National Risk Assessment Partnership - Strategic Monitoring for Uncertainty Reduction

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U.S. Department of Energy

National Energy Technology Laboratory

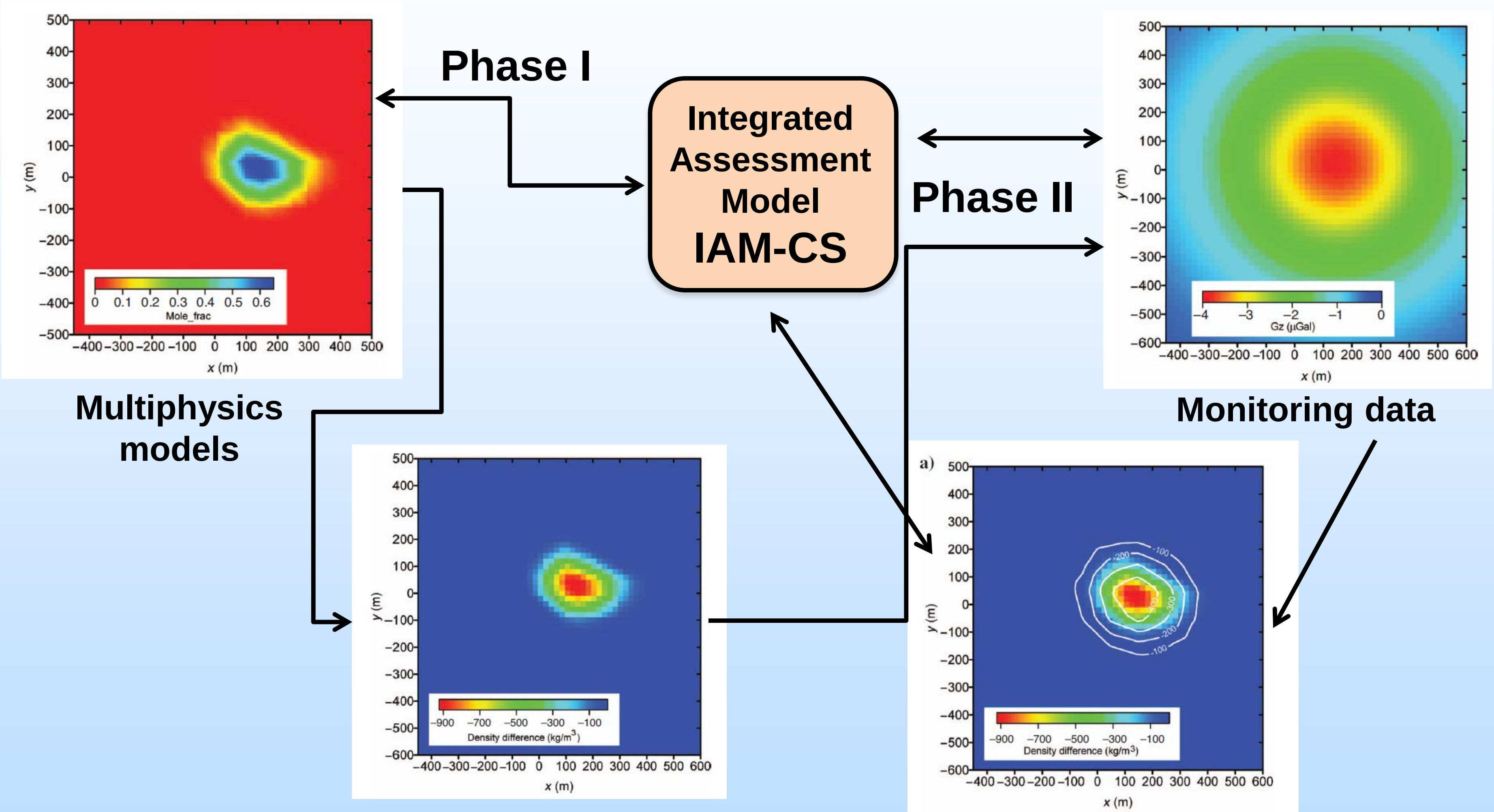
Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 1-3, 2017

Presentation Outline

- Introduction
- Subtask 4.1: Development of Methods to Model Monitoring Techniques
- Subtask 4.2: Development of Reduced-Order Models for Monitoring
- Subtask 4.3: Risk-Based Monitoring Network Design Tool
- Subtask 4.4: Integration with Risk Assessment/ Reduction
- Summary

Introduction



Phase I

Integrated Assessment Model

IAM-CS

Phase II

Multiphysics models

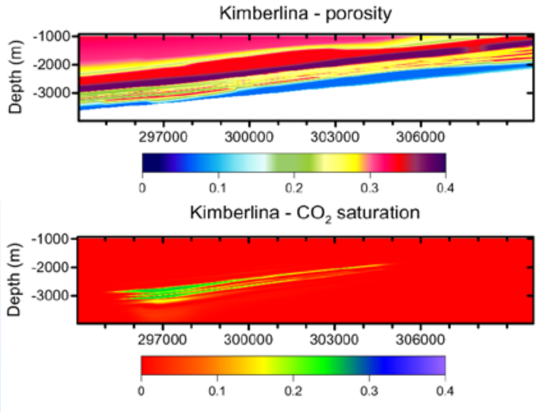
Monitoring data

Input for geophysical modeling

Inversion output

Introduction

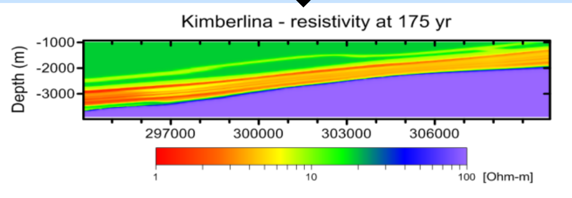
Resistivity/EM methods	Seismic methods	Gravity method
sensitivity to fluid properties	**sensitivity to changes in bulk properties**	**sensitivity to changes in density**
Porosity	Porosity	Porosity
Permeability	Permeability	
Brine/CO_2/Residual saturations	Brine/CO_2/Residual saturations	Brine/CO_2/Residual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


