National Risk Assessment Partnership - Strategic Monitoring for Uncertainty Reduction

Erika Gasperikova[1], Xianjin Yang[2], Thomas Buscheck[2], Kayyum Mansoor[2], Susan Carroll[2], Zan Wang[3], Delphine Appriou[5], Alain Bonneville[5] , Yu Chen[4], Lianjie Huang[4], Zheng Zhou[4], Youzuo Lin[4], Zhongping Zhang[4], Yue Wu[4], George Guthrie[4], Ya-Mei Yang[3], Robert Dilmore[3], William Harbert[3], Catherine Yonkofski[5], Timothy Johnson[5], Jeffrey Burghardt[5], Christopher Brown[5], Thomas Daley[1], Quanlin Zhou[1], Curt Oldenburg[1]

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U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

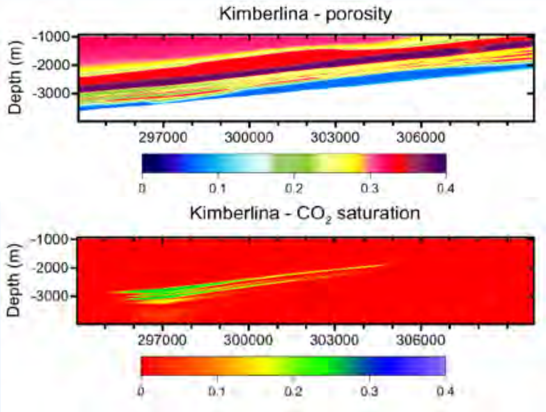
August 13-16, 2018

Presentation Outline

- Introduction
- Models and Datasets
- Geophysical Monitoring of Leakage through Legacy Wells
- Geophysical Monitoring of Leakage through a Dipping Fault
- Risk-Based Monitoring Network Design Tools
- Summary

Introduction

Resistivity/EM methods	Seismic methods	Gravity method
sensitivity to fluid properties	sensitivity to changes in bulk properties	sensitivity to changes in density
Porosity	Porosity	Porosity
Permeability	Permeability	
Brine/CO_2/Residual saturations	Brine/CO_2/Residual saturations	Brine/CO_2/Residual saturations
Brine Salinity (TDS)		
	Density	Density
	Pressure	
Temperature		
Rock type	Rock type	Rock type
Resistivity	Seismic velocities	Density

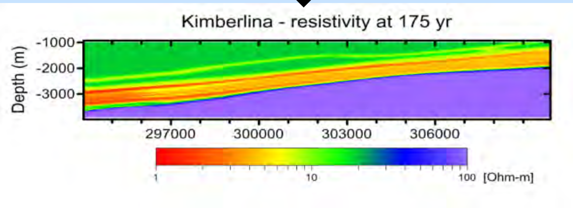


Multiphysics models

↓

Rock-physics or constitutive relationships

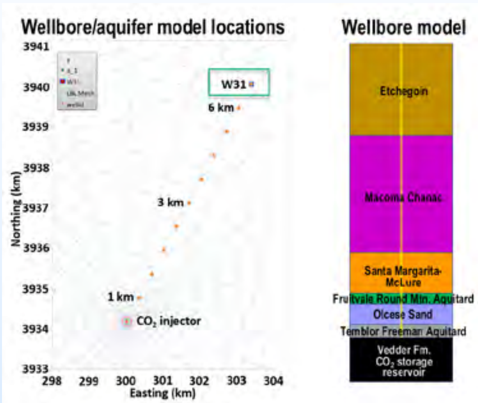
↓

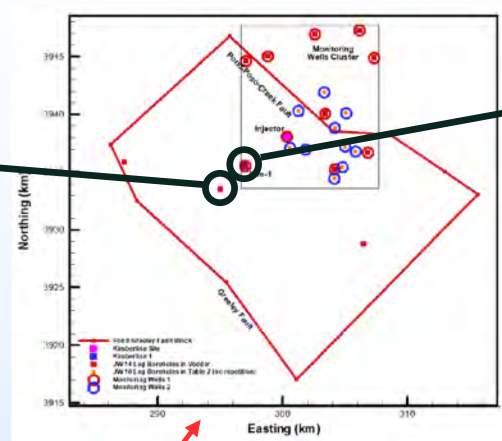


Geophysical models

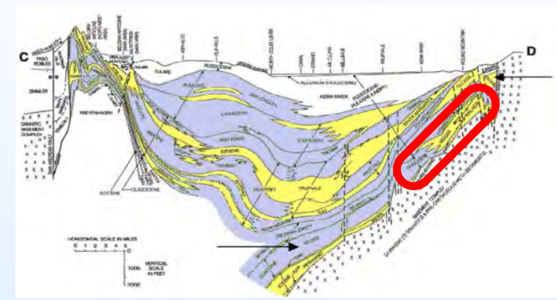
Models/Datasets

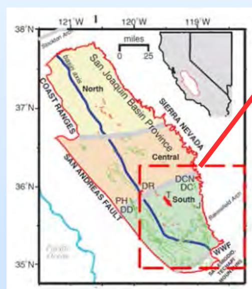
Kimberlina 1.1 and 1.2: Leakage through legacy wells

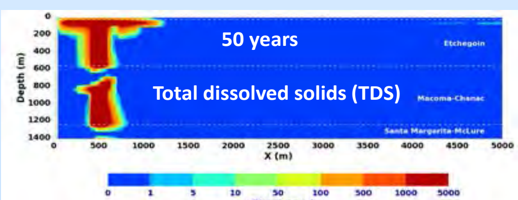


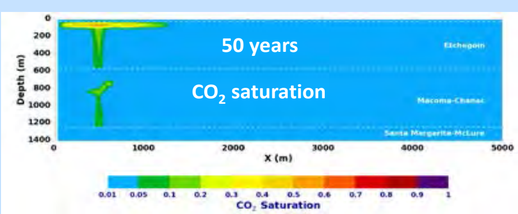


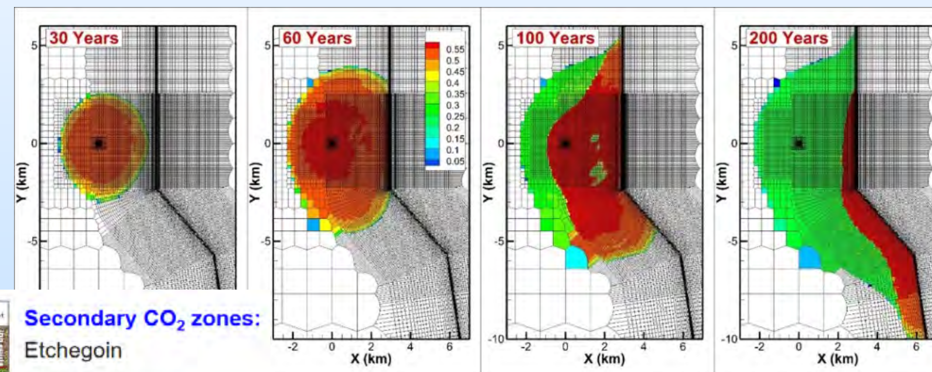
Kimberlina II: Leakage through a dipping fault











