Task 2 Containment Assurance Overview

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August 16, 2018

NRAP
National Risk Assessment Partnership

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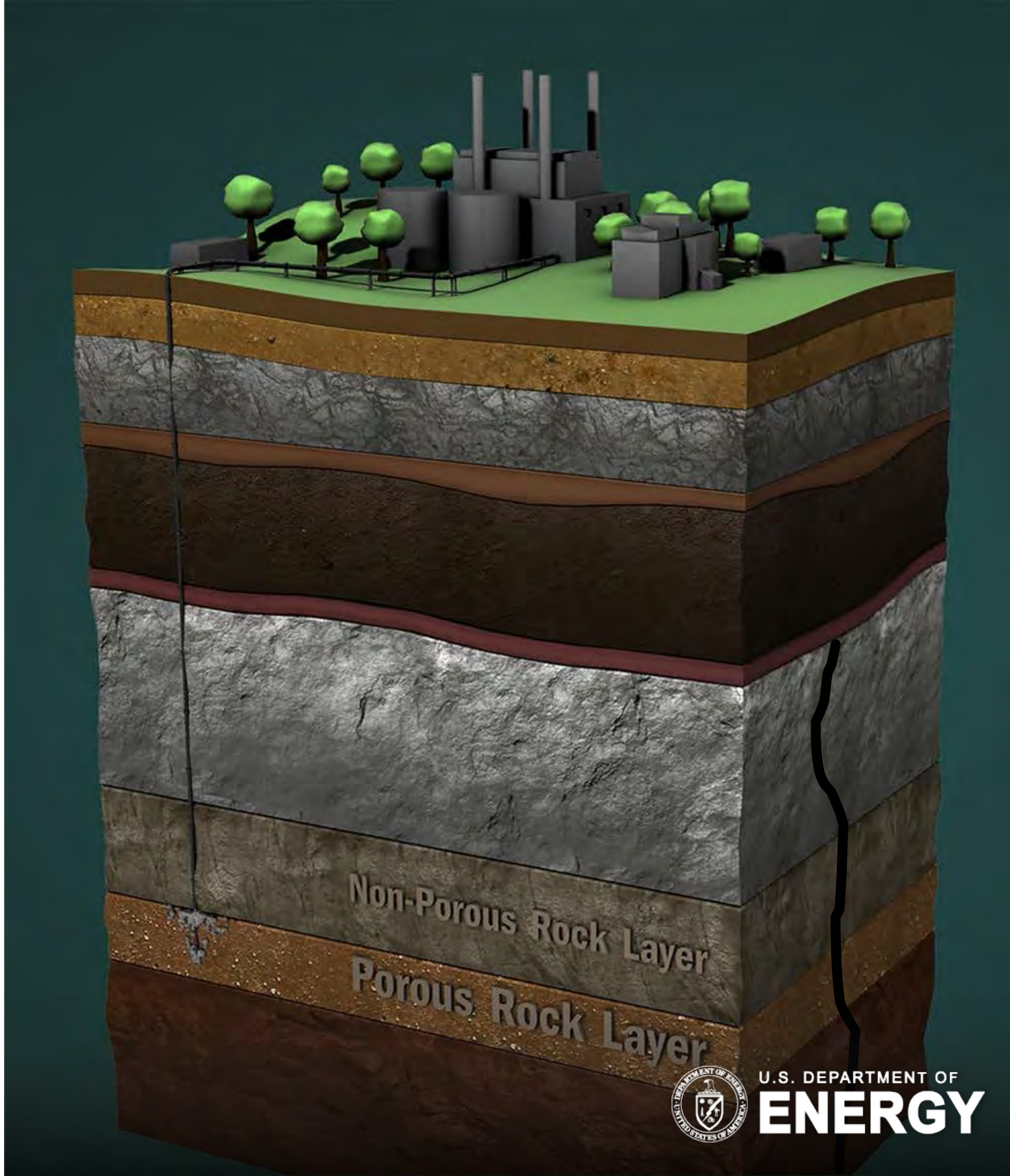

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Task 2 Objectives

1. Develop robust, science-based *workflows* and *software tools* to:
    1. *predict* containment effectiveness and leakage risk
    2. *evaluate* the effectiveness of leakage risk monitoring, management, and mitigation.