Kimberlina - porosity

Kimberlina - CO_2 saturation

Multiphysics models

Rock-physics or constitutive relationships


Kimberlina - resistivity at 175 yr

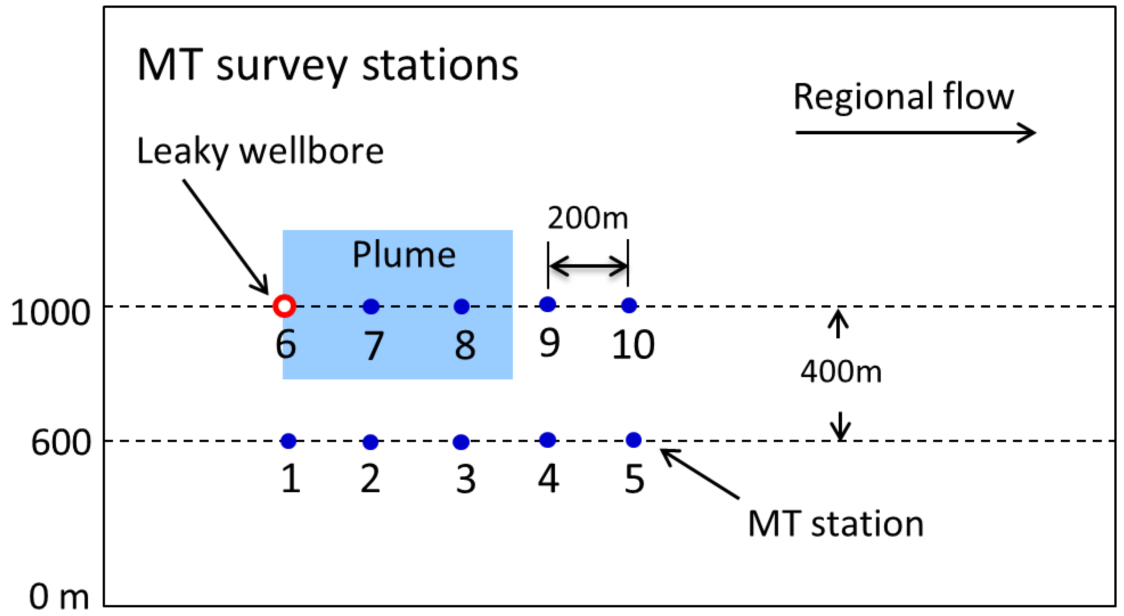
Geophysical models

4.1 Monitoring of Shallow Aquifers using the Magnetotelluric Method (1)

Xianjin Yang, Thomas A. Buscheck, Kayyum Mansoor, Susan Carroll, LLNL

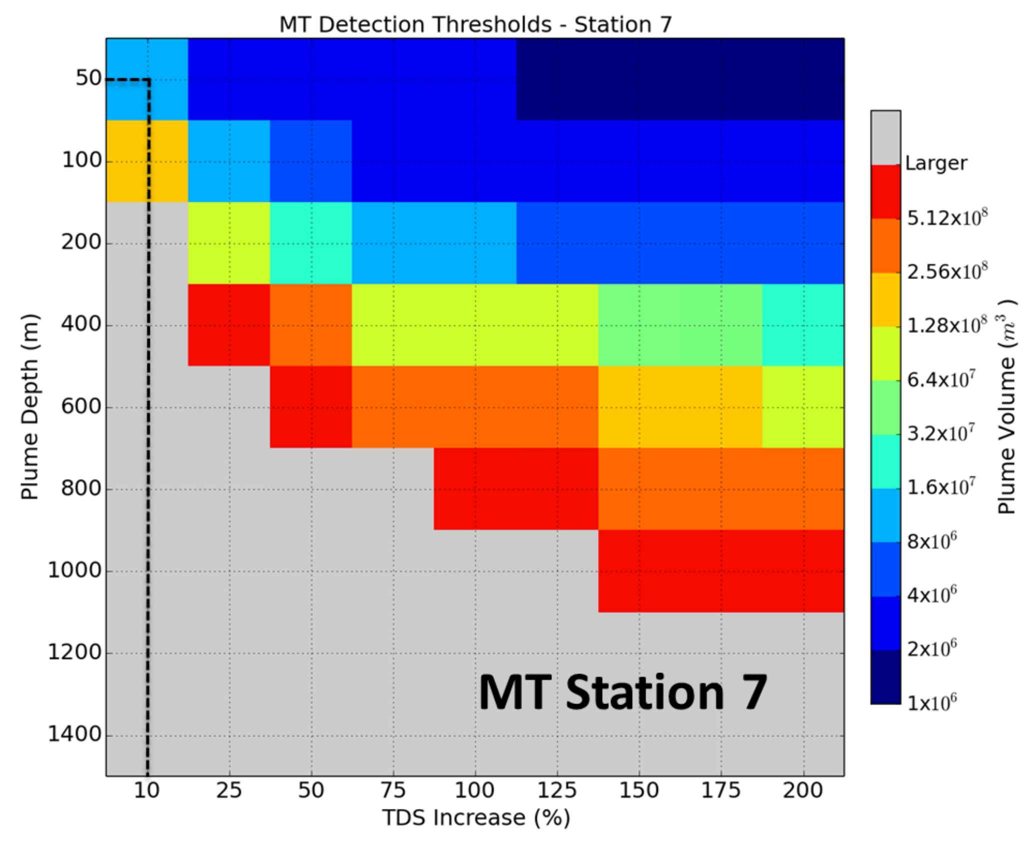
- 10 MT stations
- 17 frequencies
- 10 plume volumes
- 10 TDS increase
- 9 plume depths
- Baseline TDS = 2000 mg/L, background resistivity is 50 Ω·m

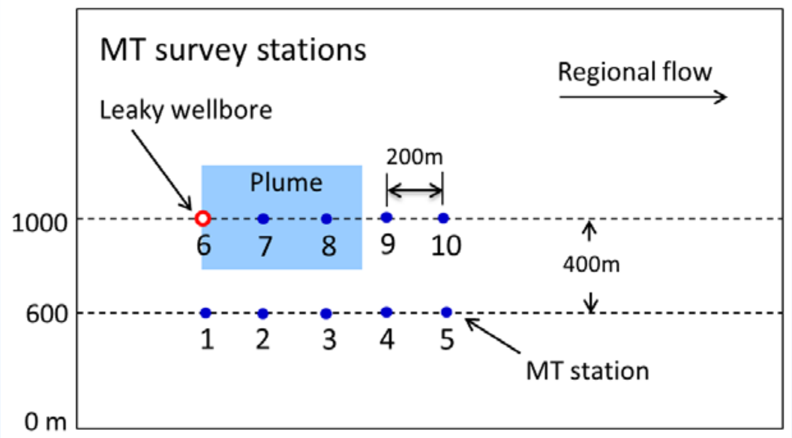
No.	Depth (m)	TDS Increase (%)	Volume ($m^3 = L\times W\times H$)
1	50	0	$1\times10^6 = 100\times100\times100$
2	100	10	$2\times10^6 = 200\times100\times100$
3	200	25	$4\times10^6 = 200\times200\times100$
4	400	50	$8\times10^6 = 400\times200\times100$
5	600	75	$1.6\times10^7 = 400\times200\times200$
6	800	100	$3.2\times10^7 = 800\times200\times200$
7	1000	125	$6.4\times10^7 = 800\times400\times200$
8	1200	150	$1.28\times10^8 = 1600\times400\times200$
9	1400	175	$2.56\times10^8 = 1600\times800\times200$
10		200	$5.12\times10^8 = 1600\times800\times400$

