Double-Difference Tomography for Sequestration MVA DE-FE0002108

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Benefit to the Program

- Program goals being addressed:
  - Funding Opportunity Announcement states that monitoring, verification, and accounting (MVA) *"will require significant research and resources to develop better technologies and protocols to verify and account for the volume of CO_2 injected into deep geologic formations."*
- Project benefits statement:
  - Successful completion of this project will have two primary impacts. First, double-difference tomography will be developed as a tool for imaging changing conditions underground. This is central to the need for MVA associated with sequestration efforts. The second impact, which is no less important, is the development of a new generation of engineers and scientists who are trained with this ability.

Project Overview: Goals and Objectives

- Establish data collection and processing requirements so that double-difference seismic tomography can be used to quantitatively map the mass and propagation of sequestered CO2 as a function of time.
- Analyze a dataset from field monitoring of microseismic activity using double-difference tomography.
- Develop a graduate course to enable students to apply the best, most recent methods for using geophysical tools to image sequestration.
- Train two graduate students as they complete the MS degree.

Sequestration MVA

Monitoring, Verification and Accounting

Where does the CO_2 go after injection?
Does it stay in the reservoir?

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Tomography 101

- Analysis of energy transmitted from one boundary to another allows imaging of body (Radon, 1917)

For best results:

- 360 degrees of coverage
- ‘many’ source and receiver locations

Shared Laboratories
NETL-RUA
Shared Intellect

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Passive Seismic Tomography

- Use events recorded by microseismic system to develop images of rock mass

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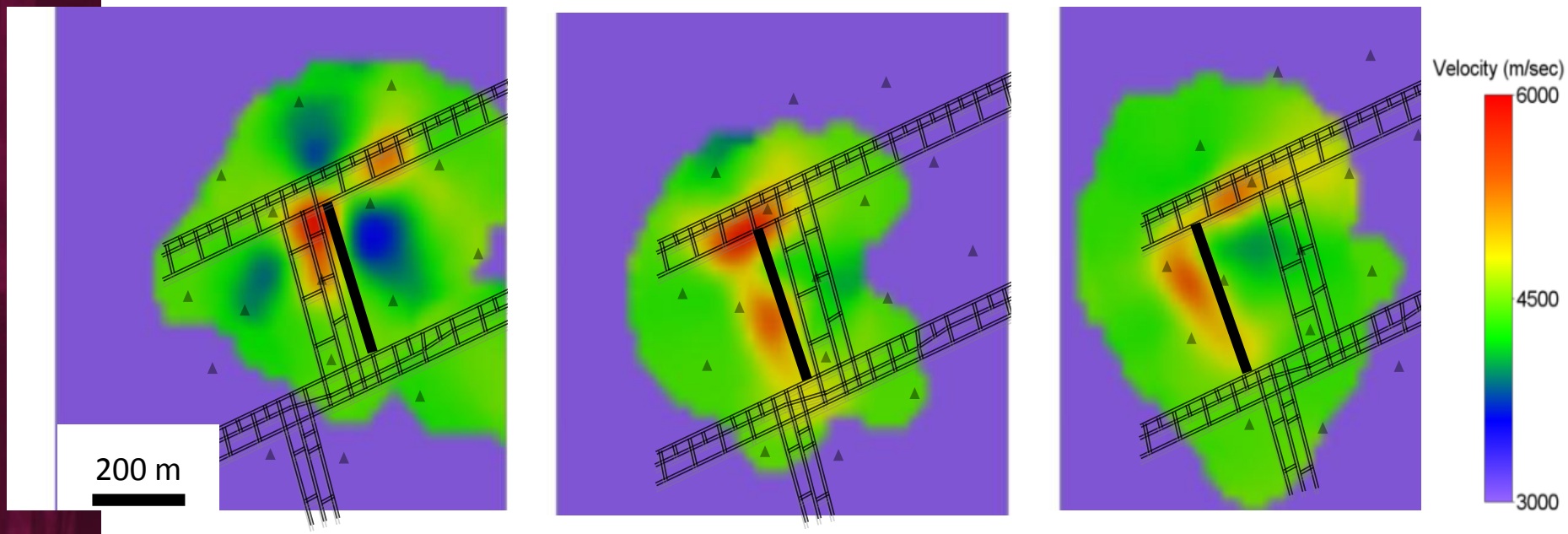
July 26

Aug 1

Aug 6



Application to Carbon Sequestration

- Quantitative MVA
- Quantitative Risk Assessment

- Analyze data from Aneth injection site
- Determine optimal sensor array

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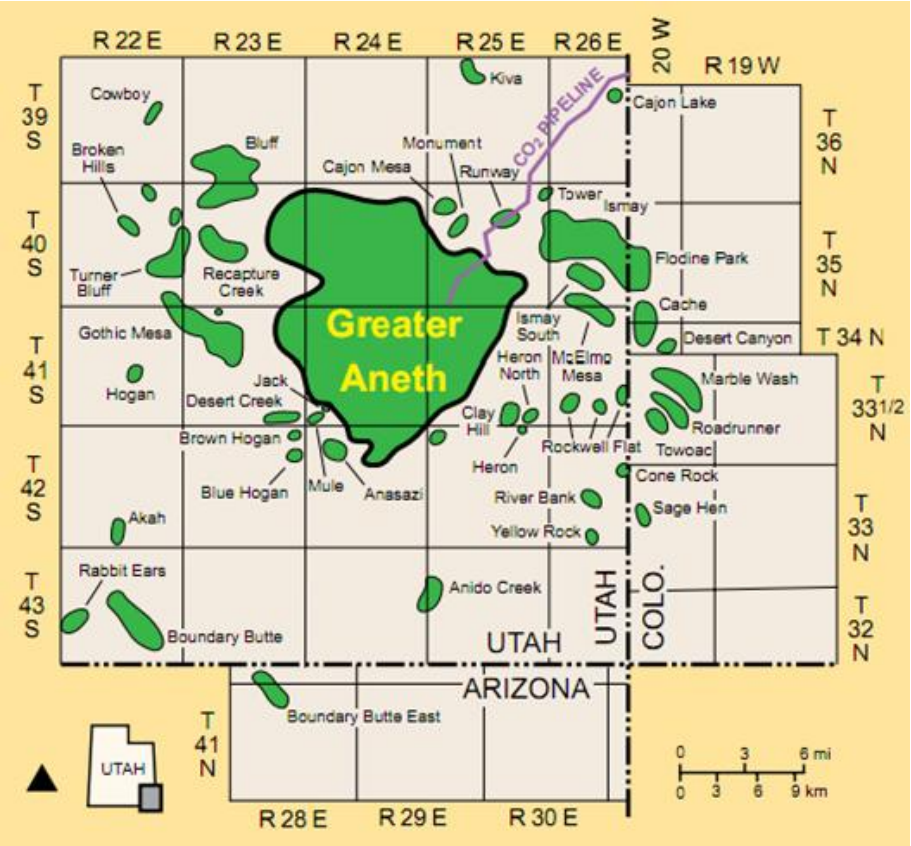
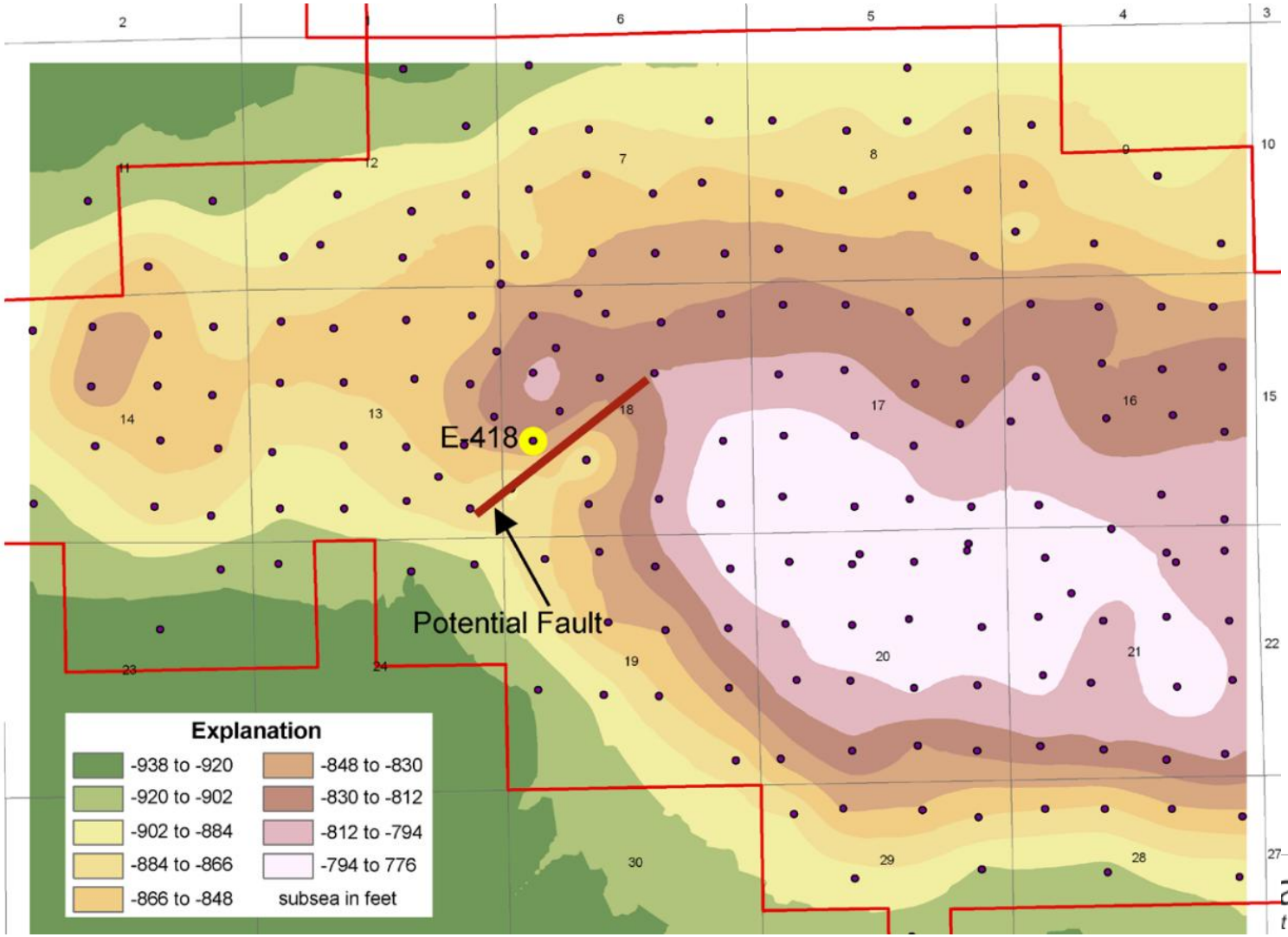
Aneth – Reservoir Information

