CHARACTERIZING AND INTERPRETING THE IN SITU STRAIN TENSOR DURING CO_2 INJECTION

Project NumberDE-FE0023313

Larry Murdoch, Clemson University

Co-PI Stephen Moysey, Clemson University

Co-PI Leonid Germanovich, Georgia Tech

Co-PI Glen Mattioli, UNAVCO

Scott DeWolf, Clemson University

Alex Hanna, Clemson University

Marvin Robinowitz, Grand Resources

ScottRobinowitz, Grand Resources

David Mencin, UNAVCO

U.S. Department of Energy

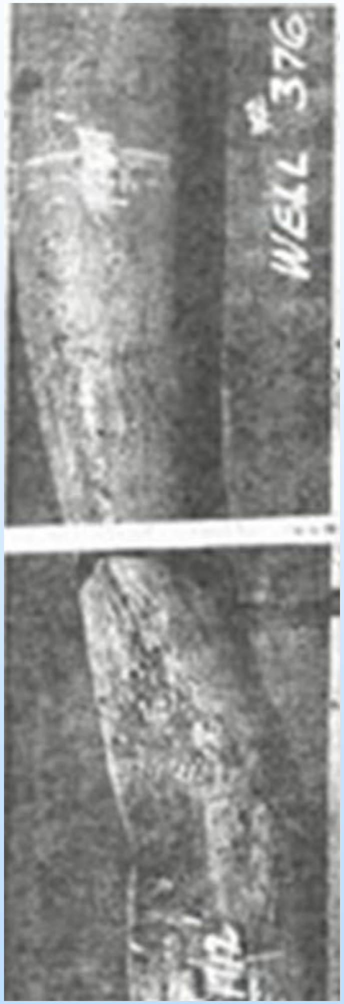
National Energy Technology Laboratory

DE-FOA0001037 Kickoff Meeting

November 12-13, 2014

Presentation Outline

- Overview
    - Benefits, Goals
- Background
    - Strains near wells
    - In situ measurement
    - Interpretation
- New Project
    - Expect Outcomes
    - People
    - Tasks
    - Risks



Benefit to the Program

Contribute to *Area of Interest 1 – Geomechanical Research* by developing and demonstrating innovative instrumentation and theoretical techniques for characterizing the strain field resulting from injection (Research Need 3)

Carbon Storage Program goal to support industry's ability to predict CO_2 storage capacity in geologic formations to within ±30 percent.

Benefits Statement: The proposed project will contribute to *Area of Interest 1 – Geomechanical Research* by developing and demonstrating innovative instrumentation and theoretical techniques for characterizing the strain field resulting from injection (Research Need 3). The field data and inversion method will advance characterization of geomechanical properties and evaluation of stress change throughout the formation, including in the vicinity of faults and lithologic contacts. These contributions will improve the reliability of theoretical models, thereby advancing estimates of storage capacity and assisting in future monitoring decisions and risk assessment. Preliminary analyses of the proposed method demonstrate an improvement in accuracy of property estimates by an order of magnitude (from 25% to a ~1%) and a reduction in uncertainty by more than 50%, relative to baseline methods. These improvements contribute to the Carbon Storage Program goal to support industry's ability to predict CO_2 storage capacity in geologic formations to within ±30 percent.

Project Overview:
Goals and Objectives

- <u>Overall Goal</u>: evaluate how subsurface strain measurements can be used to improve the assessment of geomechanical properties and advance an understanding of geomechanical processes that may present risks to CO_2 storage.

  - <u>Goal Instrument Development Task</u> Design/build instrumentation for measuring the in-situ strain tensor and evaluate performance characteristics relative to the existing state of the art.

  - <u>Goal Theoretical Analysis Task</u> Develop theoretical analyses for characterizing the strain field associated with injection in the vicinity of critical features, such as contacts and faults, and then develop and demonstrate innovative methods for inverting these data to provide a quantitative interpretation.

  - <u>Goal Field Demonstration Task</u> Demonstrate the best available strain measuring instrumentation during a field injection test, interpret the result data, and compare the interpretation with currently available information.

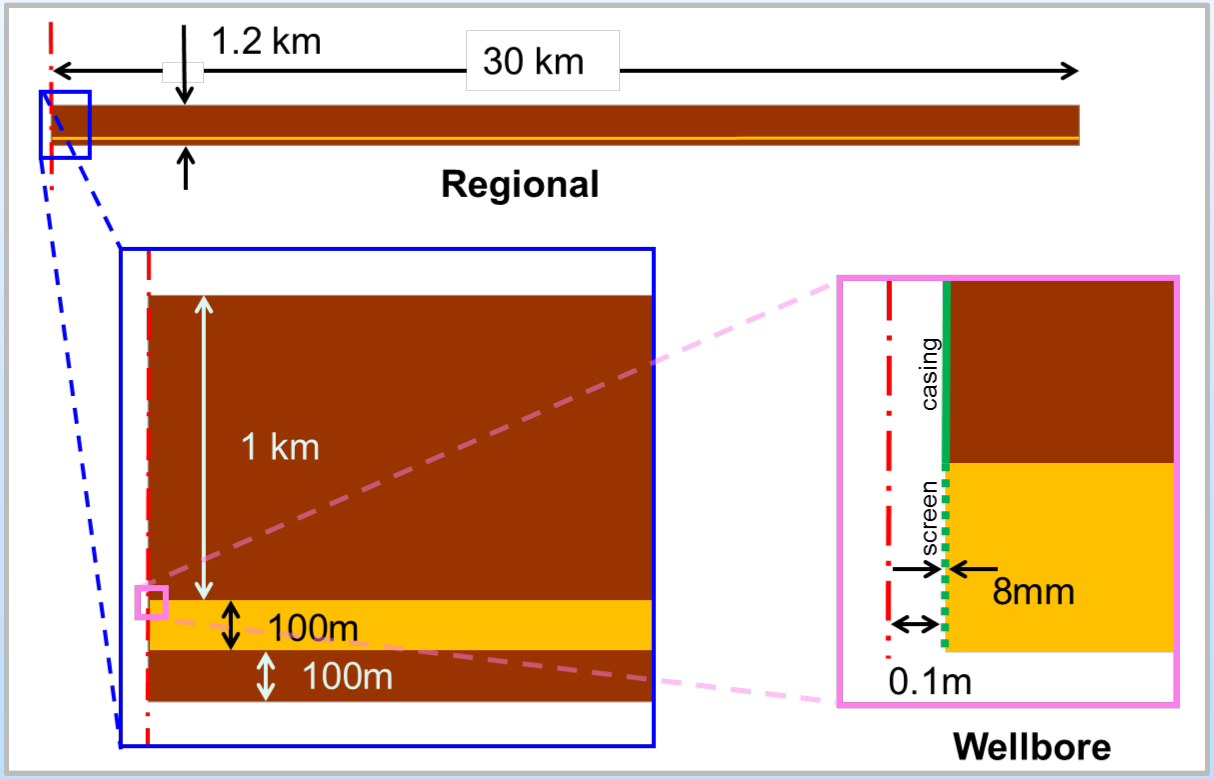
Background and Methodology

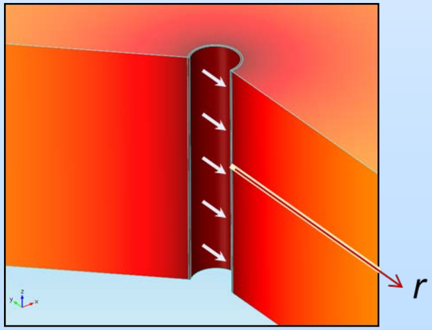
- Deformation in vicinity of well
  - Strain components
  - Strain rates
- Measure strain
  - Surface
  - In Situ
- Interpretation
  - Inversion