Task 2 Organization

Well Leakage Subtask

Lead: Jaisree Iyer (LLNL)

- *Improve models of CO_2 and brine leakage through wellbores:*
  - Laboratory experimental work
  - Numerical and reduced order model development

OpenIAM Subtask

Lead: Seth King (AECOM/NETL)

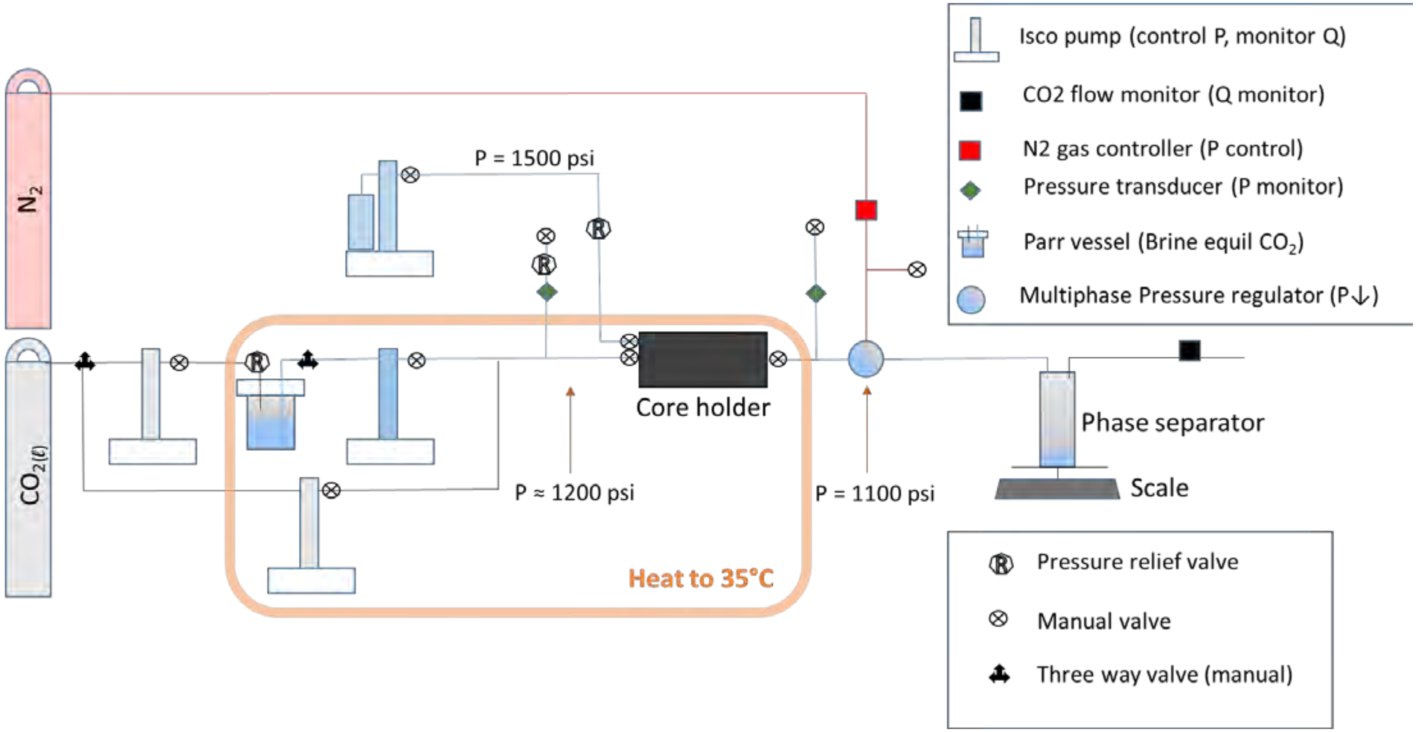
- *Develop next-generation Integrated Assessment Model - OpenIAM*
  - Coupling component models into system models
  - Development of model analysis tools