Secondary CO_2 zones:

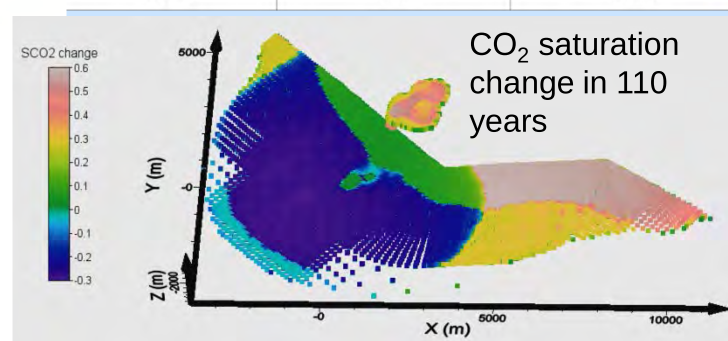
Etchegoin

Santa Margarita

Olcese

Injection Zone:

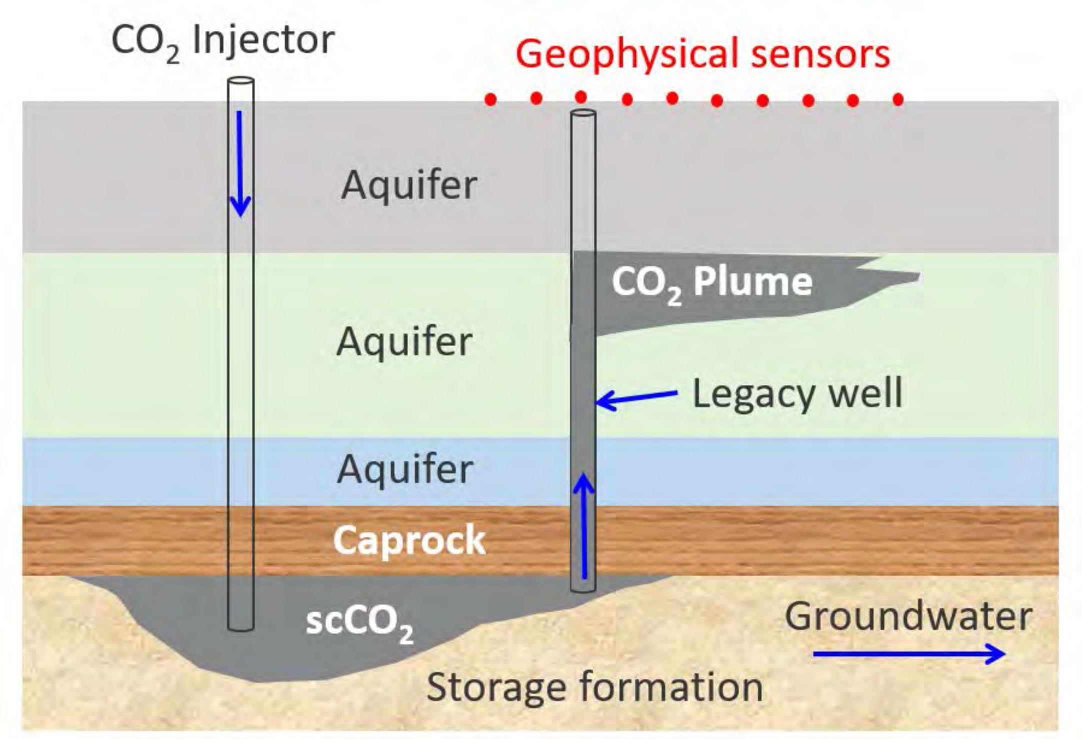
Vedder Sands



Geophysical Monitoring of Brine and CO_2 Leakage through a Legacy Well into Shallow Aquifers (1)

Xianjin Yang, Thomas A. Buscheck, Kayyum Mansoor, Susan Carroll, LLNL
Zan Wang, NETL and Delphine Appriou, PNNL

- Assess the effectiveness of monitoring methods to detect leakage
- Develop optimized monitoring designs with the DREAM tool
- Develop monitoring design and analysis approaches that can be incorporated into integrated assessment model (IAM) for reduction of uncertainty in risk performance through time.