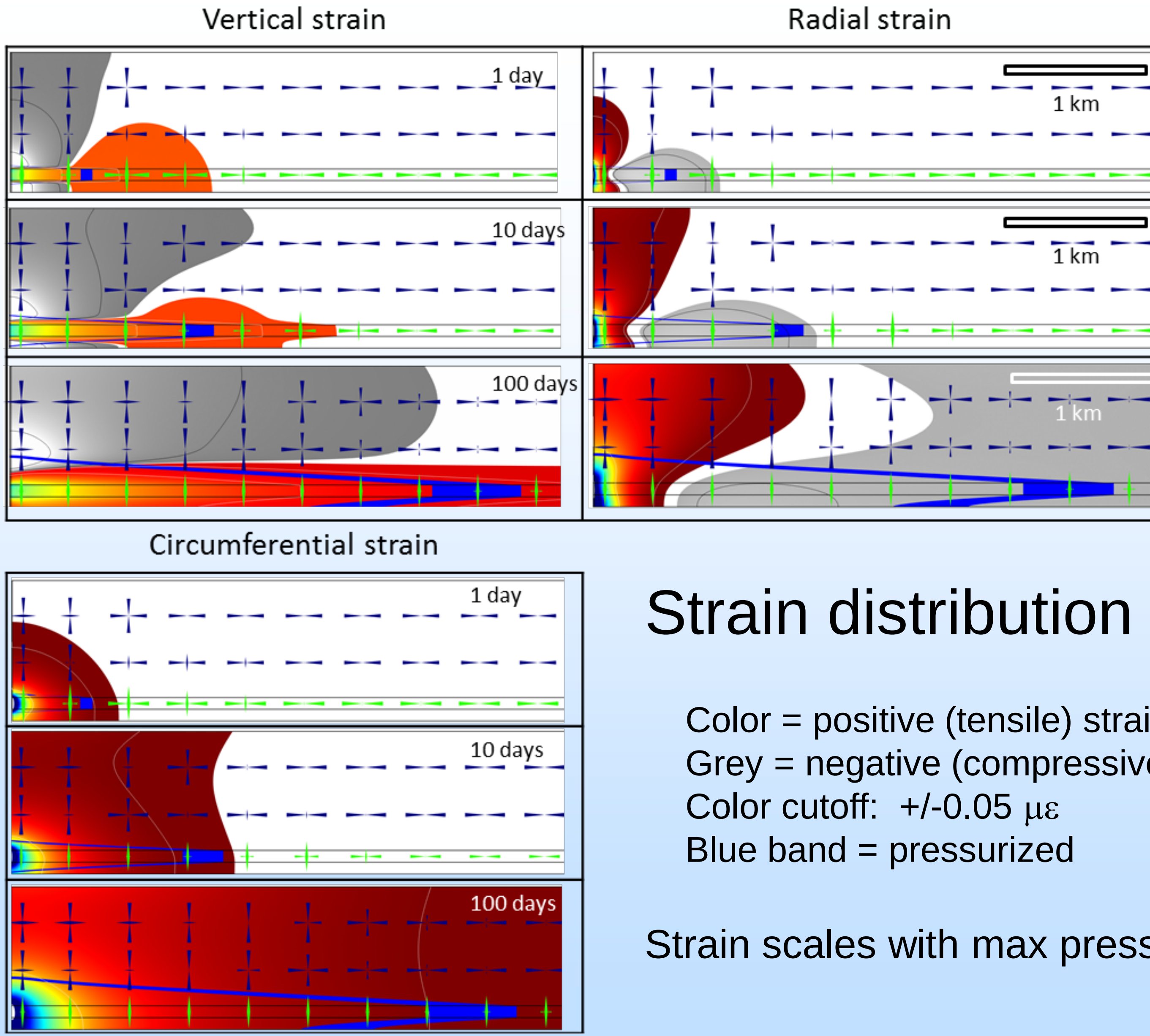
Deformation in Vicinity of a Well

What to expect?

Constant Q injection, 6 lps ~100gpm, Axial symmetry
Aquifer: k: 10^{-13}m^2, b: 100m, E: 15GPa , R = 30km
Confining : k: 10^{-16}m^2, b: 1000 m; E: 15GPa
Casing: k: 1nd; 8-inch, 8mm wall, E: 200GPa
Screen: k: 10^{-13}m^2; 8-inch, 8mm wall, E: 200GPa





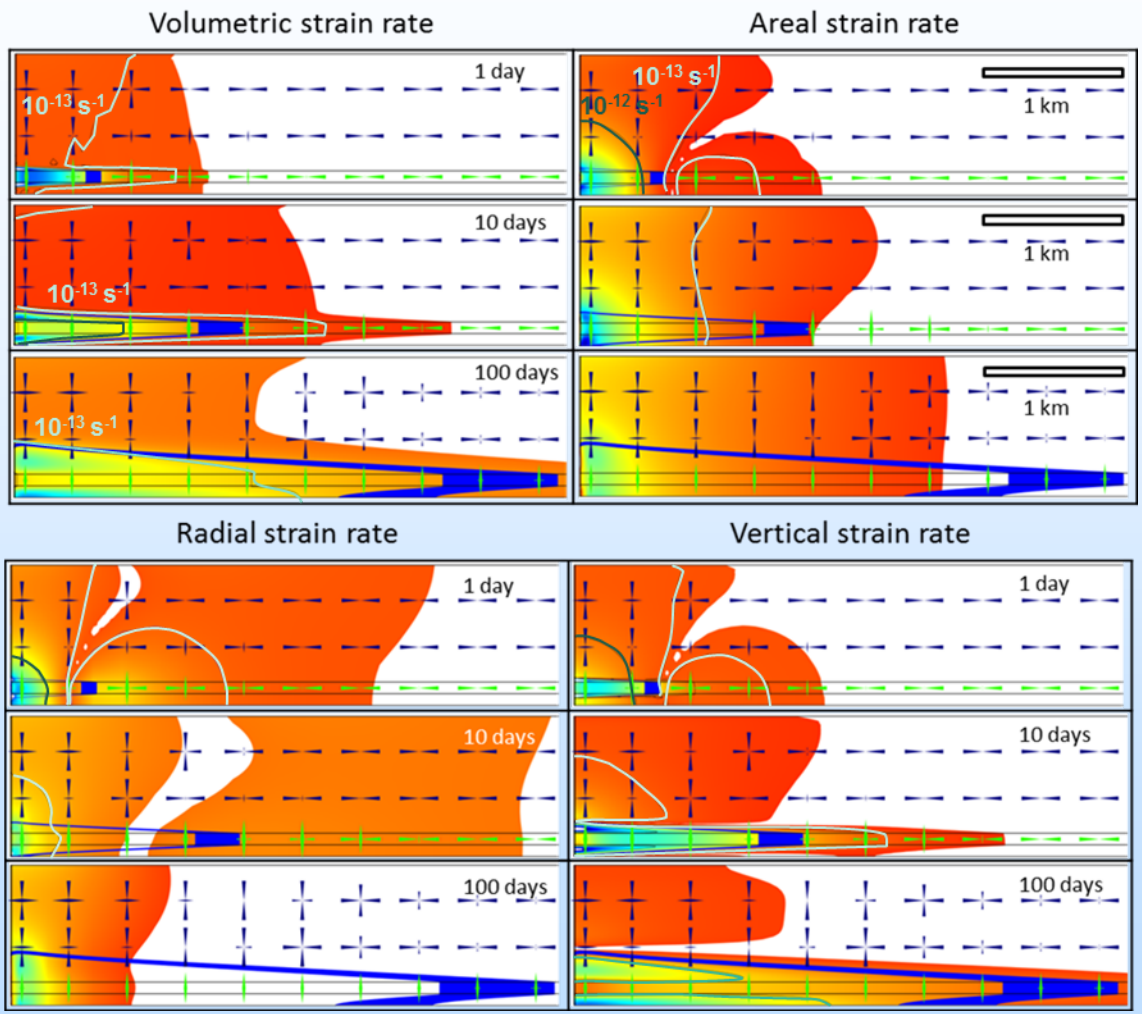


Strain distribution

Color = positive (tensile) strain
Grey = negative (compressive) strain
Color cutoff: +/-0.05 $\mu\varepsilon$
Blue band = pressurized

Strain scales with max pressure

Distribution of Strain Rate



Colored region: $>10^{-14}$ 1/s
Light green: $>10^{-13}$ 1/s
Dark green: $>10^{-12}$ 1/s

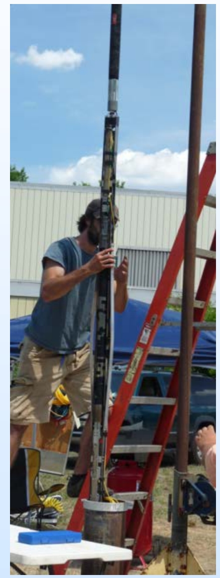
Strain rate scale with volumetric injection rate

Strain Measurement

Overview

Gladwin Borehole Strain Meter (BSM)

- 4 axis, horizontal
- ~0.001 με resolution
- Grouted in place
- Tectonic strain



Clemson *5DX*

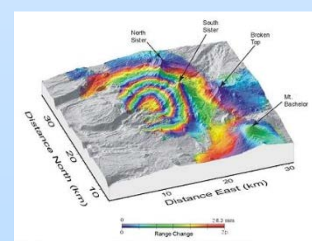
- 3D + shear
- ~0. 1με resolution
- Optical
- Removable
- Well testing

Baker Hughes *WIRE*

- Multicomponent
- ~1 μe
- Optical
- Part of casing

Clemson *Tilt-X*

- Axial+tilt
- ~0. 01με resolution
- Electrical
- AGI tiltmeter
- Removable
- Well testing



In SAR

Geodetic GPS

Strain Measurement

Geodetic strain instruments

Gladwin Borehole Strain Meter (BSM)