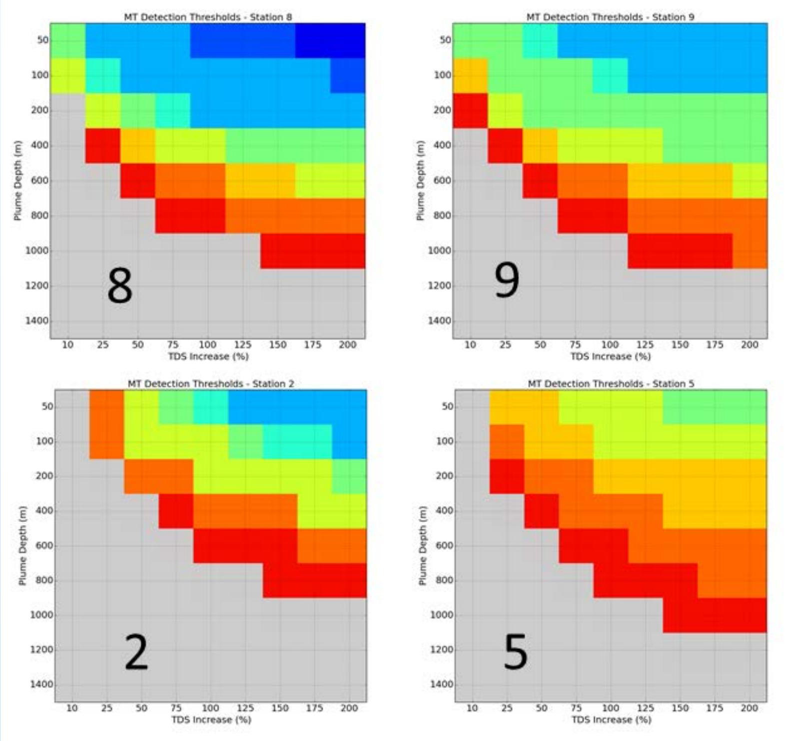


4.1 Monitoring of Shallow Aquifers using the Magnetotelluric Method (2)

MT signal and detectability depends on plume depth, volume and TDS

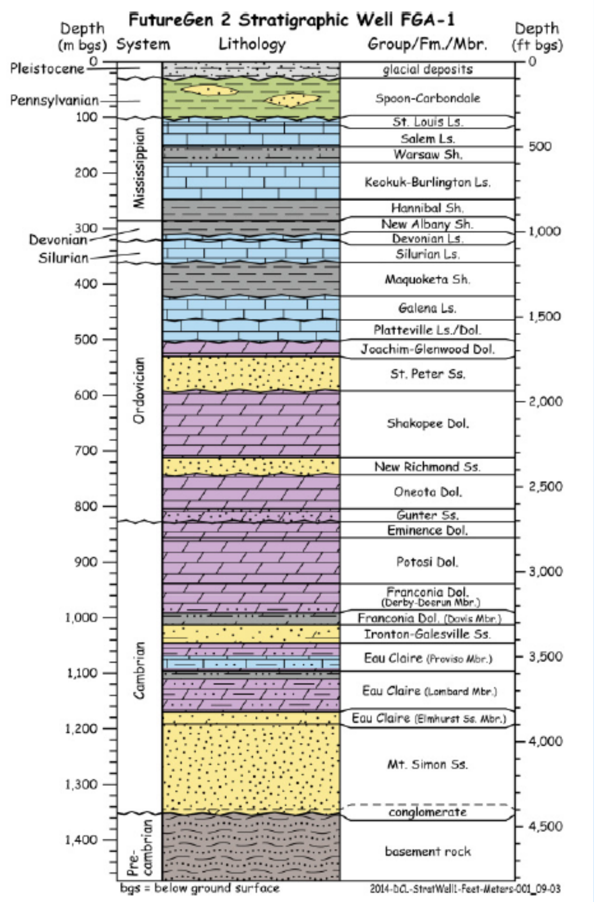


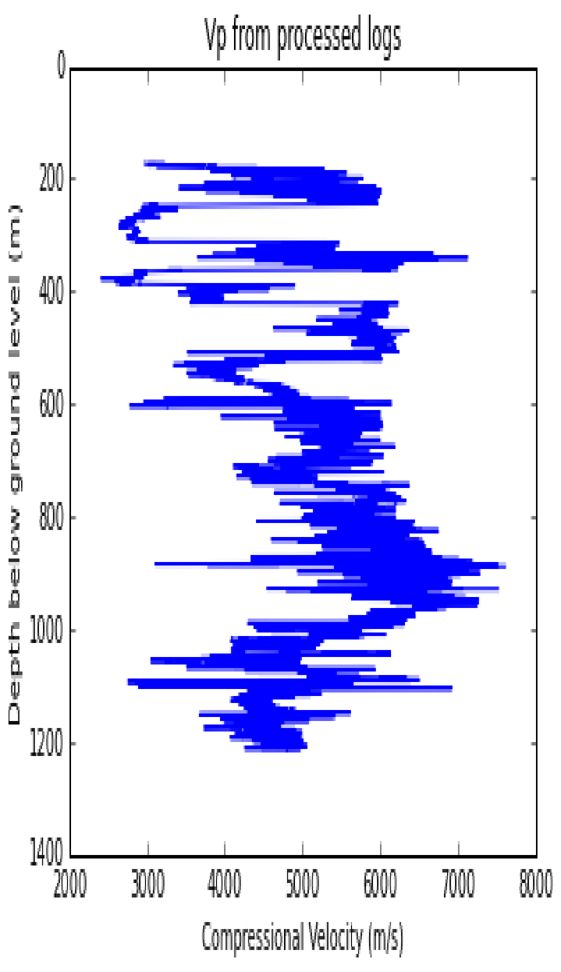


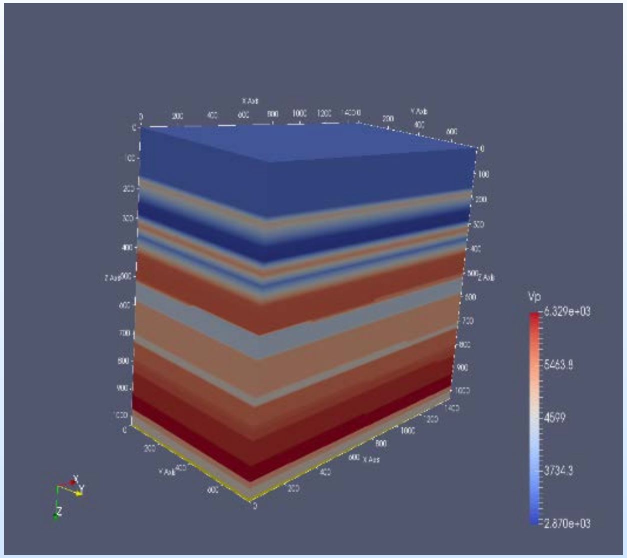


4.1 Modeling of seismic monitoring - FutureGen 2.0 CO_2 storage site (1)

Zan Wang (NETL), Robert Dilmore (NETL), William Harbert (NETL), Lianjie Huang (LANL)



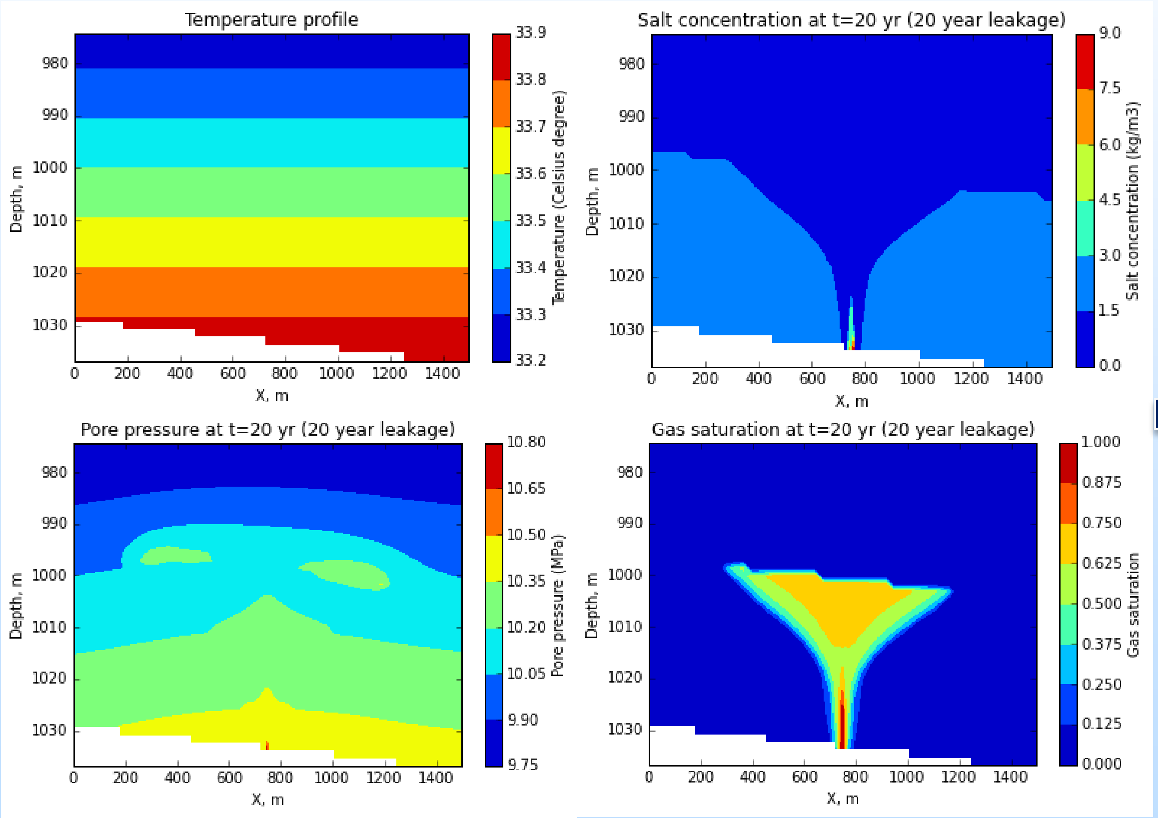




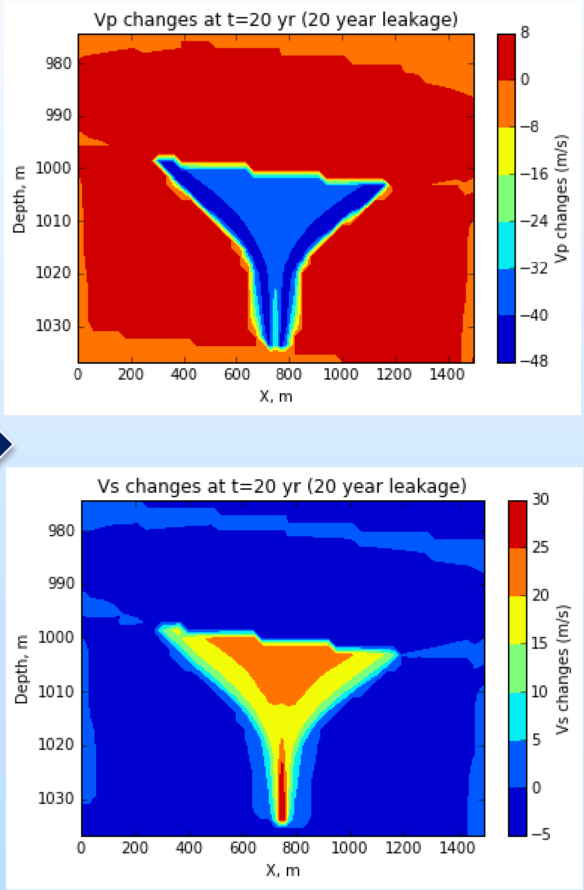
Background seismic velocity model using wireline log data from the initial stratigraphic borehole

4.1 Modeling of seismic monitoring - FutureGen 2.0 leakage scenarios (2)

- Gassmann-Biot modeling for fluid substitution
- Hertz-Mindlin contact theory for pressure effects on dry-frame moduli