Groundwater properties impacted by CO_2 leakage

- pH
- Total dissolved solids (TDS)
- Pressure
- CO_2 saturation

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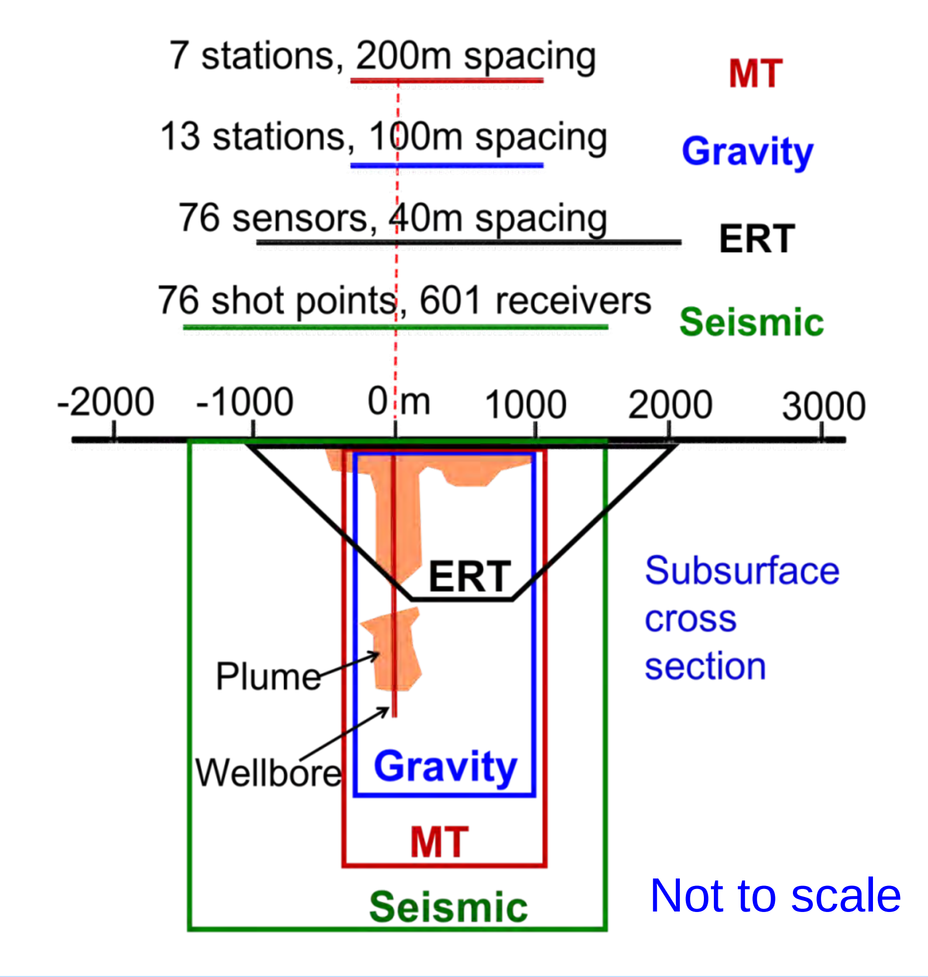
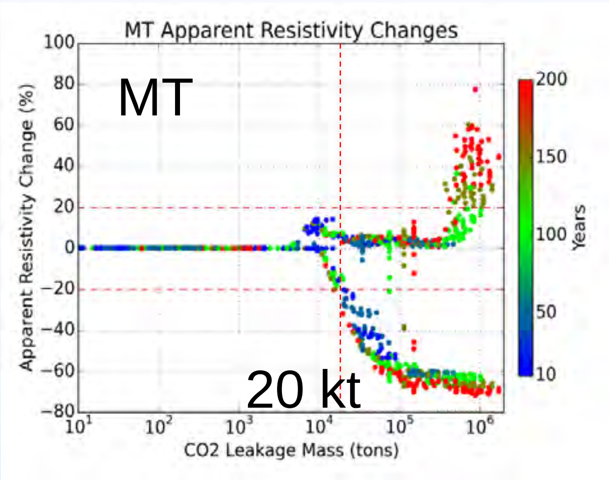
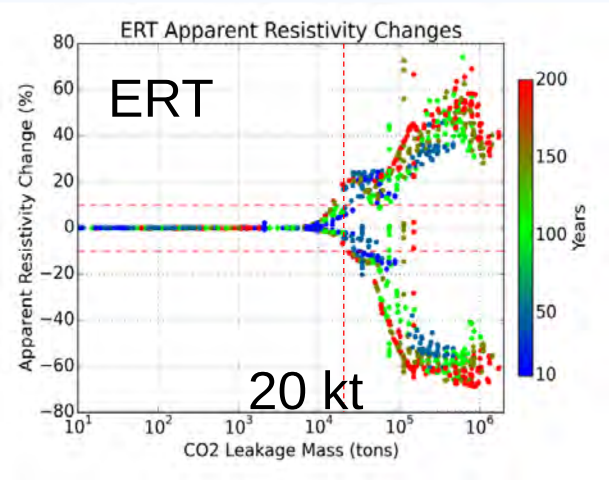
Geophysical Monitoring of Brine and CO_2 Leakage through a Legacy Well into Shallow Aquifers (2)

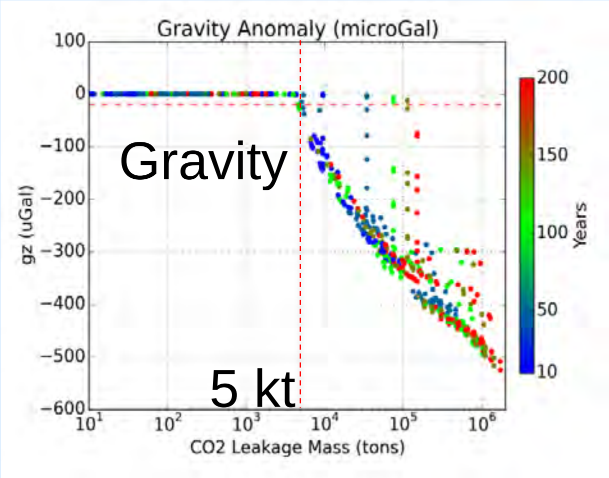


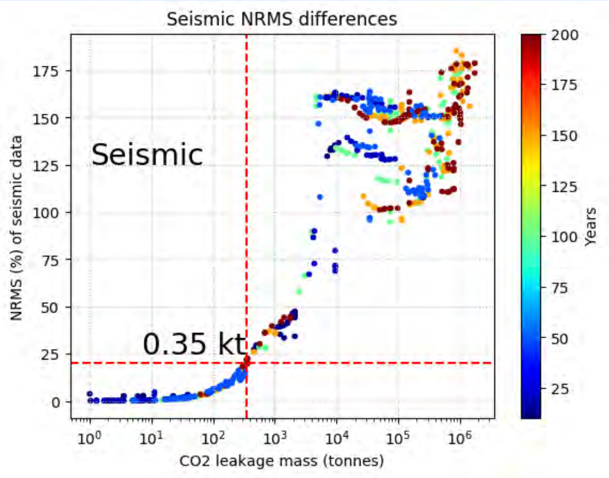
- Surface-based geophysical methods:
  (a) electrical resistivity tomography (ERT)
  (b) magnetotellurics (MT)
  (c) gravity
  (d) seismic methods
- 140 aquifer impact simulations at 7 time steps (0, 10, 20, 50, 100, 150, 200 years)
- 980 synthetic geophysical data sets per geophysical method were created

Geophysical Monitoring of Brine and CO_2 Leakage through a Legacy Well into Shallow Aquifers (3)



