SAND2011-5296C

Advanced Approaches for the Detection of Underground Tunnels

Underground Battlespace Technical Interchange Program

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Fort Belvoir, VA

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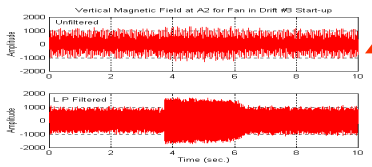
Tunnel Detection and Characterization History

- Cross Laboratory Multidisciplinary Team Approach
  - Geoscience, Signal Processing, Real-Time Processing,
  - Combine Modeling, Analysis, and Testing
- Sandia (DOE) LDRD Funding in Key Technology Areas
- Requirements driven Spiral Development
- Systems View
  - Basic Understanding - Phenomenology
  - Sensors, Signals, Processing, Analysis
  - Systems Integration

Otay Mesa Tunnel

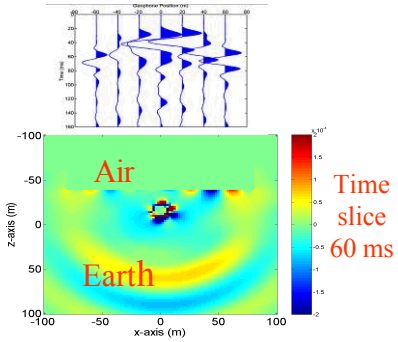
Shallow Tunnel Activity

Application to Large Tunnel HDBT's



Signals and Analysis

Sensor Dart



3D Modeling

S&T Foundations

- DOE Basic Energy Sciences
- DOE Fieldable Sensor Systems
- DOE Fossil Energy
- DOE Weapons Support in Geomechanics
- Geologic Test Support
- Non-Proliferation Global Monitoring

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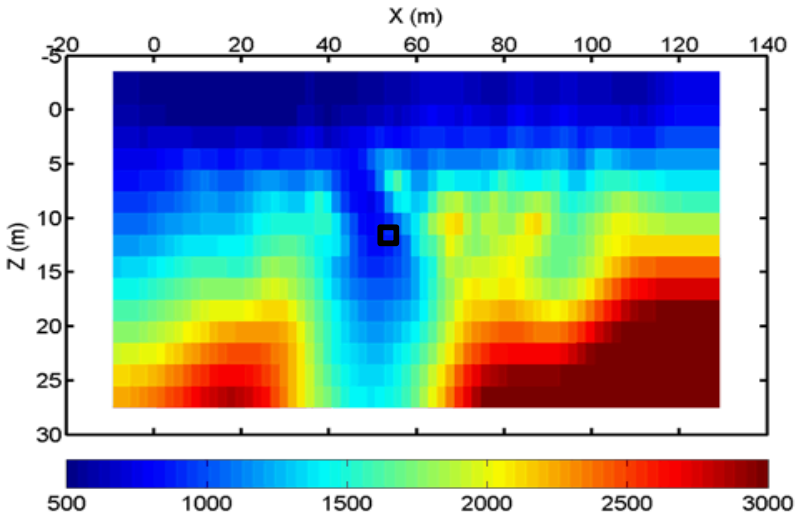
Comparison Table

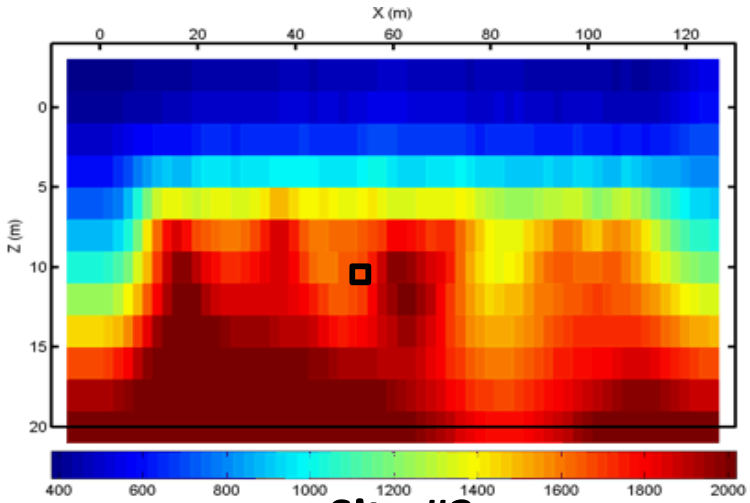
Approach	Phenomena	Pros & Cons	Comments
Seismic Tomography	Velocity variations from first arrival travel times	•Produces a nice image •Rays avoid tunnels •Smoothing effects	Want more realistic code: anisotropic, poroelastic, full waveform inversion
Seismic Raypath	First arrivals avoid low velocity (tunnel) areas	•Part of tomography process •Broad area indicator	Only recently utilized in this manner
Reverse Time Migration	Waves are reflected and scattered by inhomogeneities	•Utilizes complete wavefield •Computationally intense	Image is only as good as the background velocity model
Green's Function	Waves are reflected and scattered by inhomogeneities	•Long-term persistent surveillance •Need stationary noise sources	Assumes broadband and diffuse noise – urban may be good