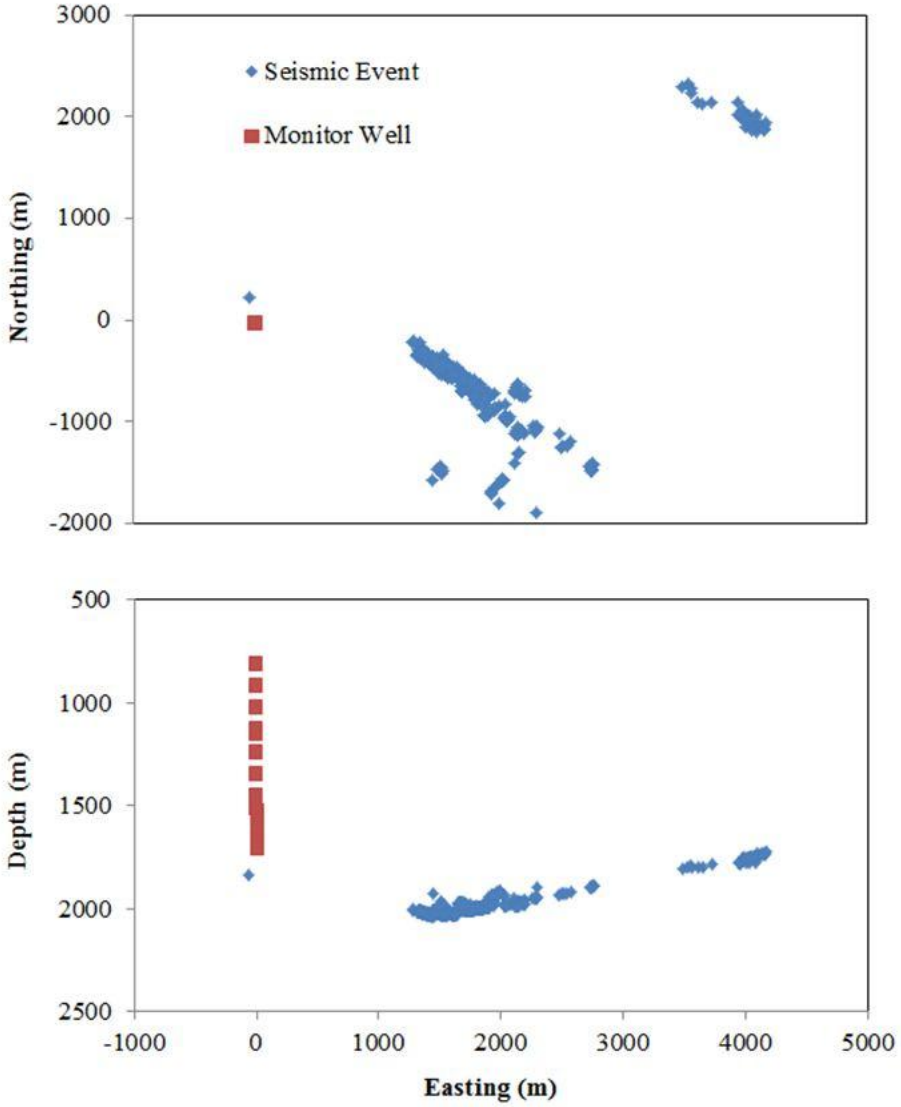


- Aneth oil field, discovered in 1956
- Limestone
- Permeability: 3-30 mD
- Porosity: 10.2%
- Water saturation: 24%
- The caprock is the low permeability Gothic shale, ranging from 5 to 27 feet in thickness

Aneth – Reservoir Extents



Aneth – Event Locations



Time Periods Examined

Time Period	Start Date	End Date	Number of Events
1	4/25/2008	8/31/2008	126
2	9/1/2008	10/31/2008	323
3	11/1/2008	12/31/2008	510
4	1/1/2009	3/16/2009	207