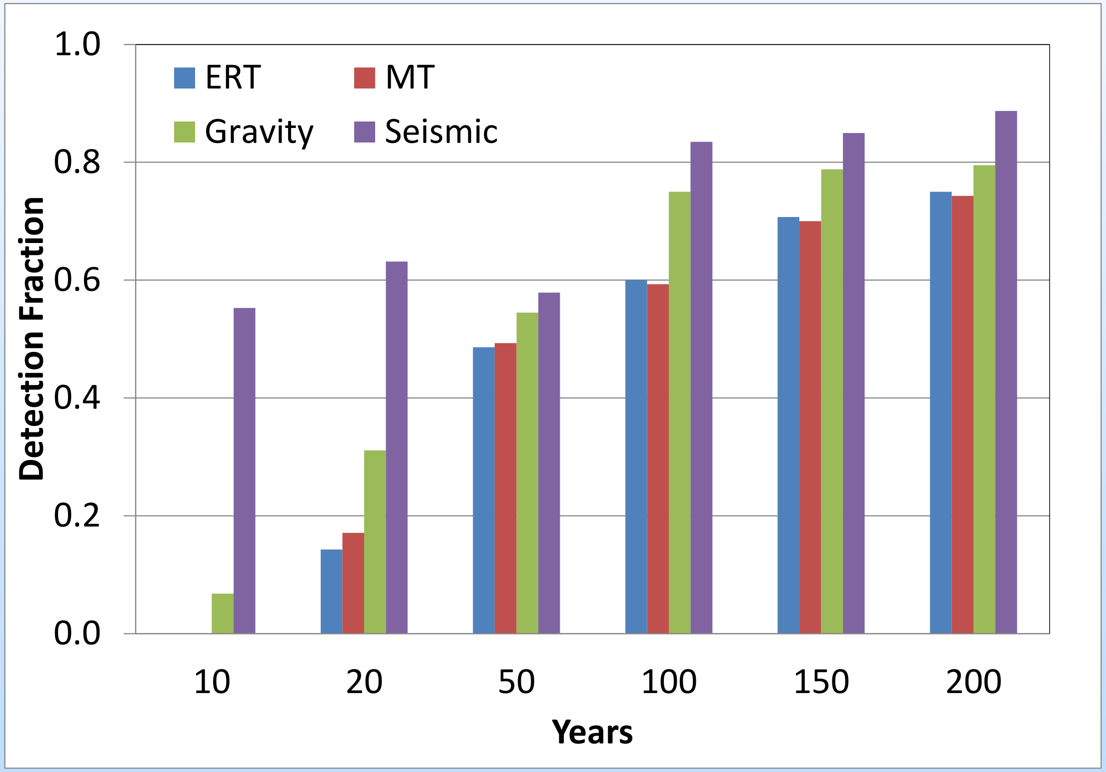






- There is a good correlation between the signal strength and CO_2 leakage mass
- ERT is sensitive to both resistivity CO_2 gas and conductive dissolved CO_2
- Seismic method can detect a CO_2 leak as small as 350 tons

Geophysical Monitoring of Brine and CO_2 Leakage through a Legacy Well into Shallow Aquifers (4)



- All four geophysical methods have more than 50% chance to detect a leak after 50 years
- Both seismic and gravity methods have better chance for early detection of a leak before 20 years

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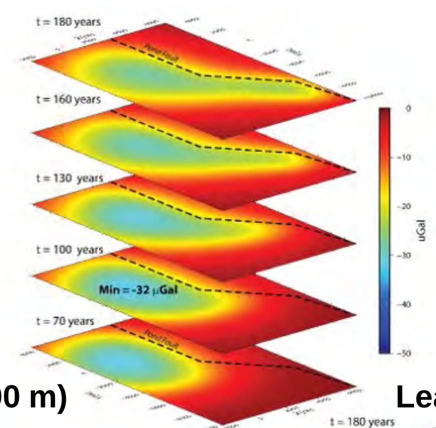
Time-lapsed gravity monitoring of CO_2 and brine leakage through a dipping fault

Delphine Appriou, Alain Bonneville, PNNL

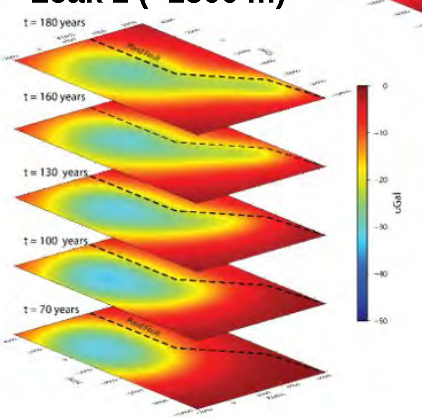
Surface Gravity Survey

Baseline

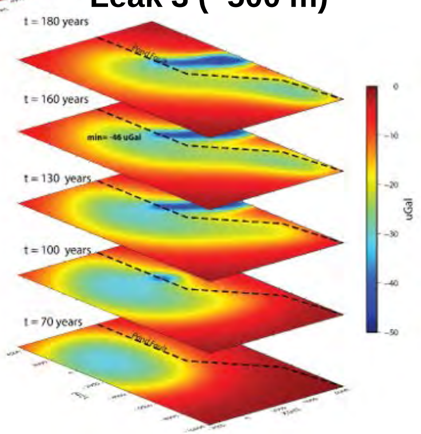


Surface gravity response detects CO_2 plume growth, migration and accumulation along a structural feature.

Leak 1 (~1500 m)



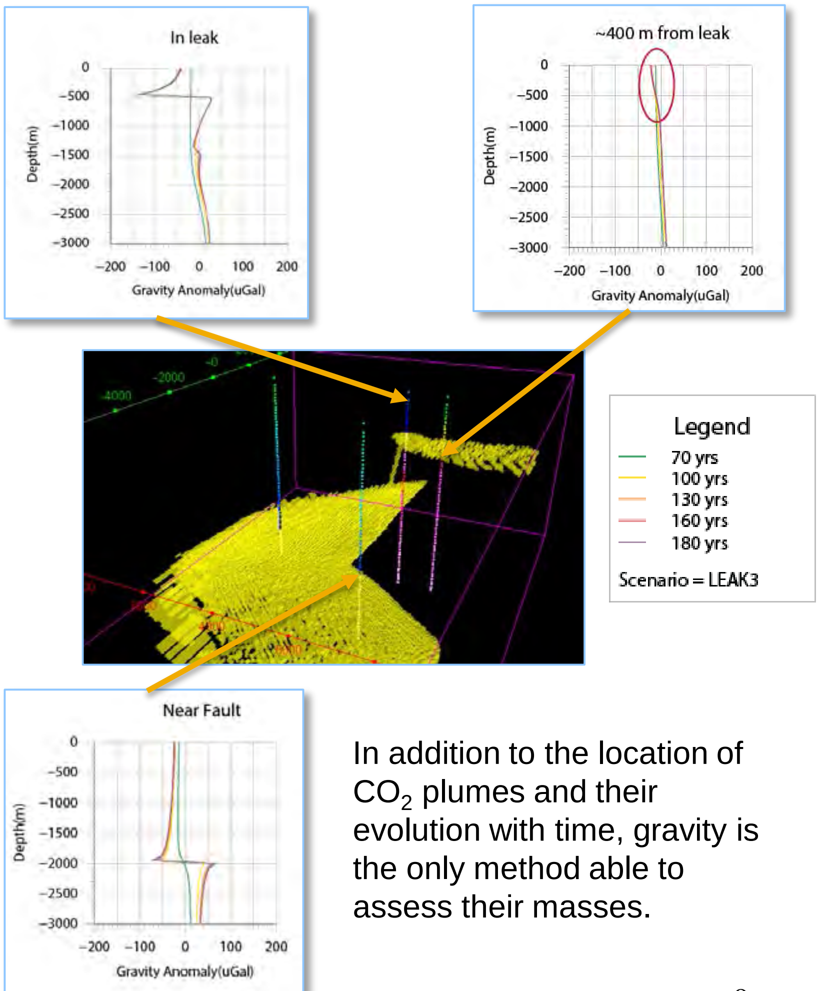
Leak 3 (~500 m)



Leak too deep and mass too small to be detectable by a surface gravity survey only.