Seismic Tomography

- Active source survey done over known tunnels show mixed results
  - Site #1 is well imaged by tomography
    - Dewatering of soil around tunnel due to age?
  - Site #2 has inconclusive results
    - Poor raypath coverage due to geologic structure
    - Larger source interval (5 m vs. 2.5 m)
- Similar tunnels in similar geology can give different results



Site #1



Site #2

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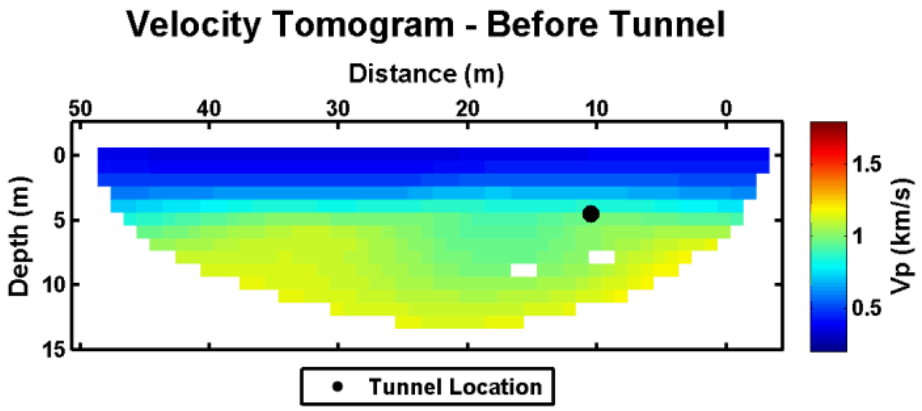
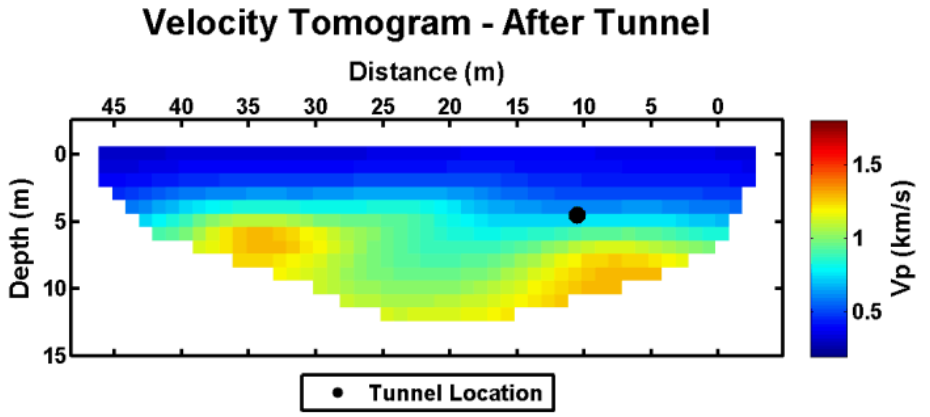
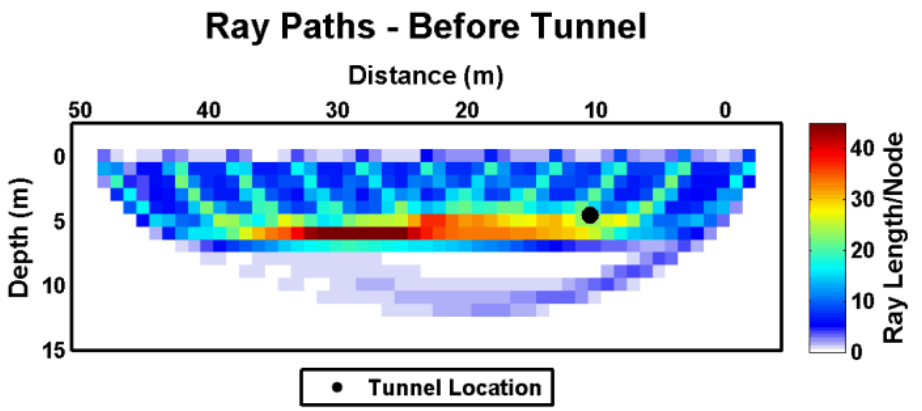
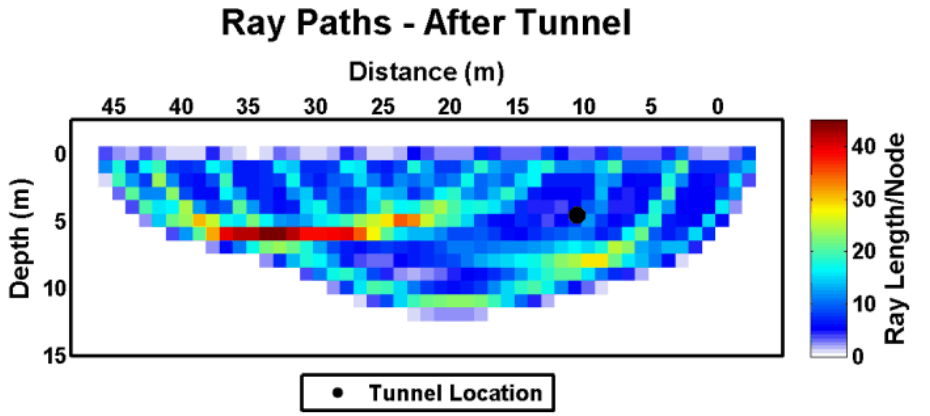
Seismic raypaths may be a better tunnel indicator than tomography