- 4 axis, horizontal
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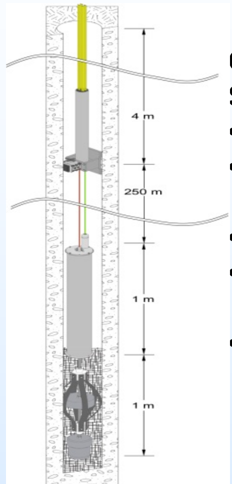
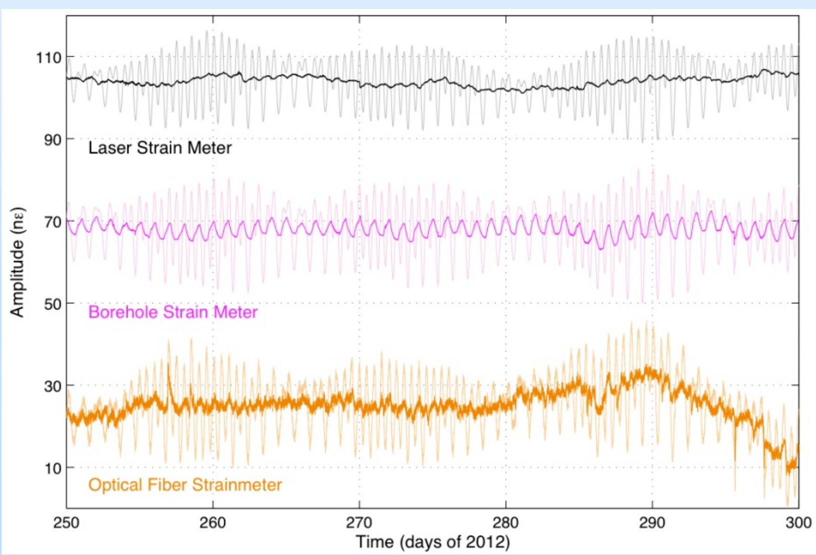


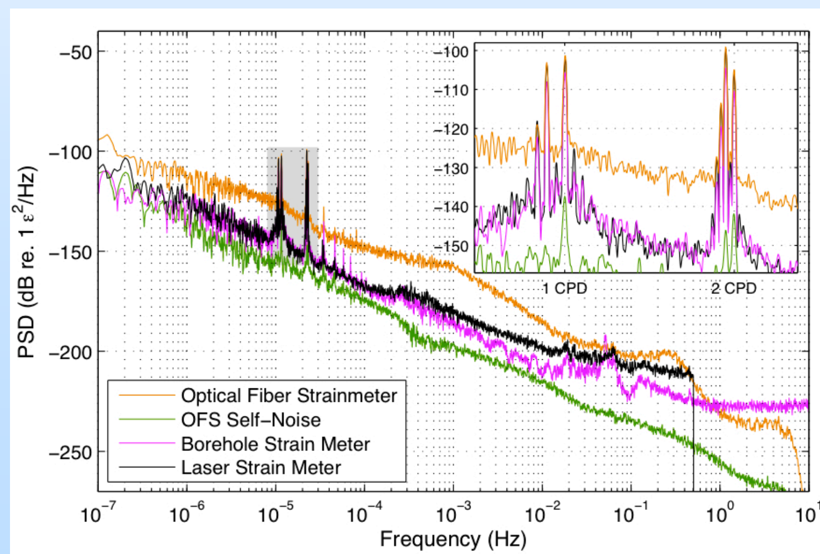
Optical Fiber Strainmeter (OFS)

- Vertical + Areal
- ~0.001 με resolution
- Grouted in place
- Long baseline(~250 m)
- Tectonic strain

Laser Strain Meter (LSM)

- 3 axis, horizontal
- <0.001 με resolution
- Surface deployed
- Long baseline(~1 km)
- Tectonic strain





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Current Status of In-Situ Strain Sensors

Resolution

Deployment Logistics/Cost

Long baseline strainmeters

- Highest resolution
- Single component strain, multiple installations
- Surface logistics, temp, cost

Grouted borehole strainmeters

- High resolution
- Horizontal strain components
- Requires dedicated borehole

Extensometer + tiltmeter

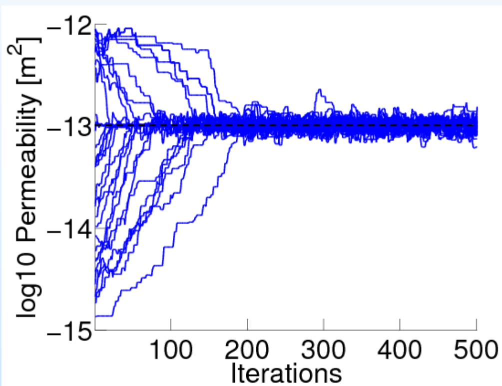
- Intermediate resolution
- Multiple strain components
- Deploy in existing well

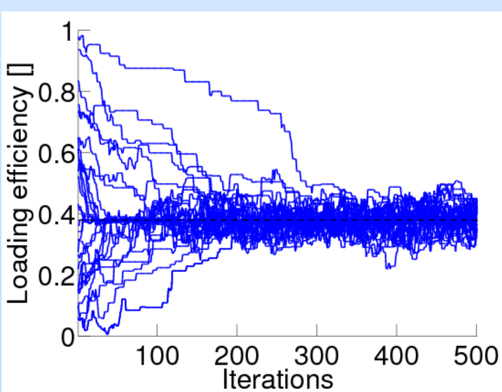
Smart casing

- Lowest resolution
- Multiple component strain
- Must install during well completion
- Well available during operation

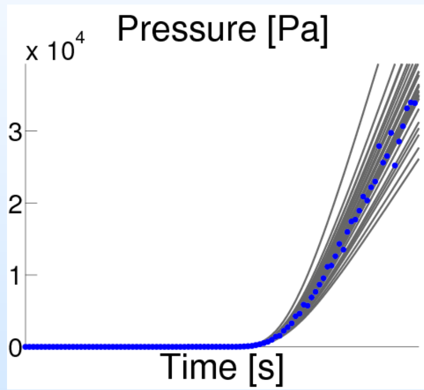
Interpreting Strain and Pressure Signals

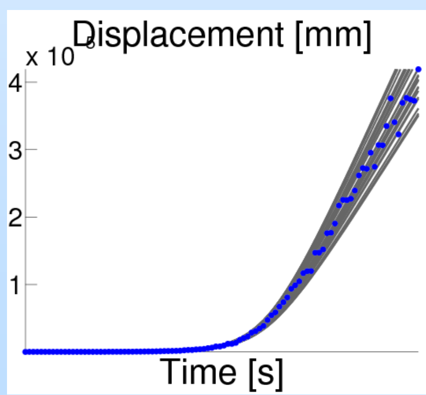
Reservoir Parameters

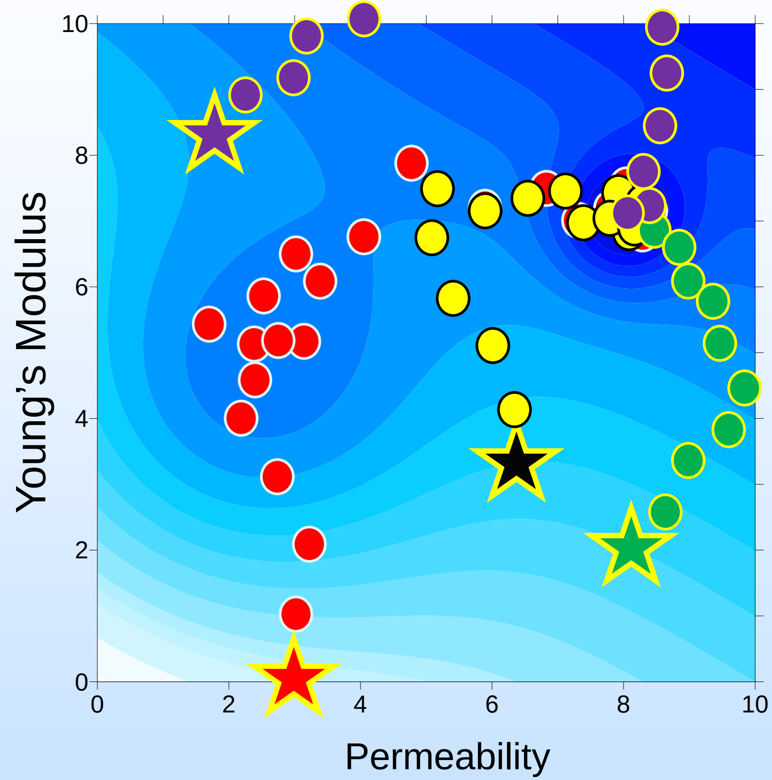




Geomechanical Signals







MCMC: Good search of parameter space. Avoid traps in local minima.

