Detecting Small Leaks over Large Areas
A New Way of Using Data

Project Number: FE-819-17-FY17

Youzuo Lin, Los Alamos National Laboratory
Carbon Storage, Oil & Gas Technologies Review Meeting
AGENDA

1. Technical Status
2. Accomplishments to Date
3. Lessons Learned
4. Synergy Opportunities
5. Summary & Path Forward
6. Appendix
Technical Status
WHY
An early assessment of CO₂ storage requires a technique capable of detection of small leaks in a large area without the need for extensive and expensive field datasets.

CHALLENGES
- Small and useful events buried in noisy and large-scale datasets
- Efficient method is required to allow early detection
- Financially effective method

SOLUTION
- Data-Driven Methods
- Multi-Physics Surface/Subsurface Measurements
PAST & NEW DIRECTIONS

Challenges

- Relevant information
- Computationally Efficient
- Financially Cheap

Previous Projects

- Detect Leak of CO₂ Using Seismic Waveform Tomography
- Imaging Geologic Features using Seismic Data
Multi-Physics-Guided Data-Driven Methods

- Improve Efficiency and Accuracy
- Compensate Missing Info
- Estimate Uncertainty

Multi-Physics Data Sets

- Data from Subsurface:
  - Seismic
  - Gravity
  - Flow
  - Pressure

- Data from Surface:
  - Unmanned Aerial Vehicle (UAV) 2D Imagery

Machine Learning | Hybrid Method
--- | ---
Data-Driven | Heuristics Based

Simulation

Previous Projects
Advanced Seismic Imaging and Inversion Techniques

Example of Previous Effort
Advanced Seismic Imaging and Inversion

- Novel full-waveform inversion and imaging methods for active seismic data to obtain subsurface fracture/fault zones.

- Novel focal mechanism inversion methods to reveal CO2-injection-induced microseismic events in pre-existing fracture zones.
Physics-Guided CO$_2$ Leakage Detection
Example of New Directions
**CHALLENGES**

- Expensive costs in acquiring data
- Limited information out of data
- Time consuming to interpret the data

**SOLUTION**

*Detect Leakage Signatures from Pressure Data*

- Pressure data from limited number of sensors
- Data-driven hybrid approach (Machine Learning + FEHM)
- Dimensionality reduction

**LANL Team:** Youzuo Lin, Dylan Harp, Bailian Chen, Rajesh Pawar, and George Guthrie.
Accurate Estimation of Unknown Leaks

- We employ the above training data to train our supervised learning methods.
- 500 unknown leak cases are created by varying the CO₂ injection rate.
- Prediction error is measured by Mean Absolute Error (MAE):
  \[
  \text{MAE} = \frac{\sum_{i=1}^{n} |y_i^{gt} - y_i^{pred}|}{n}
  \]
  - Overall MAE $\approx 3$ grid
  - Detection error:
    - within 1 grid point: 41.4%
    - within 2 grid points: 60.6%
    - within 3 grid points: 72.8%
Other Research Efforts and Data Types
Real-Time Geologic Fault/Fracture Detection from Seismic Data

Surface Feature Detection from UAV Hyperspectral Imagery

Permeability Estimation from Hydraulic Head Data

LANL Team: Youzuo Lin, Ellen Syracuse, Emily Schultz-Fellenz, David Coblentz, and George Guthrie.
Accomplishments to Date
Hybrid Method to Estimate Uncertainty

Leakage Detection and Risk Assessment

LANL Team
Youzuo Lin
Dylan Harp
Rajesh Pawar
George Guthrie

Hybrid Method to Detect Small Events

Microseismic Event Detection Using Deep Learning Method

LANL Team
Youzuo Lin
Paul Johnson
David Coblentz

External Collaborators
Yue Wu (U. of Rochester)
Ji Liu (U. of Rochester)
Ming Yan (Michigan State)

Hybrid Method to Improve Efficiency & Accuracy

Real-Time Geologic Surface/Subsurface Feature Detection

LANL Team
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Ellen Syracuse
Emily Schultz-Fellenz
David Coblentz
George Guthrie

External Collaborators
Shusen Wang (UC, Berkeley)
Jayaraman Thiagarajan (LLNL)

Hybrid Method to Compensate Missing Info

Learning-Based Hydraulic Inverse Modeling

LANL Team
Youzuo Lin
Daniel O'Malley
Brendt Wohlberg
Velimir V. Vesselinov
Lessons Learned
Lesson Learned

Lessons Learned

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<td>Relevant Information</td>
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Risks and Challenges

- Useful training data sets to characterize the physics
- Seamless fusion of multi-physics data sets
- Small events buried among the noisy environment
- Complexity of real world VS synthetic model: heterogeneity, scale,
- Early detection and warning
Synergy Opportunities
**PROJECT TEAM**

**LANL Team**
Youzu Lin, Dylan Harp, Ting Chen, Lianjie Huang, Paul Johnson, David Coblentz, Rajesh Pawar, and George Guthrie

**External Collaborators**

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<tr>
<th>University</th>
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<tr>
<td>University of Rochester</td>
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<td>LLNL Center for Applied Scientific Computing</td>
<td>Jayaraman J. Thiagarajan</td>
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**RESOURCES**

**Internal LANL Program Funding**

LANL Center for Space and Earth Science (CSES) Projects

Pathfinder

Environmental Program

UNESE
Summary & Path Forward
SUMMARY

We have developed several seismic inversion and imaging techniques. The method has been applied to Aneth CO$_2$-EOR field data. Preliminary results to demonstrate the performance and feasibility of our hybrid machine learning methods.

PATH FORWARD

Near Future
- Add more physics to our current model and flow data: 2D->3D, heterogeneity

Algorithms Development Based on Synthetic Data Test
- Develop machine learning algorithms based on synthetic models and data sets

Performance Evaluation Based on Field Data Test
- Acquire field data sets
- Acquire other types of data sets
Thank you!
Benefit to the Program

- Our techniques can detect small signals out of large noisy data.
- Our techniques can extract useful information from different types of data sets.
- All these techniques will be critical to early detection of CO$_2$ leakage.
Project Overview

The task is exploring related strategies for applying this approach to detection of a subsurface leak out of large area. It will leverage a combination of multiple types of field data and subsurface emulators (which can rapidly reproduce detailed physics-based predictions).
Organization Chart

LANL

University Collaborators

- U. C. Berkeley
- U. Rochester
- Michigan State
- Penn State

National Lab Collaborator

LLNL
**Gantt Chat**

- **FY 17 Milestone 1**
  - Defining tasks and locate resources
  - Develop algorithms to pressure data and others
  - Use ML and pressure data to detect potential leaks

- **FY 18 Milestone 2**
  - Develop ML methods for multiple data set
  - Will look into seismic, UAV and other datasets

- **FY 19 Milestone 3**
  - Develop multi-physics ML methods
  - Will look into seismic, UAV and other datasets

- **Scheduling**
  - Defining tasks and locate resources
  - Develop algorithms
  - Obtain training data from synthetic model
  - Use ML and pressure data to detect potential leaks

- **Kick-off**