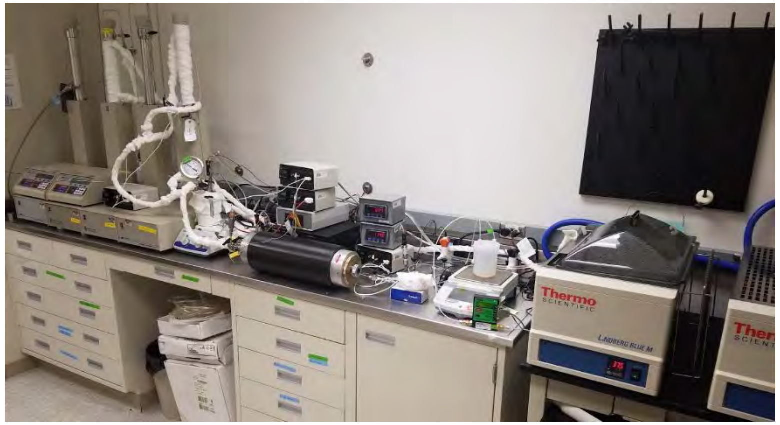
Key Personnel: Shaoping Chu, Ya-Mei Yang, Ernest Lindner, Curt Oldenburg, Kayyum Mansoor, Xiao Chen, Nicolas Huerta, Veronika Vasylkivaka, Susan Carroll, Kenton Rod, Diana Bacon, Yingqi Zhang, Bailian Chen, Bill Carey

Well Leakage: Improving the Science behind Well Leaks in CO_2 Storage Sites

Relative permeability of cement fractures exposed to brine and supercritical CO_2 mixtures

Kenton Rod, PNNL



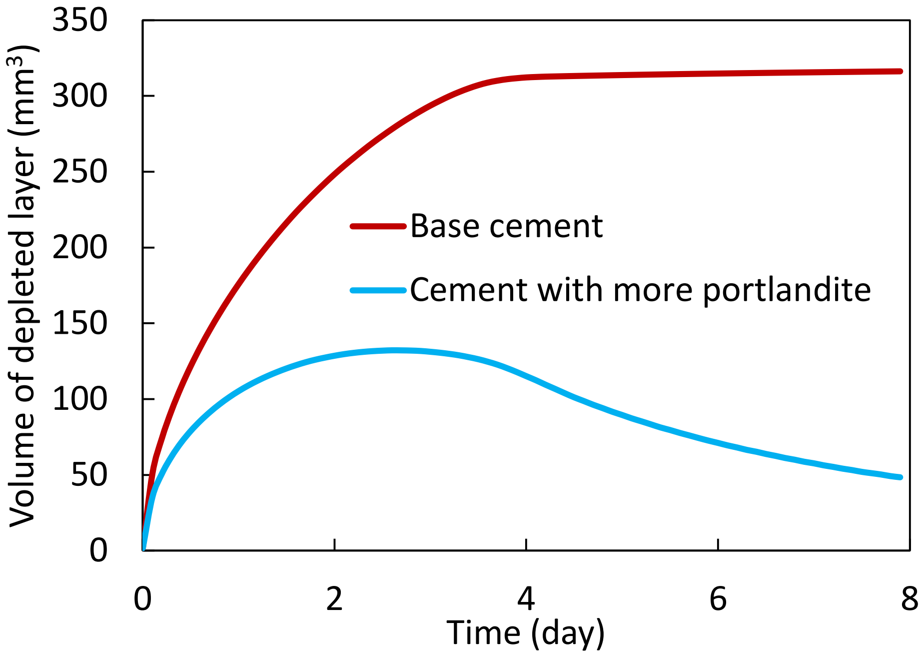


- Experimental measurements of relative permeability and sealing behavior
- Calibration of existing model using experimental data

