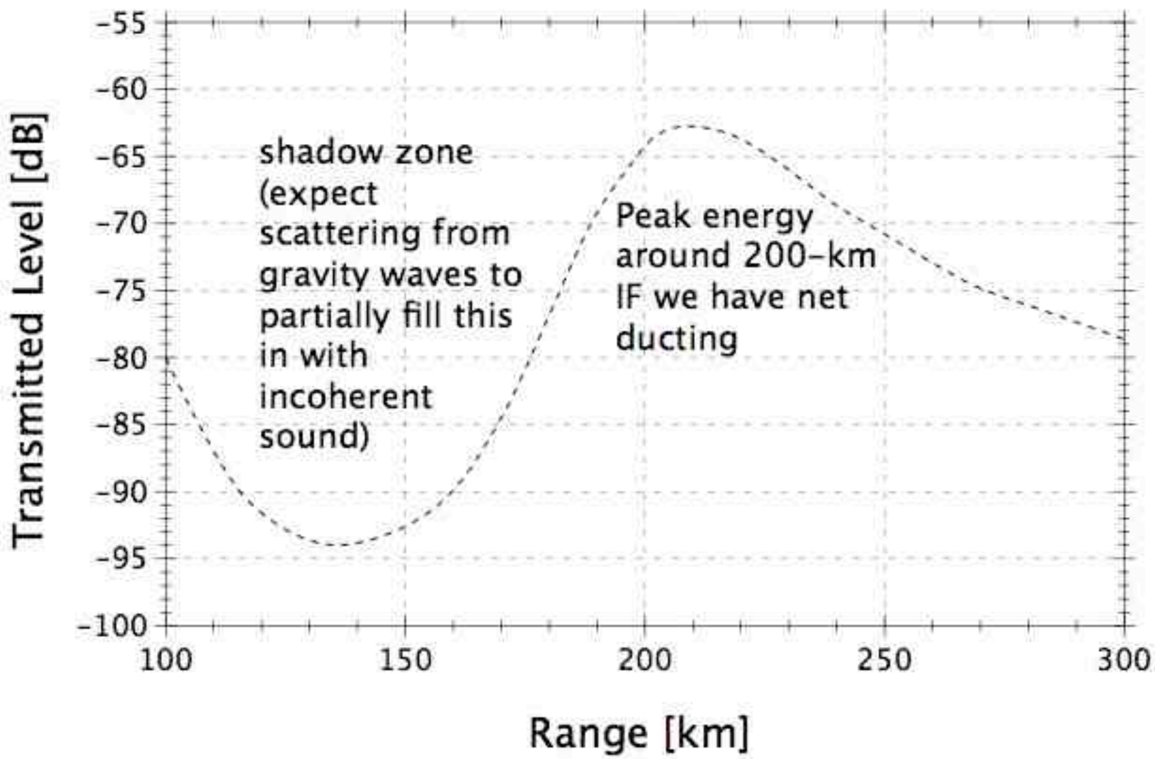


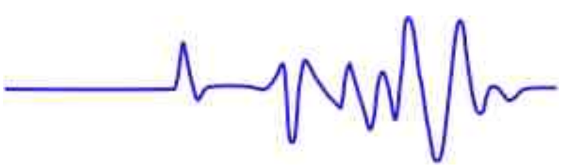

"Scalloping" probably associated with multiple arrivals associated with propagation effects.