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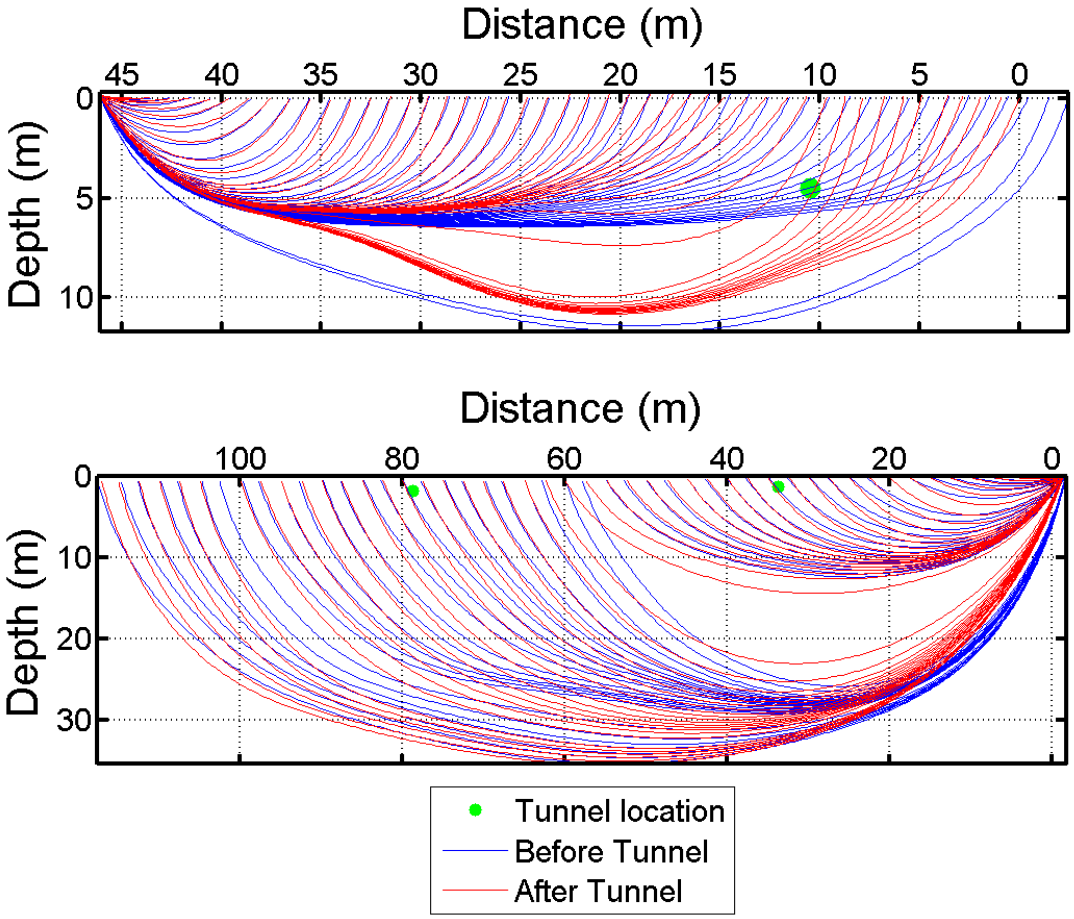
Seismic Raypaths