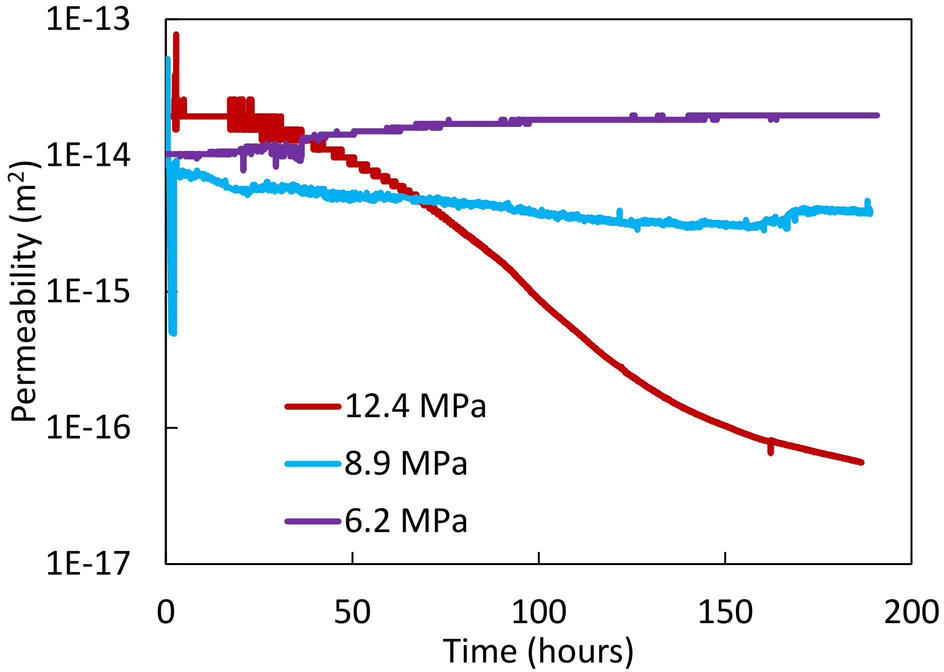
Well Leakage: Improving the Science behind Well Leaks in CO_2 Storage Sites

Permeability reduction is tied to cement composition and state of stress

Kristin Lammers, Jaisree Iyer, Wyatt Dufrane, Harris Mason, and Susan Carroll, LLNL



- Experiment showed different layers than previously observed
- Model shows that layer thickness depends on cement composition