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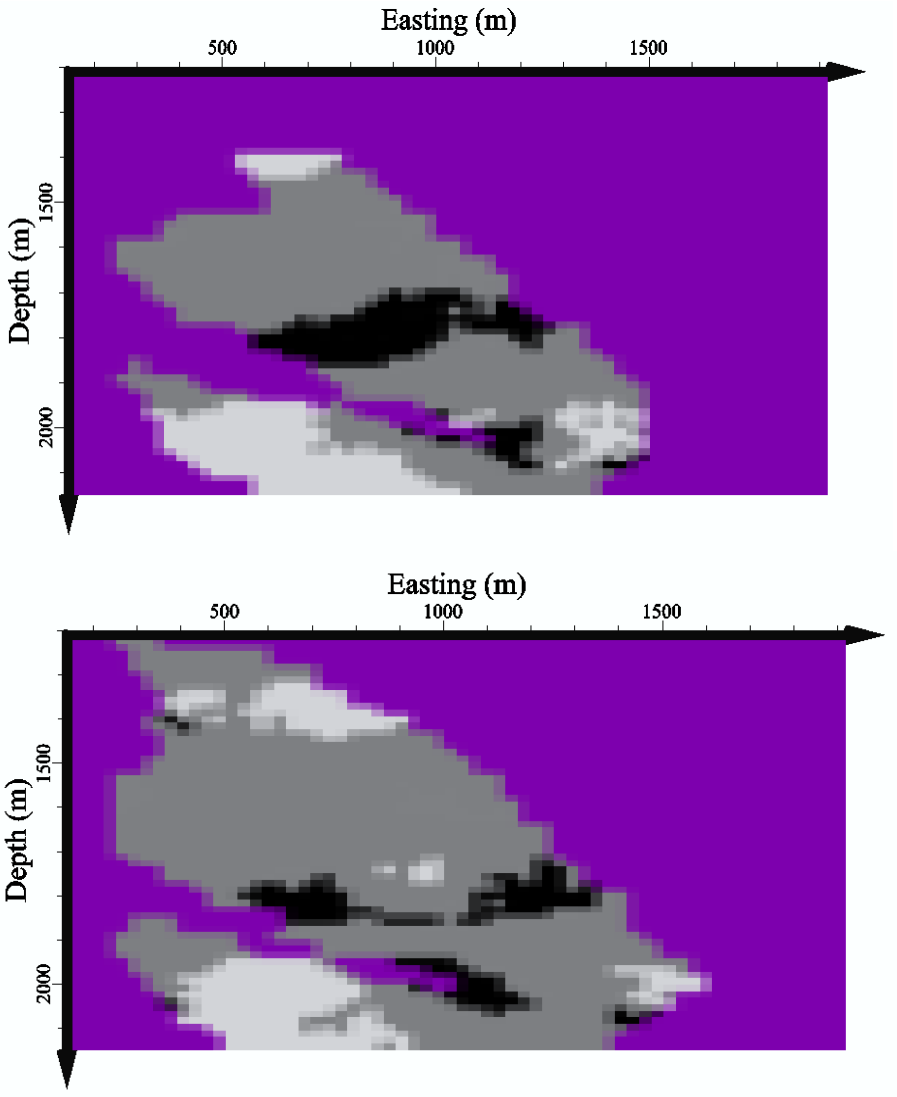
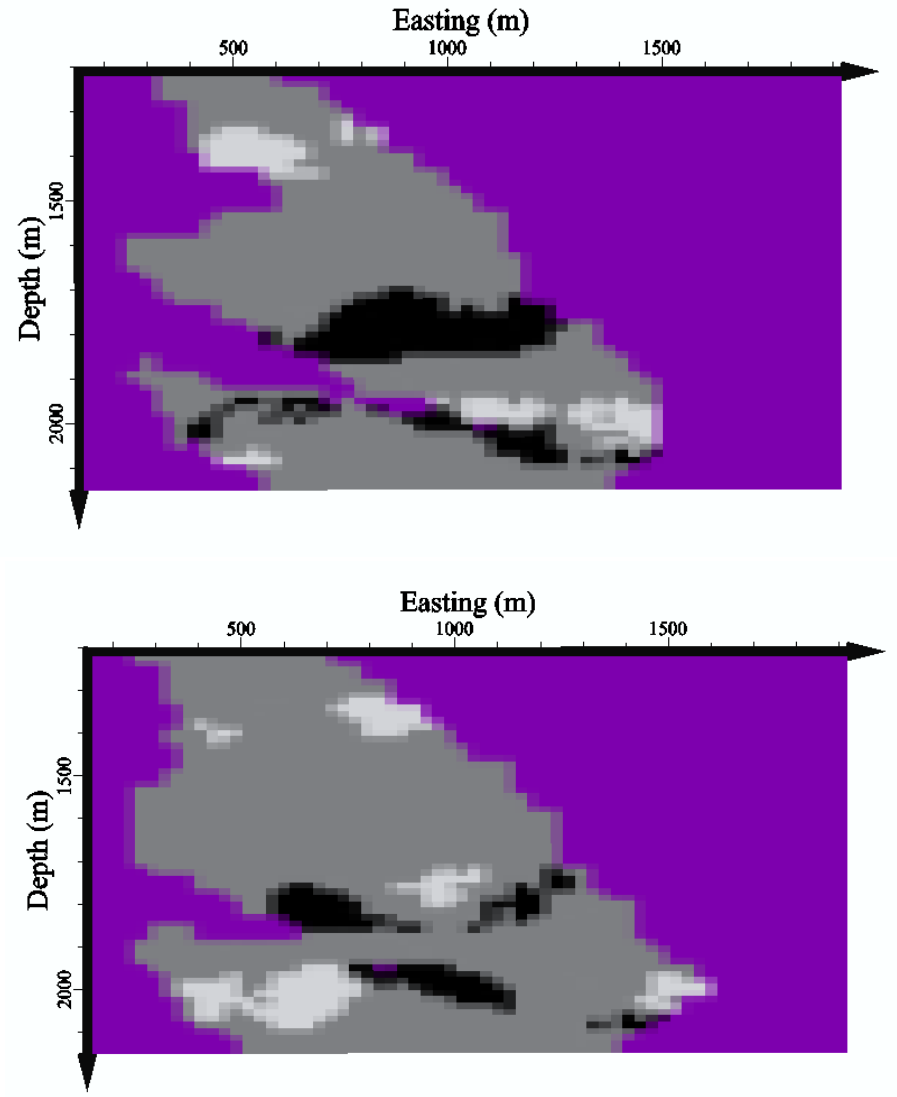
Results

- Time 3 - Time 1 results displayed with two sets of varying confidence
  - Top 25% nonzero DWS values (top)
  - Top 50% nonzero DWS values (bottom)

