Adaptive Seismic Sensor Networks

Mines, Demolition and Non-Lethal Conference & Exhibition

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Dr. Mark L. Moran
ERDC-CRREL
72 Lyme Rd., Hanover NH 03755-1290
603-646-4274
mmoran@crrel.usace.army.mil

Presentation Outline

- Intro — Problem Statement, and Background
- Methods — Solution methods, and approach validation
- Demo — Demonstration of an adaptive network
- Summary — Summary

Background UGS Systems
(Acoustics-Seismic)

Attributes

Low cost => large numbers

Low power => long field life

Over-the-hill detection/tracking

See through the “trees”

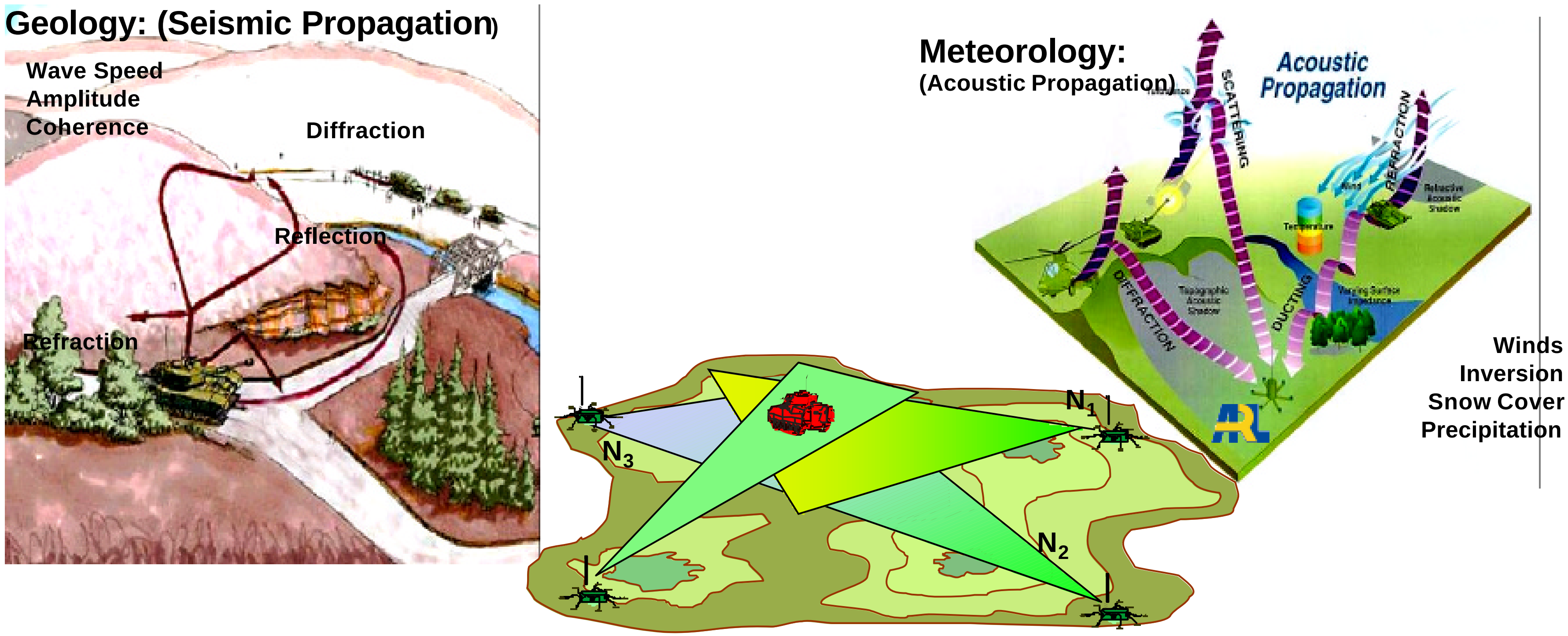
Basic Functions

	Acoustic	Seismic
Detection	✓	✓
Bearing Estimates	✓	✓
Range Estimates	✓	✓
Target Classification	✓	✓

- E/O systems have many practical limitations
- S/A systems have km scale detection/tracking
- Acoustic performance varies temporally (with meteorology).
- Seismic performance varies spatially (with geology).

Motivation

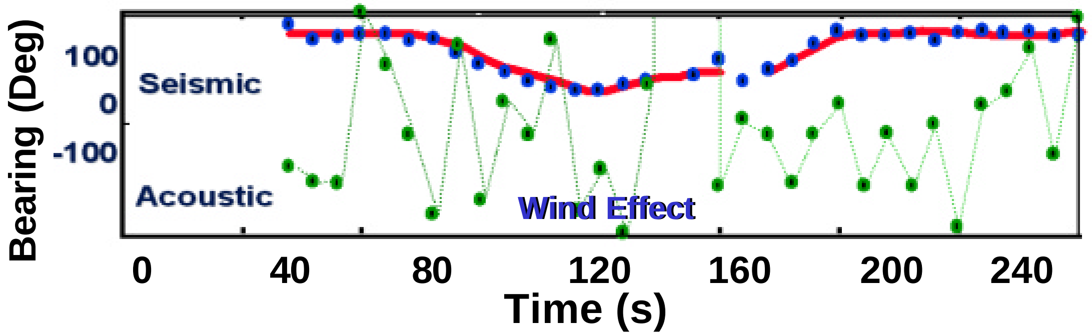
NLOS Seismic and acoustic sensors are strongly effected my the Environment