Leak large and shallow enough to be detected by a surface gravity survey.

Borehole Gravity Survey



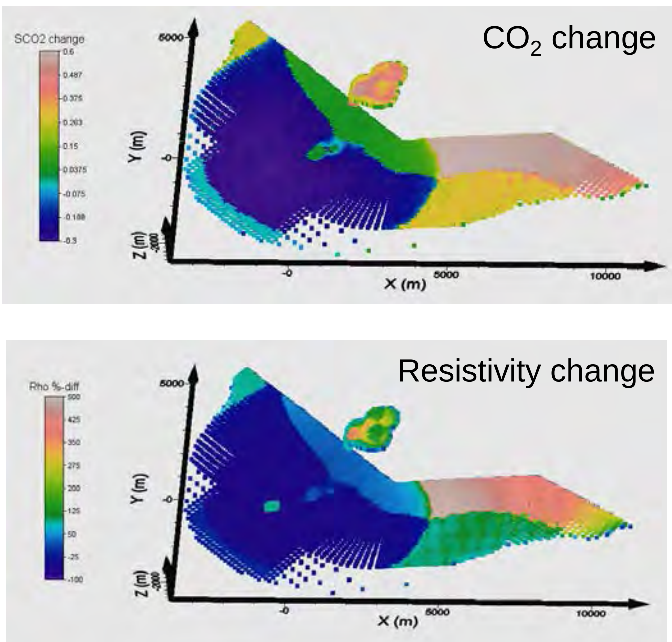
In addition to the location of CO_2 plumes and their evolution with time, gravity is the only method able to assess their masses.

Geophysical modeling of CO_2 and brine leakage through a dipping fault

Erika Gasperikova, Quanlin Zhou,
Thomas Daley, Curtis Oldenburg, LBNL

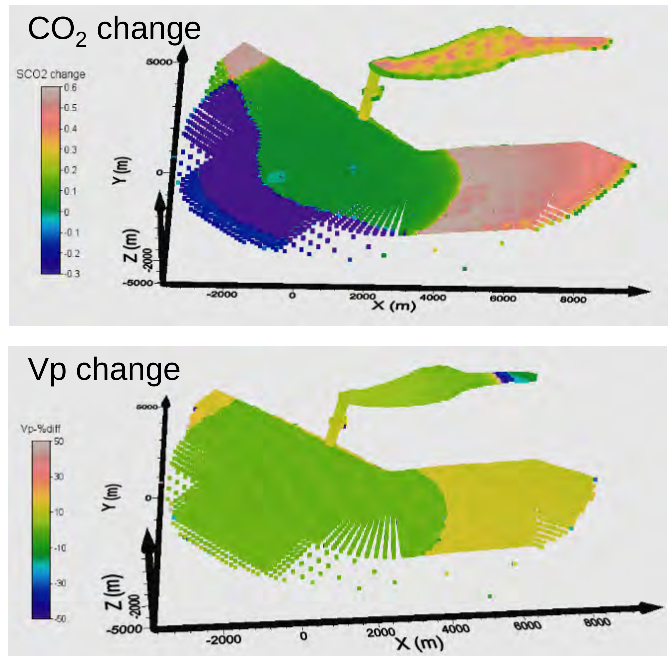
3D time-lapse monitoring

Resistivity/EM methods



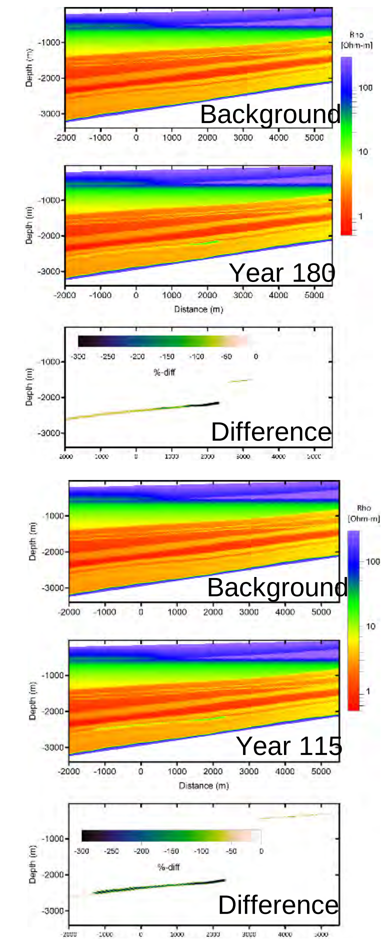
Leak at ~1500 m

Seismic methods



Leak at ~500 m

2D time-lapse monitoring

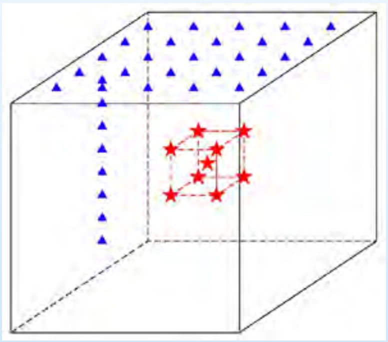


- CO_2 plume at ~1500 m depth grows slowly (1km^2/50 years) and it's localized around the leak point
- CO_2 plume at ~500 m depth grows fast (triples in size every 5 years) and it follows geological structures

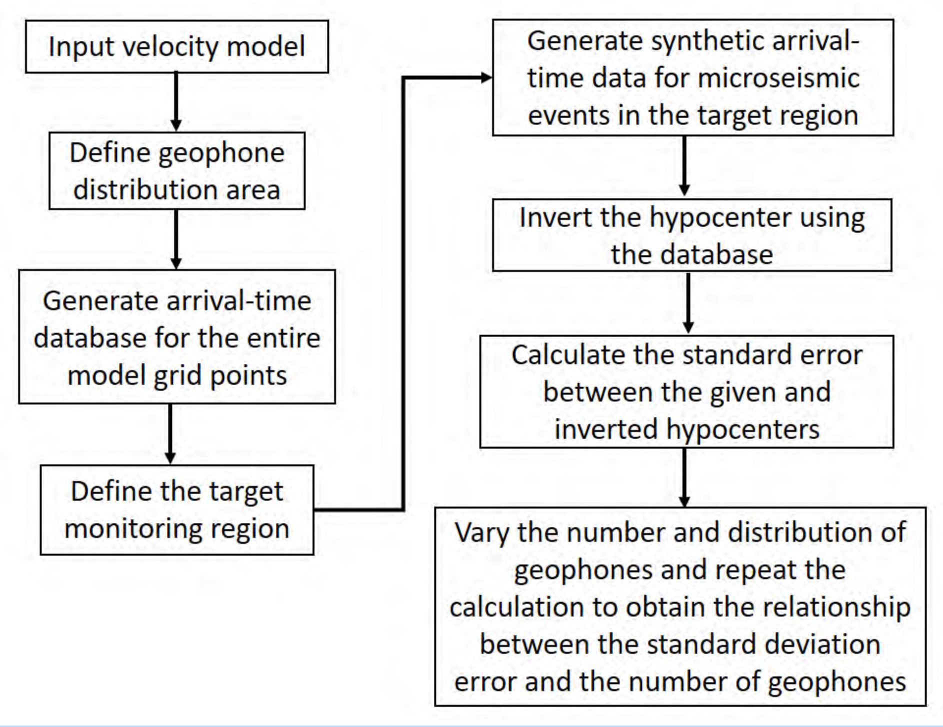
Tool for Optimal Design of Passive Seismic Monitoring Network