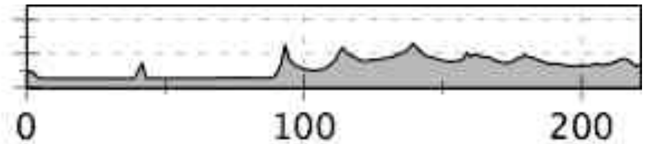
# Vertical Sound Speed Profile



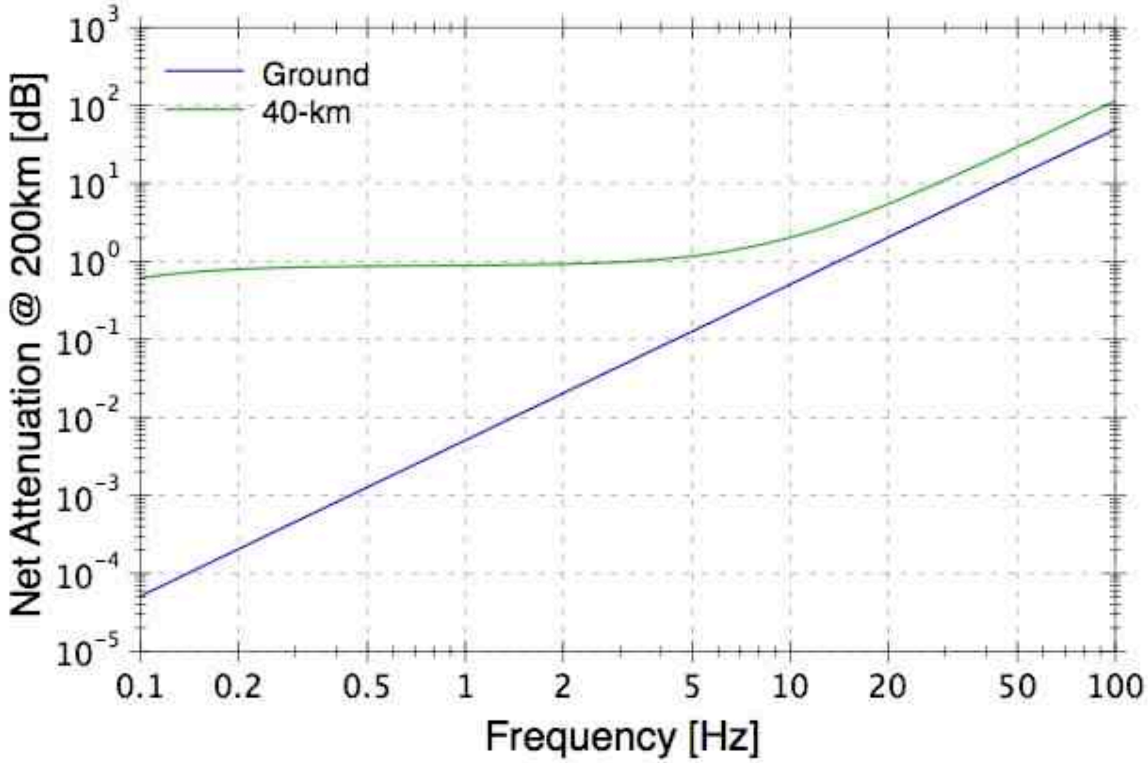
# Expected Signal Transmission



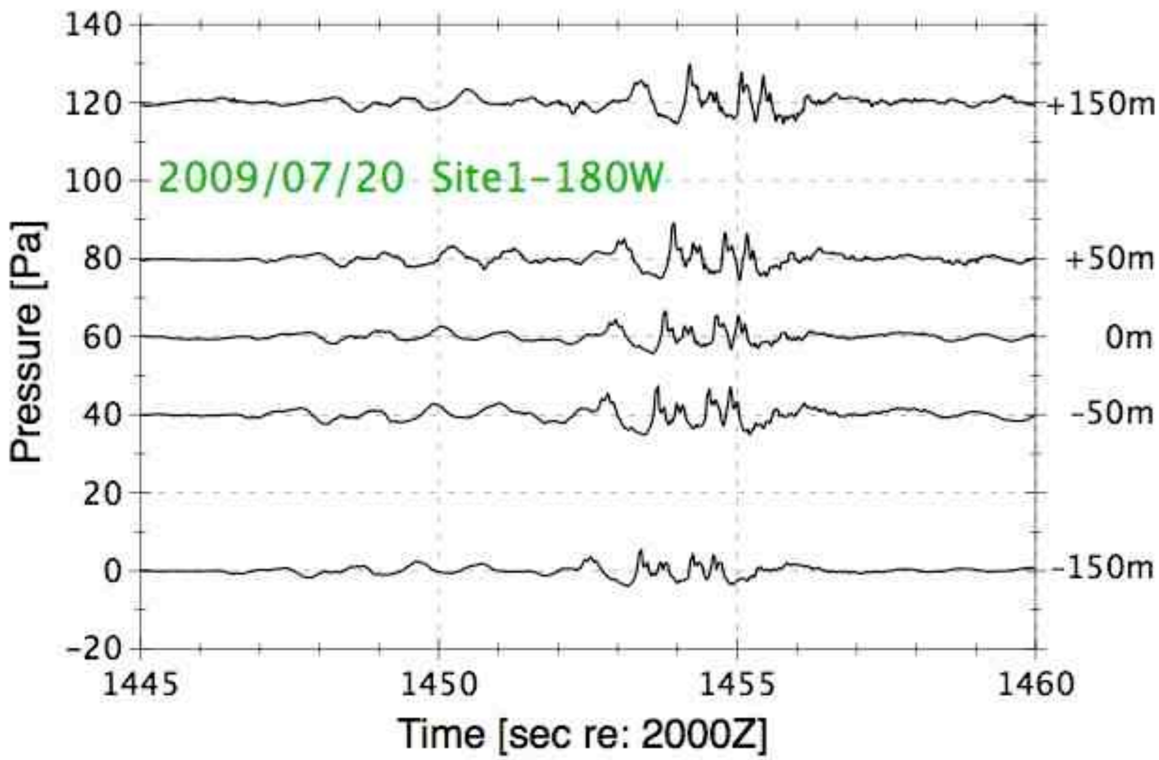