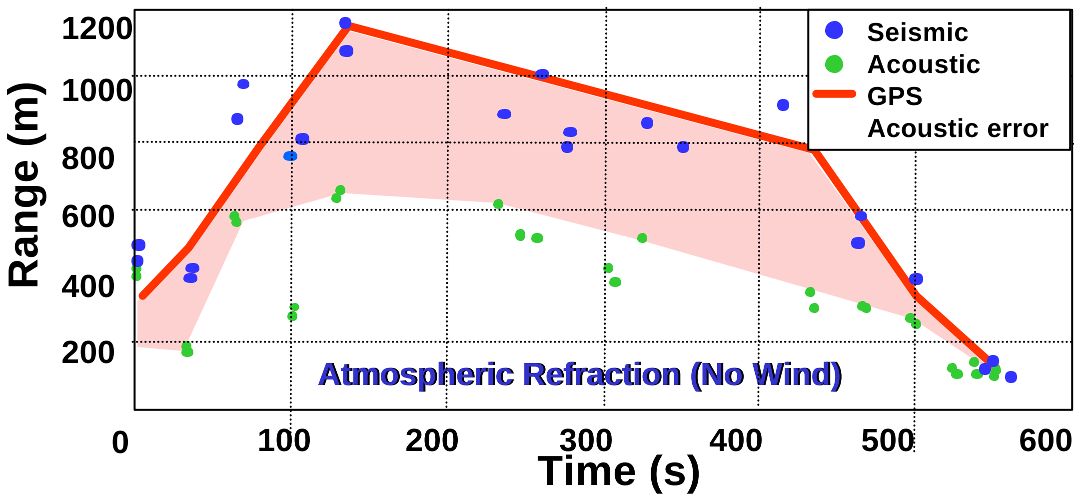


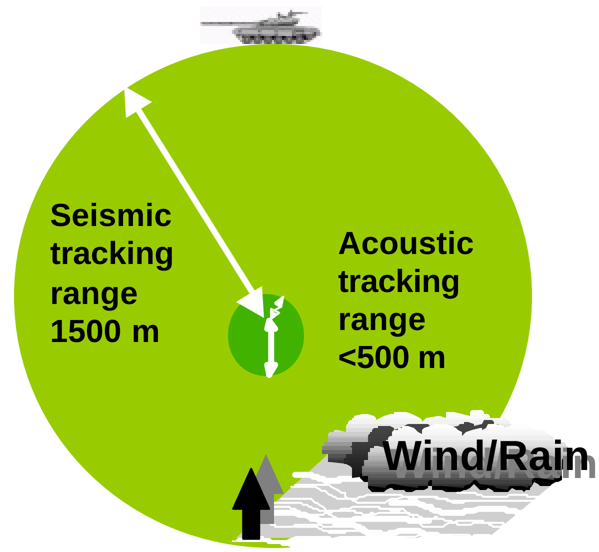
- *Sensor networks must be adapt to their specific environmental conditions*
- *Advanced simulations provide a cost effective means of system development*

Intro

Problem: Example of Environmental Effects







- Seismics must have geology
- Data are still high variance

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Methods

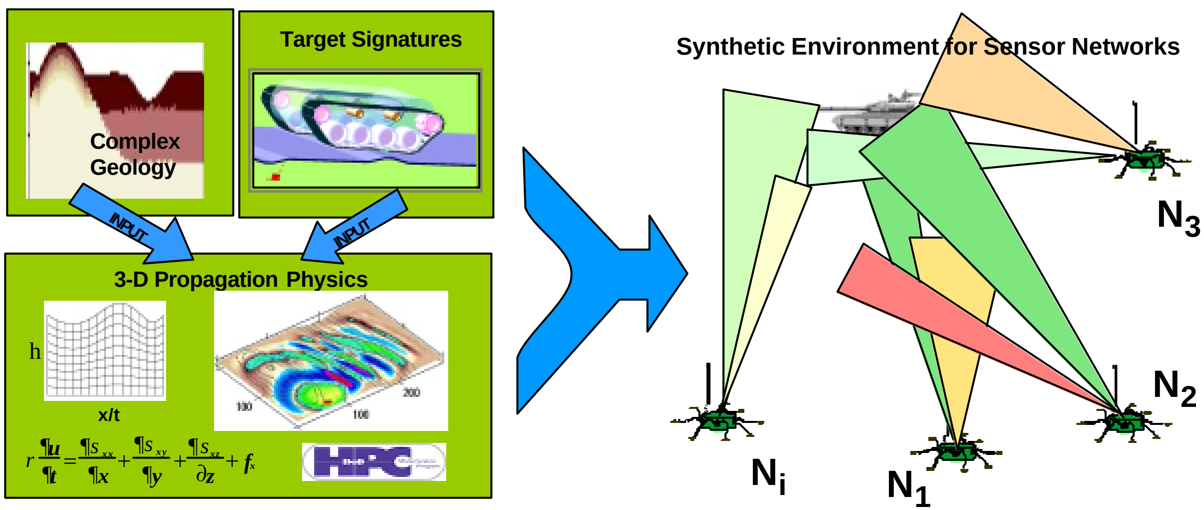
Solution Approach

OBJECTIVE:

Propagate target specific ground vibrations to sensors. Achieve fidelity comparable to field data.

APPROACH:

- **3-D wave equation**
- **Topography, heterogeneous geol.**
- **Complex ground forcing**
- **Soil attenuation**



Substantively reduce reliance on field trials in early stages of prototype development

Methods

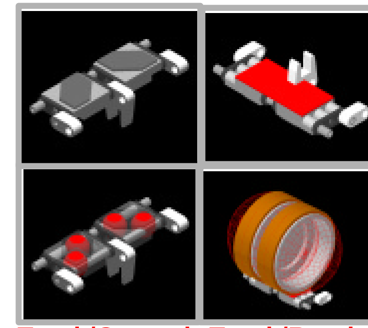
Ground Force Inputs: Vehicles

OBJECTIVE:

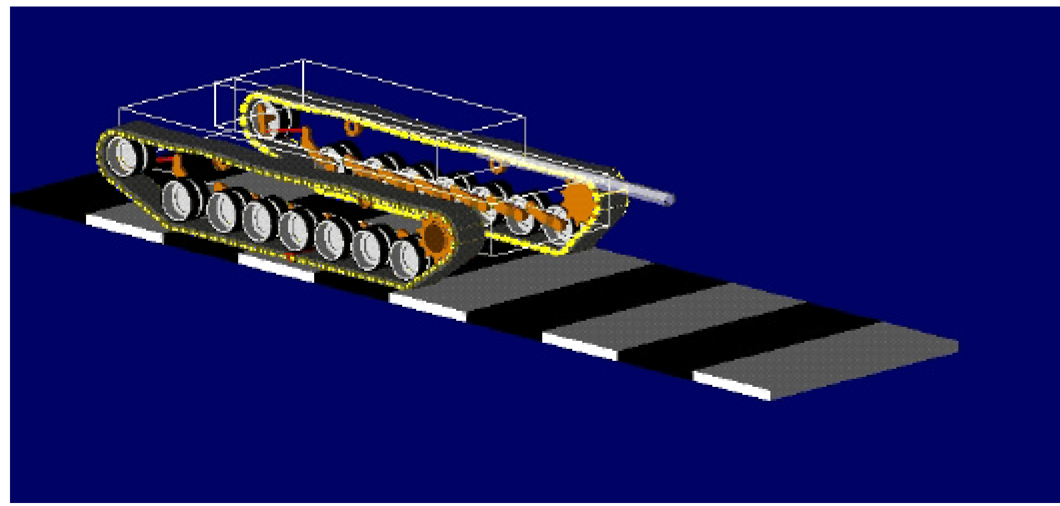
Generate ground forces for any moving target

APPROACH:

Database from 3-D dynamic mechanical vehicle modeling

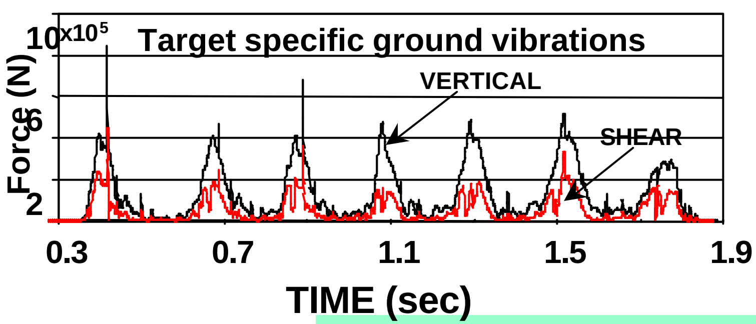


Track/Ground Track/Roadwheel



Target Inventory:

BTR80, BMP, T72, M1, and Personnel (in any combination)



Critical for signature generation, flexible, re-configurable

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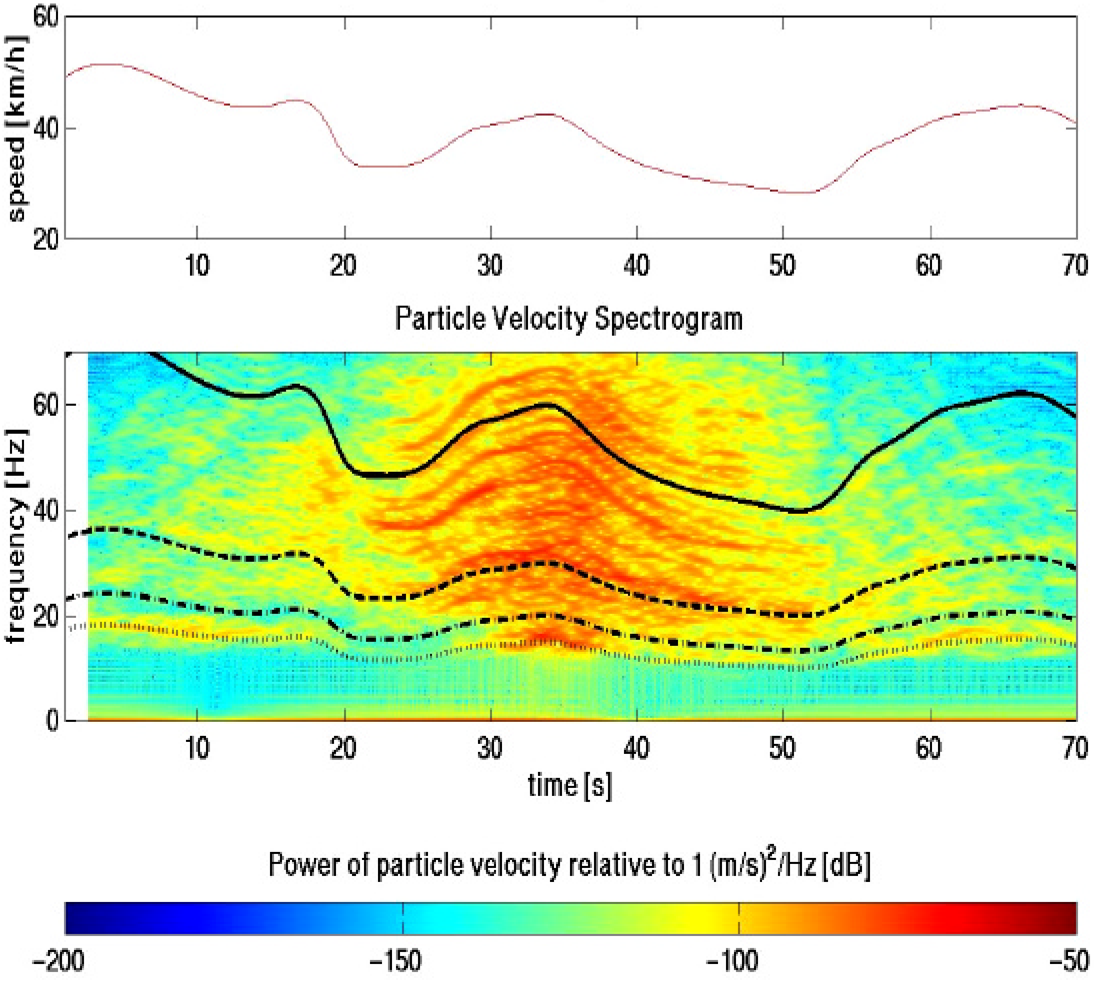
Methods

Synthetic Seismic Signature

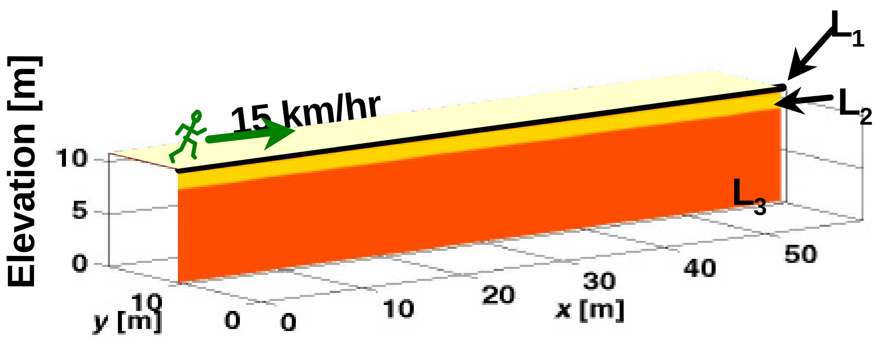
- Harmonic lines correctly follow track block impact rates.

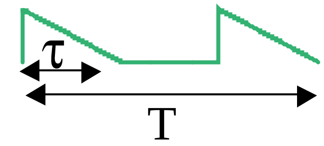
- Correct signal level and decay rates.



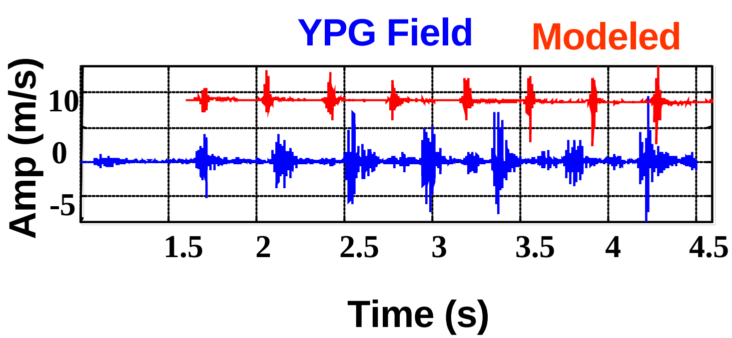
Methods

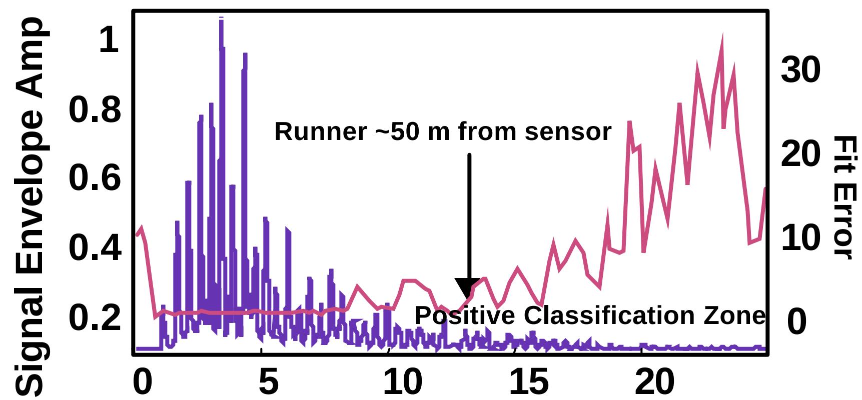
Ground Force Inputs: Personnel





Footstep Classifier:
2 parameter, Saw Tooth Pattern used as target "classifier"