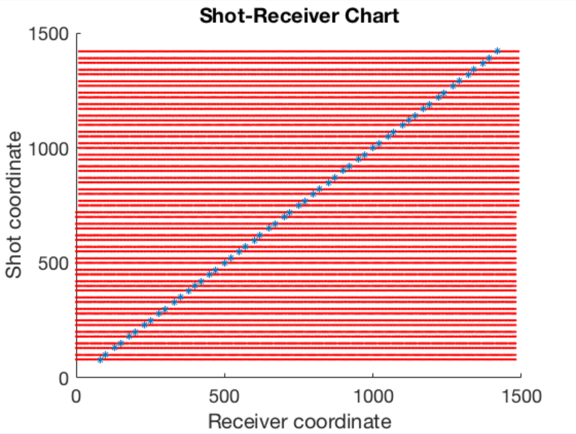


STOMP flow simulation results



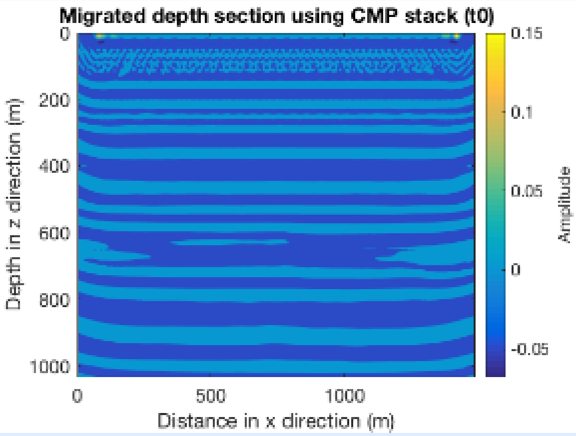
Seismic velocity models

4.1 Modeling of seismic monitoring - FutureGen 2.0 leakage scenarios (3)

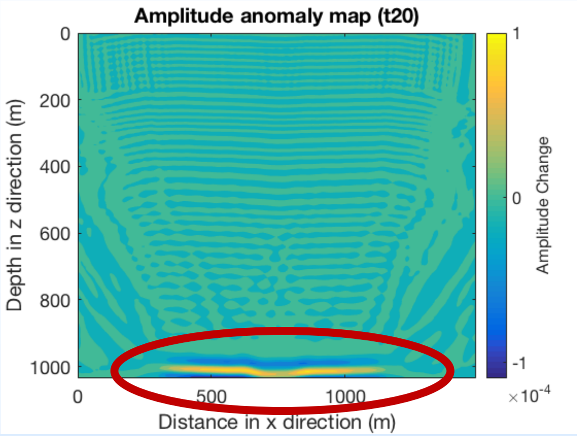


55 shots and 297 receivers

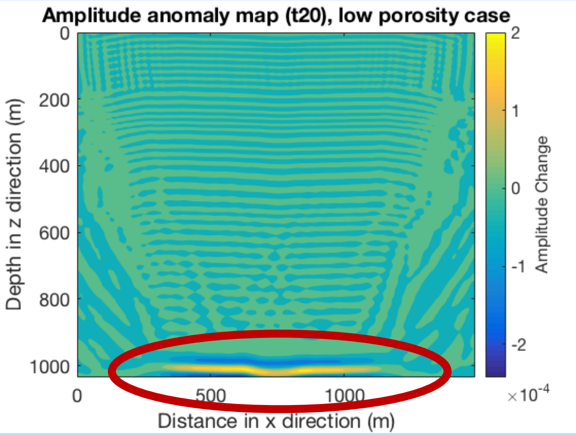
Migrated depth section - background

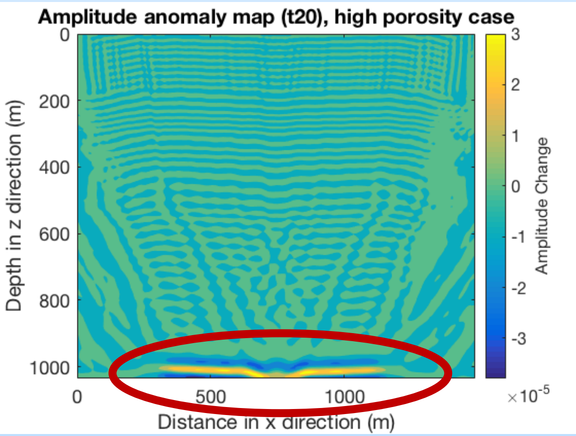


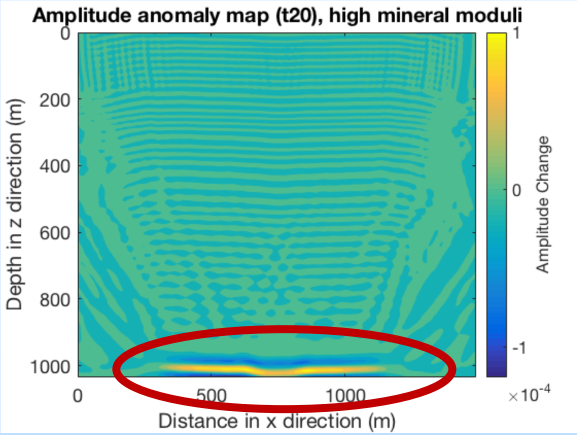
Amplitude anomaly map



Sensitivity to changes in porosity and elastic moduli of clay minerals



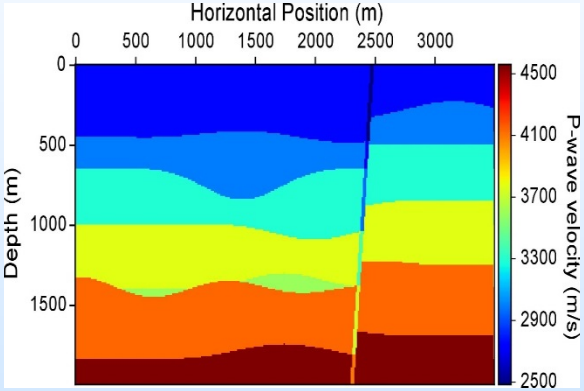




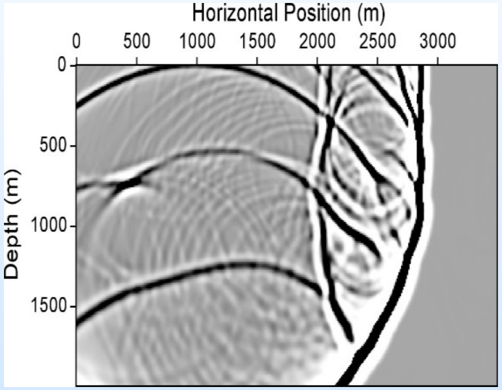
4.1 Anisotropic Acoustic-Wave Modeling

Kai Gao, Lianjie Huang, LANL

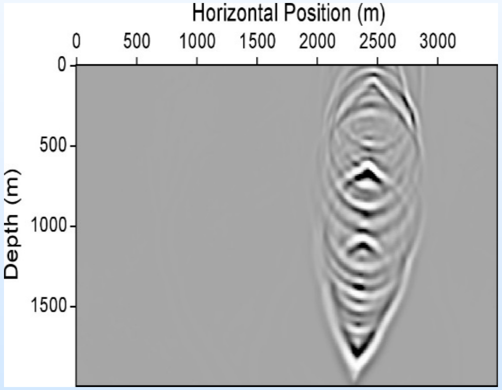
2D numerical modeling code for acoustic-wave propagation in anisotropic media such as fault/fracture zones



A velocity model with a normal fault



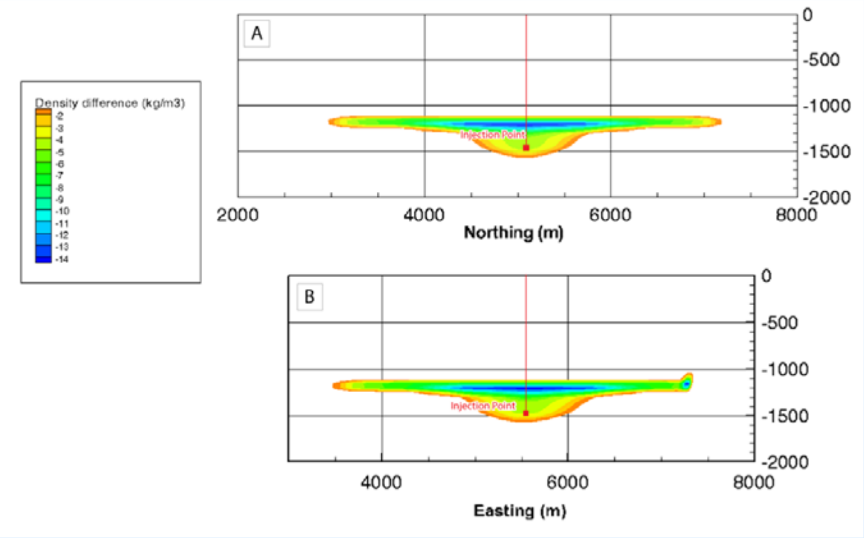
Acoustic wave propagation with TTI medium through the fault zone for a surface source at 1050 m



Difference: Assuming the fault zone is a TTI medium or a homogeneous medium

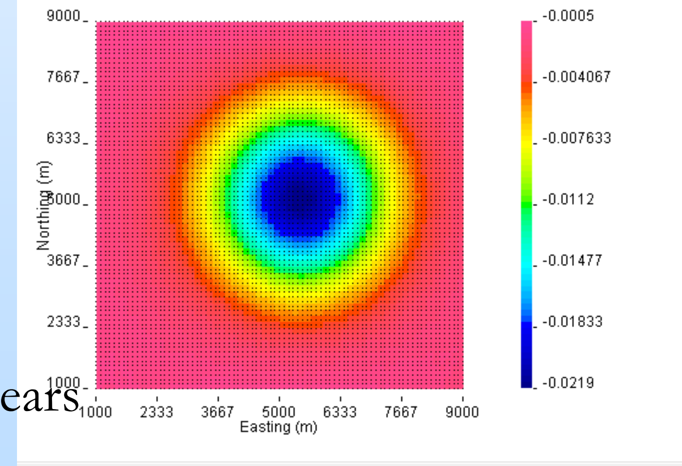
4.1 Time-lapsed gravity monitoring

Delphine Appriou, Christopher Strickland, Christopher Brown, PNNL

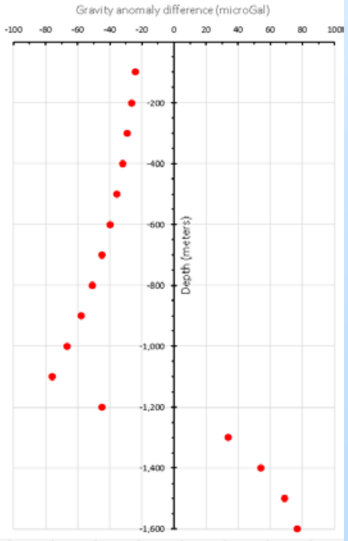


- To evaluate and map the distribution of subsurface densities
- Distribution of densities is reflected by changes in the local gravitational field
- CO_2 produces a bulk density decrease because $d_{CO2} < d_{Brine}$