# Atmospheric Absorption



# Typical Arrival Structure



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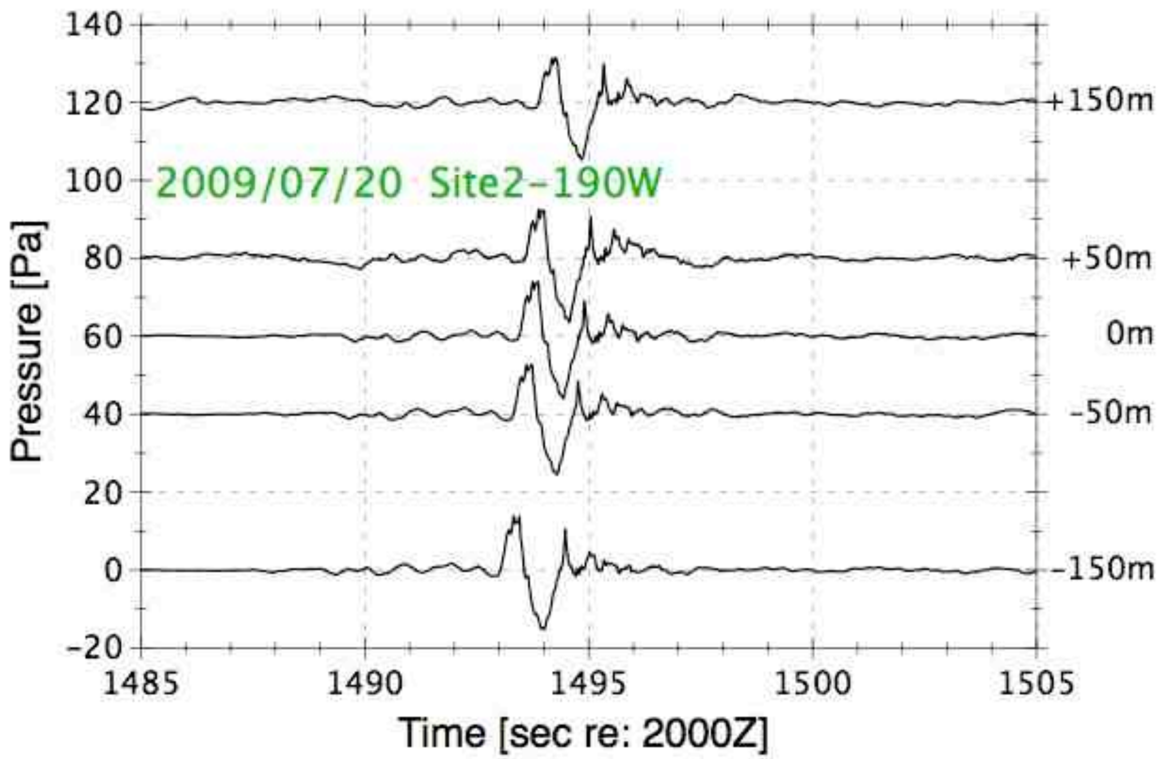

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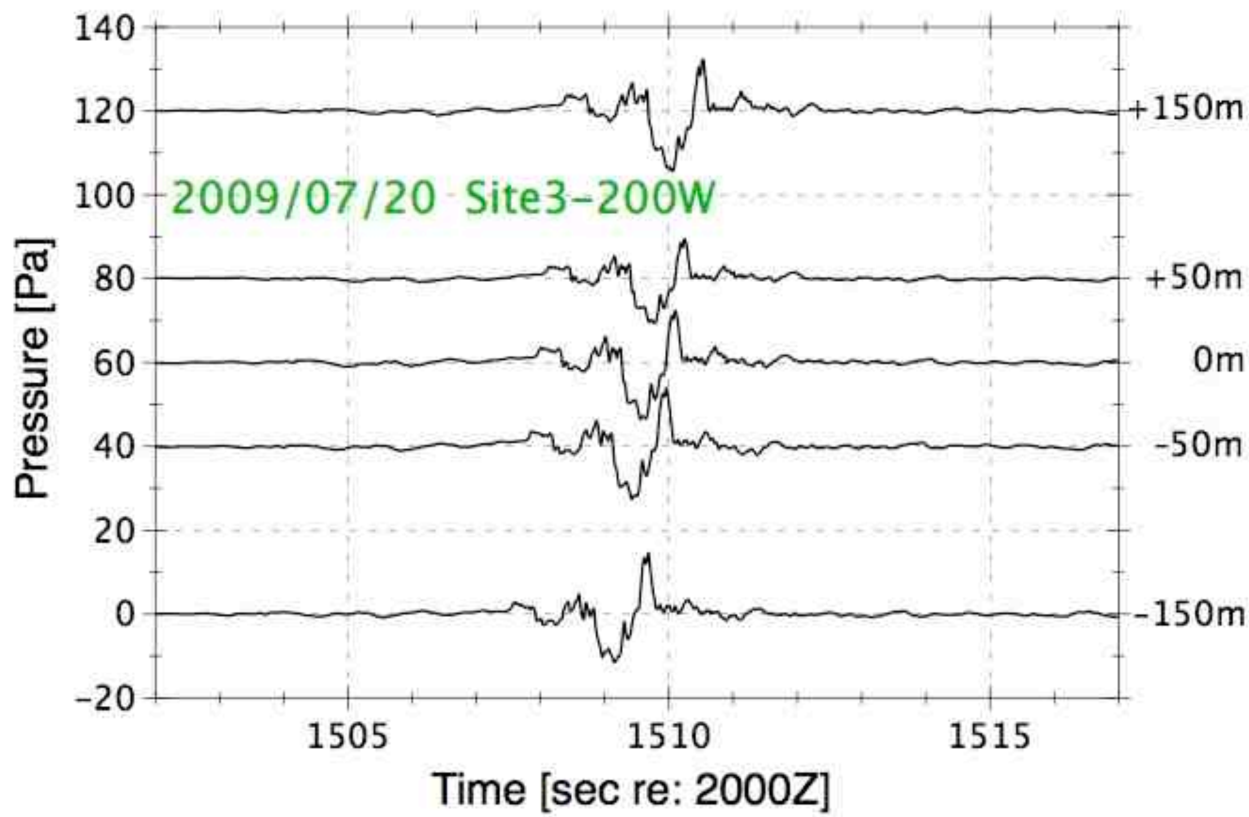