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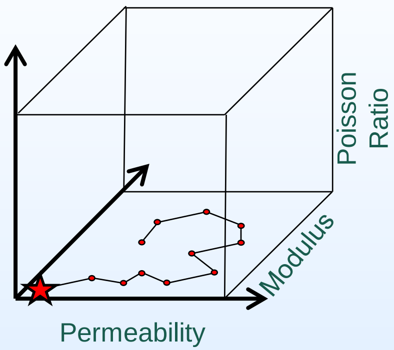
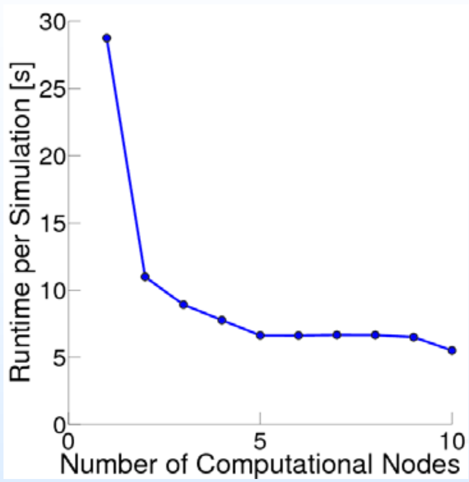
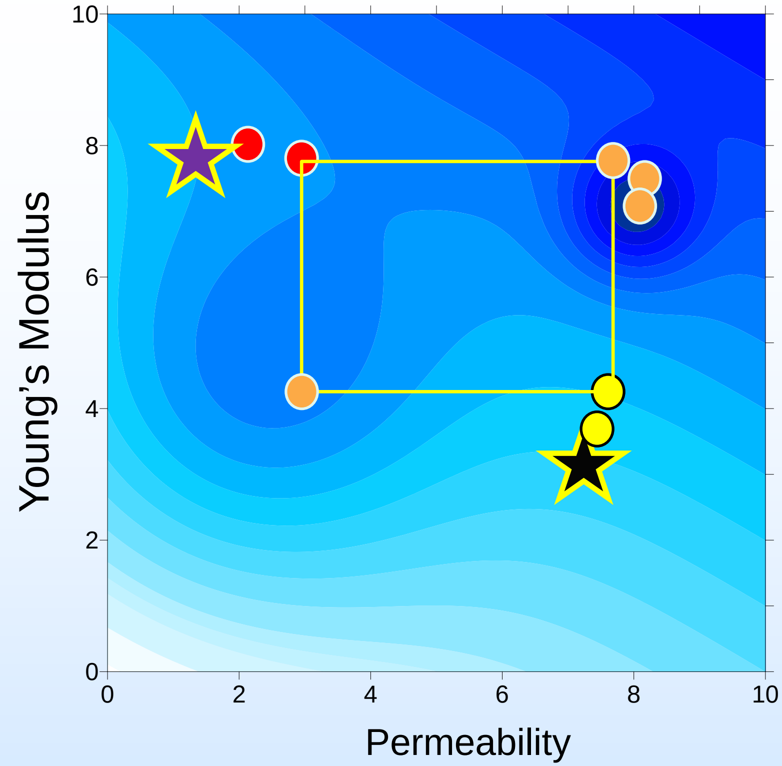
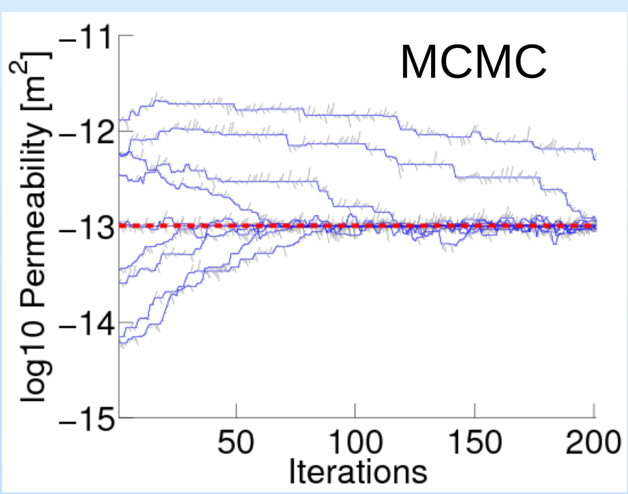
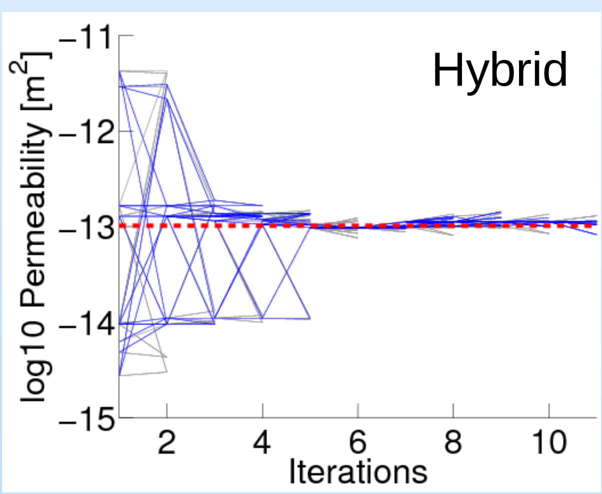
MCMC+Genetic → Hybrid Optimization







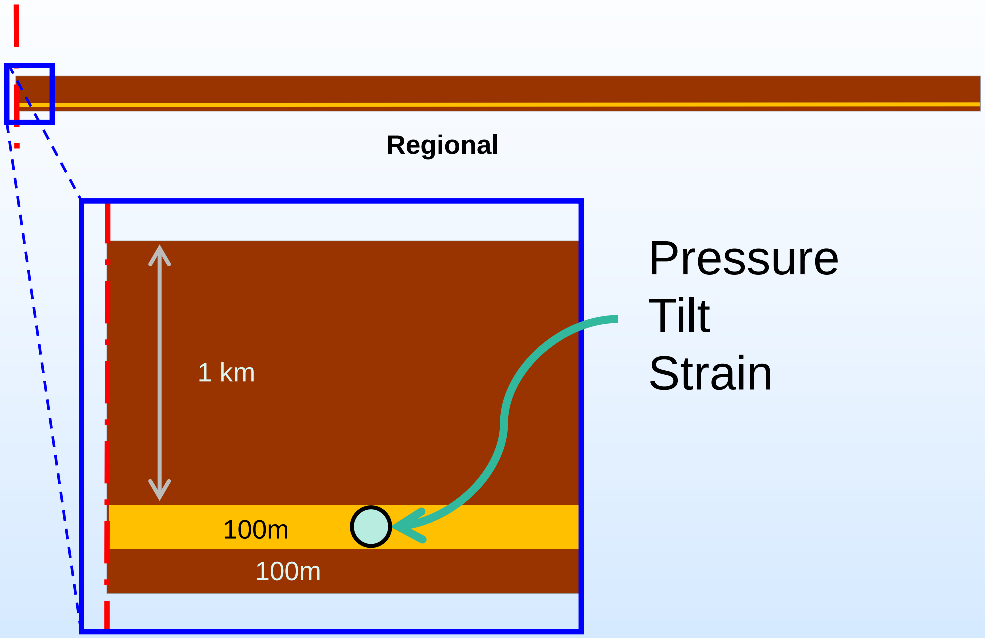




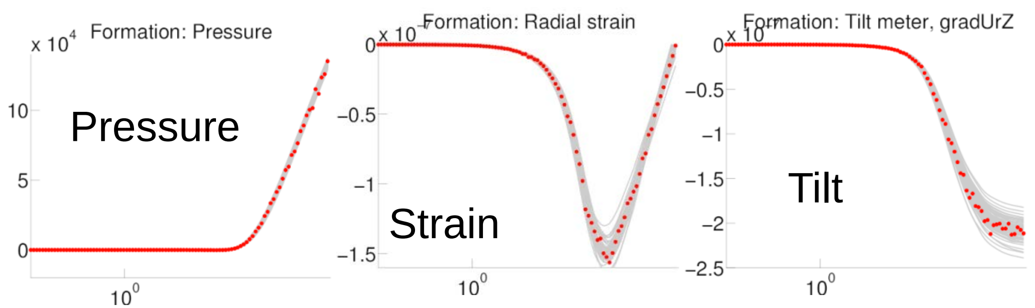
MCMC: Good coverage of parameter space
Genetic: Good convergence
Hybrid: Best of both

Applications

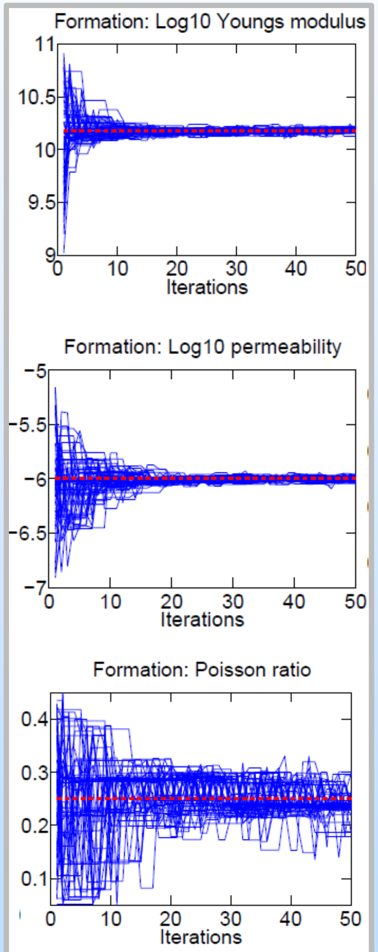
Data Location, Measurement Type, Heterogeneity