highlight

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Methods

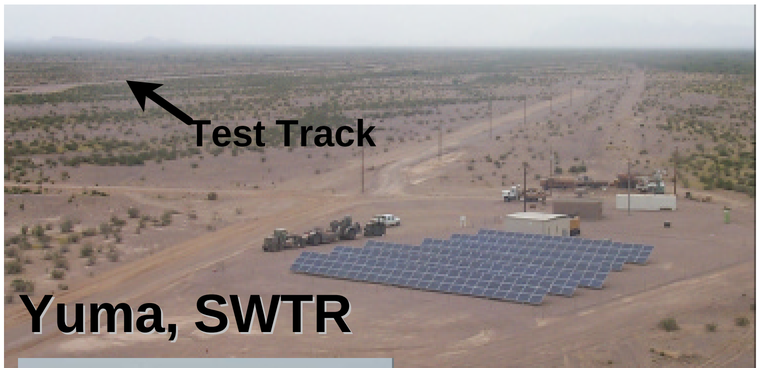
Propagation Validation

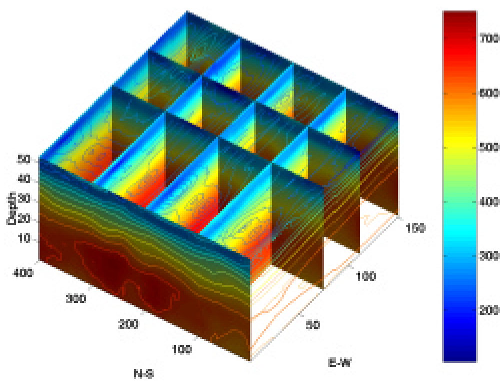
OBJECTIVES:

- <u>Validate</u> seismic model
- Provide virtual YPG seismic test environment

APPROACH:

Exhaustive direct geophysical measurement of 3-D geology





Detailed Geophysical Characterization

- Borehole logging
- Refraction
- Reflection
- Curved ray tomography
- Surface wave inversion

3-D subsurface map of geology for propagation modeling parameters

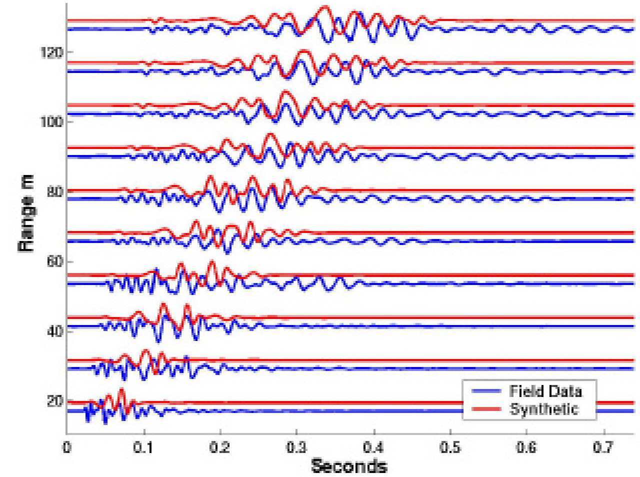
- Resolution of 0.5 m
- Vp, Vs, Qs, Qp, r

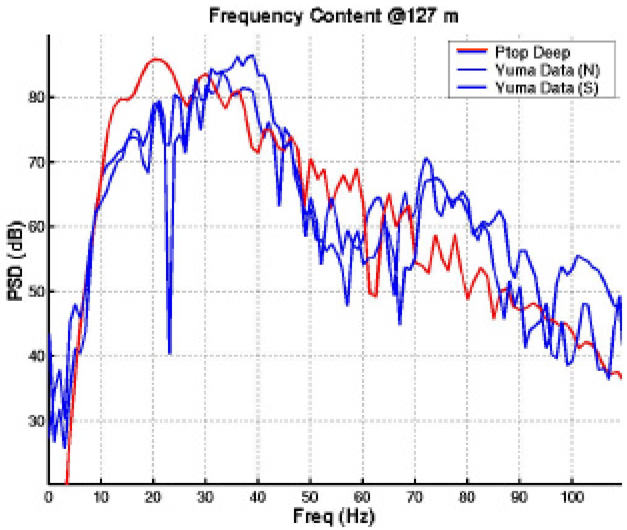
Will support system development with simulations having all characteristics of field data.

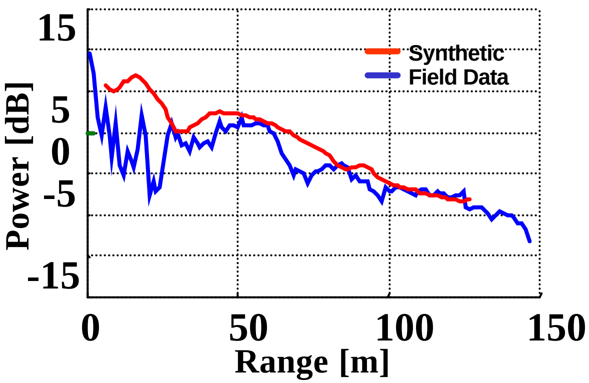
Propagation Validation Results

Excellent agreement for:

- Arrival time of body waves
- Multiple surface wave modes
- Spectral character
- Spatial decay rates