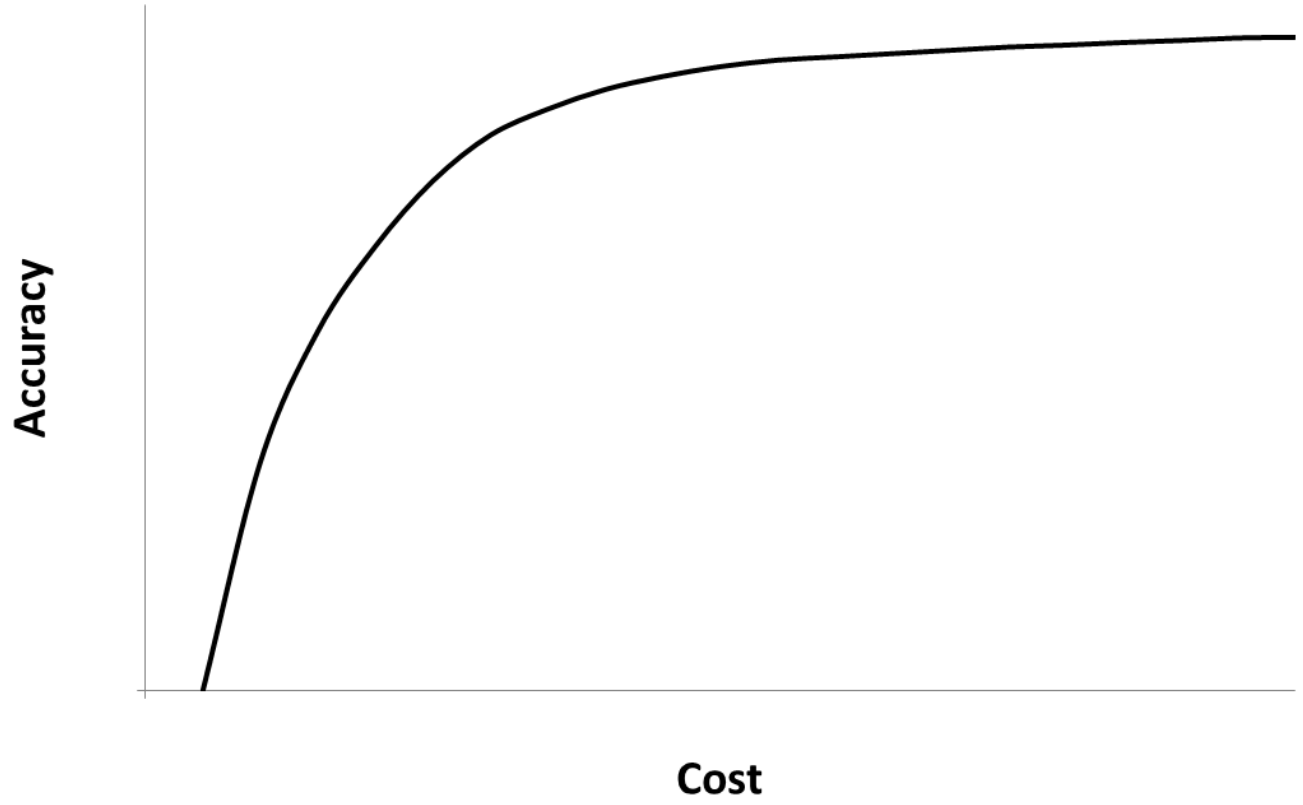


Results

- Time 4 - Time 1 results displayed with two sets of varying confidence
  - Top 25% nonzero DWS values (top)
  - Top 50% nonzero DWS values (bottom)



The Cost of Accuracy



Synthetic Data → Real Analysis

tomoDD inputs:

Event locations
Geophone locations
Travel times
Assumed velocity model

5 Plume Sizes x 5 Event Regions x 5 Geophone Arrays

= 125 Data Sets

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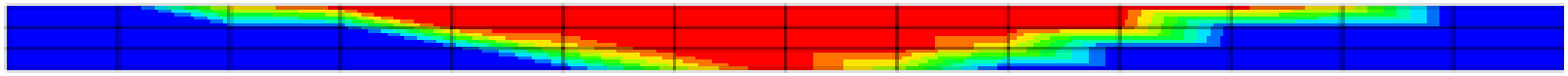
Simulated Plumes

Five velocity models

(five stages of plume growth)

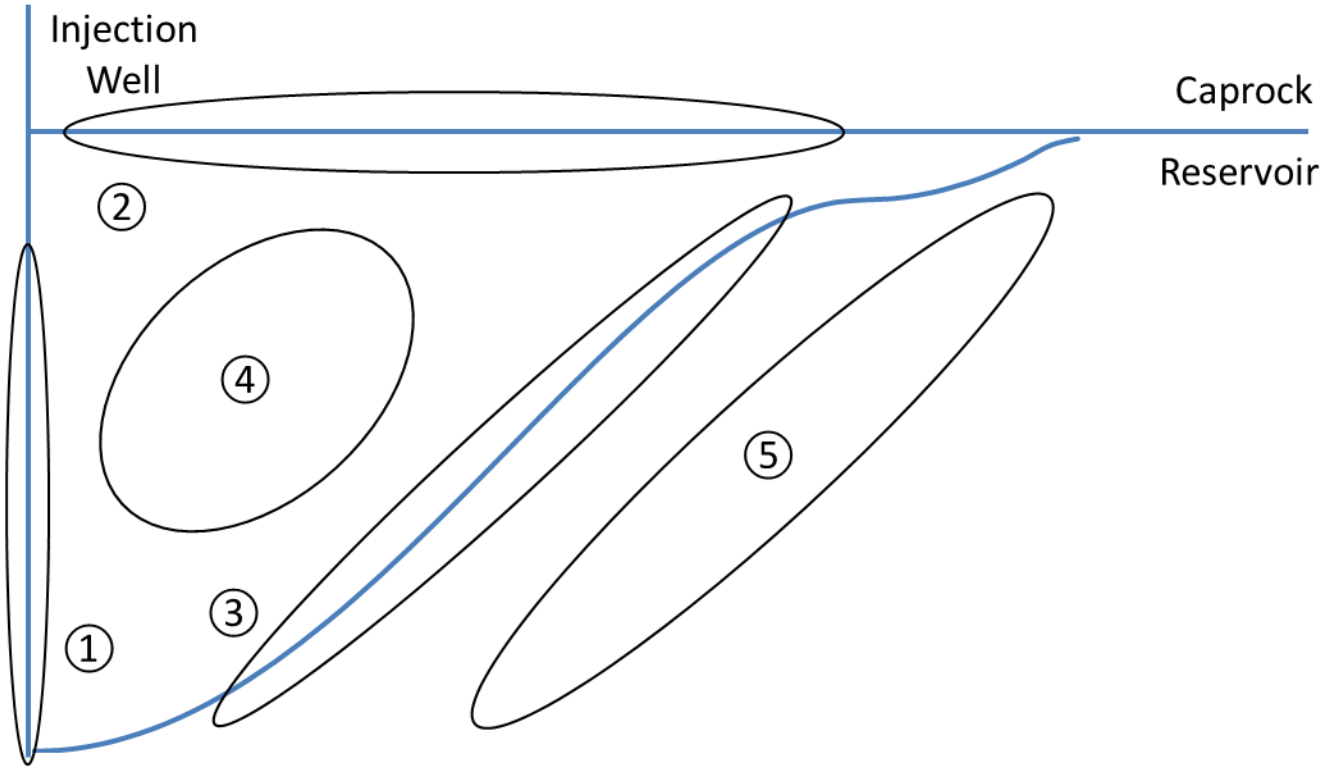
100 m, 250 m, 500 m, 750 m, 1000 m



Assumption:

CO_2 saturation results in a velocity decrease of 10%

Event Locations



Geophone Arrays

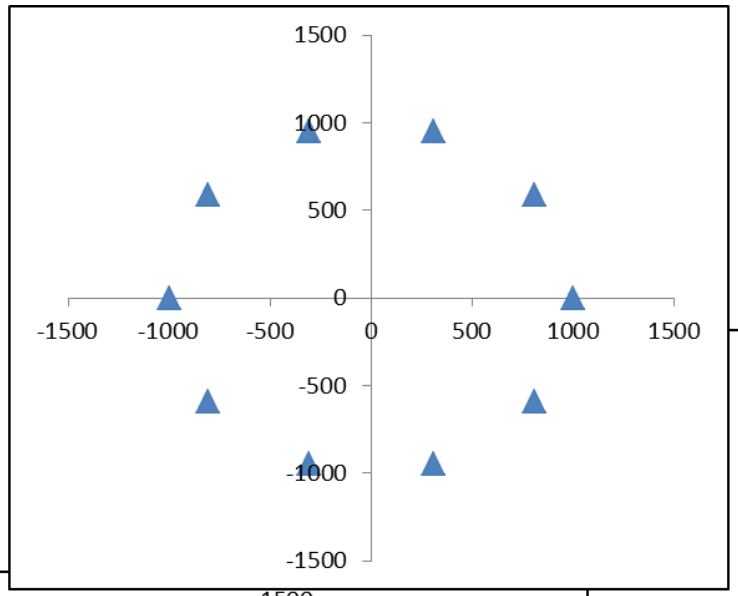
Surface

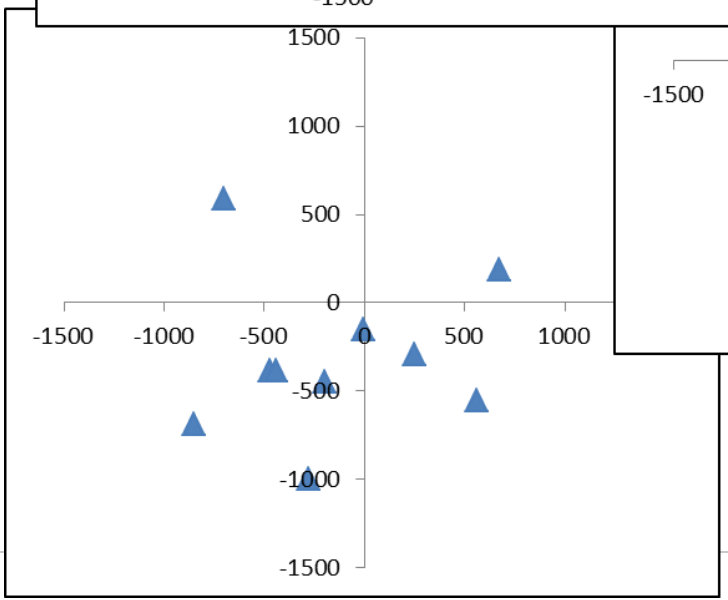
Circle

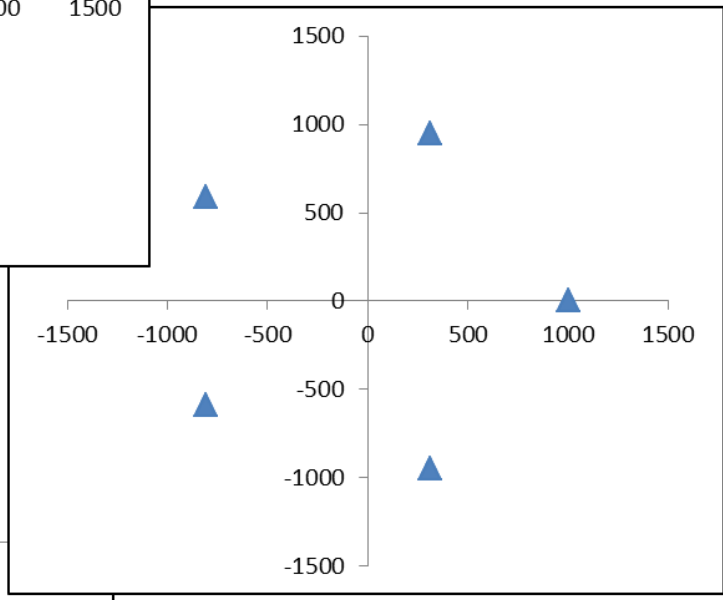
Spiral

Random

Cylindrical







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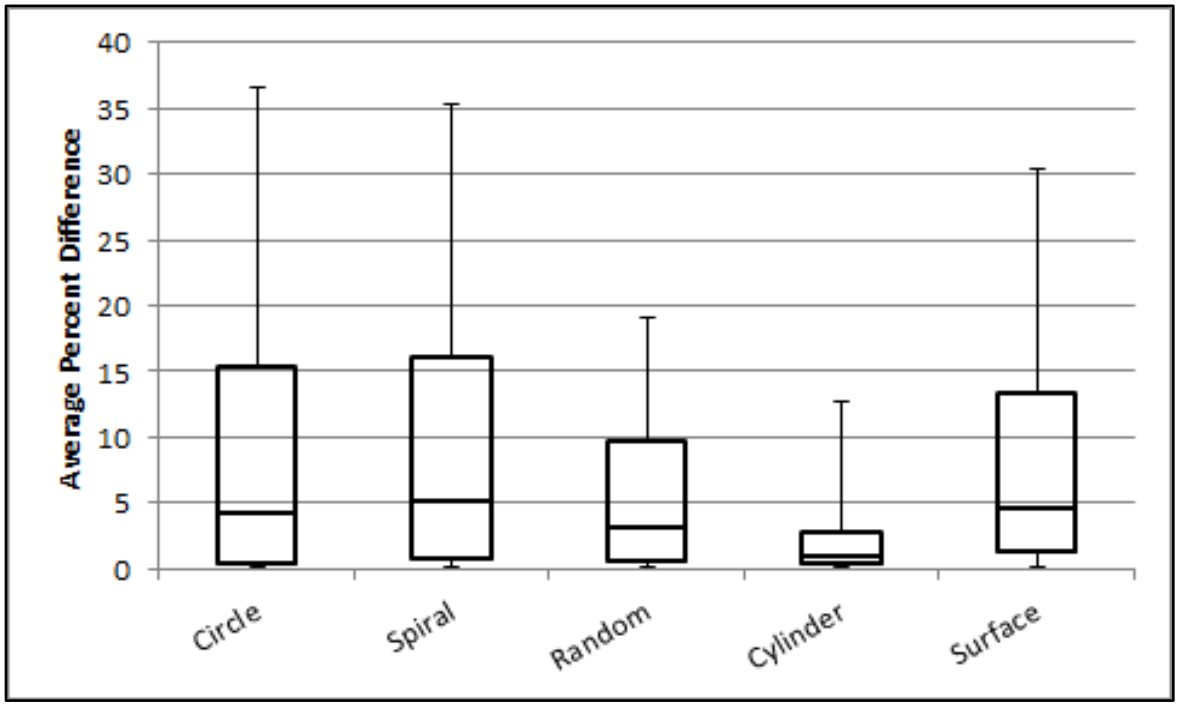
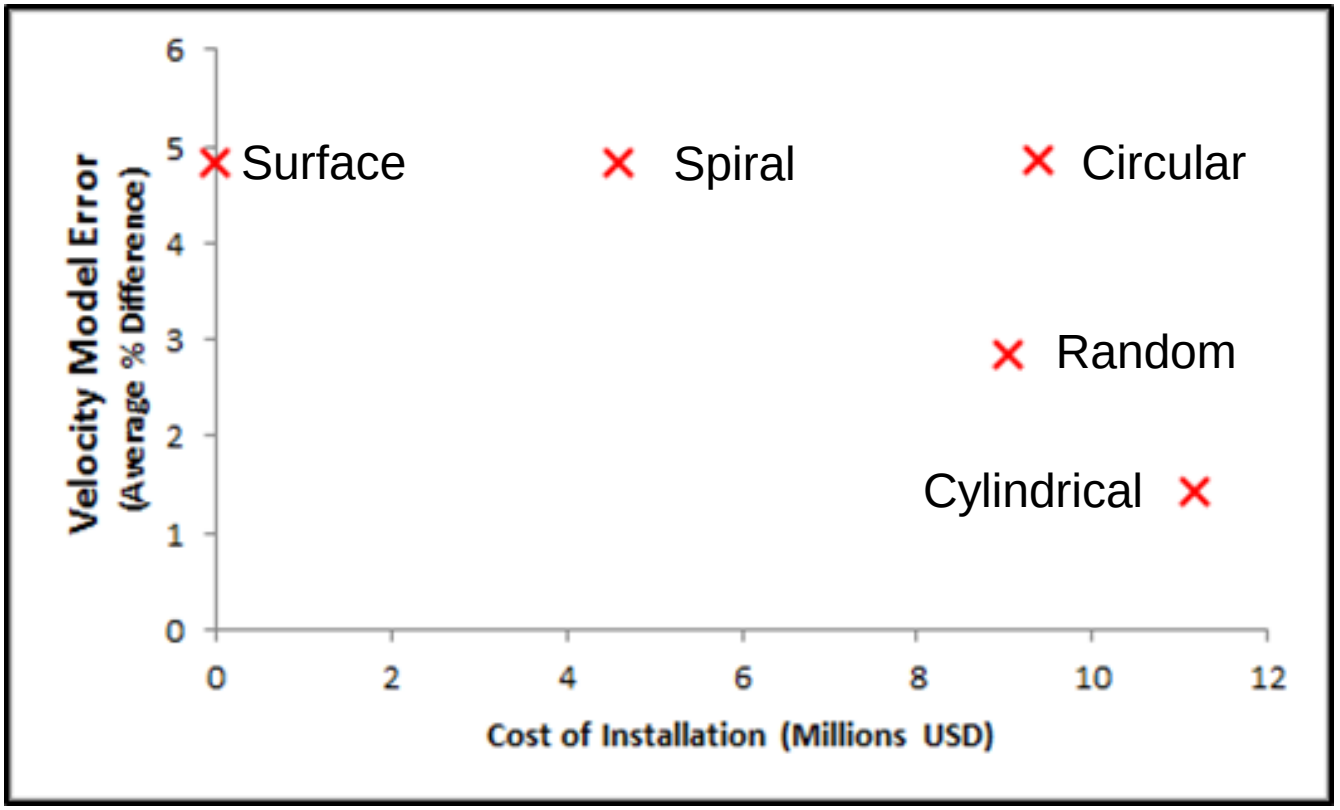
Average Percent Difference