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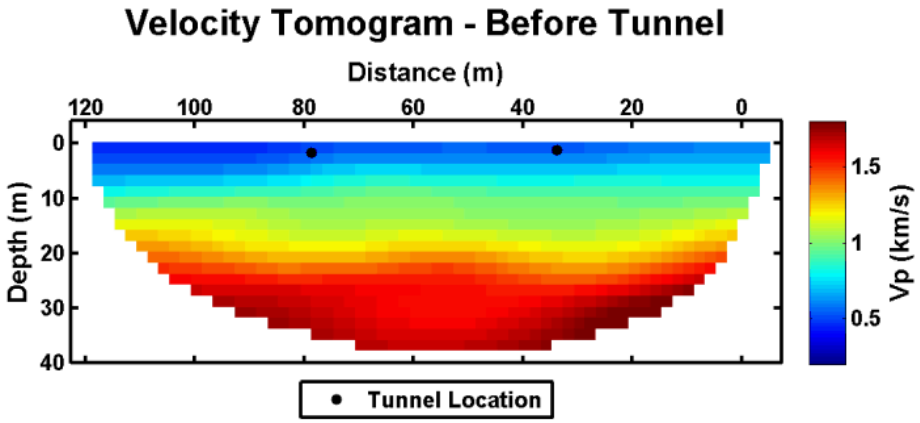
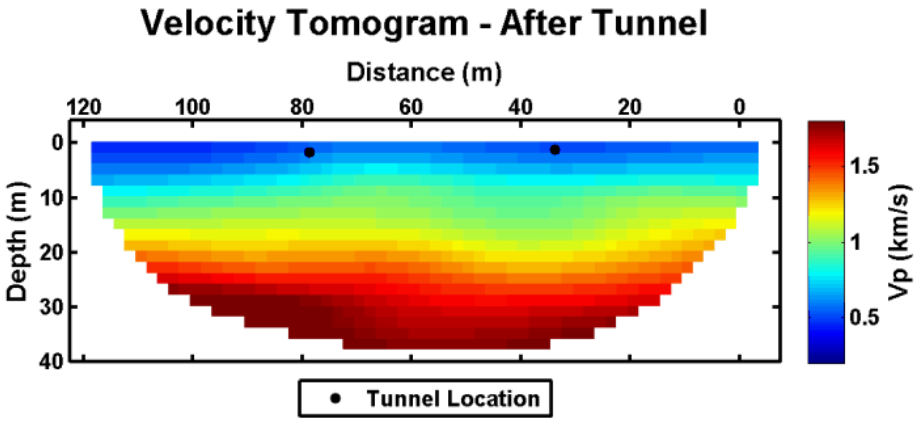
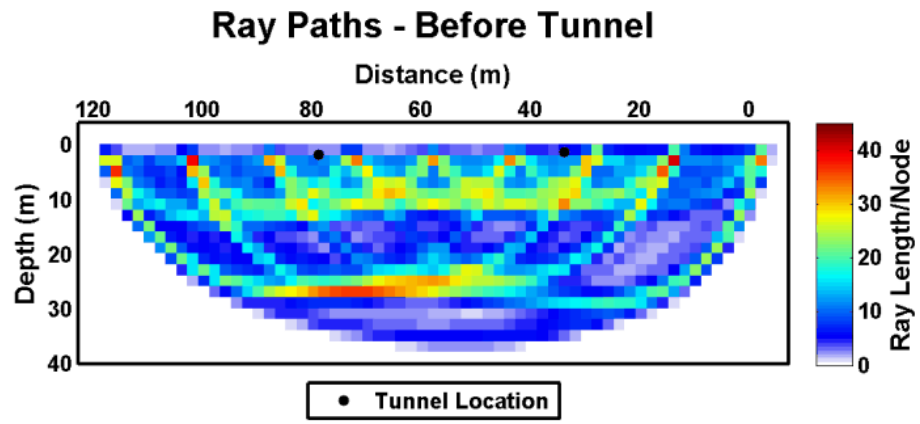
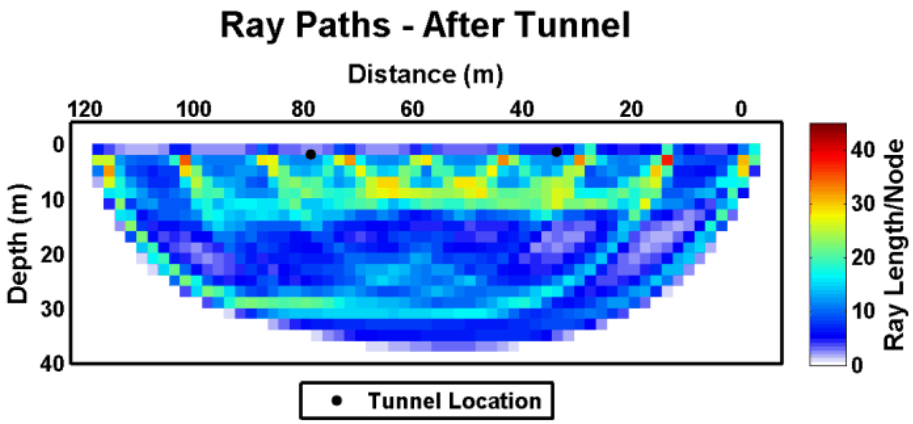
Seismic raypaths are not a good indicator for all cases