STOMP Model:
Mesh: 75 x 75 x 40 grid cells
Porosity: Sandstone: 12 %
Shale: 8%
Density: Sandstone: 2.370 g/cm^3
Shale: 2.413 g/cm^3
Injection rate: 2MMT/year for 30 years
Total volume injected: 60 MMT



Surface gravity anomaly



Borehole gravity anomaly

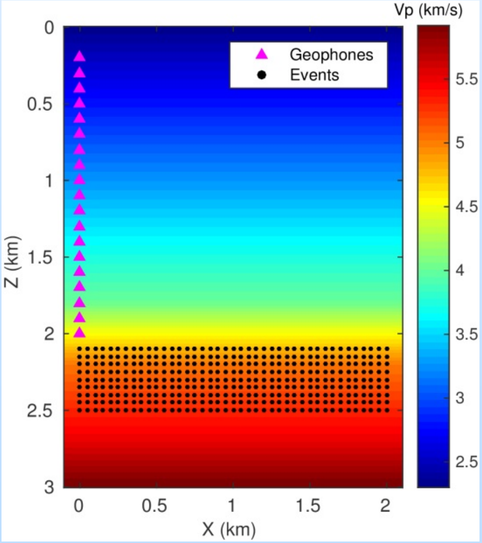
4.2 Fast detection and location of induced microseismicity (1)

Ting Chen, Miao Zhang, Lianjie Huang, LANL

- **Objective:** To develop an automatic method for fast and accurate detection and location of CO_2-injection induced microseismic events - (a) Monitor CO_2 migration

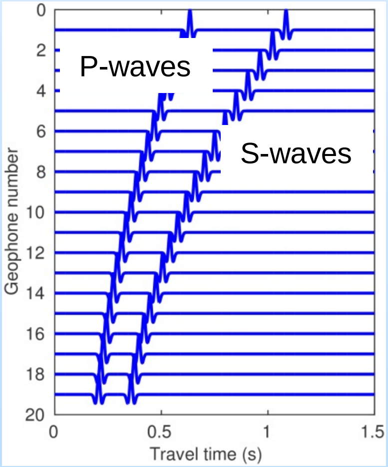
  (b) Detect fault and cap rock leakage

Method: Comparison with pre-calculated waveforms using a machine learning algorithm (k-nearest neighbors)

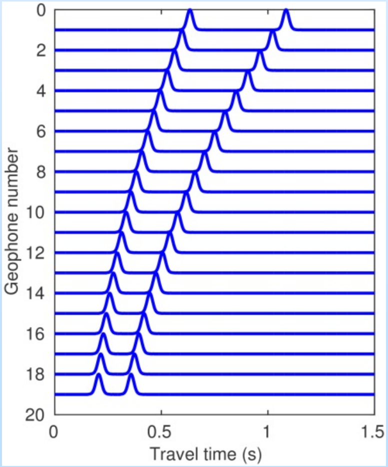


Kimberlina model

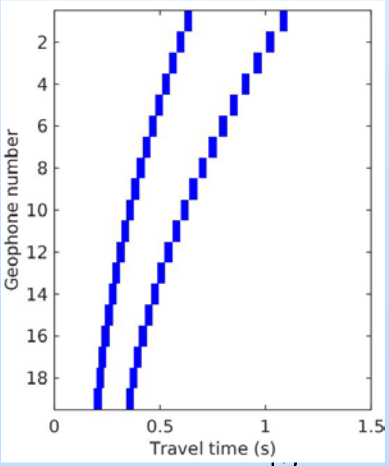
waveform



envelope



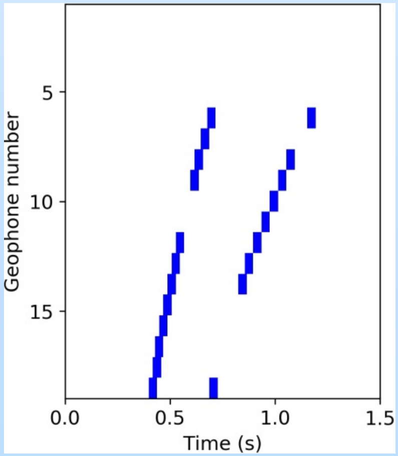
image



4.2 Fast detection and location of induced microseismicity (2)

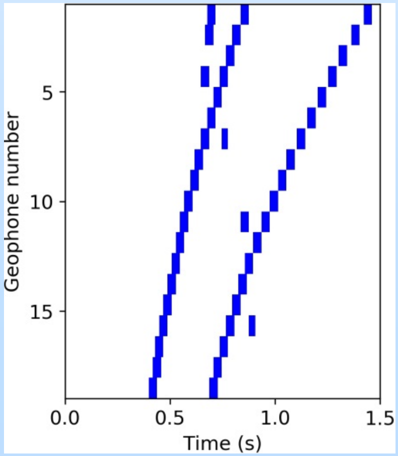
Only partial data

- True info
  - Event? Yes
  - Location (x,z): (1.98, 2.48) km
- Predicted info
  - Event? Yes
  - Location (x,z): (2.00, 2.45) km



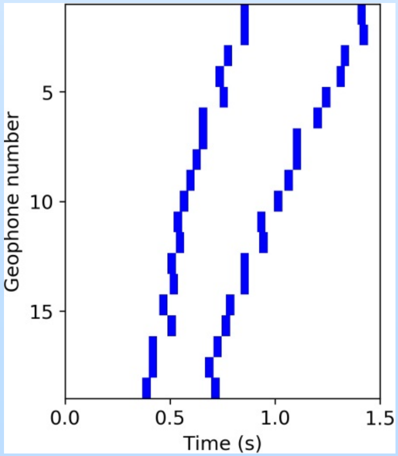
Noisy data

- True info
  - Event? Yes
  - Location (x,z): (1.98, 2.48) km
- Predicted info
  - Event? Yes
  - Location (x,z): (2.00, 2.45) km

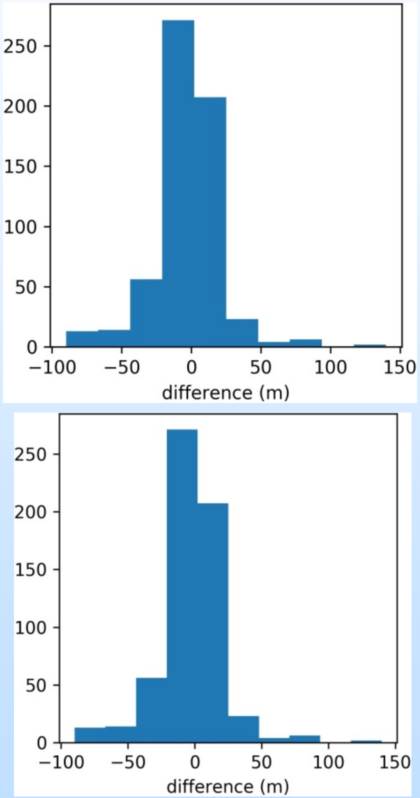


Inaccurate velocity, picks

- True info
  - Event? Yes
  - Location (x,z): (1.98, 2.48) km
- Predicted info
  - Event? Yes
  - Location (x,z): (1.90, 2.43) km

