Detecting Small Leaks over Large Areas

A New Way of Using Data

Project Number: FE-819-17-FY17

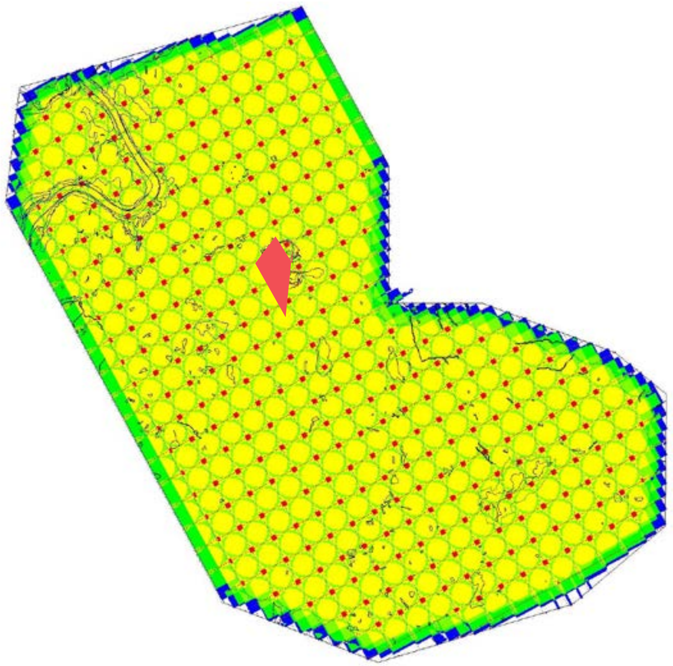
Youzuo Lin, Los Alamos National Laboratory
Carbon Storage, Oil & Gas Technologies Review Meeting

AGENDA

1. Technical Status
2. Accomplishments to Date
3. Lessons Learned
4. Synergy Opportunities
5. Summary & Path Forward
6. Appendix

Technical Status

PROBLEM DESCRIPTION



WHY

An early assessment of CO_2 storage requires a technique capable of detection of small leaks in a large area without the need for extensive and expensive field datasets