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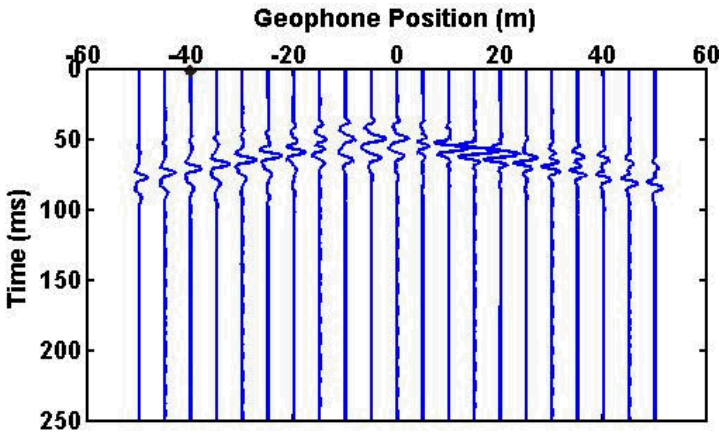
Reverse Time Migration (RTM)

- Full-waveform 3D imaging technique
- Receiver data is time-reversed
- Receivers are activated as sources
- Cross-correlate (at zero time-lag) with source field
- RTM uses the scattered field
  - Direct arrivals removed
  - Best way to do this on real data is a research topic
  - F-K filtering has been used with success
  - This example subtracts the model with no tunnel from the model with a tunnel