For nodes with very good raypath coverage (top 25%)

Cost of Accuracy



Assumes drilling cost of $1,250 per meter

Accomplishments to Date

- Establish data collection and processing requirements so that double-difference seismic tomography can be used to quantitatively map the mass and propagation of sequestered CO2 as a function of time.
- A dataset from field monitoring of microseismic activity will be analyzed using double-difference tomography.
- A graduate course will be developed to enable students to apply the best, most recent methods for using geophysical tools to image sequestration.
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Conclusions

- Project completed successfully
- Double-difference passive seismic tomography can potentially be very useful for sequestration MVA
- Acceptable event and receiver locations are critical for obtaining meaningful results
- Analysis of synthetic data provides an inexpensive means of testing proposed MVA applications.

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Questions?

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http://www.mining.vt.edu/research/GOI.htm

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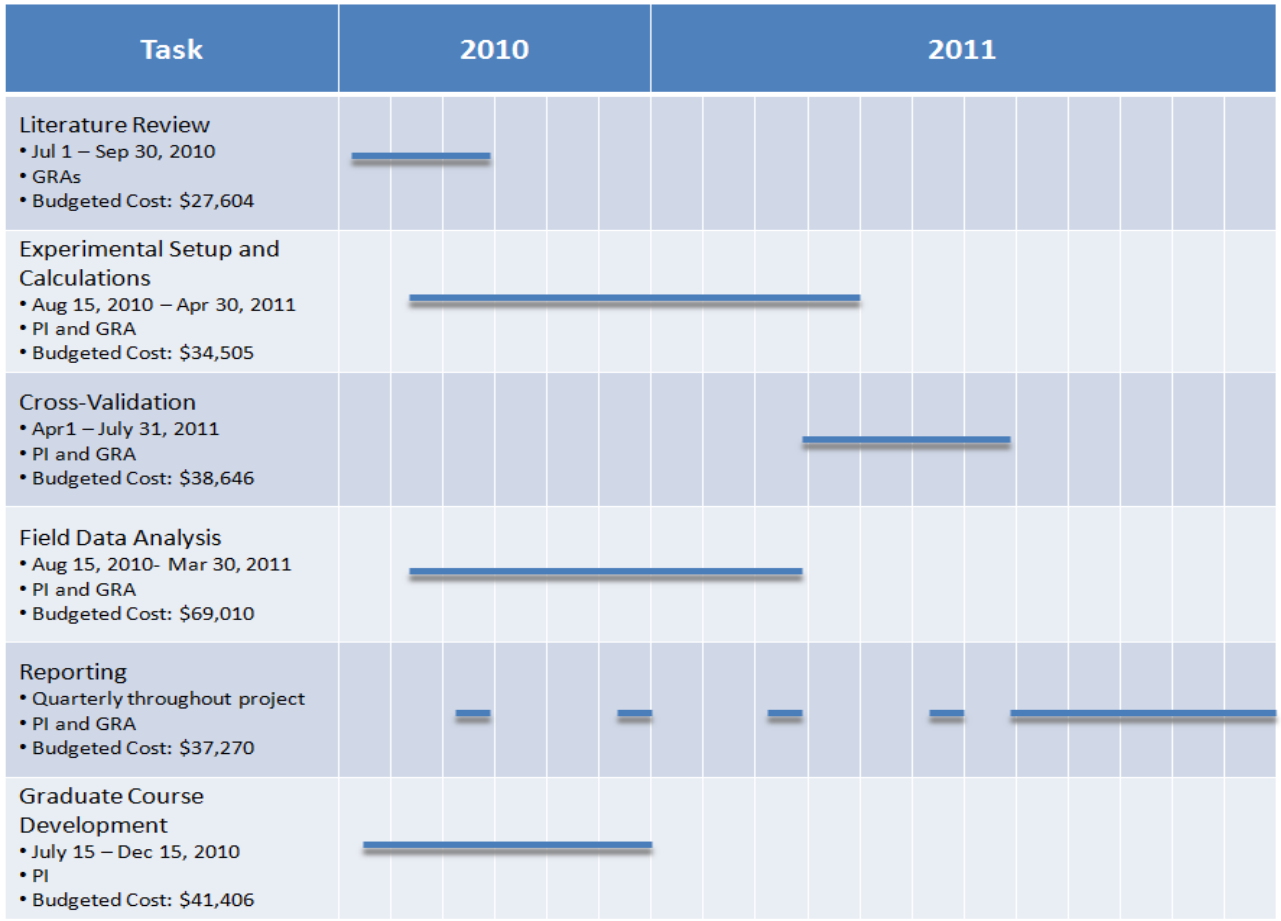
Appendix

Organization Chart

- Erik Westman, PI
  - Associate Professor
  - Mining and Minerals Engineering
  - Virginia Tech
- Benjamin Fahrman and Brent Slaker
  - Graduate Research Associates
  - Mining and Minerals Engineering
  - Virginia Tech

Gantt Chart



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Bibliography

Journal, multiple authors:

- Fahrman, B.P., E.C. Westman, K. Luxbacher, and M. Karfakis, “Optimization of Geophone Array for Monitoring Geologic Carbon Sequestration using Double-Difference Tomography,” to Computers and Geosciences, submitted Aug, 2012

- Slaker, B. A., E.C. Westman, K. Luxbacher, and N. Ripepi, “Application of Double-Difference Seismic Tomography to Carbon Sequestration Monitoring at the Aneth Oil Field, Utah,” to Journal of Applied Geophysics, submitted July, 2012.

Publication:

- Fahrman, B.P., B.A. Slaker, and E.C. Westman, 2012, “Passive Seismic Imaging for Carbon Sequestration Monitoring, Verification, and Accounting,” 46th US Rock Mechanics / Geomechanics Symposium, held in Chicago, IL, USA, June 24-27, 10 pp.

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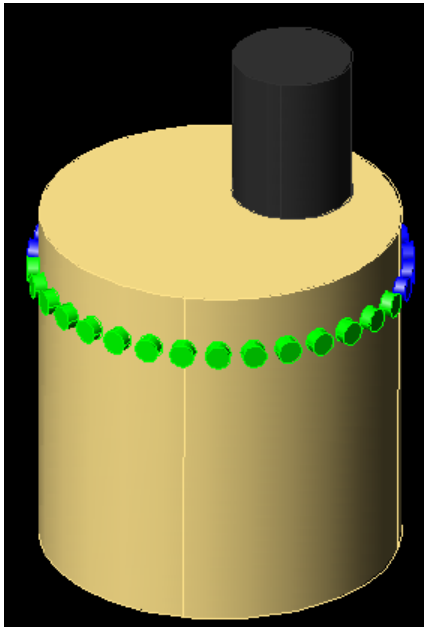
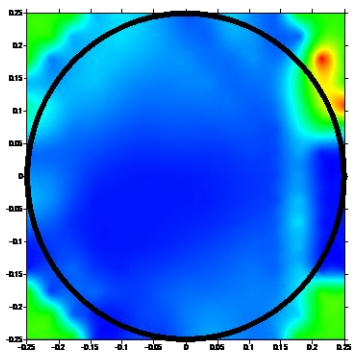
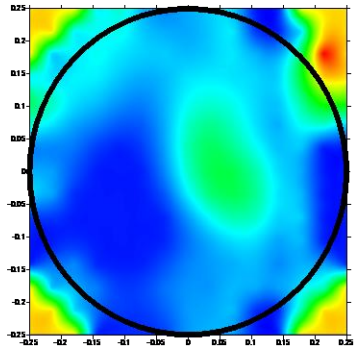
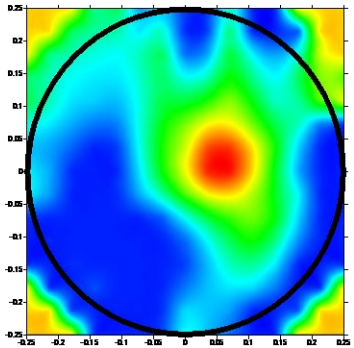
Lab Experiment