Yu Chen and Lianjie Huang, LANL

- Develop a tool to determine the relationship between the hypocenter uncertainty of microseismic events (red stars) within a target monitoring region (red box) and the geophone distribution (blue triangles).
- Design an optimal, cost-effective passive seismic monitoring network using this relationship.

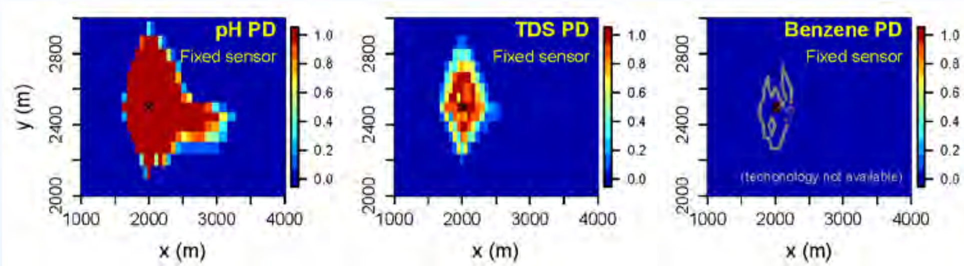


- Developed a fast-marching algorithm to calculate P- and S-wave arrival times.
- Developed a simulated heat-annealing method to search the best hypocenters through minimizing the arrival-time misfit between data and synthetics.



Risk-based Monitoring Assessment Methodology

Ya-Mei Yang, Robert Dilmore, Grant Bromhal, NETL
Mitchell Small, Carnegie Mellon



Probability of detection using monitoring response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journal homepage: www.elsevier.com/locate/ijggc
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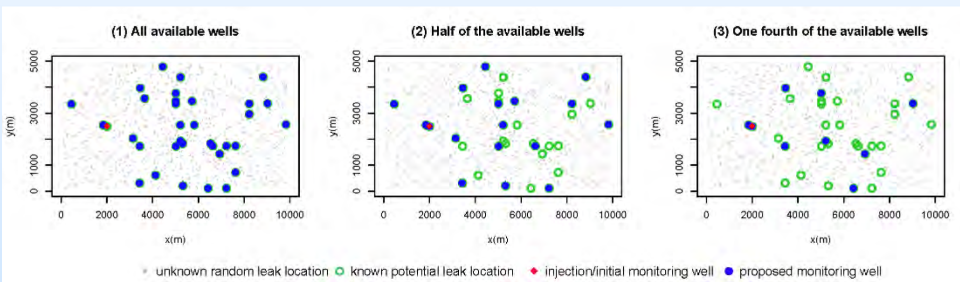
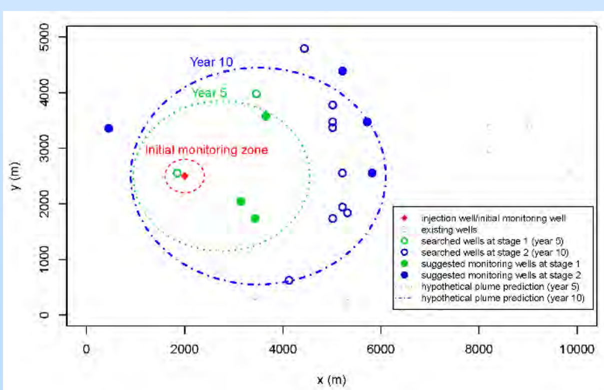
Toward an adaptive monitoring design for leakage risk – Closing the loop of monitoring and modeling

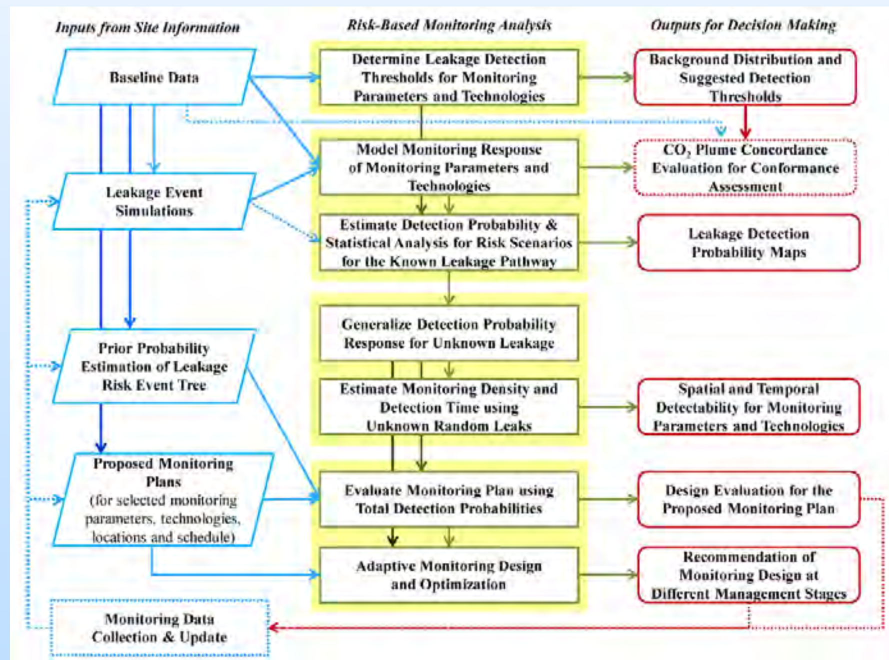
Ya-Mei Yang[a,c,*], Robert M. Dilmore[a], Grant S. Bromhal[a], Mitchell J. Small[b]