Difference between responses with and without the tunnel

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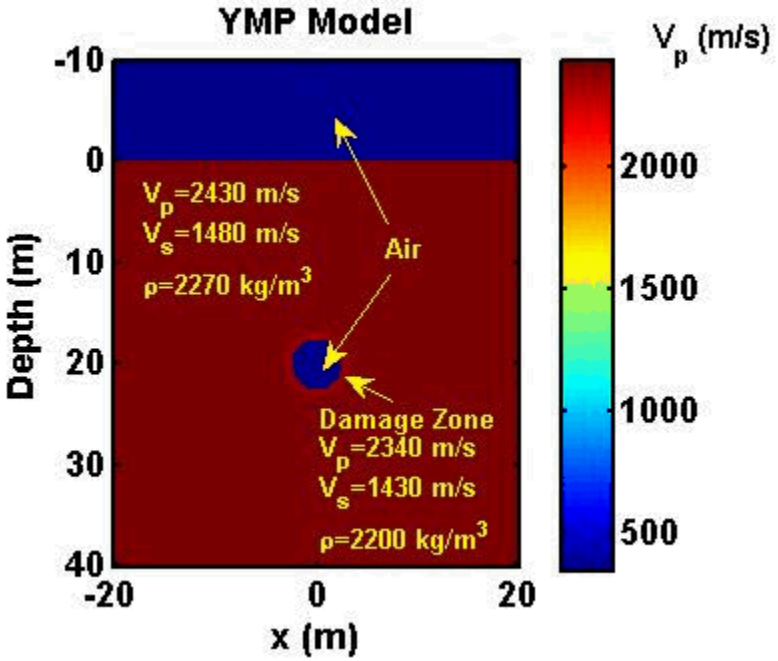
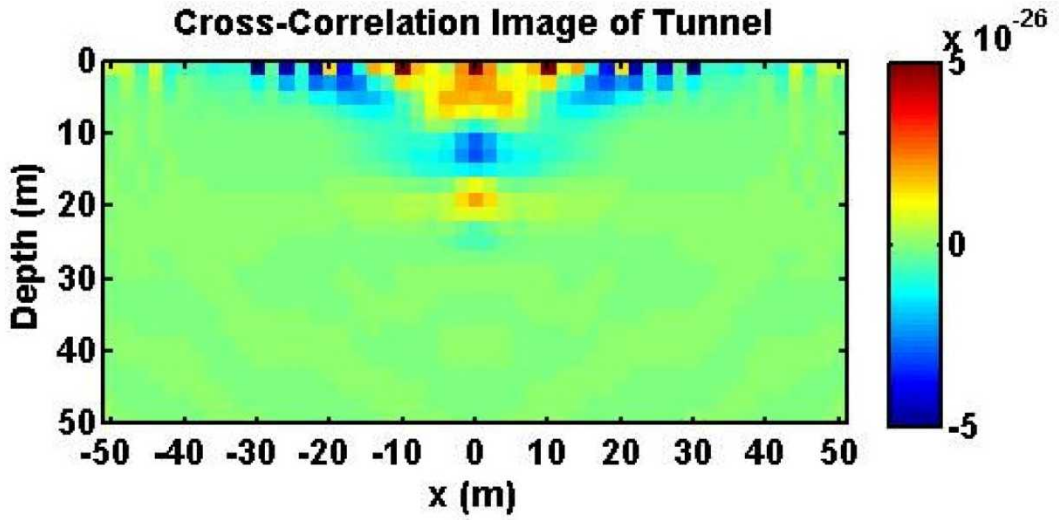
Reverse Time Migration (RTM)
Synthetic Data





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Passive Green's Function

- Long-time cross-correlation of noise
  - Urban environment is an advantage
- Signals are reflected and scattered by inhomogeneities along the path between two receivers
- Result is Green's Function (impulse response)
- If we can prove this method
  - Very powerful for detection of new tunnels
  - Change in subsurface causes a change in the impulse response
  - Advantages of passive source methods
    - Covert
    - Uses sensors that are in place
    - Minimize labor and personnel exposure

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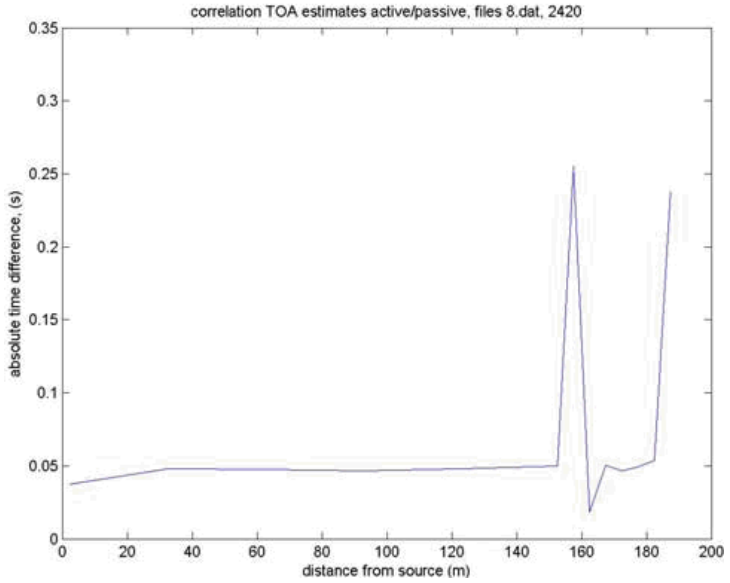
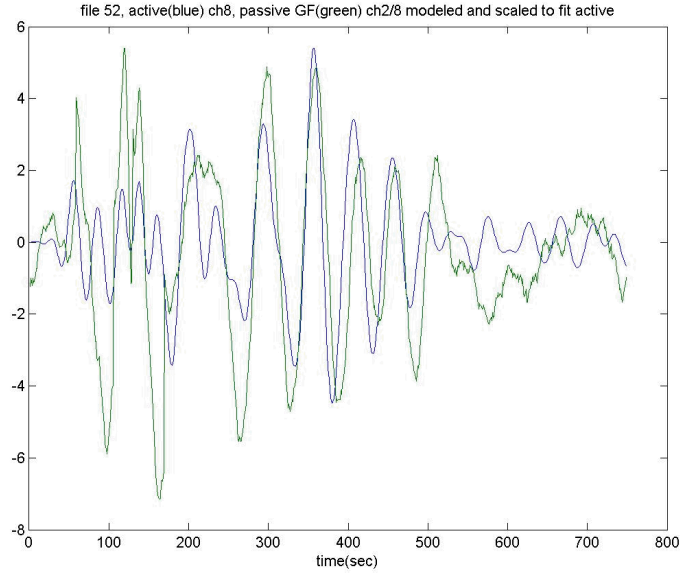
Experiment to test passive Green's Function