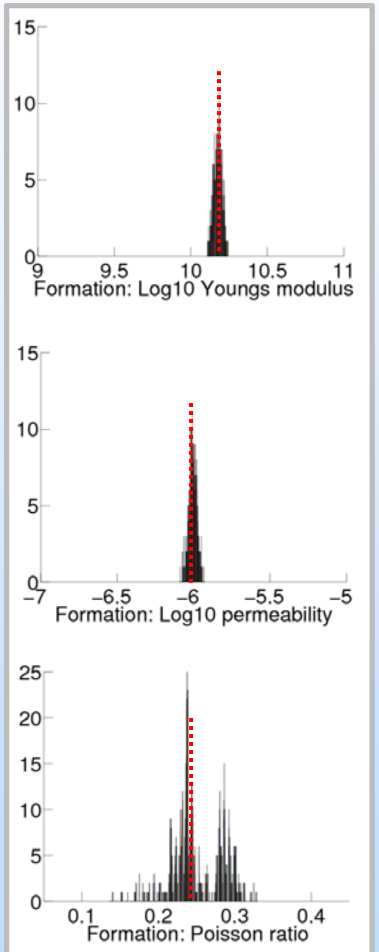
Data (Observed + Fit)



Iterations

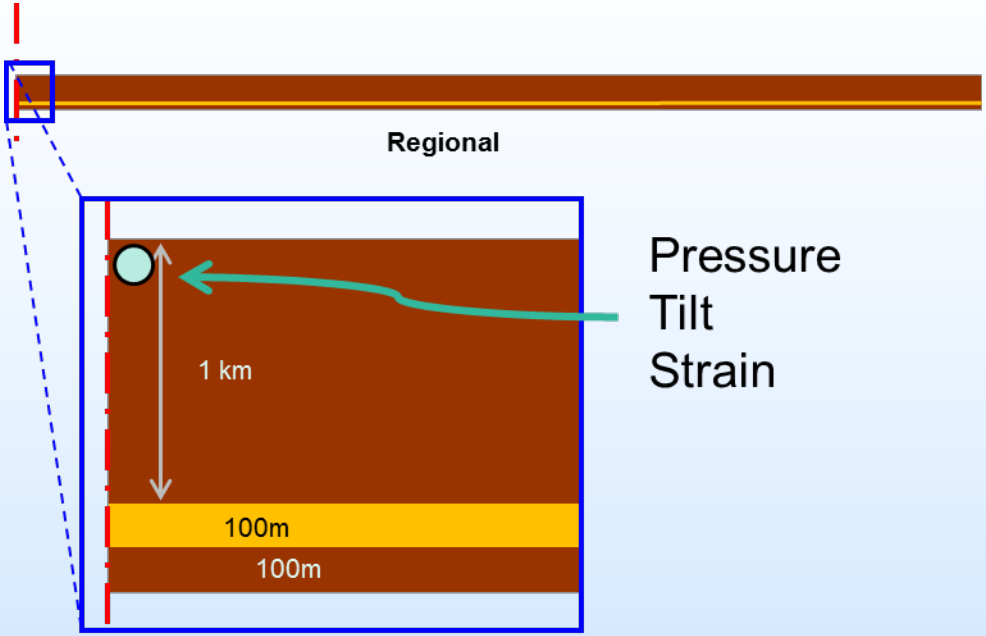


Estimated Parameters



Applications

Data Location, Measurement Type, Heterogeneity



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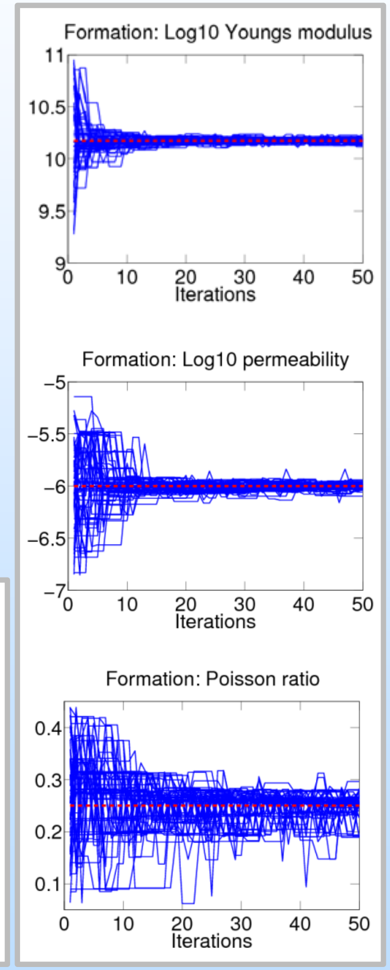

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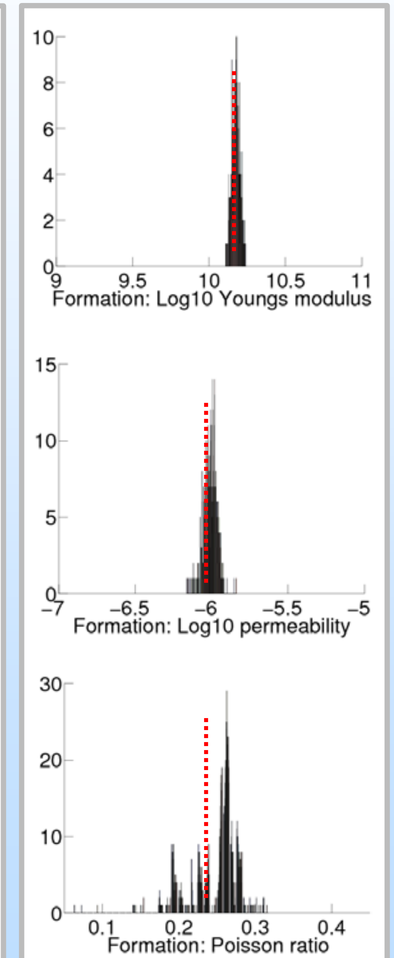

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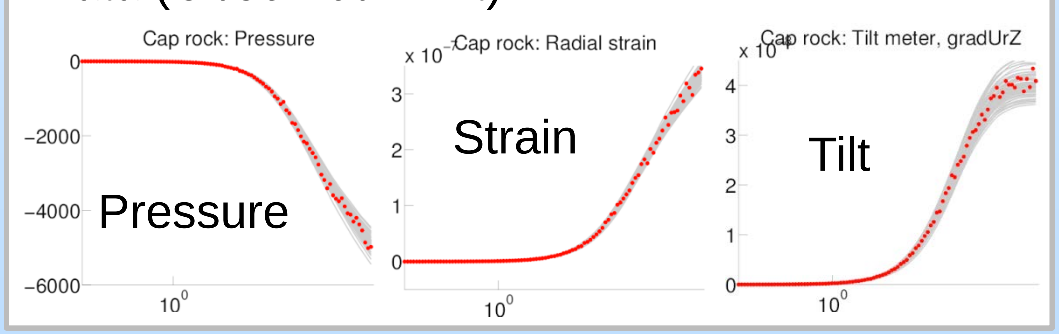
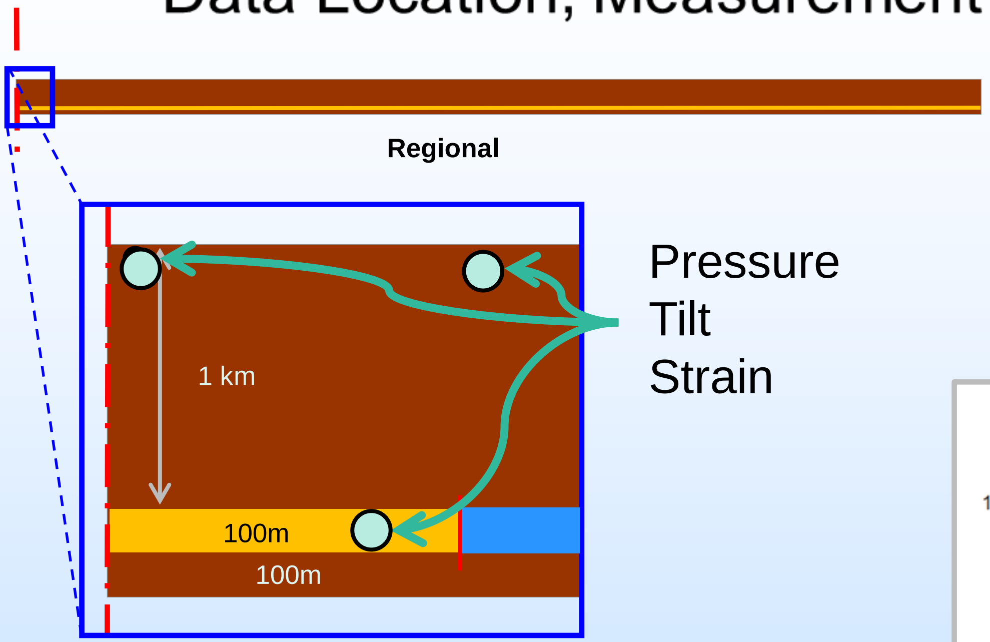