Proposed monitoring well locations



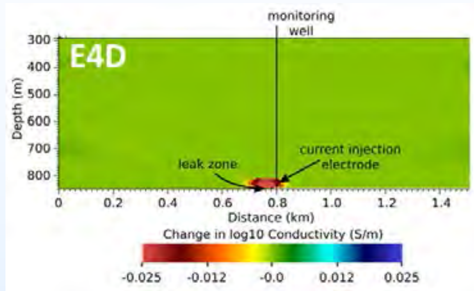
Two-stage monitoring design solution

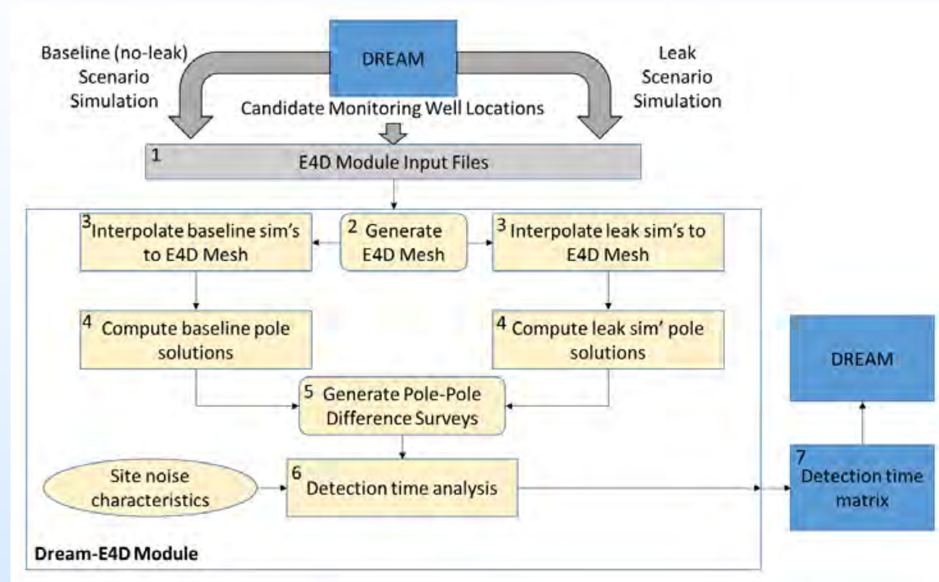


Risk-based monitoring design

Risk-Based Monitoring Network Design Tools

Catherine Yonkofski, Timothy Johnson, Christopher Strickland, Jeffrey Burghardt, PNNL



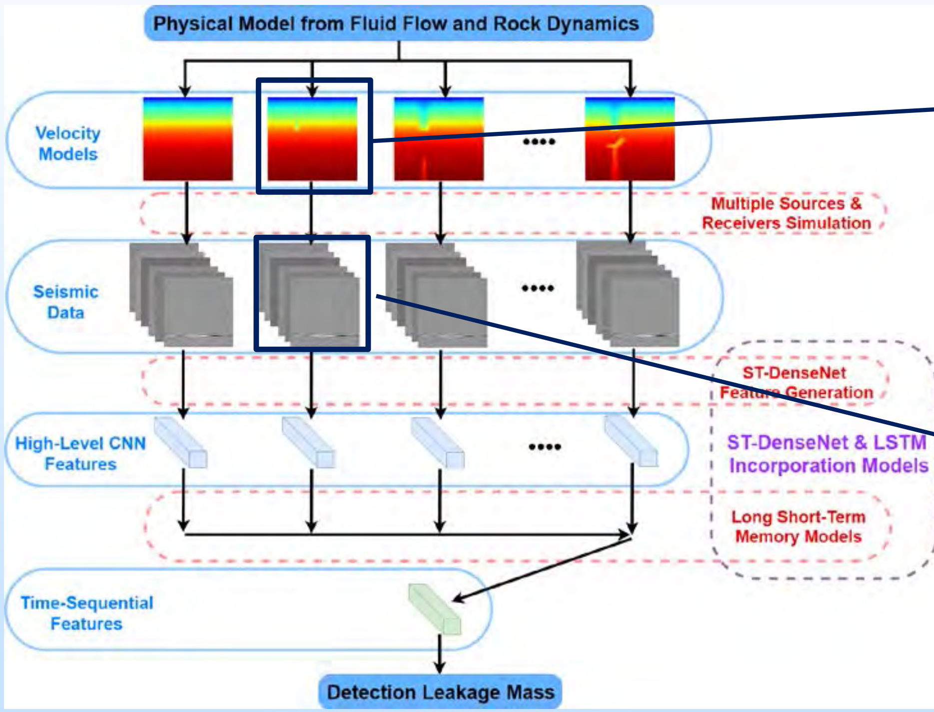


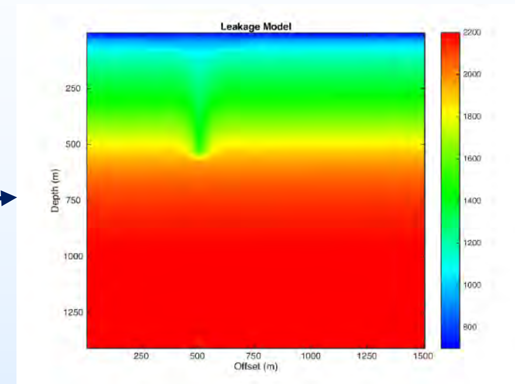
- DREAM v2 ERT module Beta released
- Considers both remote and point source monitoring parameters in a novel way
- More flexible user input including compatibility with OpenIAM output
- Improvement in memory usage for significantly faster data processing times
- Importance of evaluating detectability of monitoring technology with respect to leak magnitudes

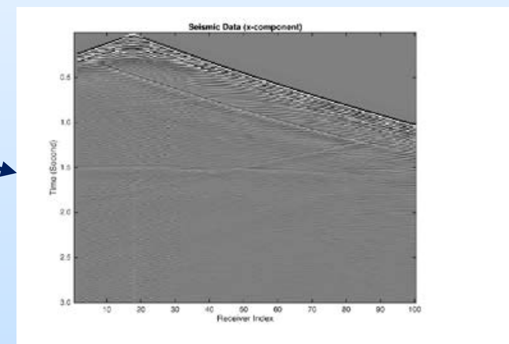
Deep Learning Techniques to Detect CO_2 Leakage Using Seismic Data

Zheng Zhou, Youzuo Lin, Zhongping Zhang, Yue Wu, George Guthrie, LANL
Zan Wang, Robert Dilmore, NETL

Method







Zhou et al. (SEG, 2018), Zhou et al. (GJI, 2018)

- Build on deep neural networks to detect indirect physical changes caused by CO_2 leaks
- Combine 1D and 2D convolutional networks to account for both spatial and temporal information
- Incorporate long short-term memory (LSTM) to utilize time-sequential characteristics