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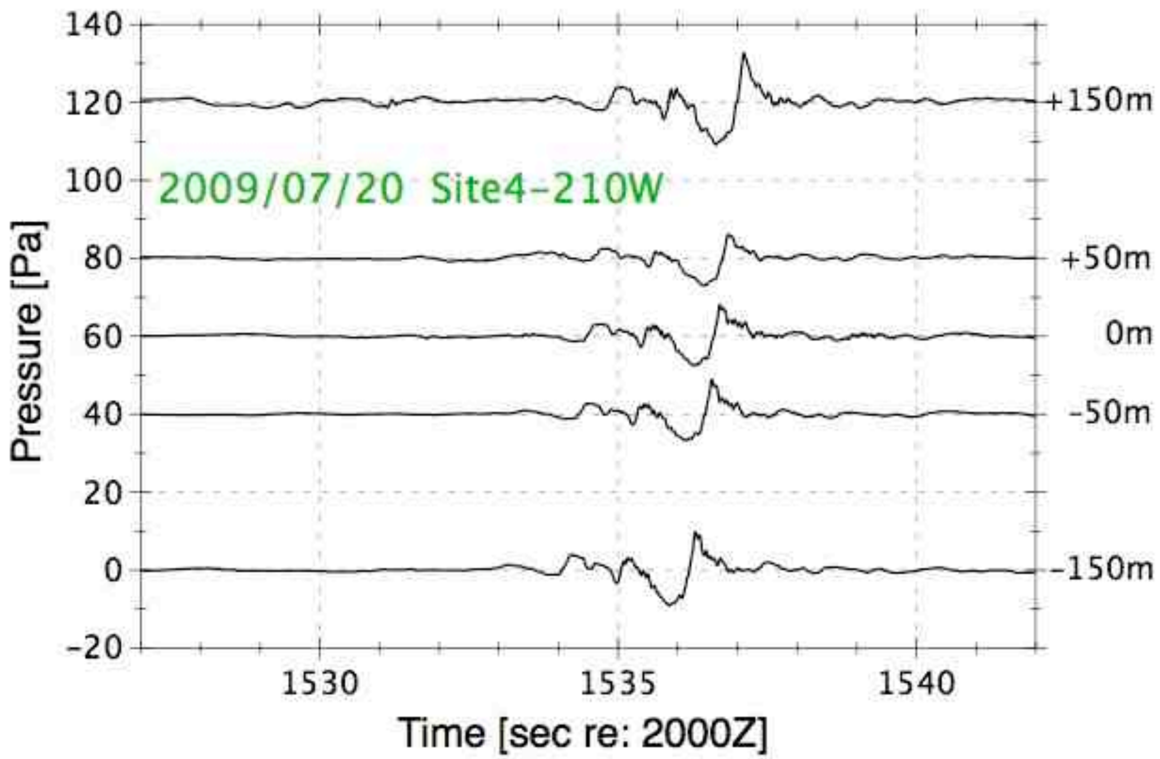

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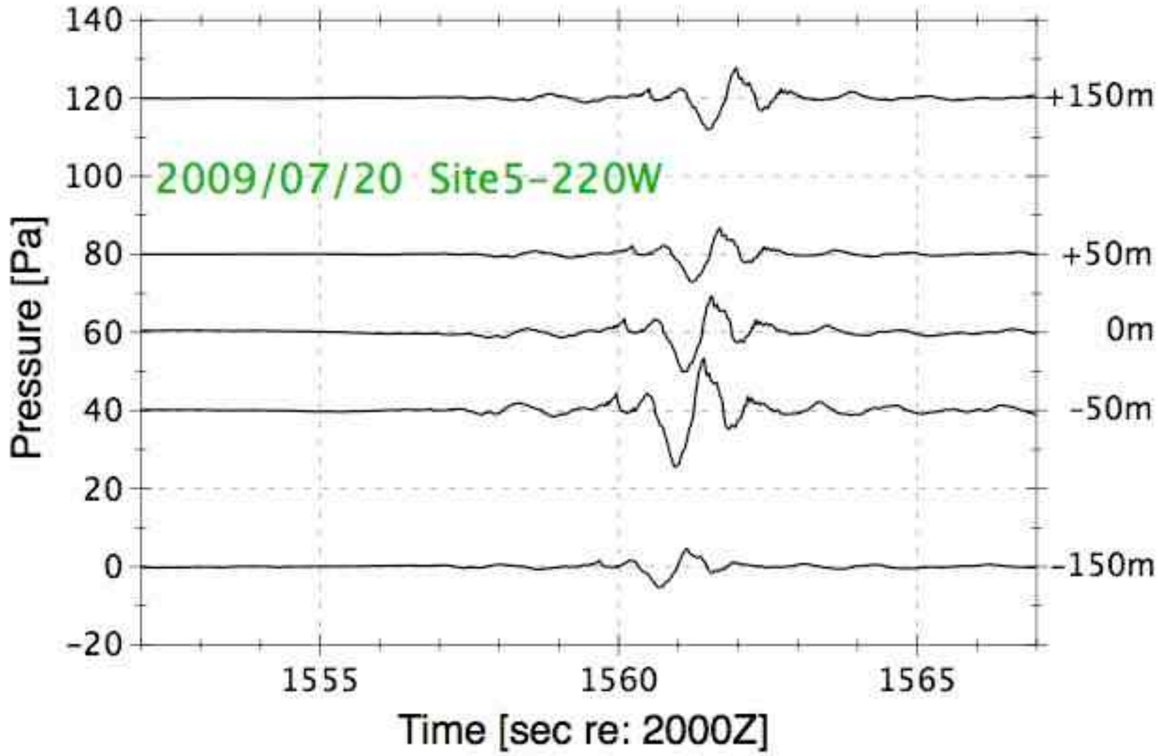