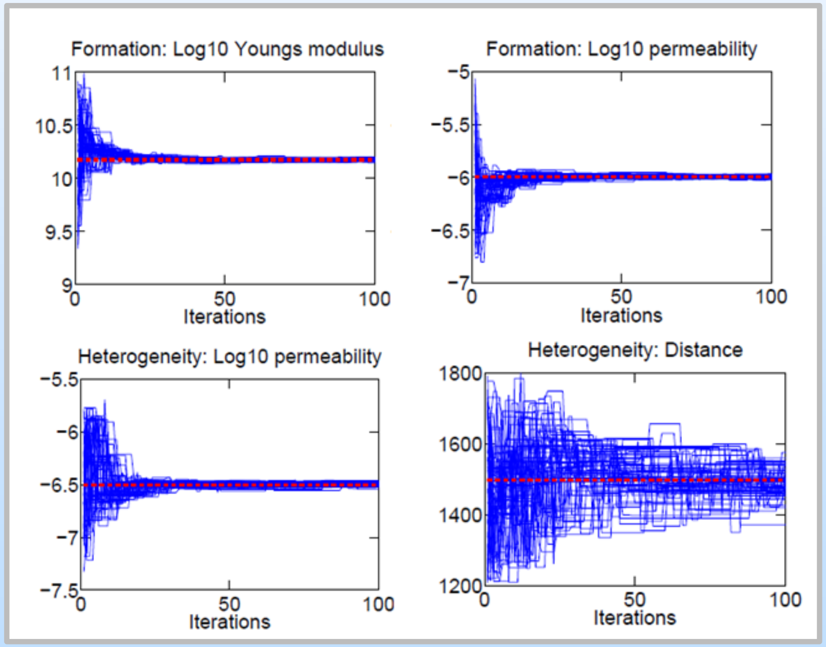
Applications

Data Location, Measurement Type, Heterogeneity



Pressure
Tilt
Strain

Iterations



Applications

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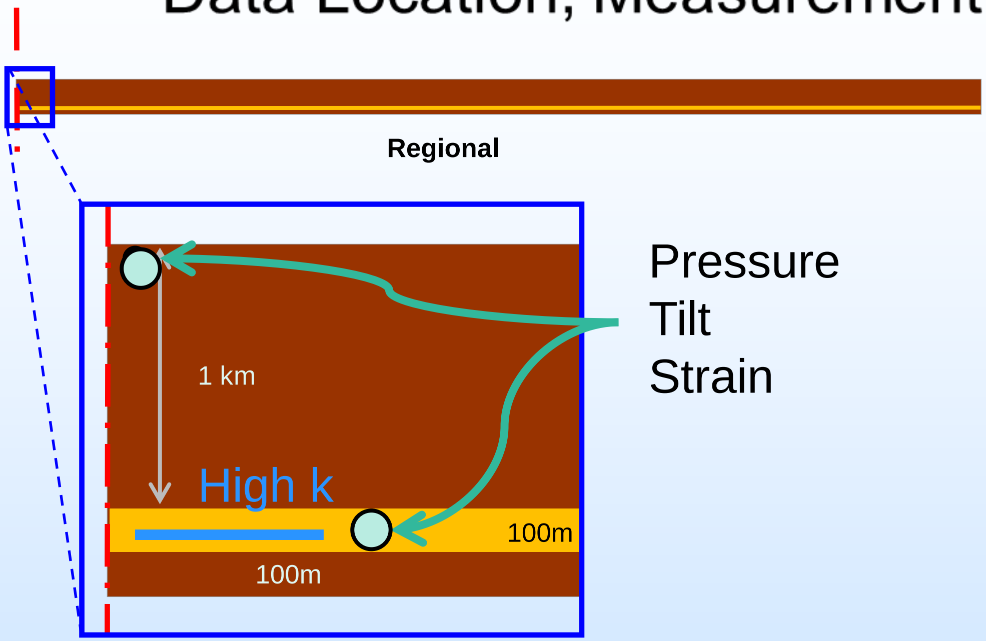
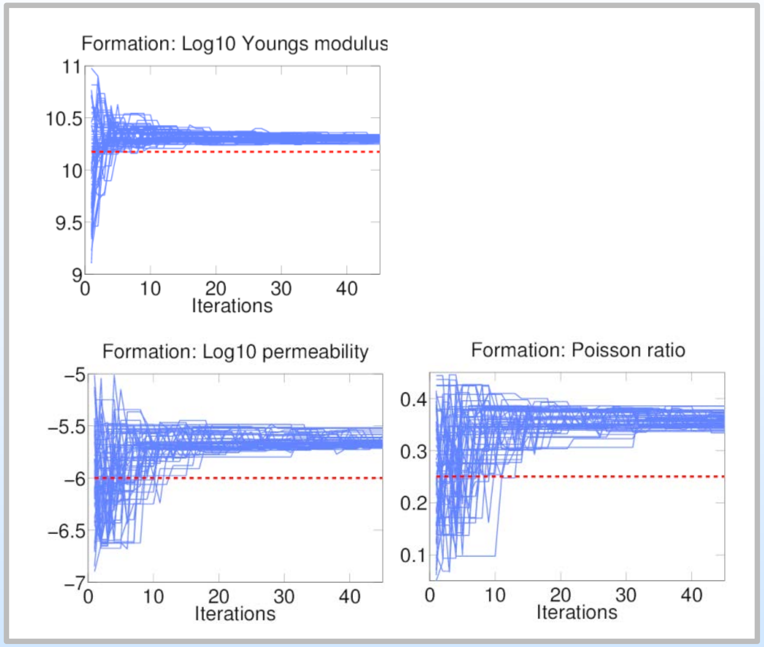
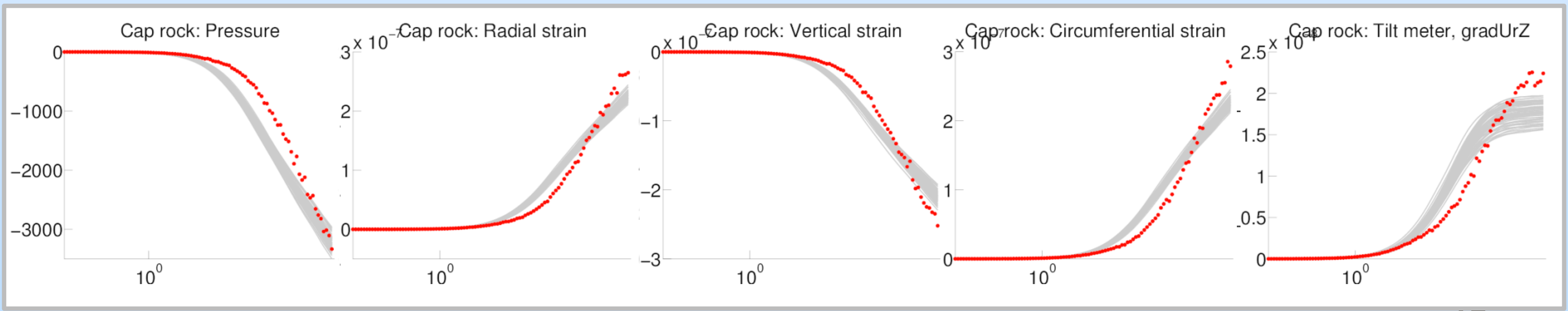






Expected Outcomes

1. In-situ instruments to measure strain
   Resolution ~ grouted borehole strainmeters
   Deployment ~ extensometer + tiltmeter

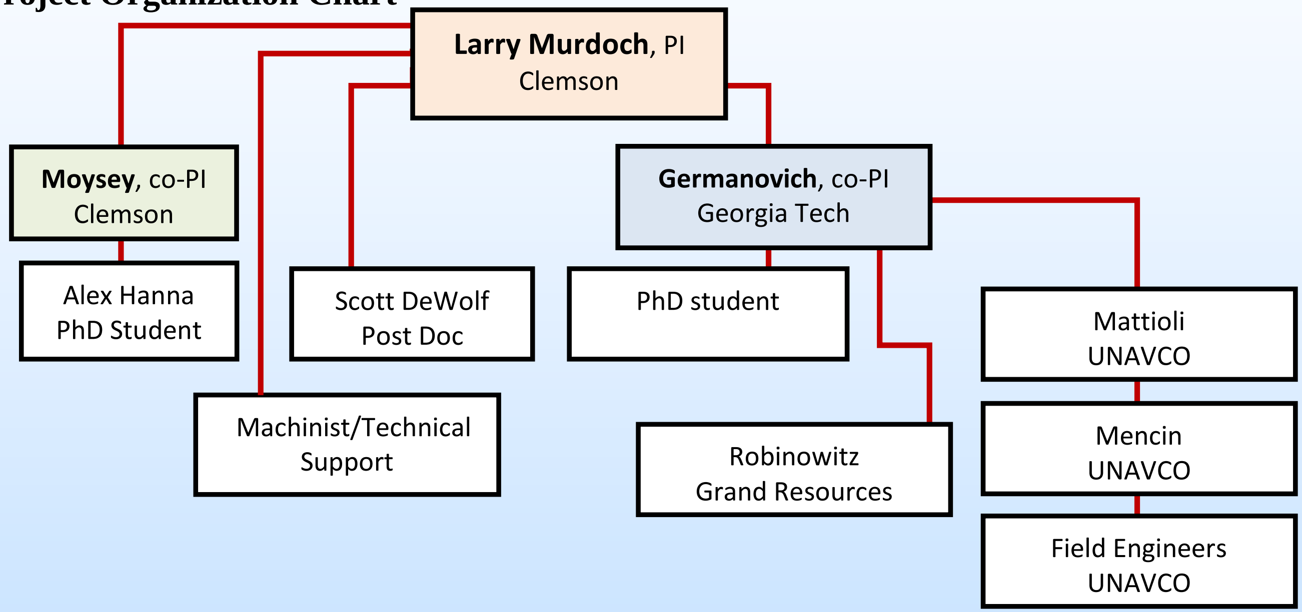
2. Inversion methods for interpreting strain signals
   Faster convergence, enable large forward models
   Characterize geomechanical properties, heterogeneities
   Remote monitoring of pressure
   Anticipate geomechanical problems