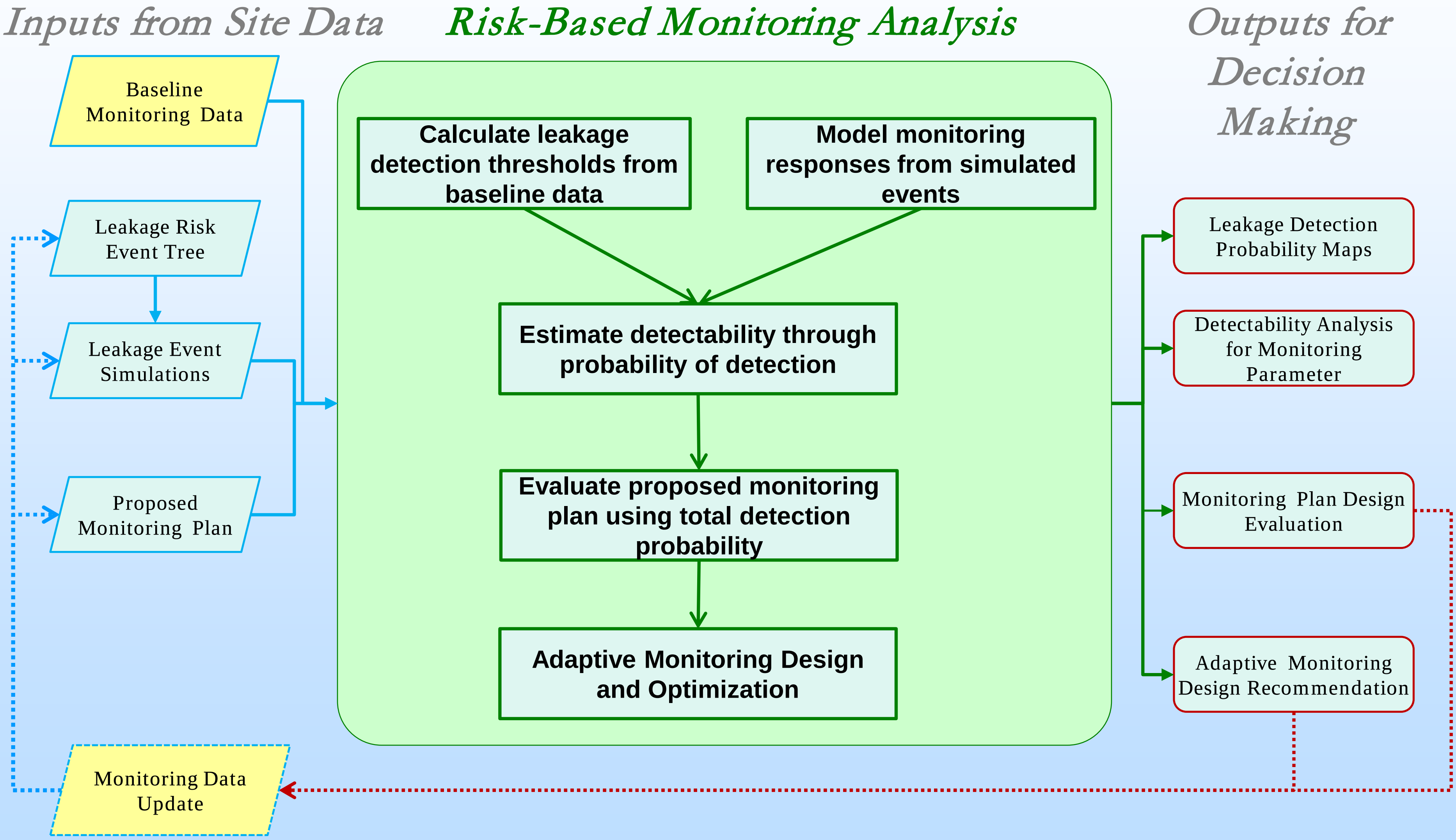


Performance



4.2-4.4: Risk-based Monitoring Assessment Methodology (1)

Ya-Mei Yang, Robert Dilmore, NETL



Inputs from Site Data

Baseline Monitoring Data

Leakage Risk Event Tree

Leakage Event Simulations

Proposed Monitoring Plan

Monitoring Data Update

Risk-Based Monitoring Analysis

Calculate leakage detection thresholds from baseline data

Model monitoring responses from simulated events

Estimate detectability through probability of detection

Evaluate proposed monitoring plan using total detection probability

Adaptive Monitoring Design and Optimization

Outputs for Decision Making

Leakage Detection Probability Maps

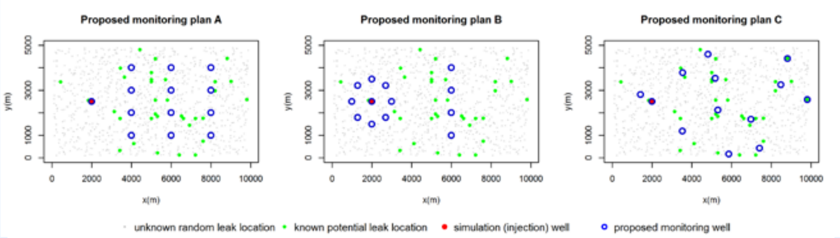
Detectability Analysis for Monitoring Parameter

Monitoring Plan Design Evaluation

Adaptive Monitoring Design Recommendation

4.2-4.4: Risk-based Monitoring Assessment Methodology (3)

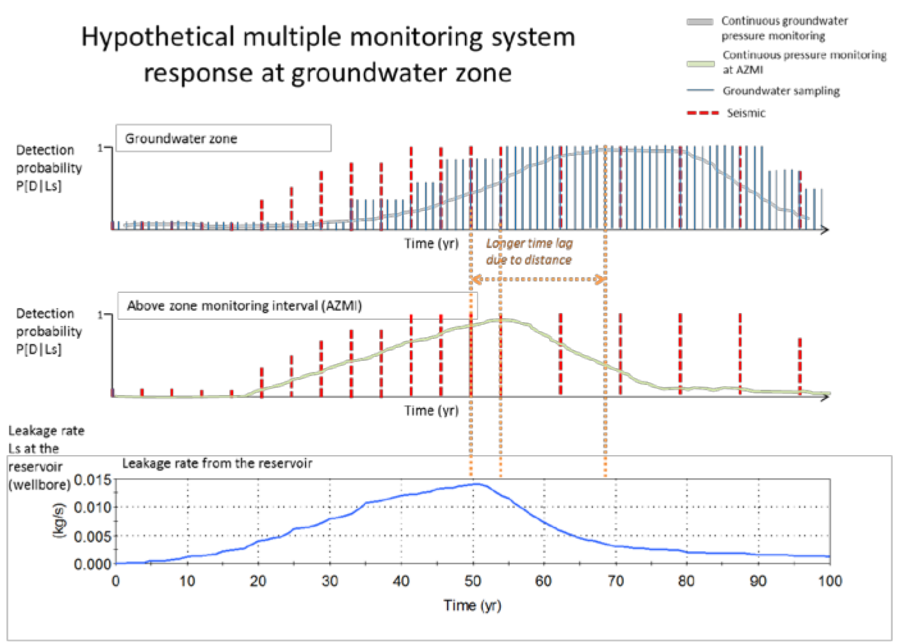
Design Evaluation of Proposed Monitoring Plans



Scenarios	Monitoring Plan A			Monitoring Plan B			Monitoring Plan C		
Year	Low	Median	High	Low	Median	High	Low	Median	High
1	0.00	0.04	0.04	0.00	0.04	0.05	0.00	0.13	0.13
2	0.04	0.04	0.05	0.04	0.04	0.05	0.13	0.13	0.15
3	0.04	0.04	0.08	0.04	0.05	0.06	0.13	0.13	0.18
4	0.00	0.05	0.10	0.00	0.05	0.07	0.00	0.13	0.19
5	0.04	0.05	0.10	0.04	0.05	0.07	0.13	0.13	0.21
10	0.04	0.05	0.21	0.04	0.05	0.12	0.13	0.13	**0.52**
20	0.00	0.06	**0.54**	0.00	0.06	0.34	0.00	0.17	**0.71**
30	0.00	0.10	**0.74**	0.00	0.06	**0.57**	0.00	0.18	**0.80**
40	0.00	0.10	**0.79**	0.00	0.06	**0.62**	0.00	0.18	**0.87**
50	0.00	0.10	**0.86**	0.00	0.06	**0.72**	0.00	0.18	**0.90**
100	0.00	0.10	**0.83**	0.00	0.07	**0.62**	0.00	0.21	**0.92**

Same number of monitoring locations and high, median and low monitoring response scenarios

Known potential leakage pathways play a central role in designing the monitoring plans

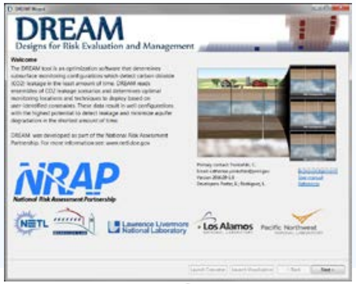


CO2-PENS (Gen2) 2014, http://co2-pens.lanl.gov/
Y. Yang, R. Dilmore and G. Bromhal, 2015

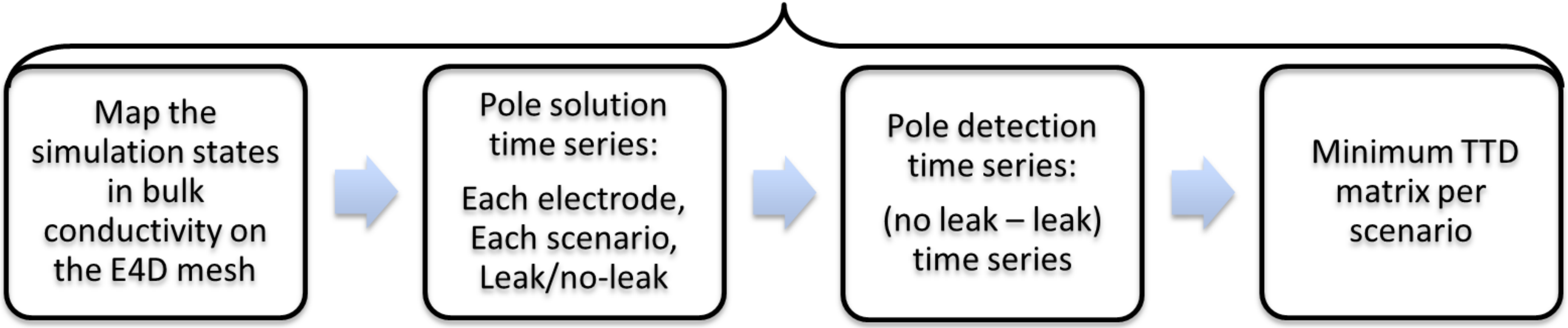
Combine different monitoring technologies with complementary spatial and time resolutions, e.g., use 3D seismic to identify high risk zone, use pressure monitoring for more efficient detection in time and use groundwater and soil gas monitoring to confirm the impact domain