- Smaller spatial scale so much higher frequencies
  - Regional scale models typically used
- Compare Green's Function to measured impulse response
  - From accelerated weight drop (AWD)
  - Active data
- Results
  - Signals are similar
  - Green's Function could be a good estimate of impulse response





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Sensing for persistent surveillance

- All detection techniques require interpretation
- Continuous monitoring with change detection to indicate tunneling activity (new voids) has merit
- Requires relatively low cost wide coverage sensing system
- Networked unattended sensors provide solution
  - Layered architecture matches computational power to data processing needs
  - Multi-layer processing optimizes cost per unit area

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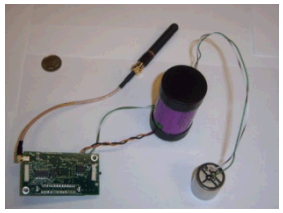
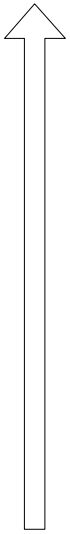
Networked Sensor Technology to support Border Tunnel Solutions

- Leverages many years of LDRD, DoD and OFA Development
- TRL 6 applications in DoD Unattended Ground Sensor Applications
- TRL 6 application to site security
- COTS based Flexible, Extendable Architecture
- Reuse of Algorithms and Software

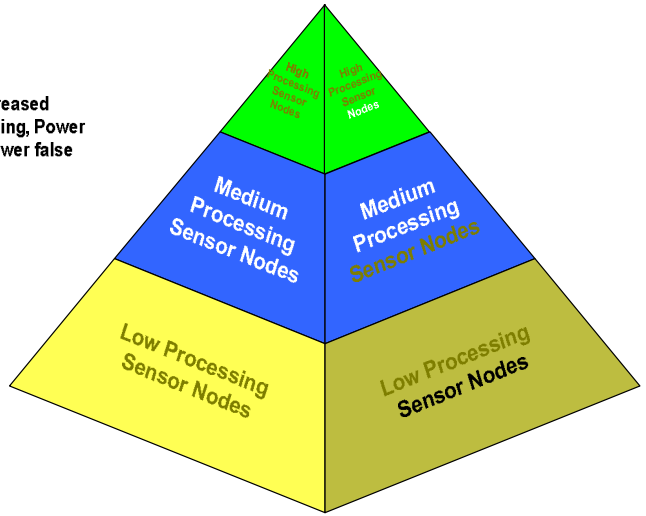
Intelligent Sensor Node
Medium Processing