3. Field demonstration
   Existing and new borehole strainmeters
   Evaluate ~real time inversion
   Overall proof-of-concept at field scale

Described in project reports, presentations, journal papers

Organization Chart/ Communication Plan

Project Organization Chart



- Communication plan
  - Weekly meetings
    - GaTech, UNAVCO on-line
  - Ad hoc ~quarterly meetings
  - Quarterly Reports

Task/Subtask Breakdown

<u>Task 1.0. Project Management and Planning</u>

<u>Task 2.0. Instrument Development and Assessment</u>

2.1 – Wellbore Completion
2.2 –Components to Measure Strain
2.3 – Instrument Integration
2.4 – Assessment and Refinement

<u>Task 3.0 – Theoretical Analysis</u>

3.1 Method Development
3.2 Analysis of Scenarios
3.3 Analysis of Field Site

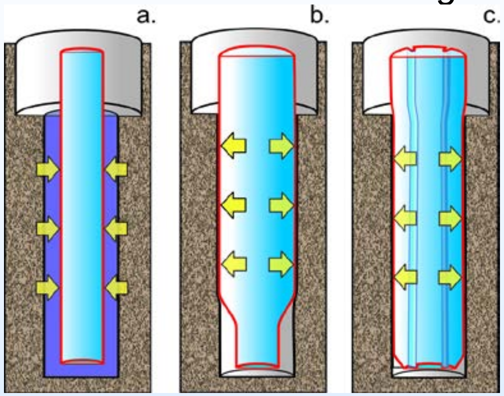
<u>Task 4.0 – Field Demonstration</u>

4.1 Reconnaissance and Planning
4.2 Well Installation and Instrument Deployment
4.3 Injection Test
4.4 Analysis

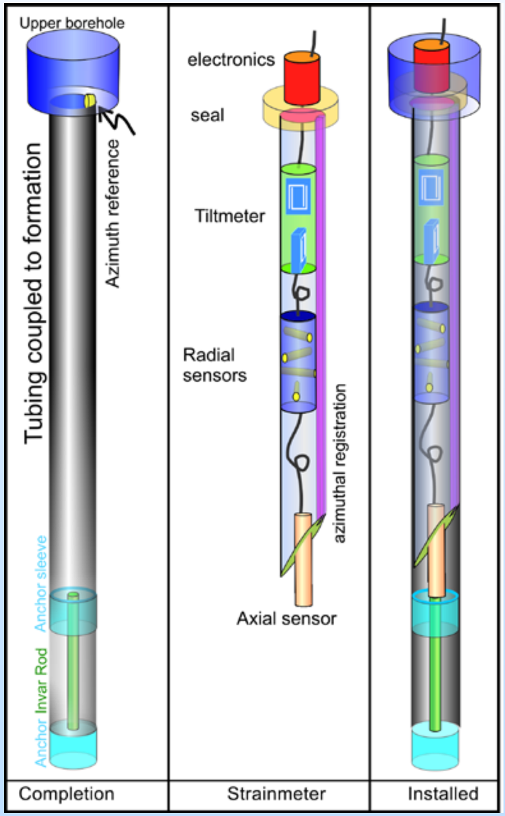
Task 2 Instrument Development

Scott DeWolf

Design instrumentation for measuring the in-situ strain tensor and evaluate performance and cost characteristics relative to the existing state of the art.



- Completion
  - Couple to rock
- Sensors
  - nε resolution
  - Electromag, optical
- Strainmeter
  - deployable package
  - removable or disposable
- Refinement & Testing
  - Earth tides in Clemson



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Task 2 Instrument Development

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Scott DeWolf

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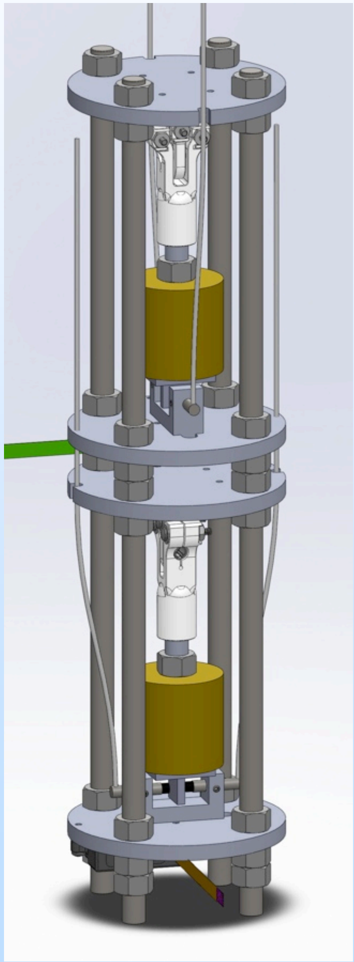
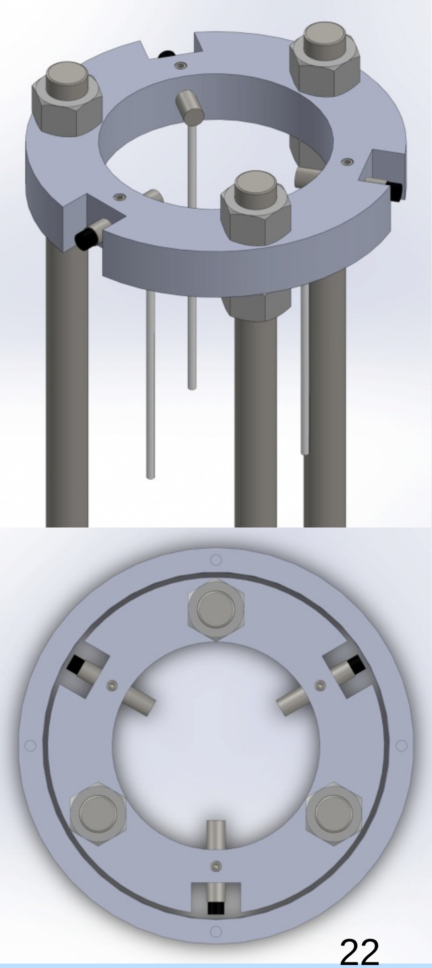




Task 3 Theoretical Analysis

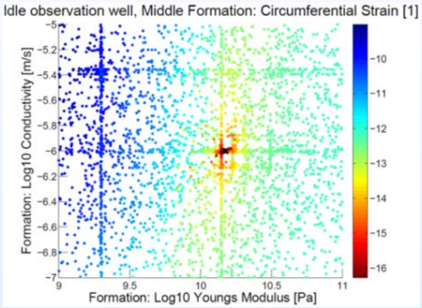
Alex Hanna

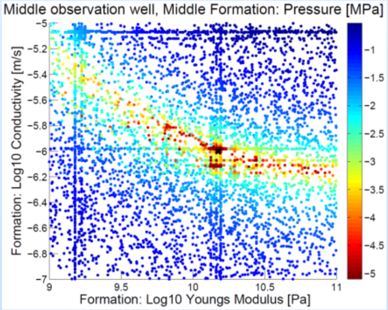
Develop theoretical analyses for characterizing the strain field associated with injection in the vicinity of critical features, such as contacts and faults, and then demonstrate innovative methods for inverting these data to provide a quantitative interpretation.