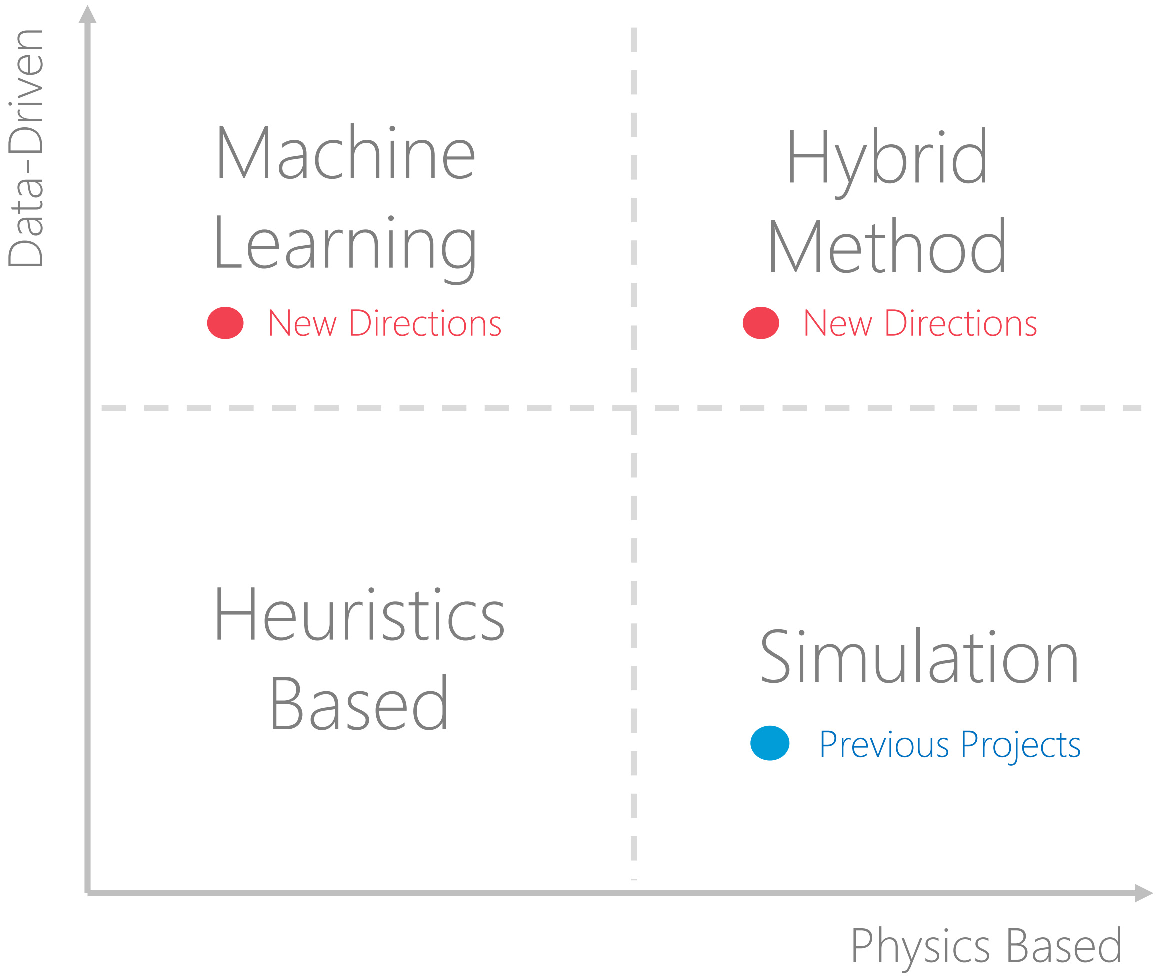
CHALLENGES

- **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



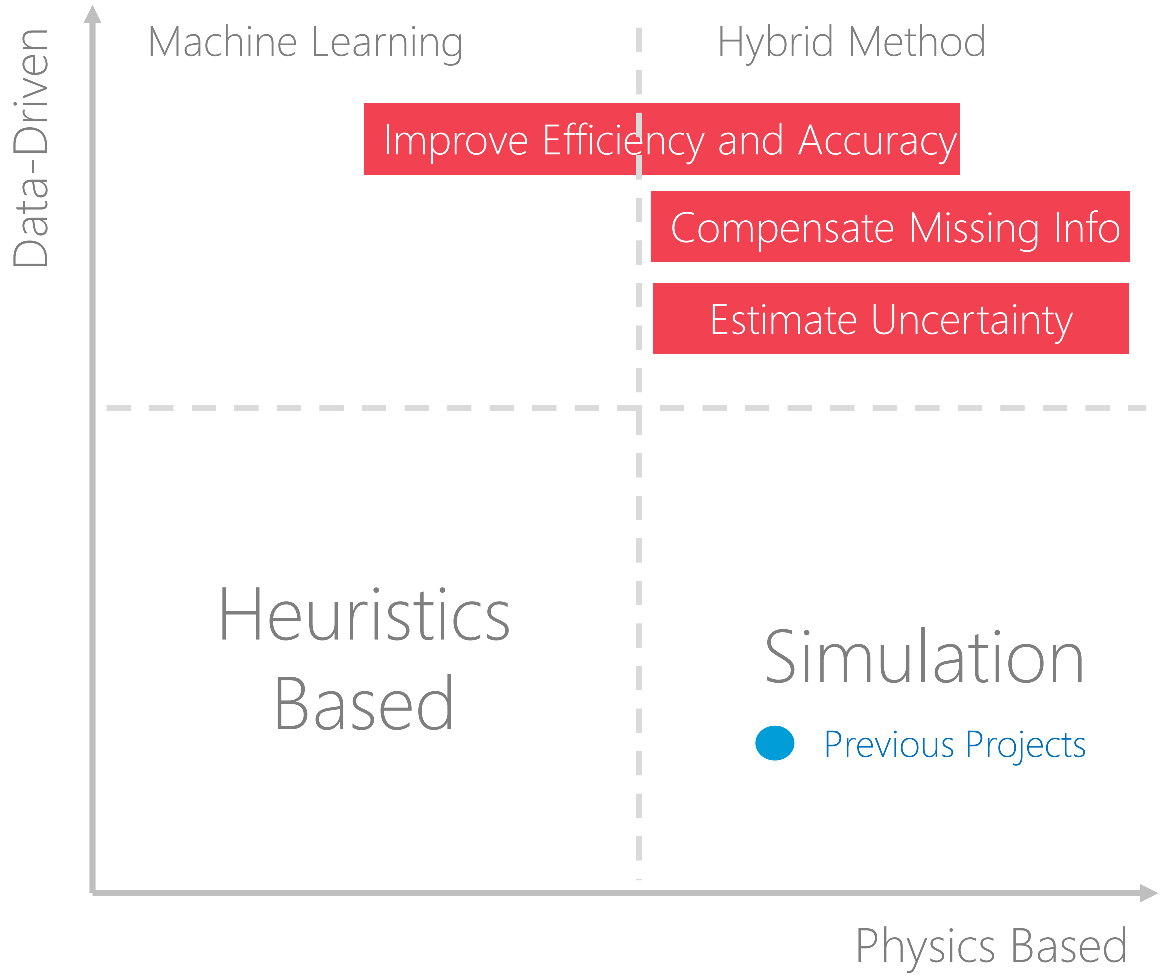
Challenges

- Relevant information
- Computationally Efficient