MOTES based Nodes
Low Processing



Increased Processing, Power with lower false



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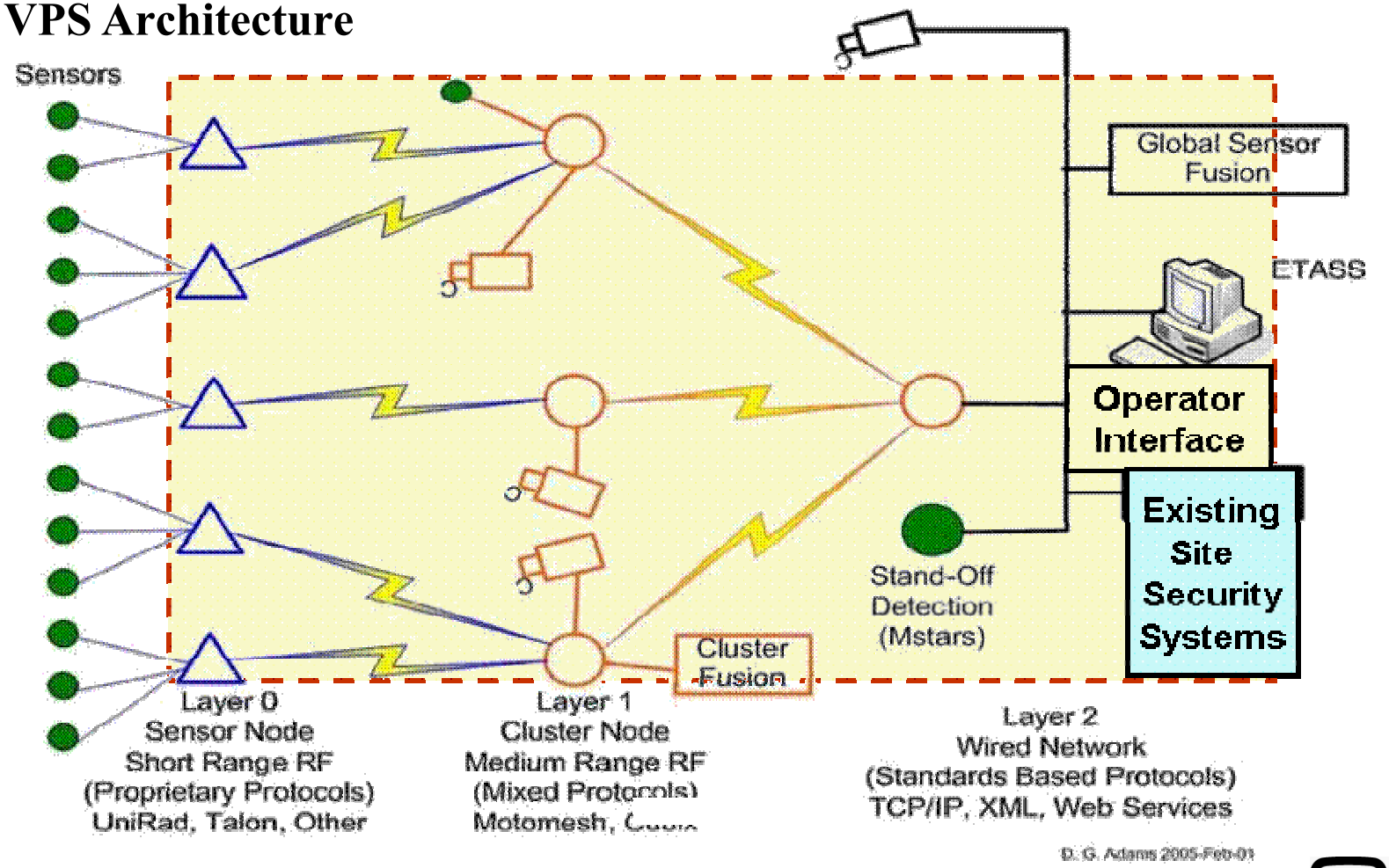
Networked detection architectures and data fusion techniques provide intelligent sensing systems

VPS Architecture



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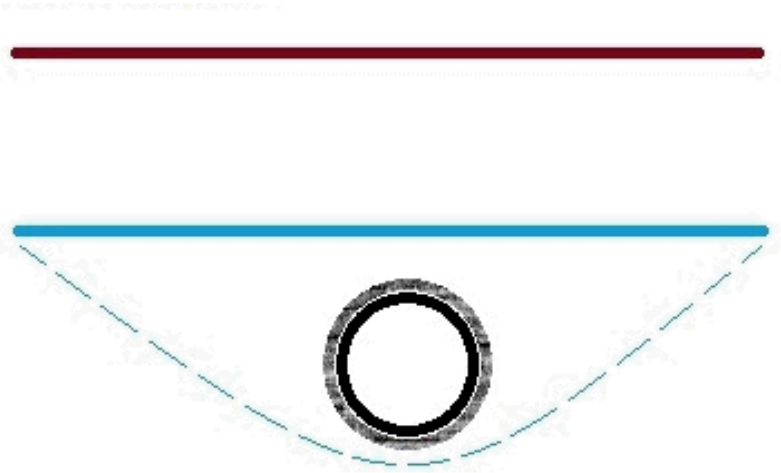
Dewatering of Pore Spaces around Tunnel

- Model multi-phase fluid flow in pore spaces around the tunnel
  - Pumping
  - Evaporation
- Effect on seismic waves



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Path Forward

- Theory, model, experiment approach
  - Modify and iterate as needed
  - Cannot get the whole story from only 1 approach
- Enhance processing techniques
  - Green's Function
  - RTM
- Persistent monitoring & change detection
  - Long-term effects
  - Natural versus man-made changes
- Effects of damage and pore-water around tunnel

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