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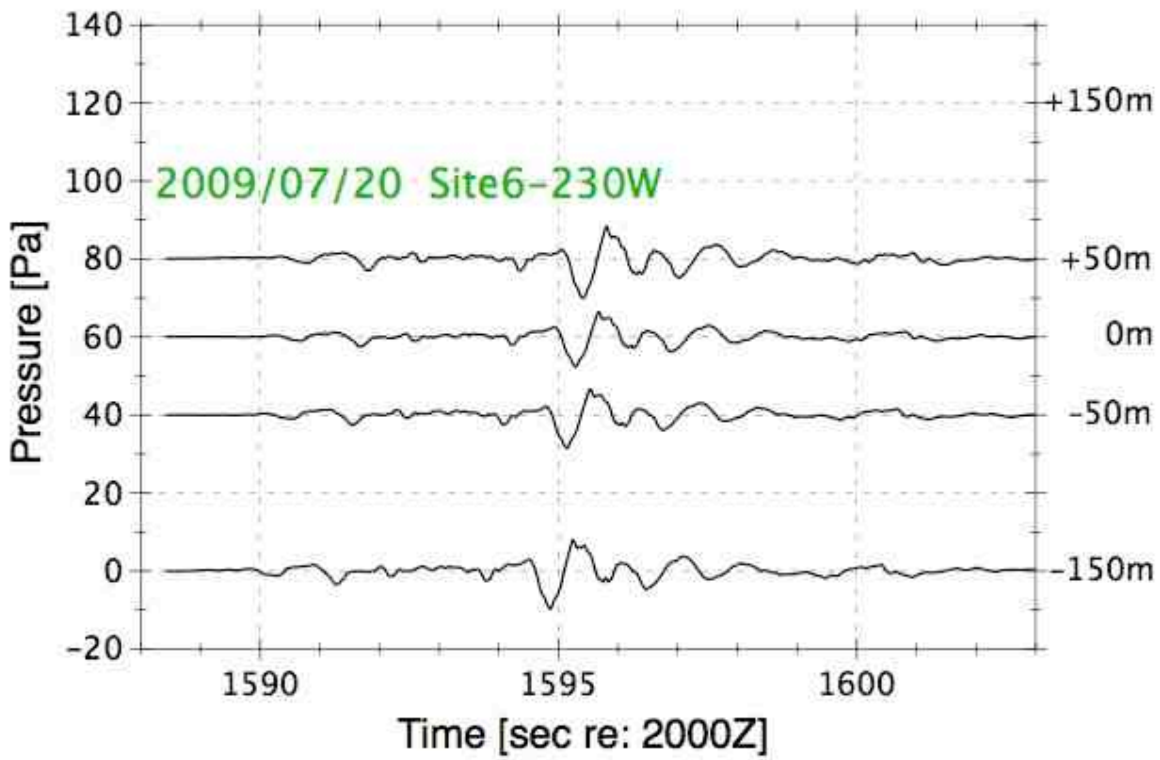

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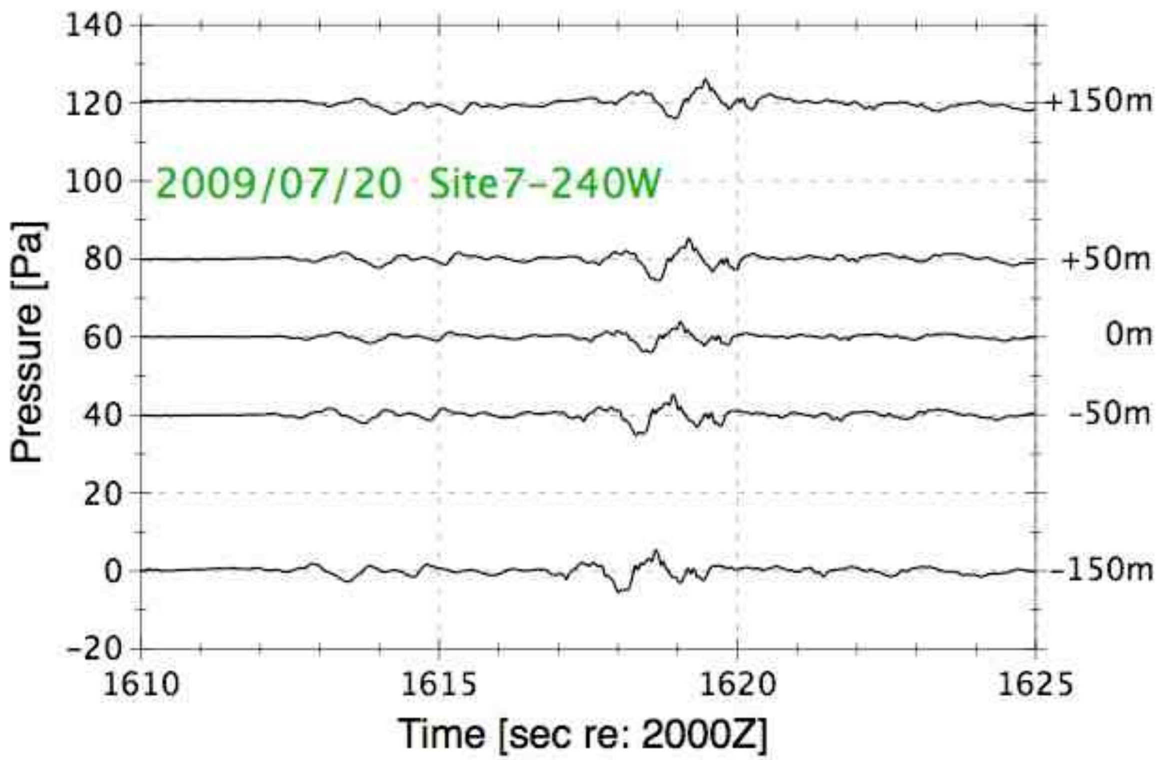