Demo

Demonstration of Geologic Adaptation

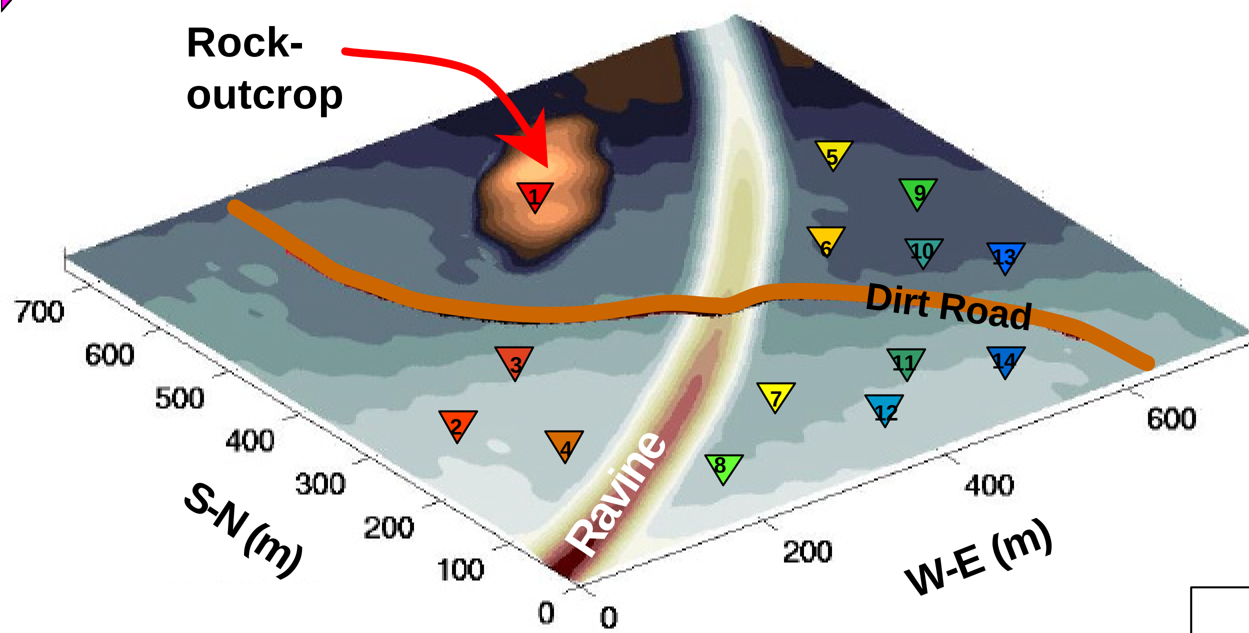
OBJECTIVES:

- Estimate geologic specific parameters needed for Range and LOB tracking.
- Compensate for geologic heterogeneity

APPROACH:

- Deploy/utilize seismic sources with known location and magnitude
- Invert for needed geologic information

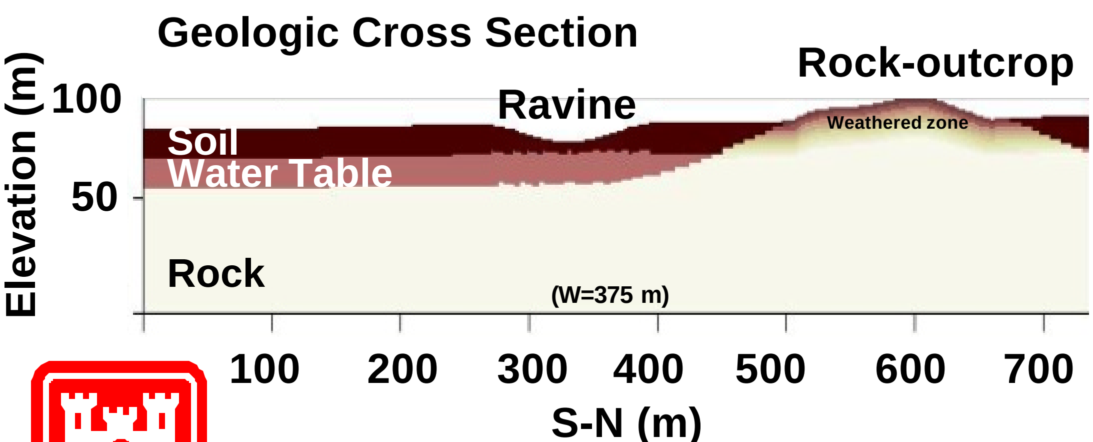
Terrain - Geology - Network



- Real-world geologic features common to many “hot-spots”
- Seismic UGS’s can be placed anywhere
- Spatial scale is practical for system development

Network Node:

Seismic Array: 3 m radius, 6 sensors



	Vp (m/s)	Vs (m/s)	Density (kg/m^3)	Q
Soil	1000	577	1750	10
Water Table	1600	625	2000	15
Rock	3500	2333	2650	36

Calibration Events for Network Adaptation

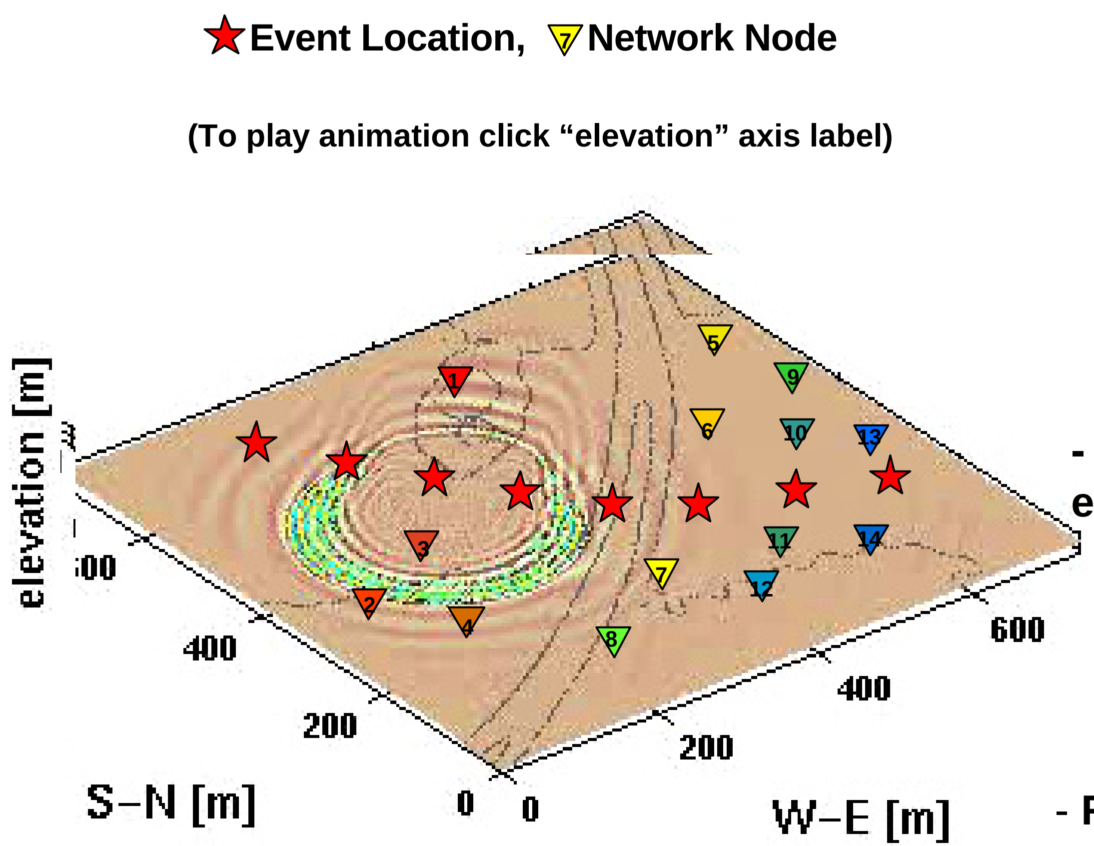
Large Amp variations (>25 dB)