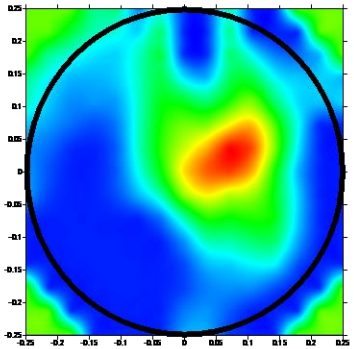
- ‘Stress’ vs. seismic velocity



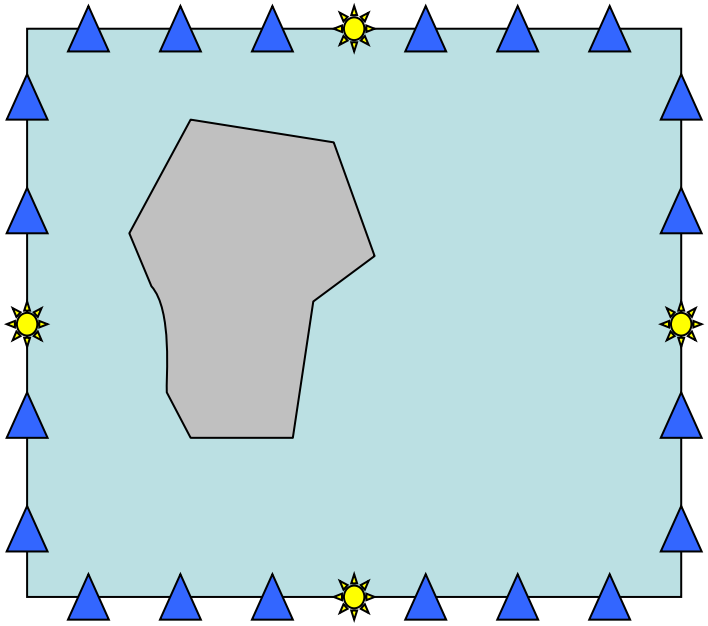








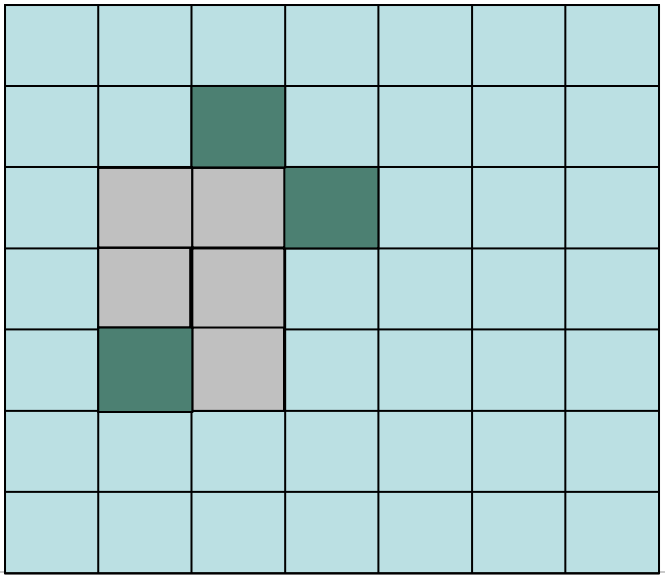
Field conditions

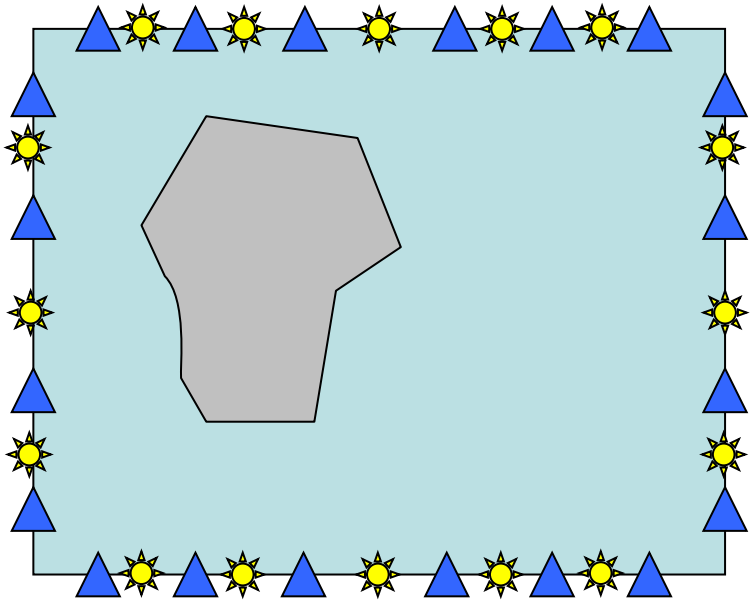


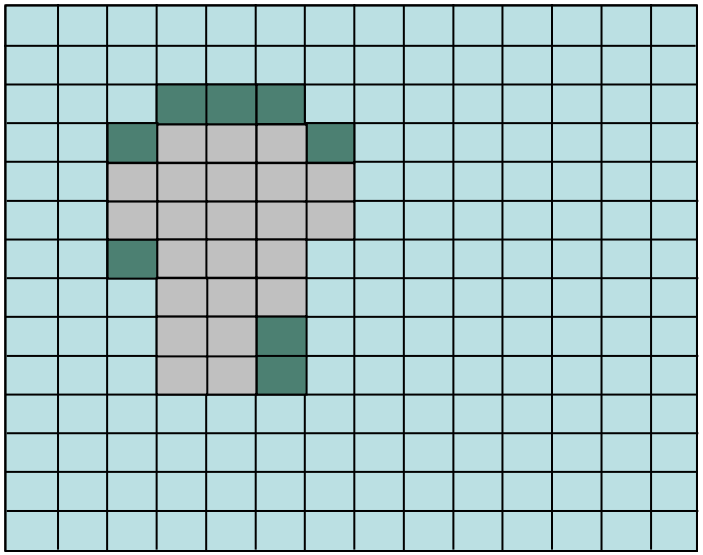
Source

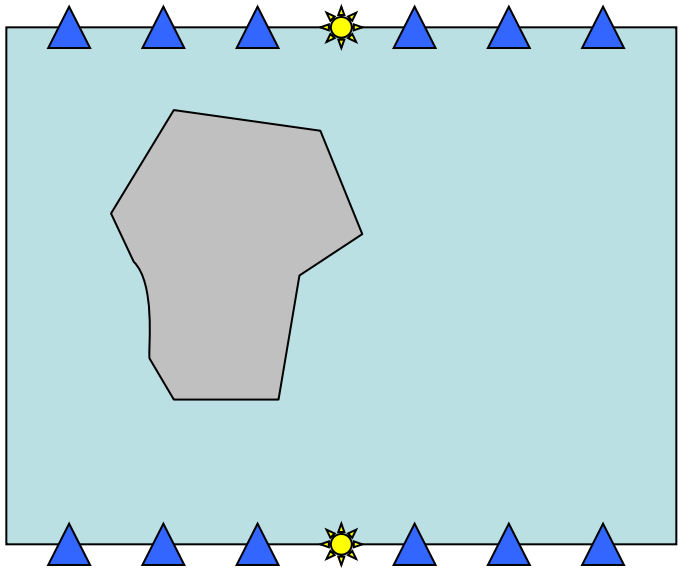
Receiver

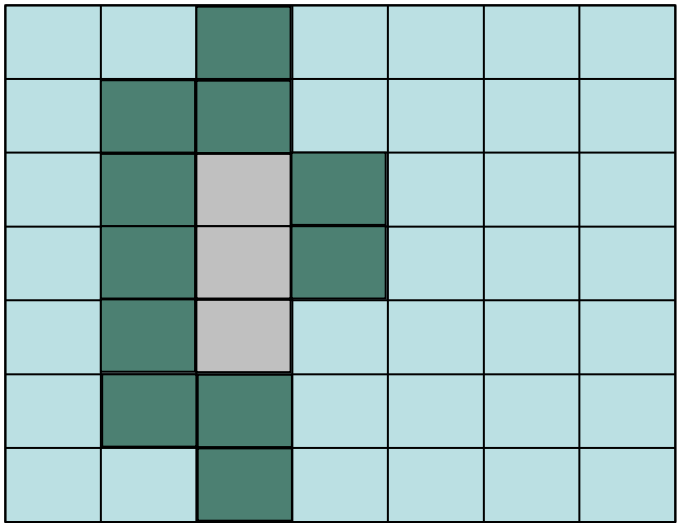
Resulting tomogram





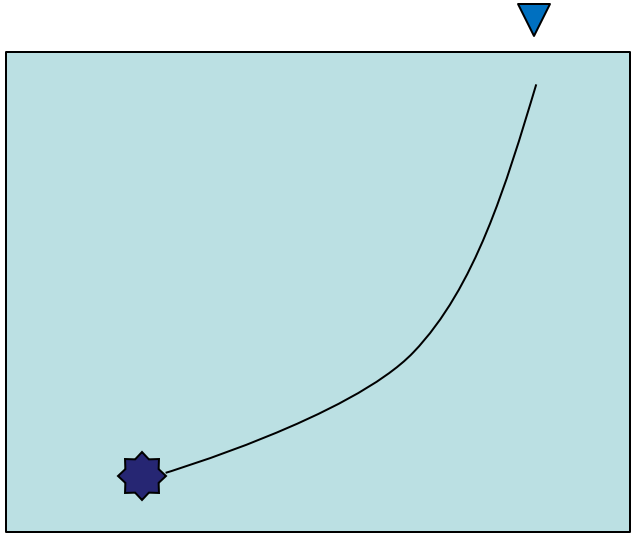






Background

- Traditional vs. Double-Difference Tomography