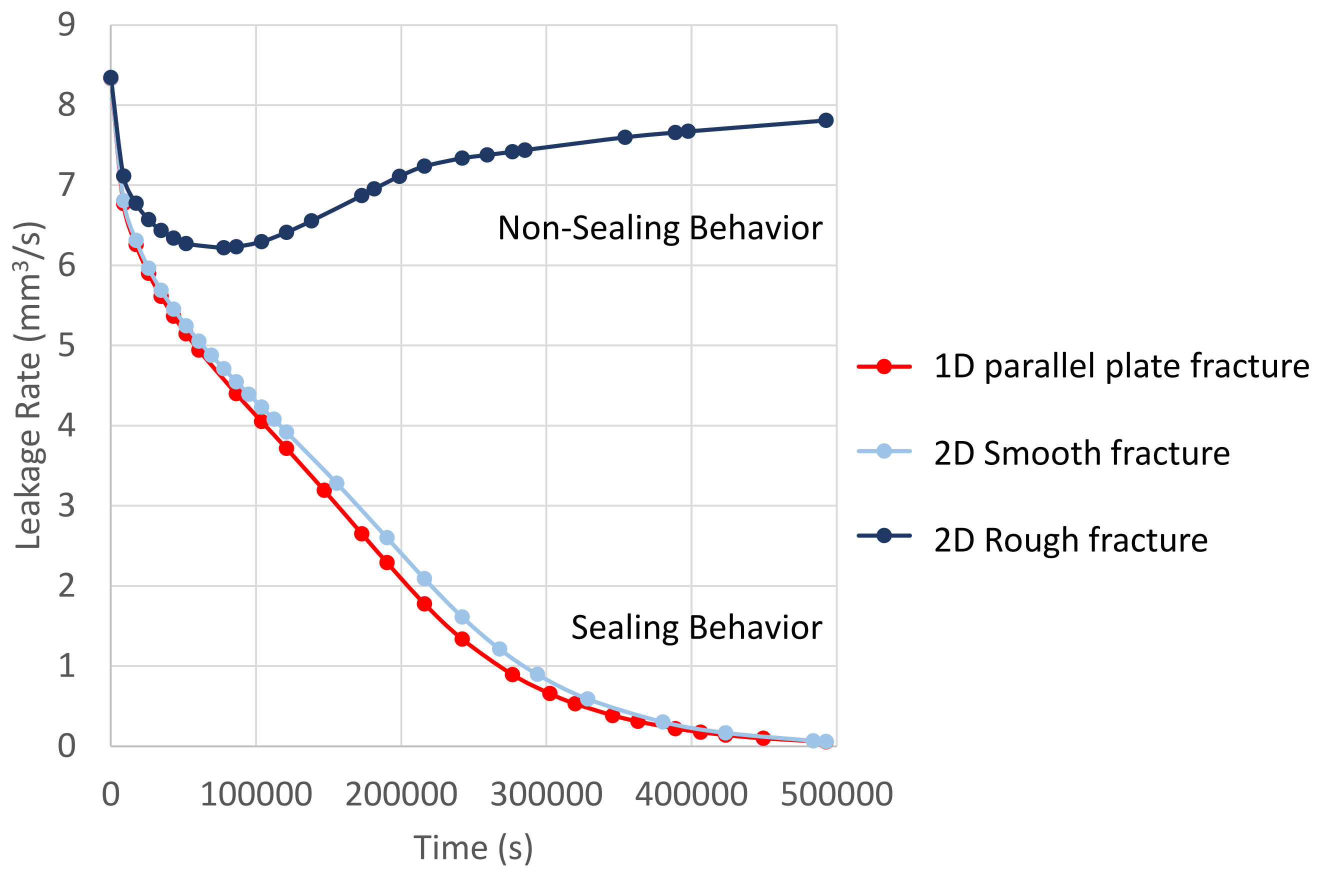


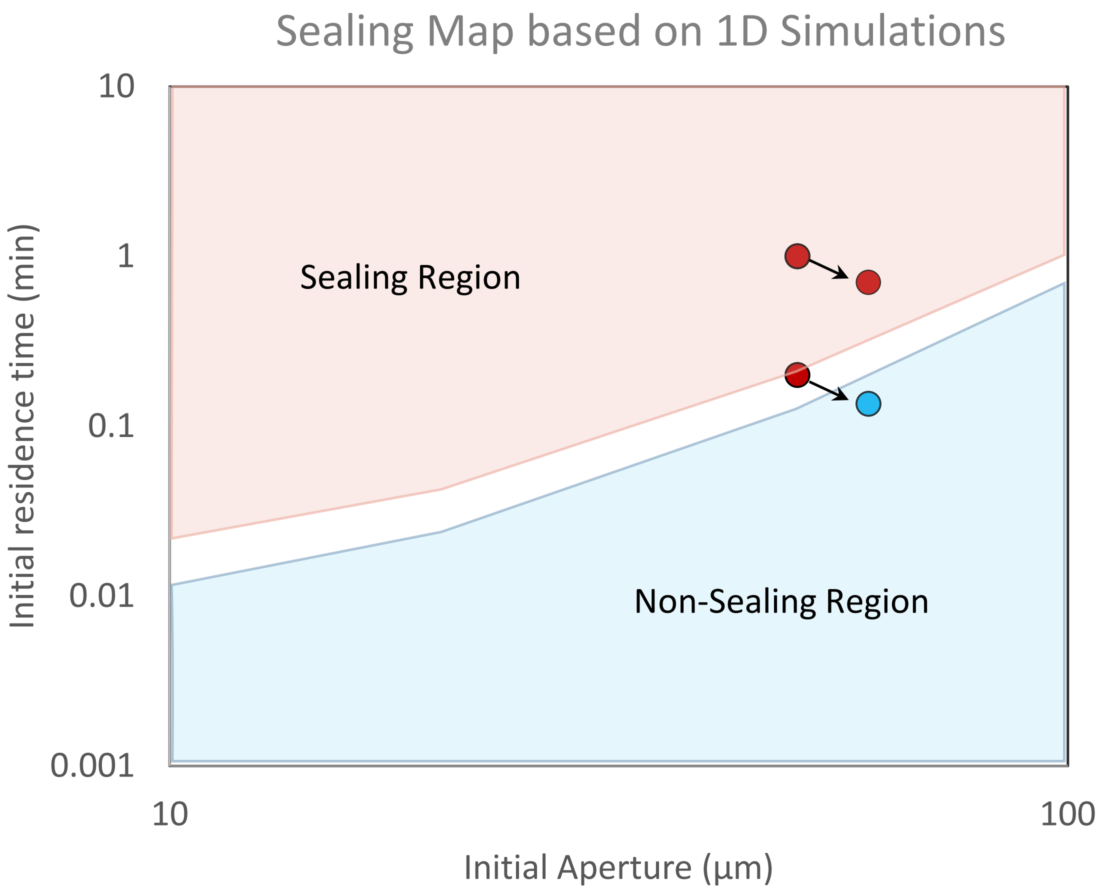
- Experiments showed less reduction in permeability at lower stress