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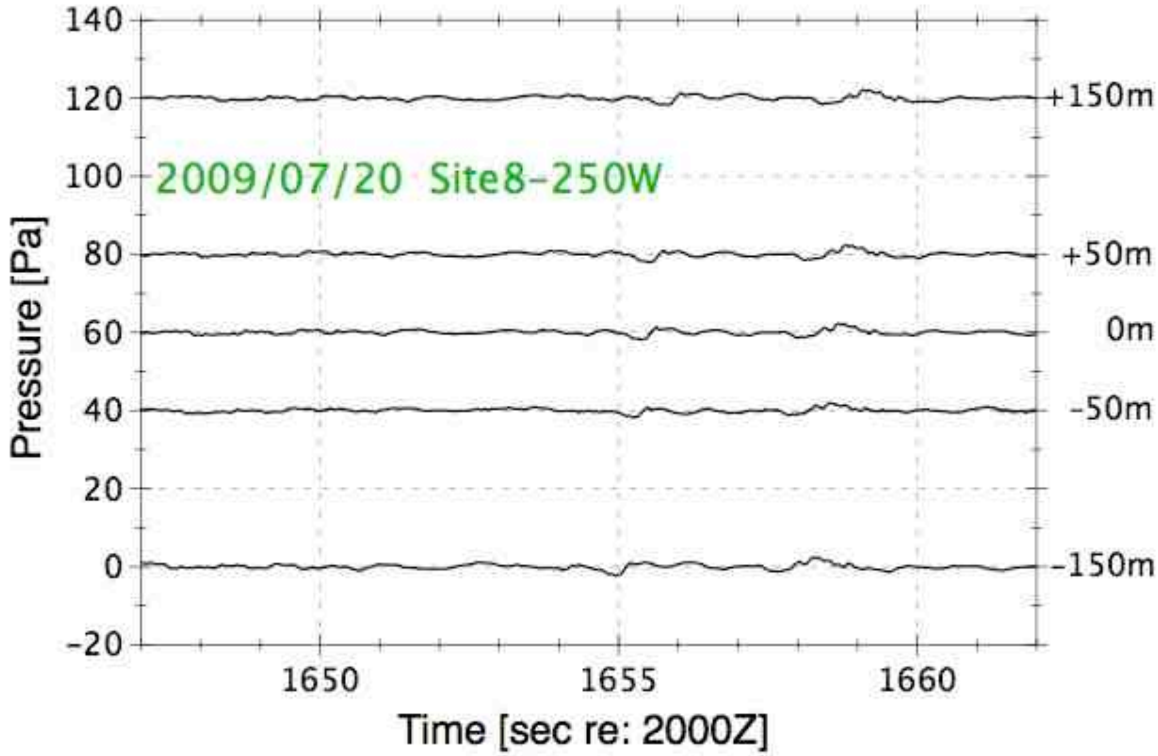