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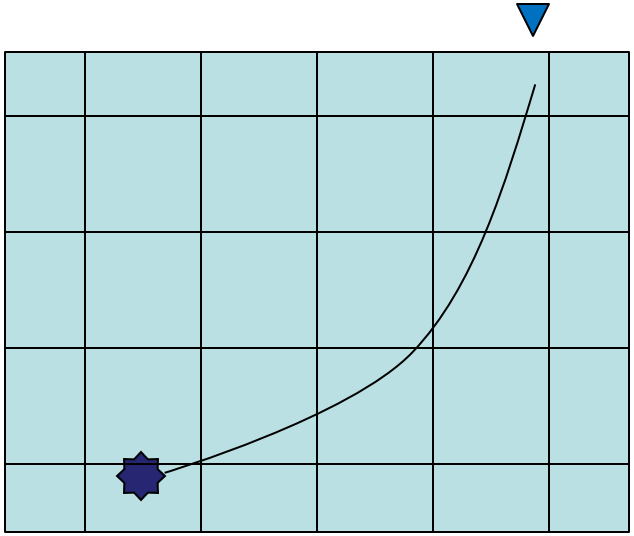

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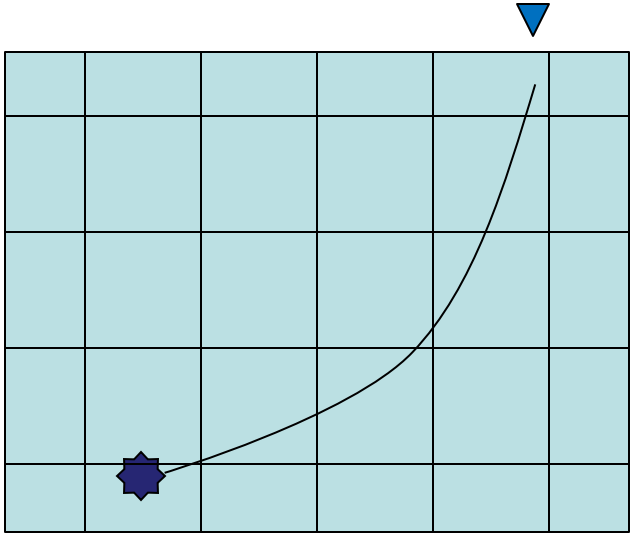
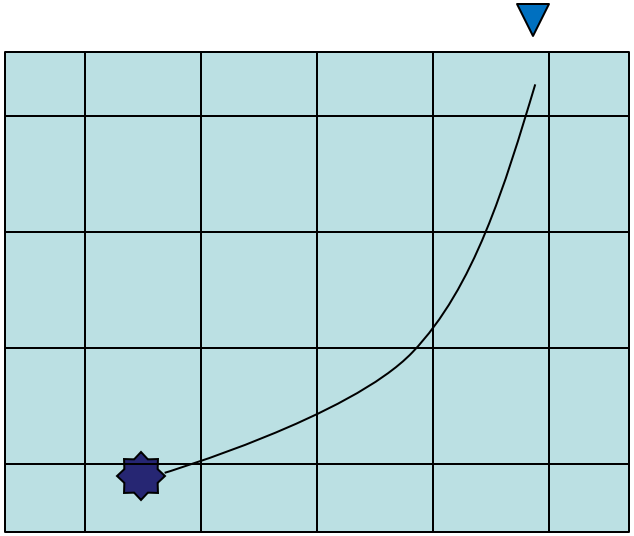
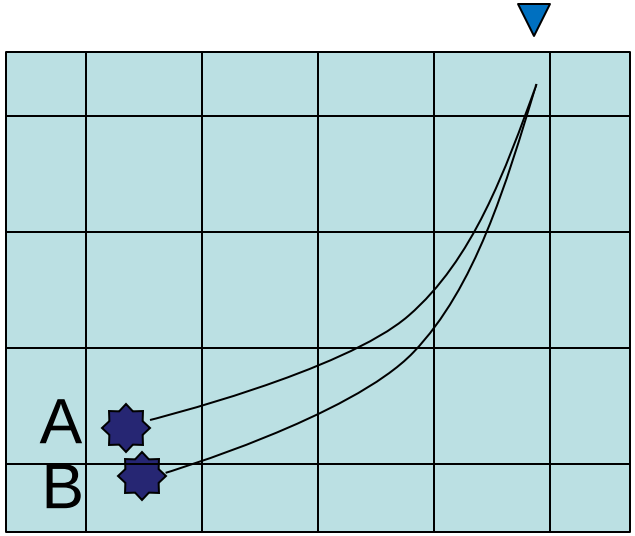


Resid = tt_{obs} - tt_{model}

Background

- Traditional vs. Double-Difference Tomography





Resid = $tt_{obs} - tt_{model}$

Resid = $(tt_{obs,A} - tt_{model,A}) - (tt_{obs,B} - tt_{model,B})$

Ref: Zhang and Thurber, 2003