- Financially Cheap

Previous Projects

- Detect Leak of CO_2 Using Seismic Waveform Tomography
- Imaging Geologic Features using Seismic Data

Multi-Physics-Guided Data-Driven Methods



Multi-Physics Data Sets

- **Data from Subsurface**:
  - Seismic
  - Gravity
  - Flow
  - Pressure
- **Data from Surface**:
  - Unmanned Aerial Vehicle (UAV) 2D Imagery

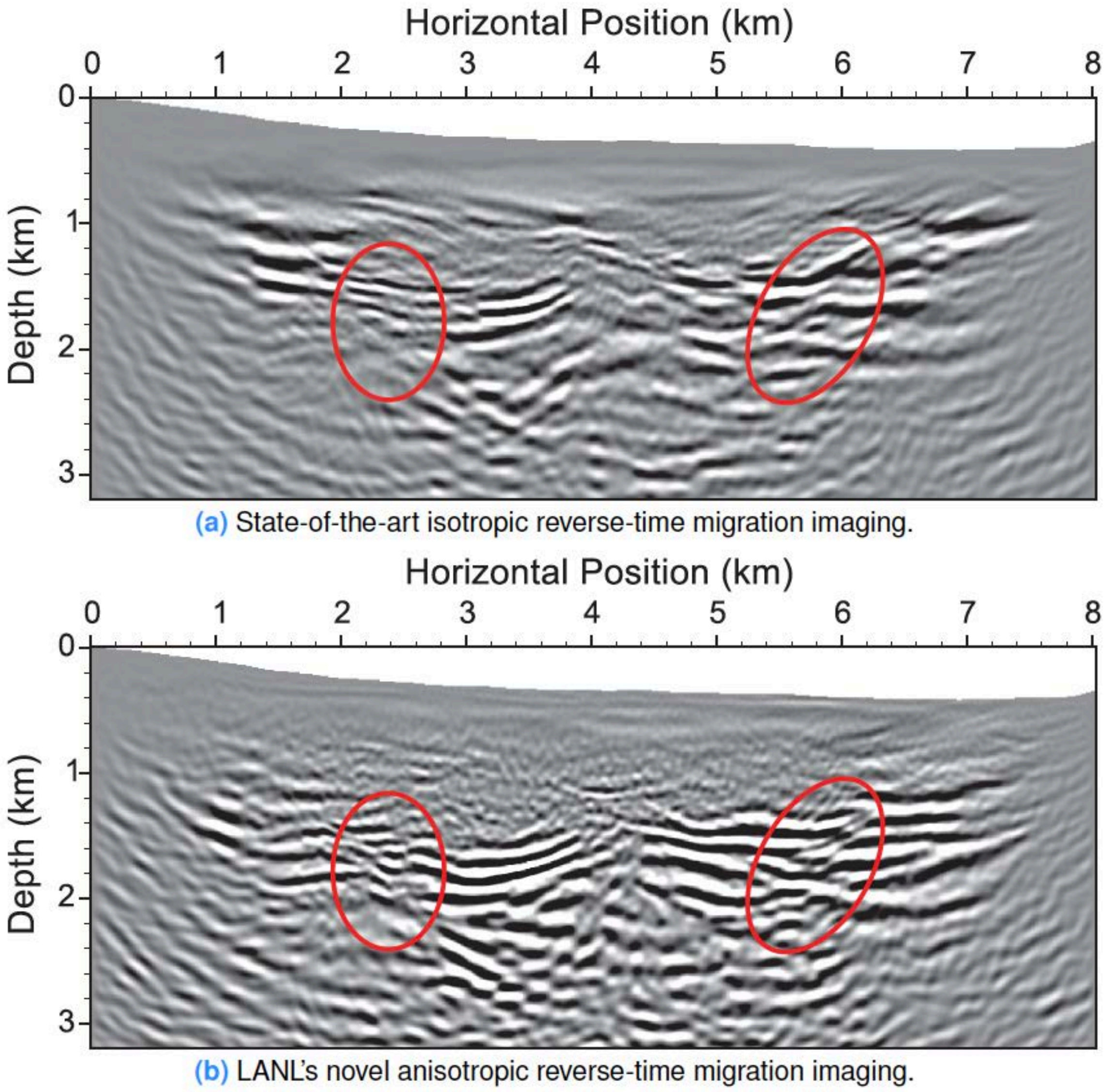
Advanced Seismic Imaging and Inversion Techniques