Large Ray Deflections (>20º)

Strong Reflections

Strong Dispersion

Asymmetric Wavefronts



-Required for Adapting to Geology

-8 Pulse events at 1s interval

- Pulses spaced evenly along expected path

-Vertical ground motion shown

- Realistic validated propagation

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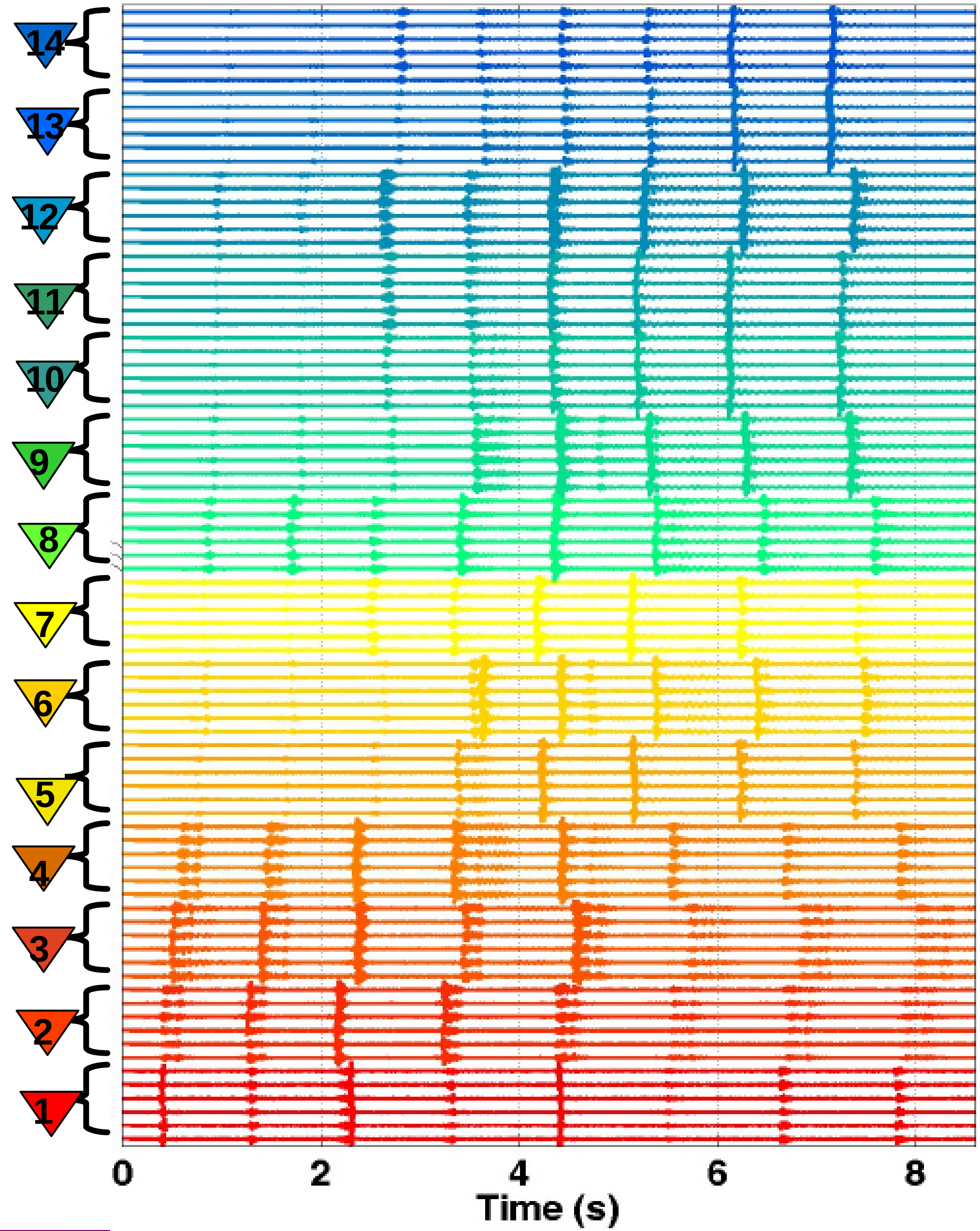
Network Signals

Each Pulse event occurs with:
Known Location
Known Time
Known Magnitude

Large Changes in character of each calibration event

Each UGS Node, 6 vertical motion seismic sensors (84 total sensor channels)



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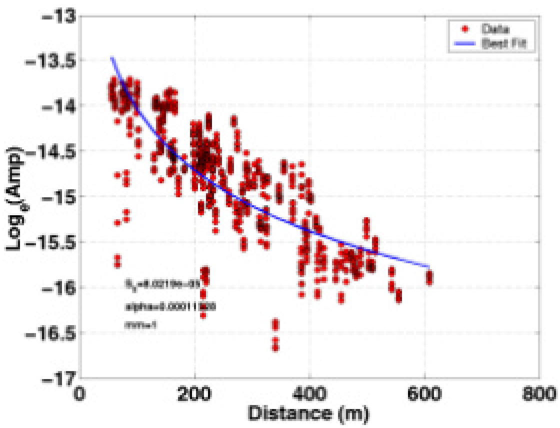
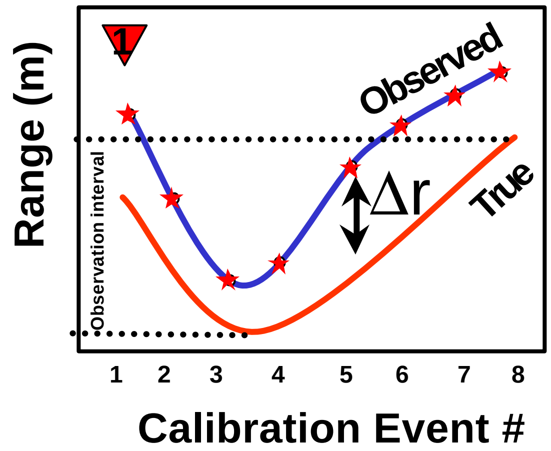
Determination of Range and LOB Adaptation Functions

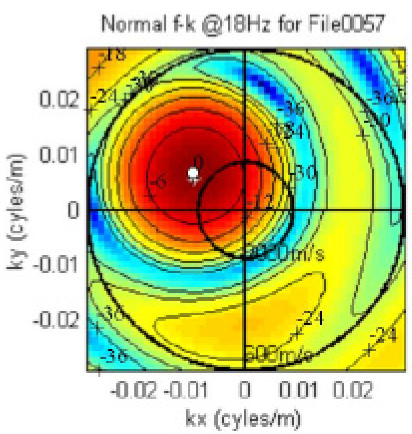
Inversion for "gross" Range parameter (a), w/ Range Eq.