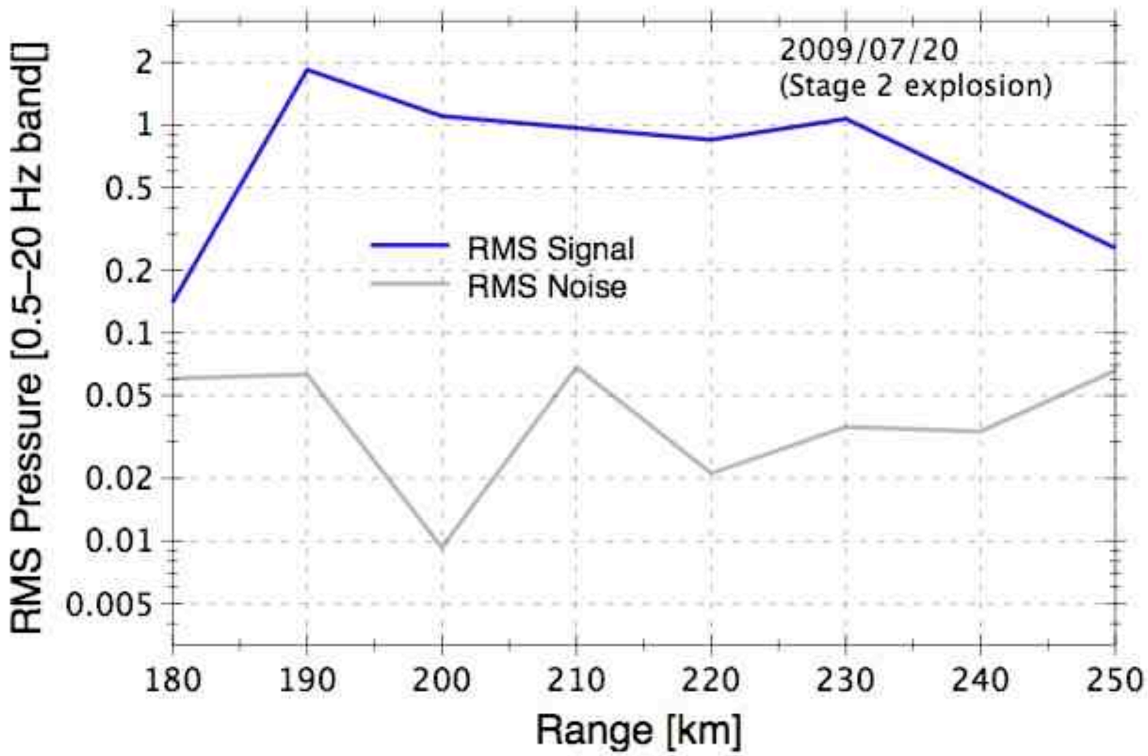
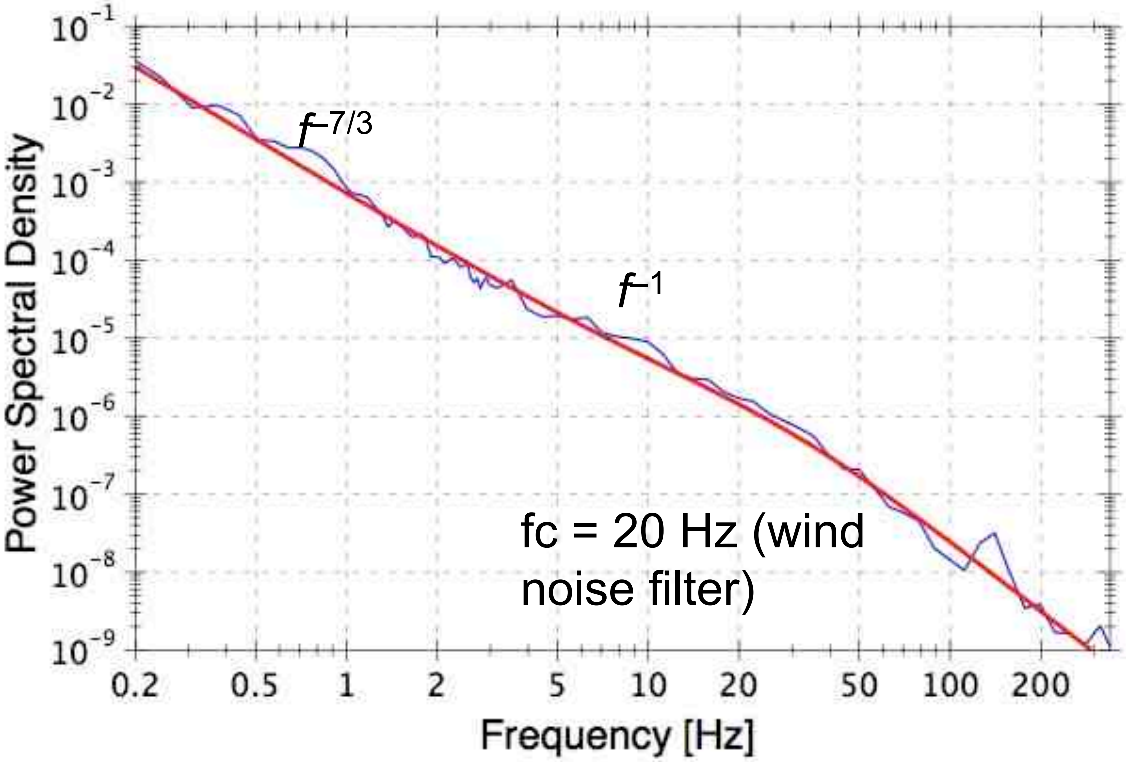