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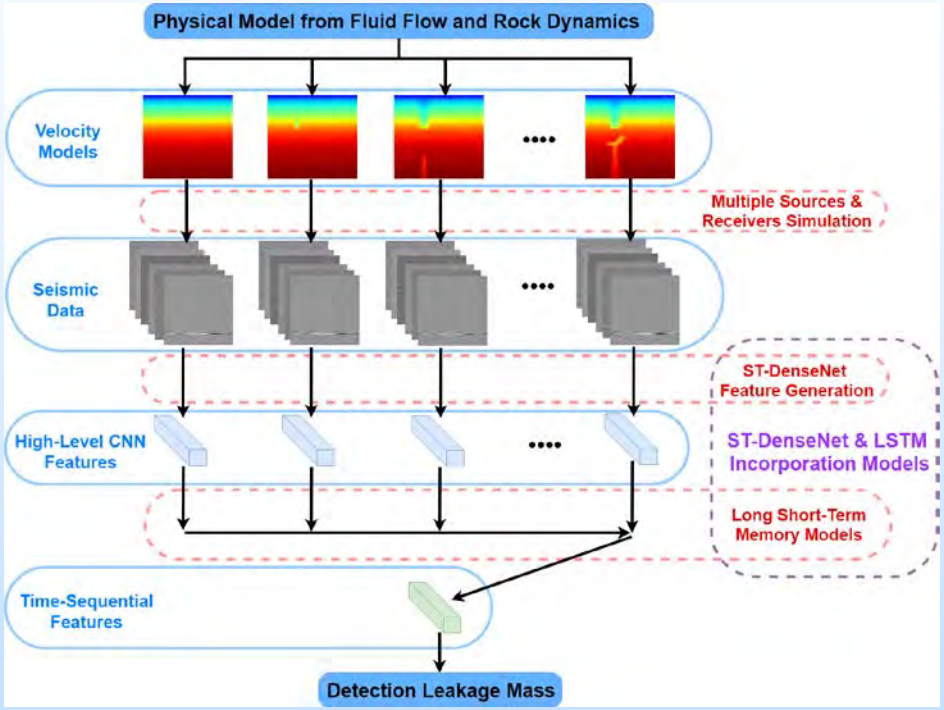
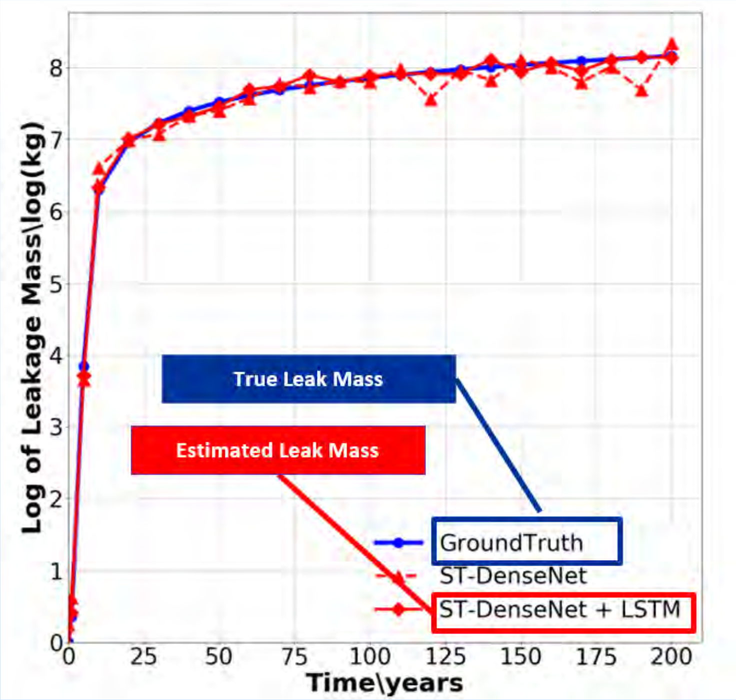


Results



Zhou et al. (SEG, 2018), Zhou et al. (GJI, 2018)

- Build on deep neural networks to detect indirect physical changes caused by CO_2 leaks
- Combine 1D and 2D convolutional networks to account for both spatial and temporal information
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Accomplishments to Date

- Four model datasets available for monitoring modeling – FutureGen 2.0, Kimberlina 1.1, 1.2, and Kimberlina 2
- Release of DREAM tool with E4D extension
- Report on geophysical techniques for CO_2 plume monitoring
- Report on effectiveness of multiple geophysical monitoring methods in detecting brine and CO_2 leakage in underground sources of drinking water
- Peer reviewed journal articles and presentations at scientific conferences

Future Work

- Continue with simulations of monitoring of modeling for various geophysical monitoring technologies
- Quantify the size of leak that can be detected and the earliest detection time for various monitoring techniques
- Develop prototype stochastic analysis based on a simple example case based on preliminary reduced-order model of monitoring
- Continued development of DREAM tool

Future Work

- Initiate consideration of how models of monitoring (numerical simulations or ROMs) can be used for design of monitoring networks for early detection of unwanted fluid migration
- Develop characterization of technical performance of monitoring technology detection thresholds, and attributes of spatial and temporal resolution
- Detectability maps of different monitoring technologies
- Establish conceptual framework for integration of multiple monitoring signals

Synergy Opportunities

- Noise levels from actual field data could be incorporated into modeling and improve statistical estimates of derived parameters

- Field data sets from active experiments could be used to test and verify monitoring approaches

- Developed codes and methodologies will be shared with other projects

Appendix

Benefit to the Program

- To develop a science-based method for quantifying the risks (and associated potential liabilities) for CO_2 storage sites and to develop efficient, risk-based monitoring protocols. The work is based on detailed multi-physics process models, coupled with reduced order modeling to facilitate stochastic analysis of risk and uncertainty.

- The development of monitoring approaches and risk assessment methodologies will lead to more efficient use of monitoring resources with risk reduction as an optimization metric.

Project Overview

Goals and Objectives

- Assess the effectiveness of monitoring methods to detect leakage, develop optimized cost-effective monitoring designs, and integrate monitoring into the IAM to reduce risk and uncertainty in risk.

- The integration will include feedbacks that allow a monitoring protocol to be influenced or driven by the IAM assessment of risks, as well as allowing the risk profiles to be modified by monitoring and mitigation. The influence of monitoring will be in identifying the need for mitigation (i.e., identification of leakage) and then the monitoring of mitigation to assess its success.

Milestones and Deliverables

- M1.17.4.A Report on initial selection of scenarios from Kimberlina impact models to be used for geophysical modeling December 2017
- Release of DREAM tool with E4D extension - December 2017
- Estimate effectiveness of multiple geophysical monitoring methods in detecting brine and CO_2 leakage in underground sources of drinking water - June 2018
- Briefing to NRAP Stakeholder Group on progress and status of strategic monitoring task – August 2018
- D4.B Propose a conceptual design for effectively integrating geophysical models/monitoring technology characterizations into a risk assessment framework – December 2018

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