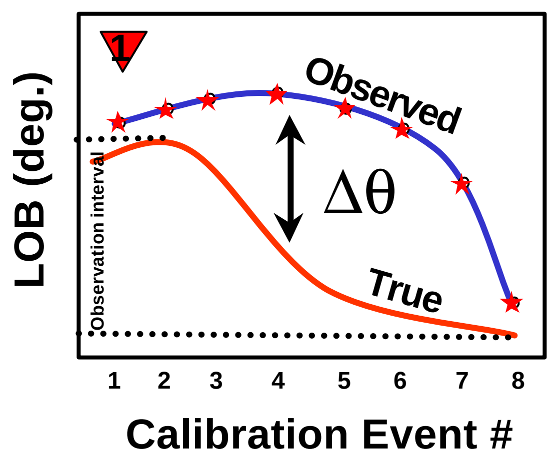




Range Correction Function Over observation interval

$\Delta r_1\ (r_{observed})$





LOB Correction Function Over observation interval

$\Delta\theta_1\ (\theta_{observed})$

Demo

Simulated Vehicle Drive Through

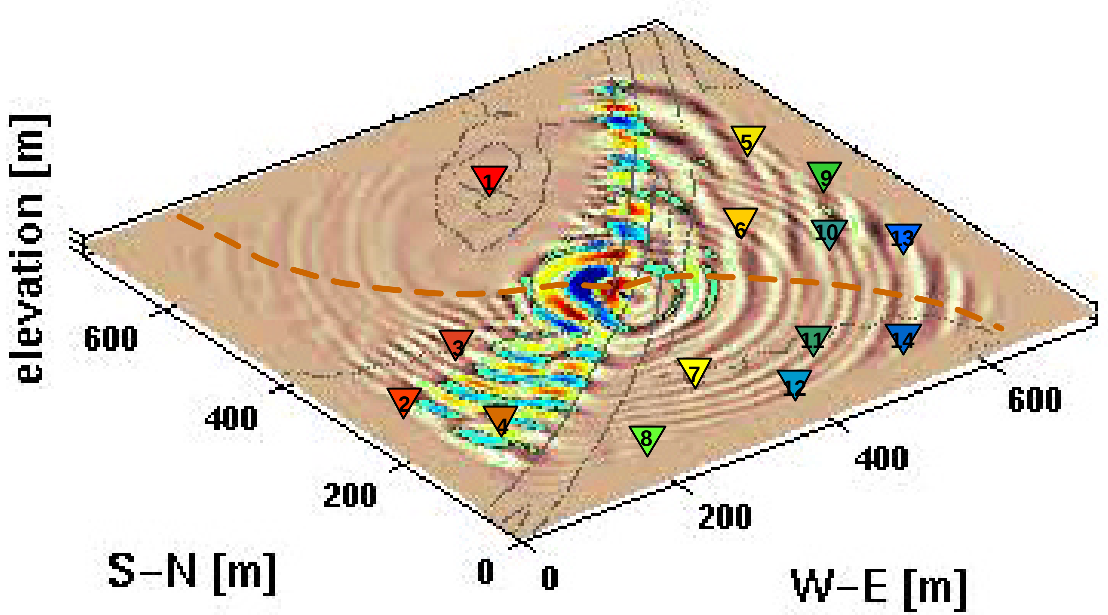
Continuously moving vehicle with changing speed

CRAY T3E
256 Processors
90 h calculation

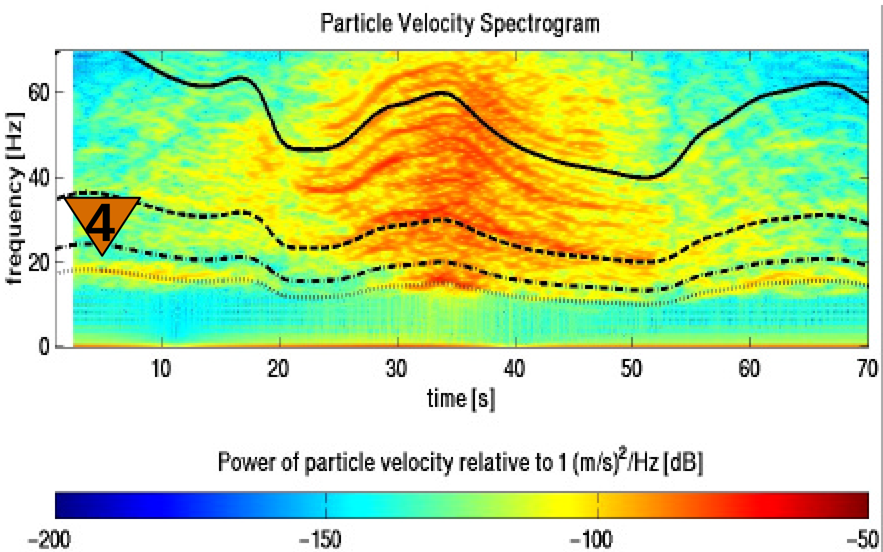
DoD HPC Challenge Grant
(500k CPU-h/yr, ~$1.75M/yr)