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.

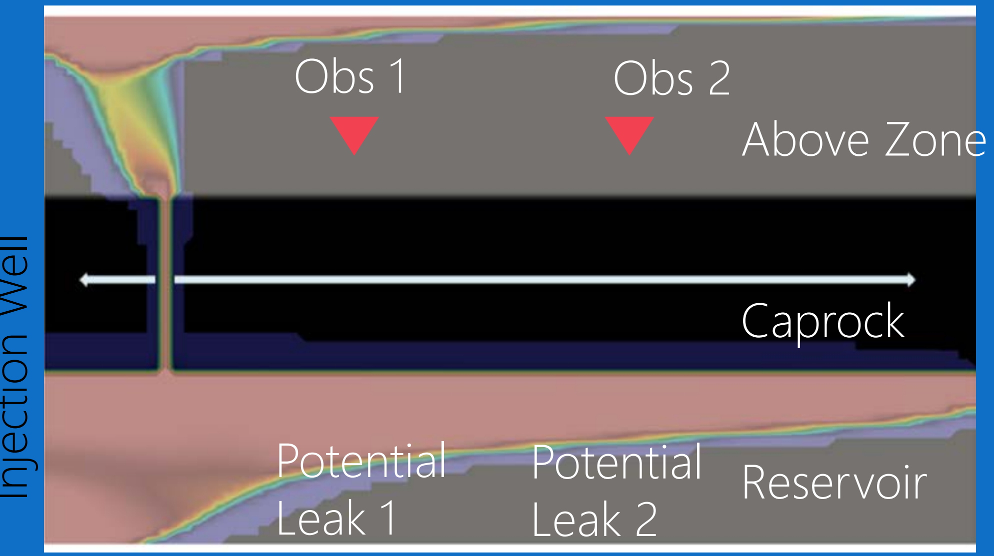


Physics-Guided CO_2 Leakage Detection

Example of New Directions

CHALLENGES

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



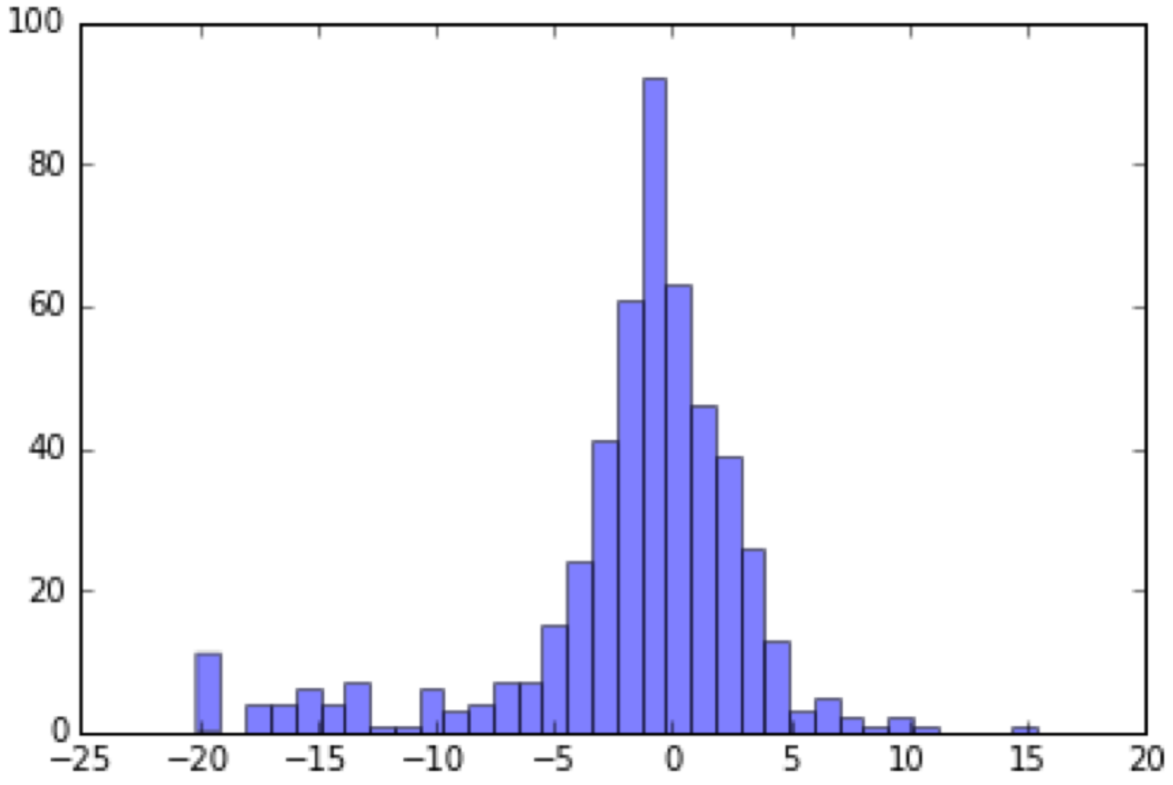
SOLUTION

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



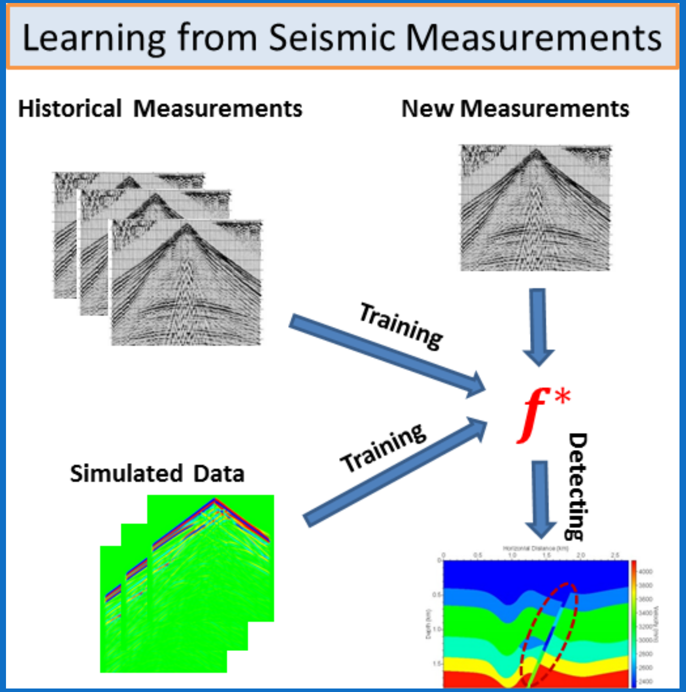
- We employ the above training data to train our supervised learning methods.
- 500 unknown leak cases are created by varying the CO_2 injection rate.
- Prediction error is measured by Mean Absolute Error (MAE):