Well Leakage: Improving the Science behind Well Leaks in CO_2 Storage Sites

Heterogeneity may prevent wellbore pathways from sealing

William Czyzewski, Jaisree Iyer, and Susan Carroll, LLNL



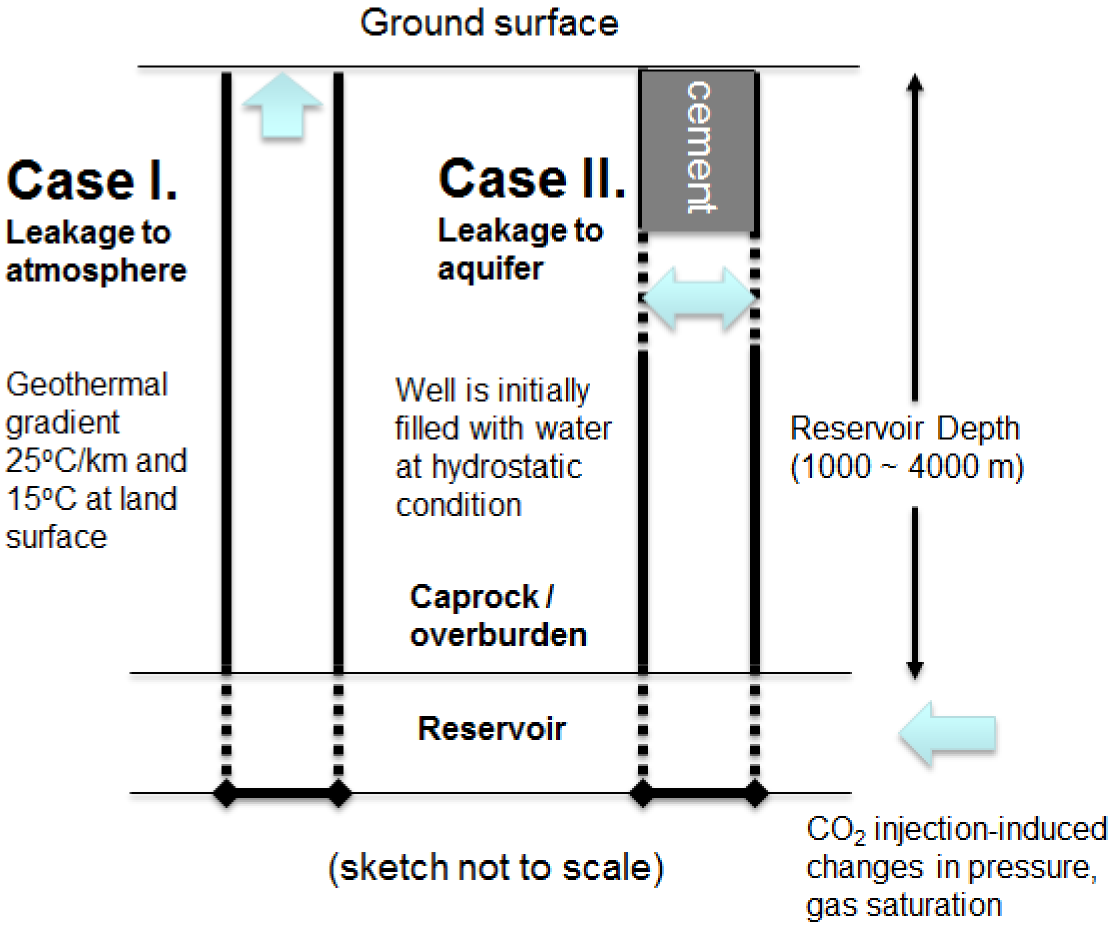


- Rough fractures can have large channels which can shift the boundary between sealing and non-sealing region
- Far away from the boundary, behavior of 2D heterogeneous fractures is similar to 1D fractures