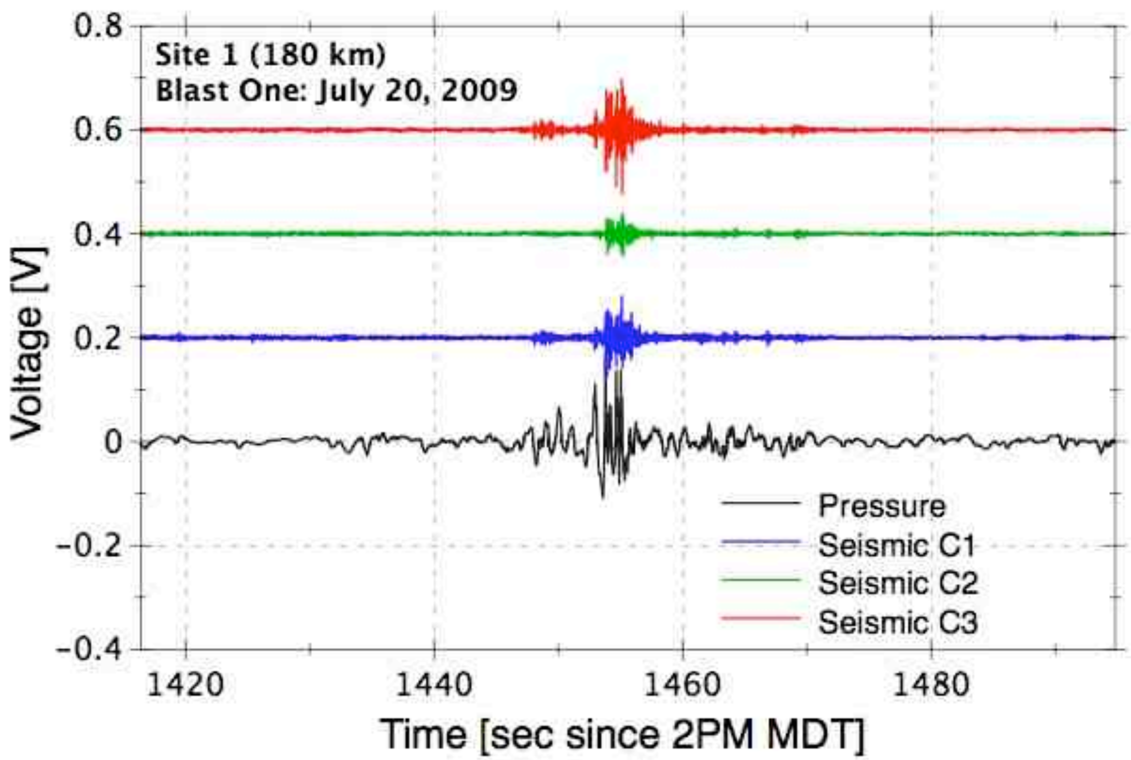
# Observed Power



# Average Noise Floor



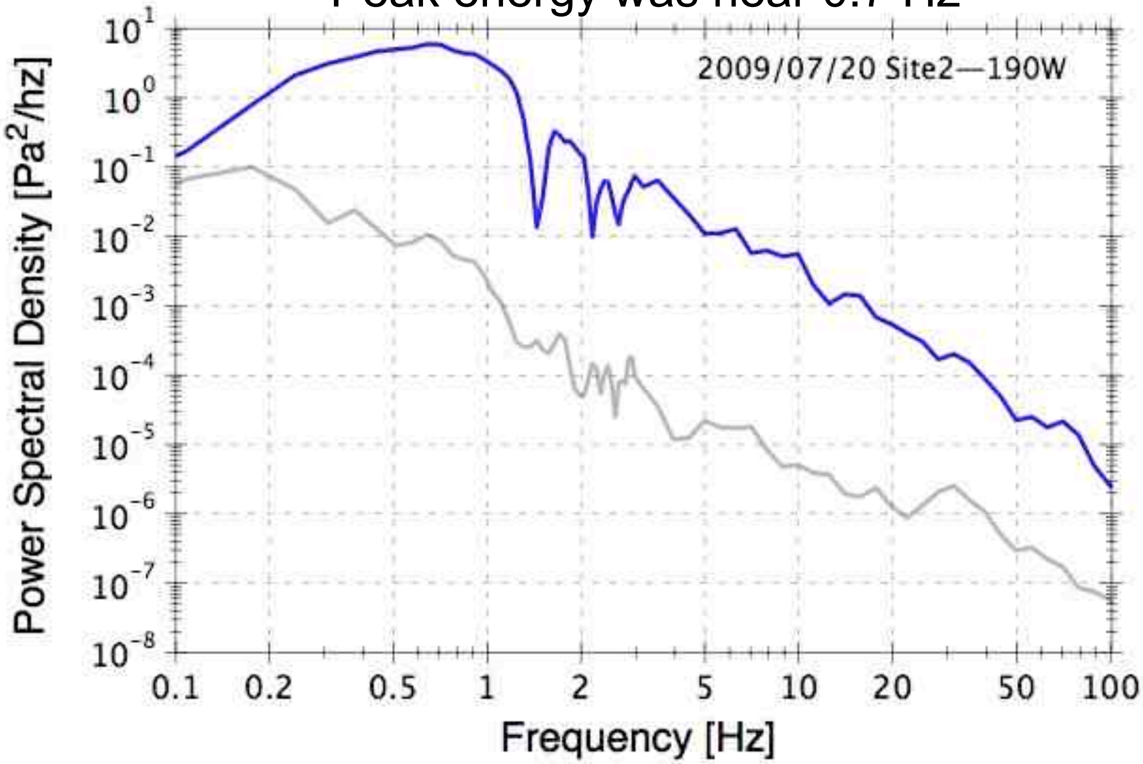
# Seismic Signals




Miltech Fence posts had 3-axis geophones (Geospace GS-32CT). Arrivals were observed on these sensors coincident with the infrasound sensors.

# Frequency Spectrum

Peak energy was near 0.7 Hz




High-frequency tail above 20-Hz was unexpected. However, it was observed at all sites with two different recording systems, and with two different technologies (infrasound mikes, seismometer)

# Conclusions

- A new sensor technology incorporating piezoceramic sensors has been developed at the NCPA.
- This technology was successfully field tested in a large scale deployment in Utah/Nevada from July 13–September 22, 2009.
- Very few sensor related problems were encountered during experiment.
- Main surprise was observation of high-frequency signals which are ***probably*** associated with nonlinear propagation effects at stratospheric elevations.