$$\mathbf{MAE} = \frac{\sum_{i=1}^{n} |y_i^{gt} - y_i^{pred}|}{n}$$

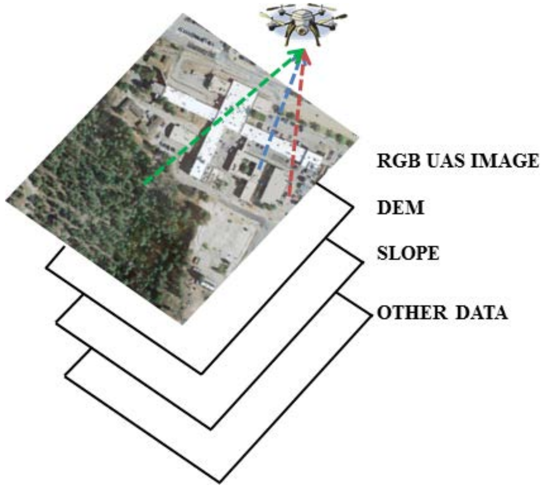
- **Overall MAE ≈3** grid
- Detection error:
  - within 1 grid point: **41.4%**
  - within 2 grid points: **60.6%**
  - within 3 grid points: **72.8%**

Other Research Efforts and Data Types

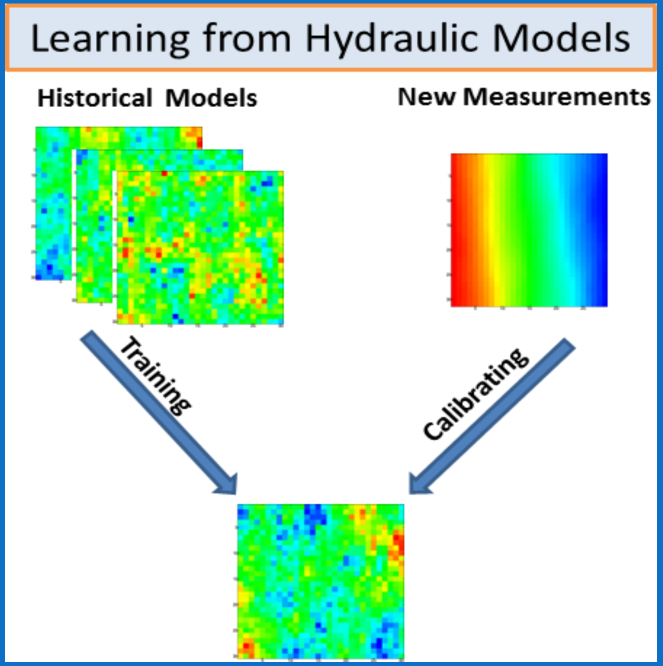
Real-Time Geologic Fault/Fracture Detection from Seismic Data



Surface Feature Detection from UAV Hyperspectral Imagery



Permeability Estimation from Hydraulic Head Data



Learning-Based Inverse Modeling

LANL Team: Youzuo Lin, Ellen Syracuse, Emily Schultz-Fellenz, David Coblentz, and George Guthrie.
External Collaborators: Shusen Wang (UC, Berkeley), Jayaraman J. Thiagarajan (Center for Applied Scientific Computing, LLNL).

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
Youzuo Lin
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

	Physics-Based	Machine Learning	Hybrid Method
Relevant Information	X		X
Computationally Efficient		X	X
Finacially Cheap		X	X

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

Youzuo Lin, Dylan Harp, Ting Chen,
Lianjie Huang, Paul Johnson, David Coblentz,
Rajesh Pawar, and George Guthrie

External Collaborators

University of Rochester Dept. of Computer Sciences	Yue Wu, Zhen Zhou, and Dr. Ji Liu
University of California, Berkeley Dept. of Statistics	Dr. Shusen Wang
Michigan State University Dept. of Computational Sciences	Dr. Ming Yan
Penn State University Dept. of Geosciences	David Chas Bolton
LLNL Center for Applied Scientific Computing	Jayaraman J. Thiagarajan

RESOURCES

Internal LANL Program Funding

- LANL Center for Space and Earth Science (CSES) Projects
- Pathfinder
- Environmental Program
- UNESE

Summary & Path Forward

SUMMARY

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!