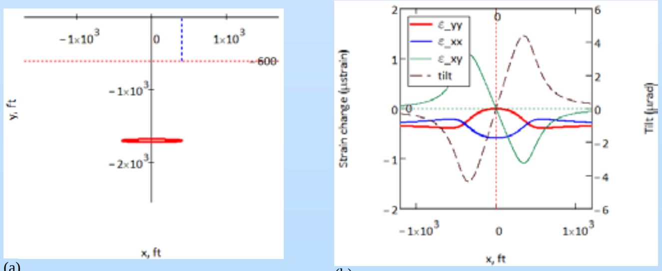
Version 1: Hybrid MCMC/GA
- High convergence rate
- Efficient where a unique solution exists

Version 2: Hybrid MCMC/GA+
- Thorough search of parameter space
- Slower convergence
- More confidence when tradeoffs exist

Version 3: Hybrid MCMC/GA++
- Multiple forward models
- New analytical soln to find neighborhood
- Numerical for final steps
- Fast and thorough







(a) (b)

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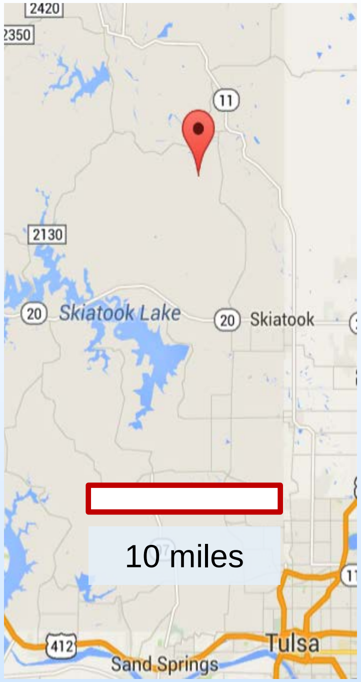
Task 4 Field Test

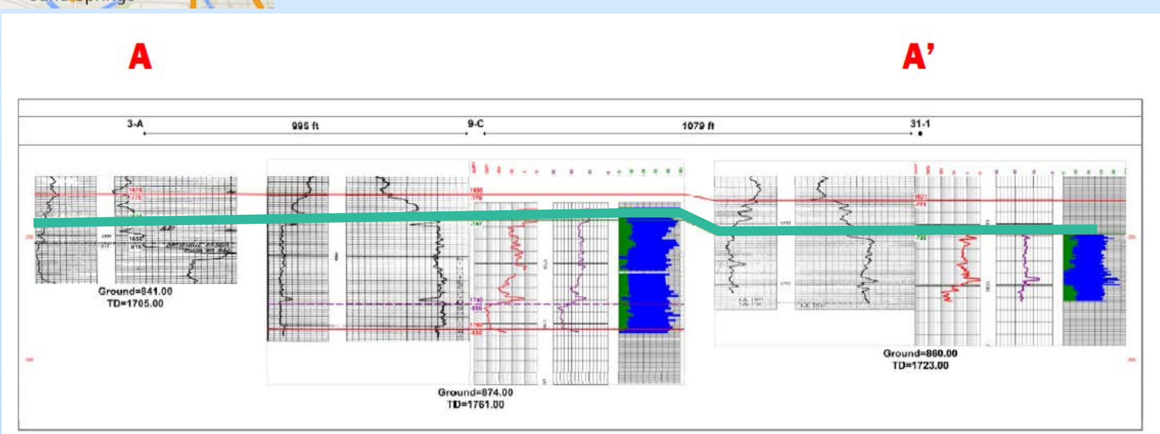
Avant Oil Field
Osage County, OK

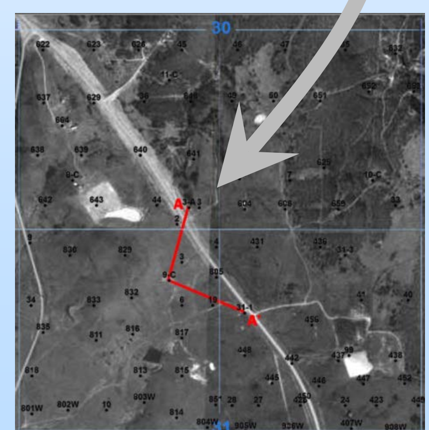


Grand Resources

Leonid Germanovich

Bartlesville Sandstone





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Task 4 Field Test

1. Develop Work Plan with Grand Resources
2. UNAVCO installs Gladwin (Geodetic) Borehole Strainmeter
3. Clemson installs new strainmeter
4. Equilibrate and background data
5. Initiate waterflood
6. Monitor strains
7. Analyze data using inversion methods

UNAVCO Installing
Borehole Strainmeter

75 Existing Geodetic Borehole Strainmeters installed by UNAVCO for the Plate Boundary Observatory

Deliverables / Milestones / Decision Points

BP1 Success Criteria

- Completion of Kickoff meeting and PMP
- Advanced optimization algorithms able to interpret strain data at execution times less than 0.7 of current baseline

BP2 Success Criteria

- Field demonstration designed and Workplan completed.
- **Go-NoGo:** Workplan describing field test accepted by DOE. Decision whether to deploy Gladwin strainmeter and start field test.
- Gladwin strainmeter installed by UNAVCO at Avant Field and generating data.
- **Go-NoGo**: Performance of new strainmeter assessed and evaluated relative to expected signals from field test. Decision whether to deploy new strainmeter

BP3 Success Criteria

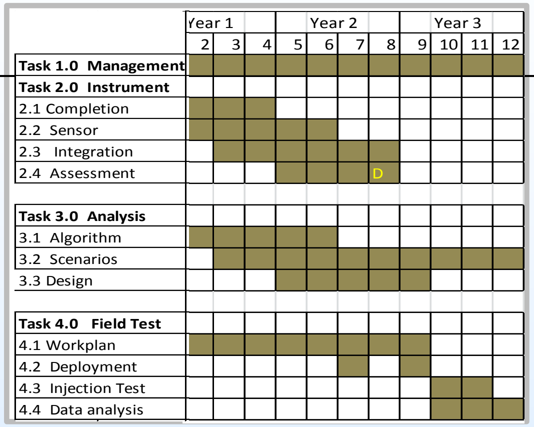
- Field data showing the evolution of the strain tensor during injection are obtained.
- A quantitative evaluation of the field data is complete.
- Final Report describing the feasibility of using measurements of the strain tensor to improve CO_2 storage complete.

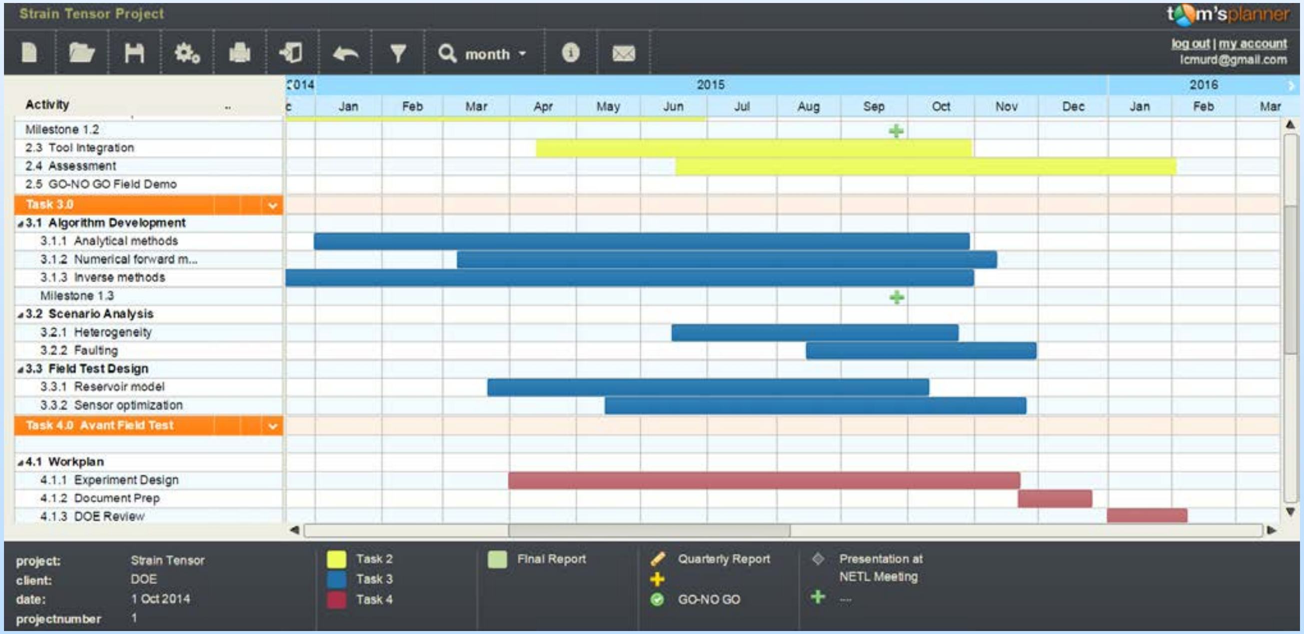
Risk Matrix

Type	Category	Problem	Mitigation
Technical			
	Strain Sensors	Performance Noise, drift, power, heat, environment	Evaluate multiple sensors. Use proven method (Gladwin meter) for baseline data set.
	Completion	Performance/cost Stability, logistics, fabrication	Option to use proven method (expanding grout)
	Tiltmeter	Performance Noise, drift, power, heat, environment	Option of using proven method, electrolytic tiltmeter
Resource			
	Investigator	Cannot participate	Overlap expertise, revise scope
Logistics			
	Site access	Site is sold, production postponed	Consider alternative sites, Regional Partnerships?
Management			
	Personnel	Leave the project	Hire new personnel, revise scope

Proposed Schedule

Develop during yr 1
Refine during yr 2
Demonstrate during yr 3





Cloud-based software for planning and tracking schedule

Summary

1. Instruments for practical measurement of strain tensor
2. Computational methods to interpret strain signals
3. Demonstrate in the field