Well Leakage: Improving the Reduced Order Models (ROMs)

Improvements in Open-Well Leakage ROM

Lehua Pan and Curt Oldenburg, LBNL



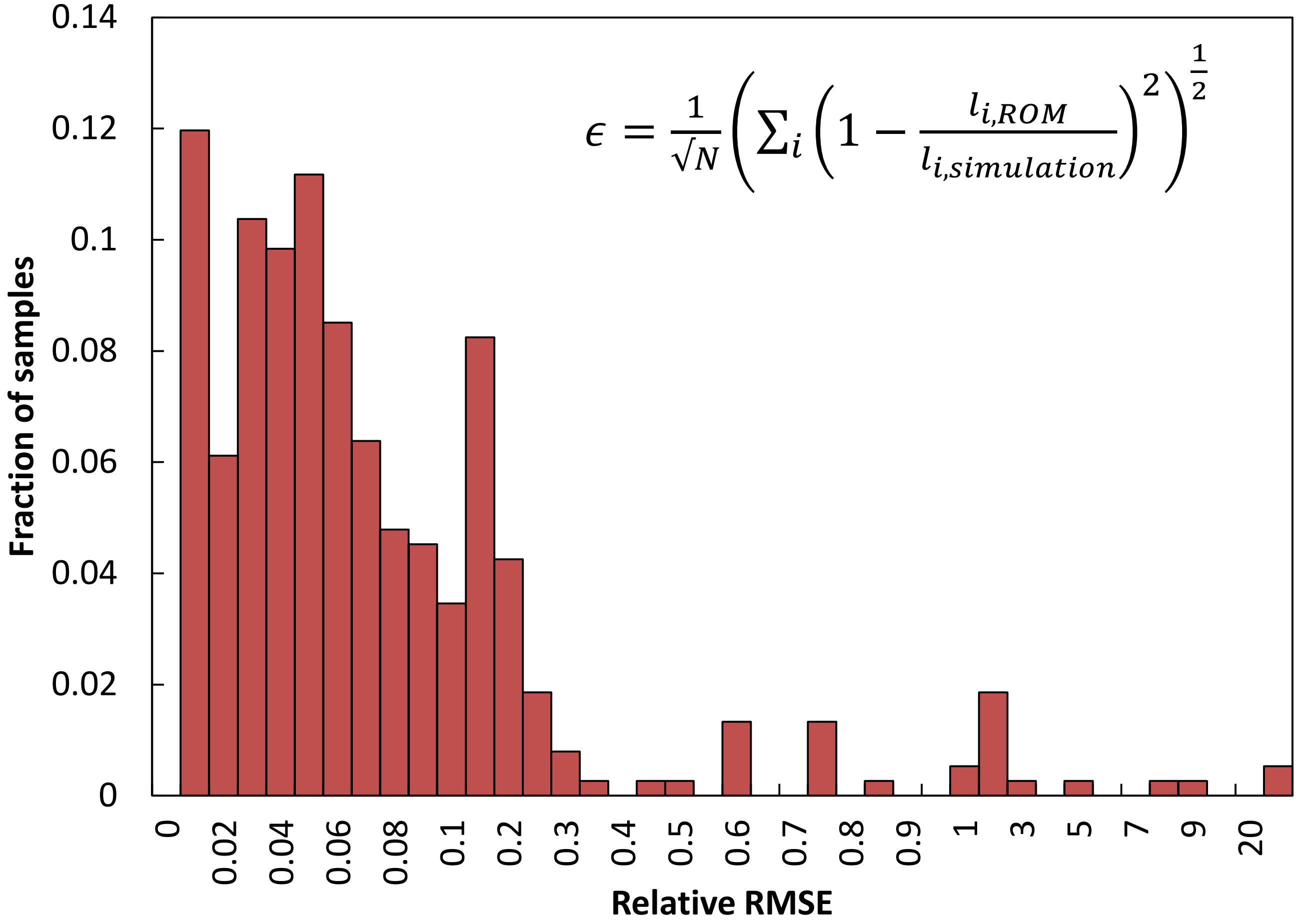
- Two cases:
  - Case I. Leakage to atmosphere
  - Case II. Leakage to aquifer at 500 m depth
- New version of T2Well/ECO2N V2.0 used for accurate phase properties
- New look-up tables for finer depth resolution (every 100 m) of storage reservoir depth.
- Case I: 11,625 simulations
- Case II: 58,125 simulations