Appendix

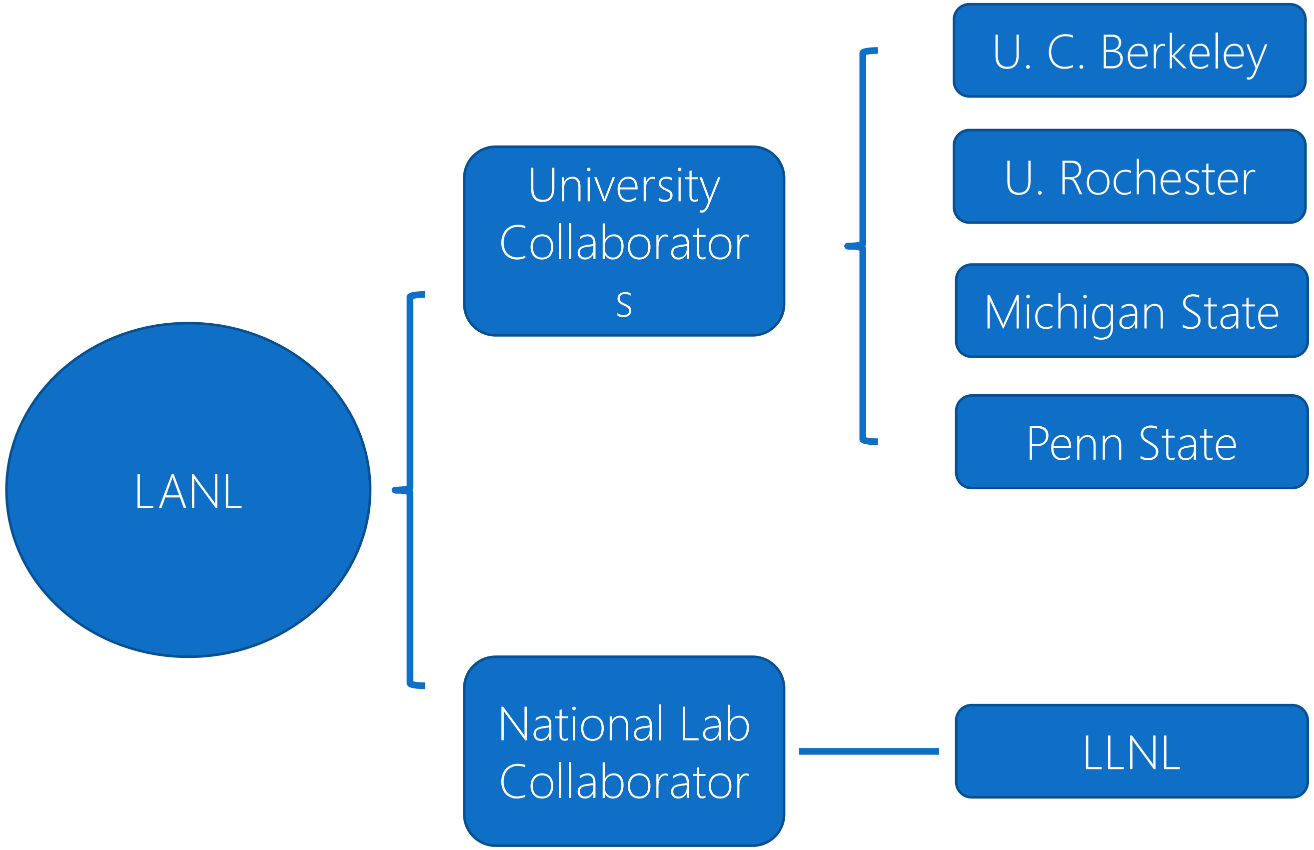
Benefit to the Program

- 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.