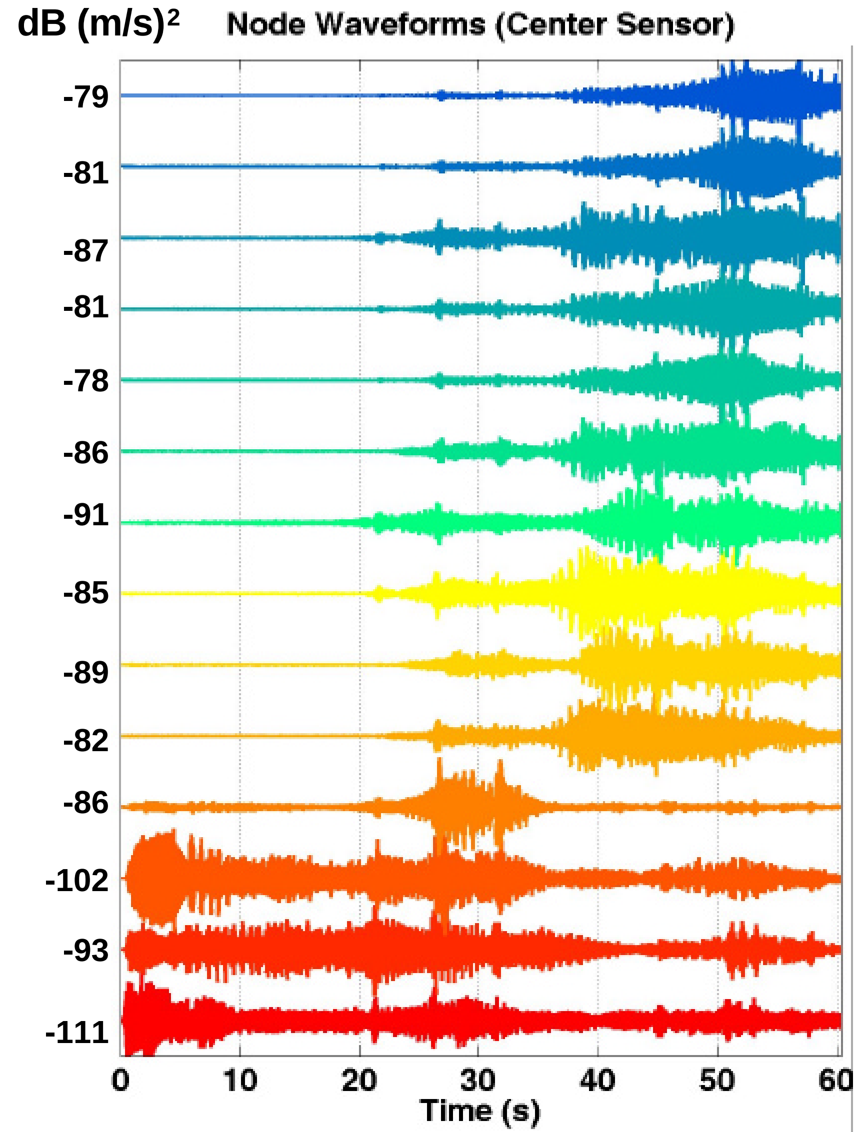
<u>Comparable to acoustic tracking in a wind storm!</u>

(To play animation click "elevation" axis label)



Network Signals





- Peak signal power varies over 30 dB

•More sever than any current field tests

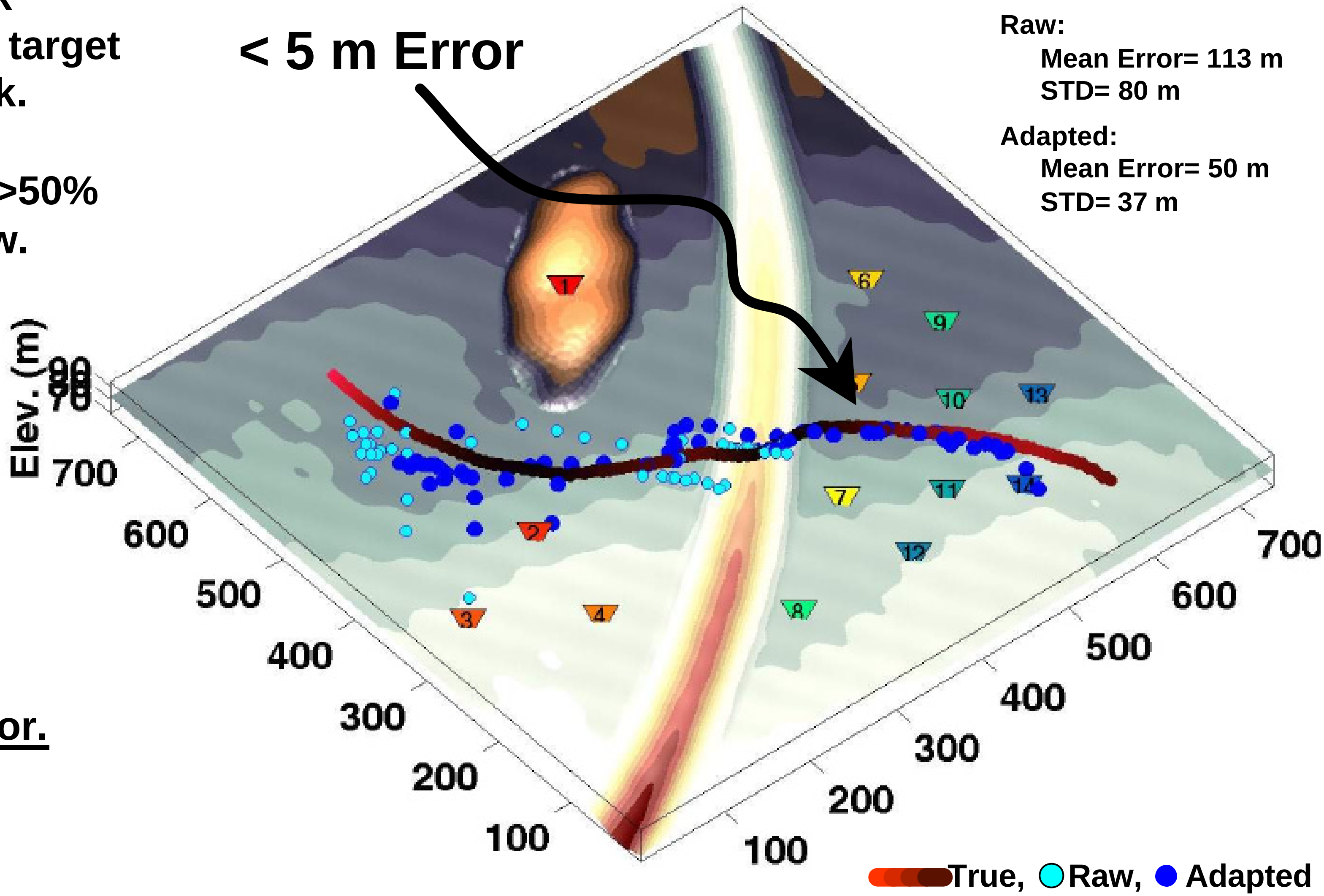
Network Tracking Performance

Excellent track location when target enters network.

Adaptation is >50% better than raw.

Raw:
Mean Error= 113 m
STD= 80 m

Adapted:
Mean Error= 50 m
STD= 37 m



<u>Error closely resembles calibration error.</u>

Summary

Summary

Seismic Sensors are under-exploited in battlefield systems

- Effective performance out to 1,000 m
- Bearing Estimation (~3 degrees RMS LOB error @ 1km)
- Range Estimation (~75 m RMS range error @ 1 km)
- Robust performance under poor atmospheric conditions (winds > 50 km/hr)

Simulations:

- Exceptional fidelity with all the attributes of field data
- Target specific signatures
- Virtual test environment is highly cost effective (reduced reliance on field trials in early developmental stages)
- Enabled by modern high performance computing

Demonstration:

- Adaptation to sever geologic conditions
- Fully realizable implementation w/ minimal impact on primary system components
- Comparable field experiments are > 5yrs away.