4.3 Risk-Based Monitoring Network Design Tools

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



+ERT module

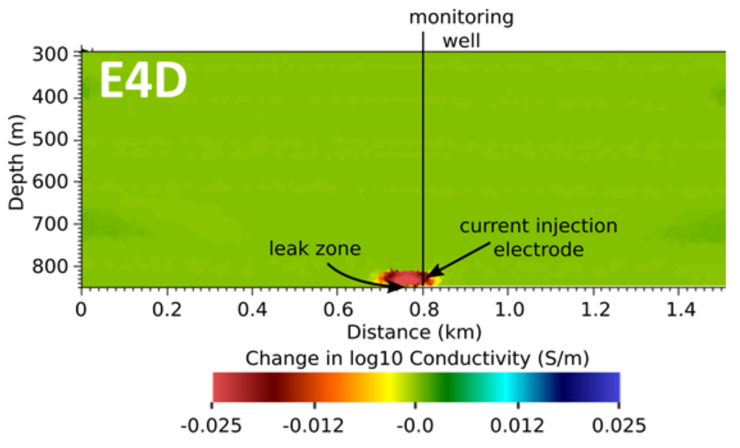


Map the simulation states in bulk conductivity on the E4D mesh

Pole solution time series:
Each electrode,
Each scenario,
Leak/no-leak

Pole detection time series:
(no leak – leak) time series

Minimum TTD matrix per scenario



Timeline:

DREAM extension beta tool 12/31/2017

Cross-cutting opportunities:

- *Subtask 4.1:* Inclusion of additional methods (i.e., Gravity monitoring)
- *Task 6:* Demo. of the DREAM/ERT module with leakage simulations

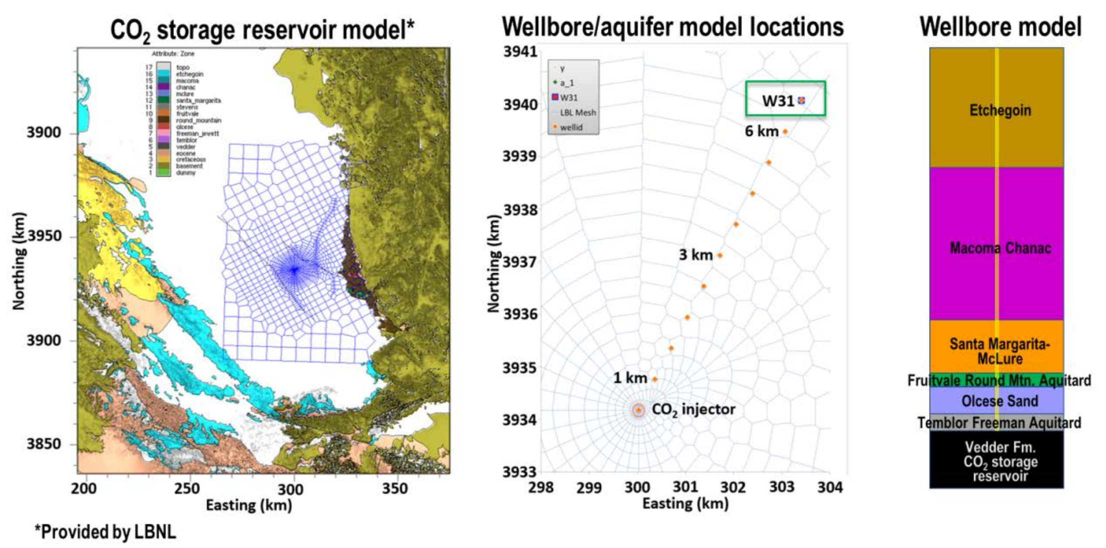
4.4 and 4.1 Kimberlina 1.1 models (1)

Thomas Buscheck, Kayyum Mansoor, Xianjin Yang, Susan Carroll, LLNL

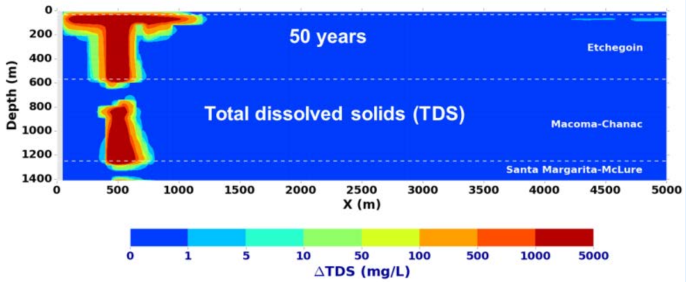
NUFT 144 simulations of flow and geochemical models

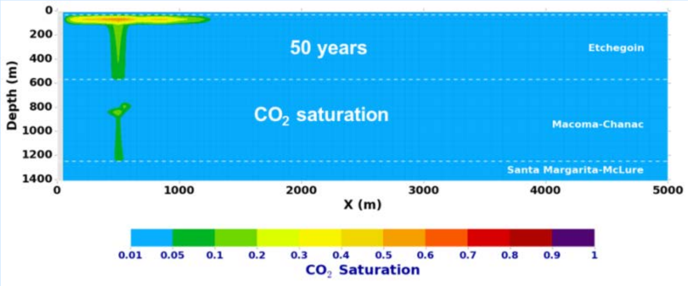
Variable simulation parameters:

- injector-wellbore distances: 1 km, 3 km and 6 km
- bottom hole pressures: P10, P50, P90 percentiles
- CO_2 saturation levels: S10, S50, S90 percentiles
- 5 aquifer parameter sets – low/high groundwater gradient
  medium/high wellbore permeability
  number of leaky aquifers – two, three, four



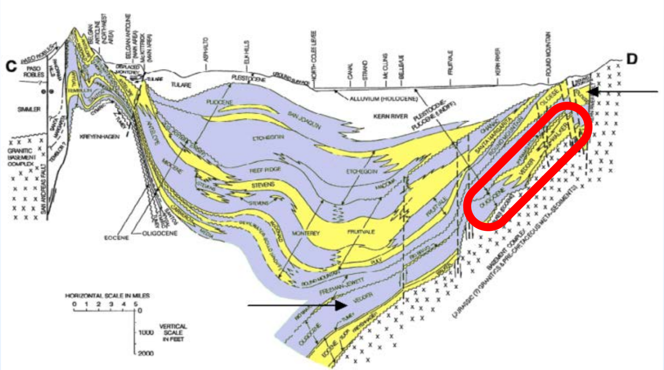
*Provided by LBNL

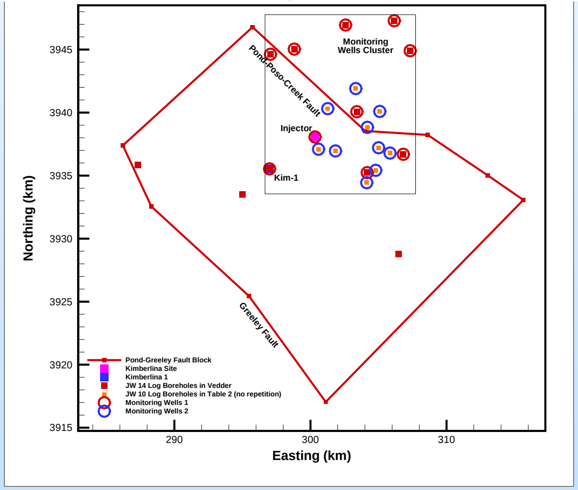


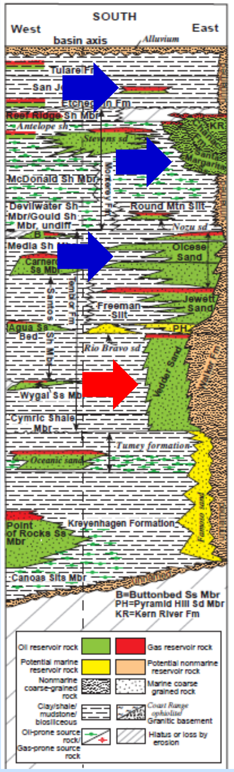


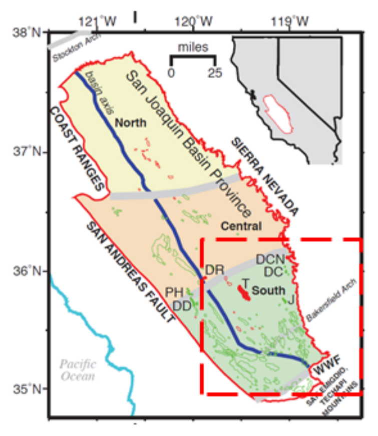
4.4 and 4.1 Kimberlina II models (1)

Quanlin Zhou, Erika Gasperikova, Jens Birkholzer, Thomas Daley, LBNL









Secondary CO_2 zones:

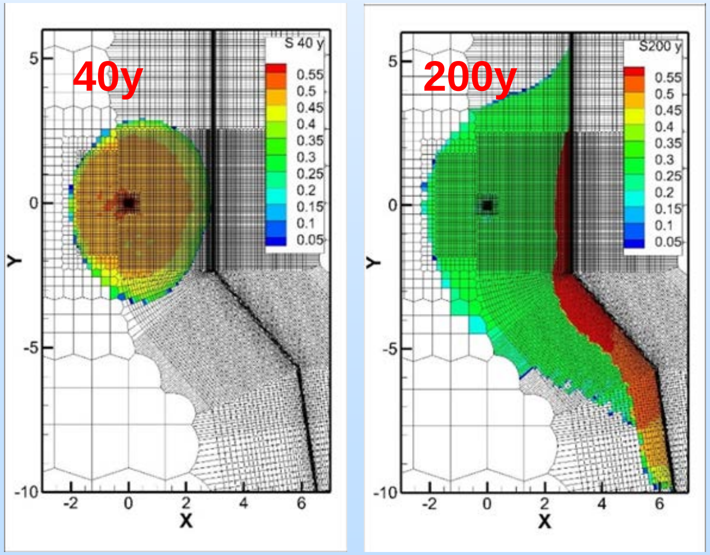
Etchegoin

Santa Margarita

Olcese

Injection Zone:

Vedder Sands

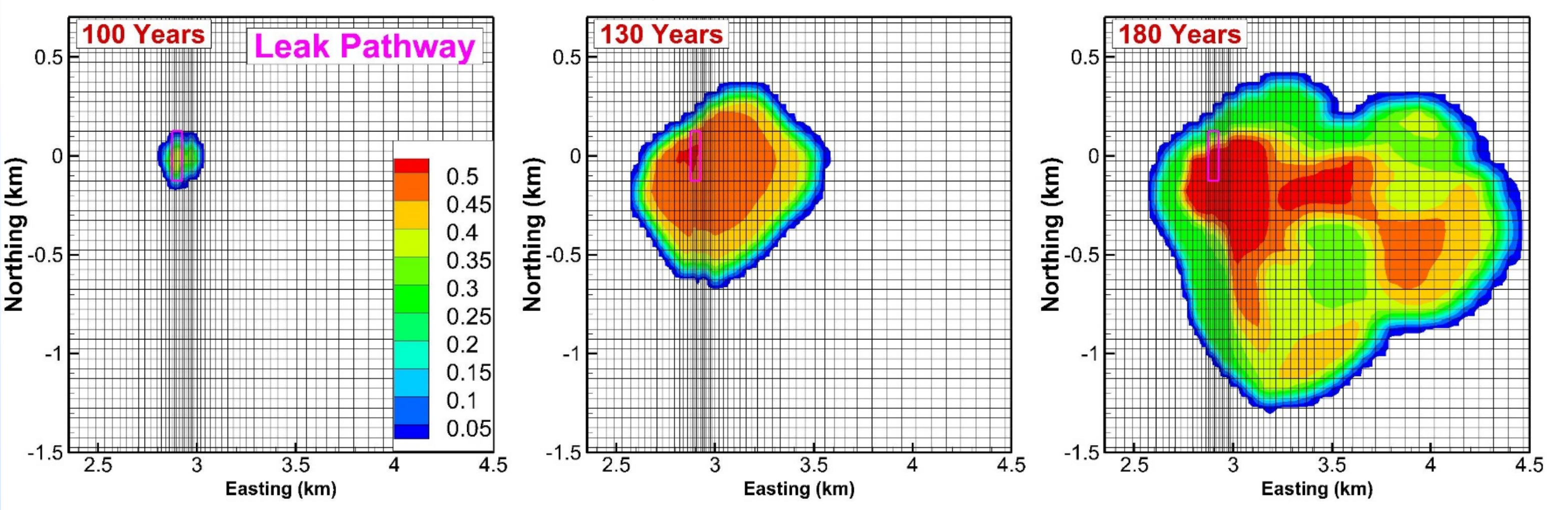


CO_2 saturation

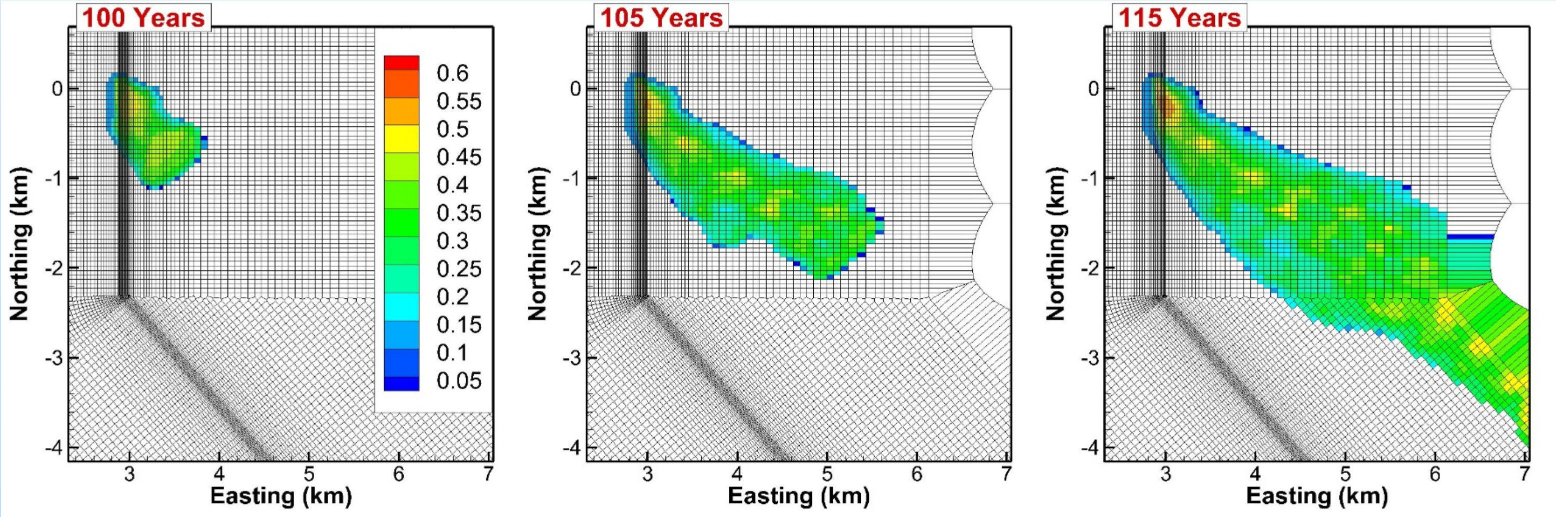
- **Injection:** 2.5 Mt/year for 60 years in the middle Vedder
- CO_2 arrives at the fault by 40 years, then migrates along the fault up-dip southeast
- **The Pond Fault (70° dip)** is simulated as a barrier to the flow

4.4 and 4.1 Kimberlina II models (2)

Olcese Secondary Plume



Echegoin Secondary Plume



- A leakage window of 250 m x 50 m is used for the fault damage zone

- The seals of the secondary plume is not affected by the fault

- A fault permeability of 80 md is used for the leakage pathway

Accomplishments to Date

- Three model datasets available for monitoring modeling – FutureGen 2.0, Kimberlina 1.1 and Kimberlina 2
- Set of parameters needed as input from system component models/ROMs and/or integrated assessment model and supporting documents to allow modeling of monitoring
- Summary of MT detection thresholds as a function of plume volume, depth and changes of TDS
- Codes developed and available for use by other researchers:
    - Leakage detection probability maps
    - Spatial and temporal detectability for monitoring parameters and technologies
    - Monitoring plan design evaluation

Synergy Opportunities

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

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

- Developed codes and methodologies will be shared with other projects

Future Work

- Develop initial methodology concept for modeling of monitoring for a set of monitoring technologies
- Develop geophysical models for Kimberlina II leakage scenarios
- Conduct sets of 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

Future Work

- Continued development of DREAM tool -
    - Incorporate EM monitoring optimization functionality
    - Modify tool user interface and user manual to reflect changes in DREAM tool
    - Release of DREAM tool (monitoring optimization) extension beta tool
    - Develop a concept for modeling of monitoring using gravity and ERT
    - Integrate MT data sets into DREAM tool

Future Work

For Integration with Risk Assessment/Reduction:

- 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 initial 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

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.B Develop initial monitoring methodology concept including report on: MT monitoring modeling, EM monitoring modeling, Seismic monitoring modeling, gravity monitoring modeling, and ERT monitoring modeling (09/30/2017)
- M1.17.4.A Report on initial selection of scenarios from Kimberlina impact models to be used for geophysical modeling (12/31/2017)
- Briefing to NRAP Stakeholder Group and Executive Committee on approach and status of modeling of monitoring methodology, and monitoring optimization tool development (08/31/2017)
- Report on initial selection of scenarios from Kimberlina impact models to be used for geophysical modeling (12/31/2017)
- Release of DREAM tool (monitoring optimization) extension beta tool (12/31/2017)

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