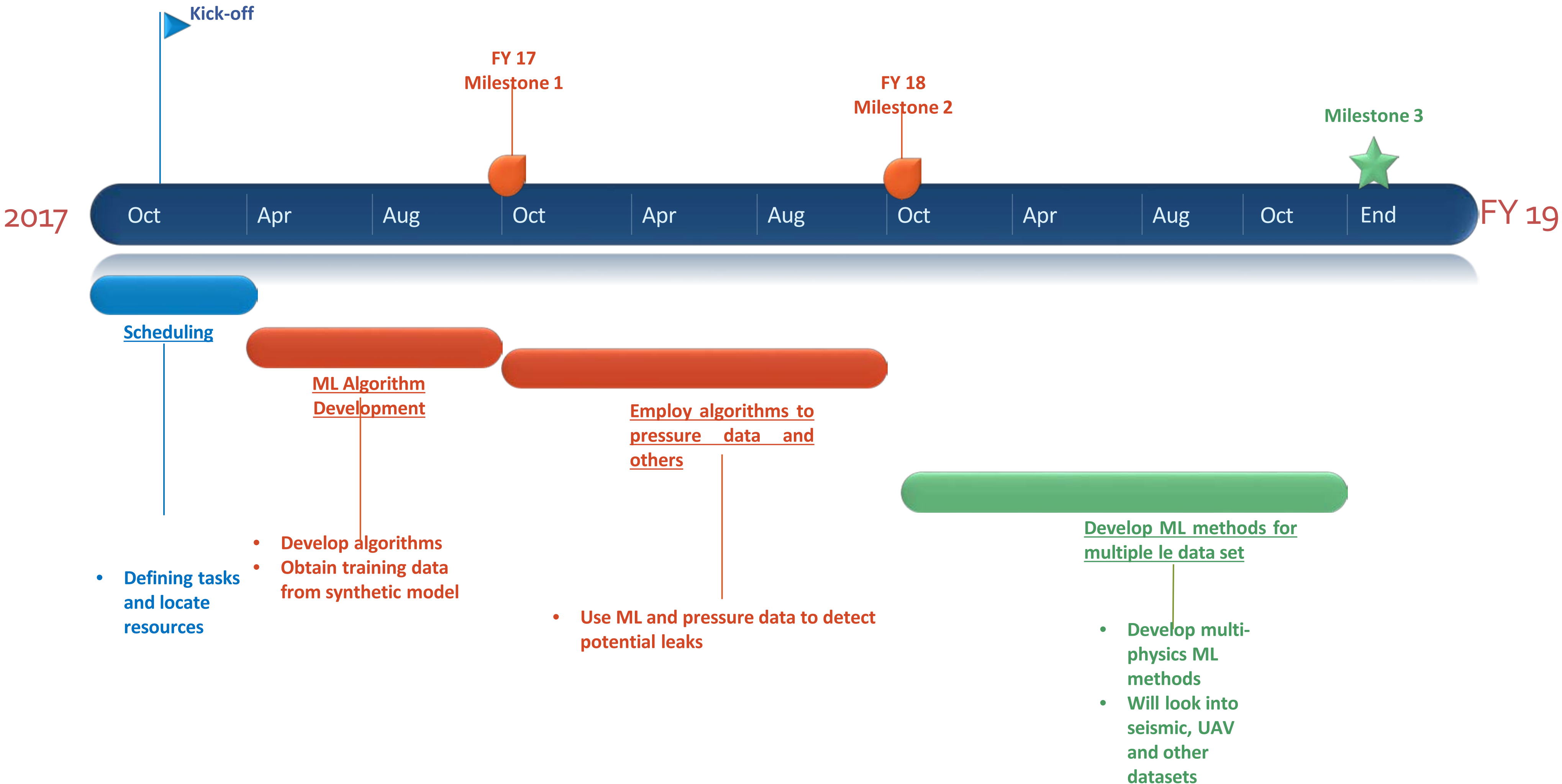
Project Overview

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



Gantt Chat



Kick-off
FY 17
Milestone 1
FY 18
Milestone 2
Milestone 3
2017
Oct
Apr
Aug
Oct
Apr
Aug
Oct
Apr
Aug
Oct
End
FY 19
Scheduling
ML Algorithm Development
Employ algorithms to pressure data and others
Develop ML methods for multiple le data set
• Defining tasks and locate resources
• Develop algorithms
• Obtain training data from synthetic model
• Use ML and pressure data to detect potential leaks
• Develop multi-physics ML methods
• Will look into seismic, UAV and other datasets

Bibliography

[1]. Youzuo Lin, Ellen B. Le, Daniel O'Malley, Velimir V. Vesselinov, and Tan Bui-Thanh, "Large-Scale Inverse Model Analyese Employing Fast Randomized Data Reduction", Water Resources Research, 2017 (accepted).

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[4]. Youzuo Lin and Lianjie Huang, "Quantifying Subsurface Geophysical Properties Changes Using Double-difference Seismic-Waveform Inversion with a Modified Total-Variation Regularization Scheme," Geophysical Journal International, 203 (3): 2125-2149, doi:10.1093/gji/ggv429, *2015*.

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