Well Leakage: Improving the Reduced Order Models (ROMs)

Coupled Chemical and Mechanical ROM

Xiao Chen, Jaisree Iyer, and Susan Carroll, LLNL

- New ROM that incorporates the chemical and mechanical impacts on permeability reduction
- Current leakage rate predicted based on input parameters and leakage rates at previous two time steps
- Leakage rate at t_0 and t_1 are predicted using two ROMs that map leakage rates to input parameters
- ROM does well on training data set



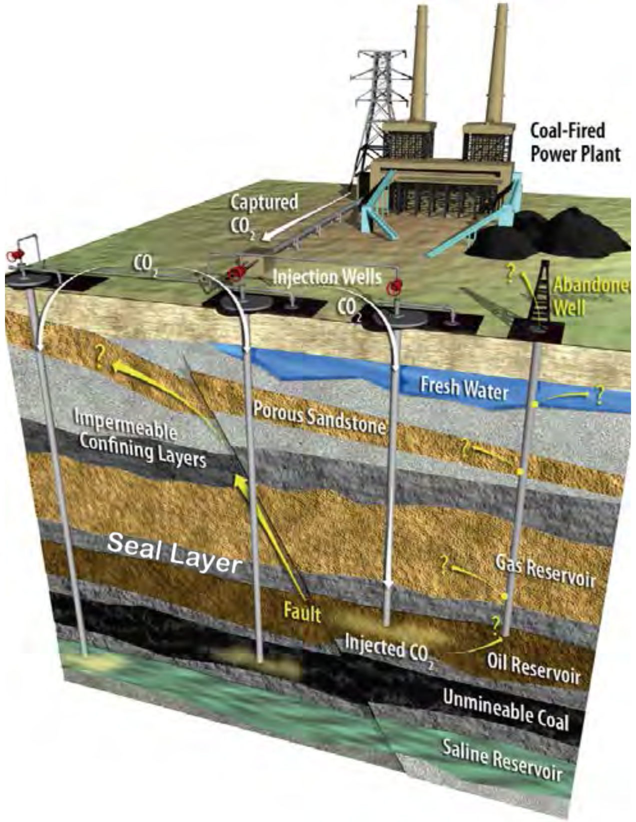
- Error for 77% of the training examples is <10%
- Error for 4% of the training examples is >100%

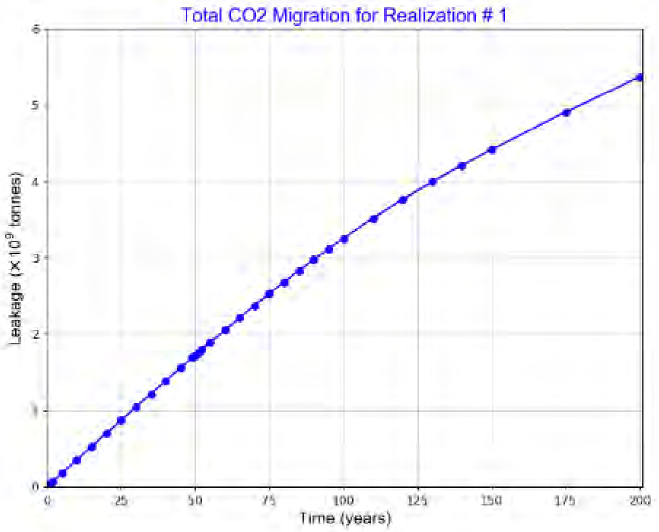
Well Leakage: Improving the Reduced Order Models (ROMs)

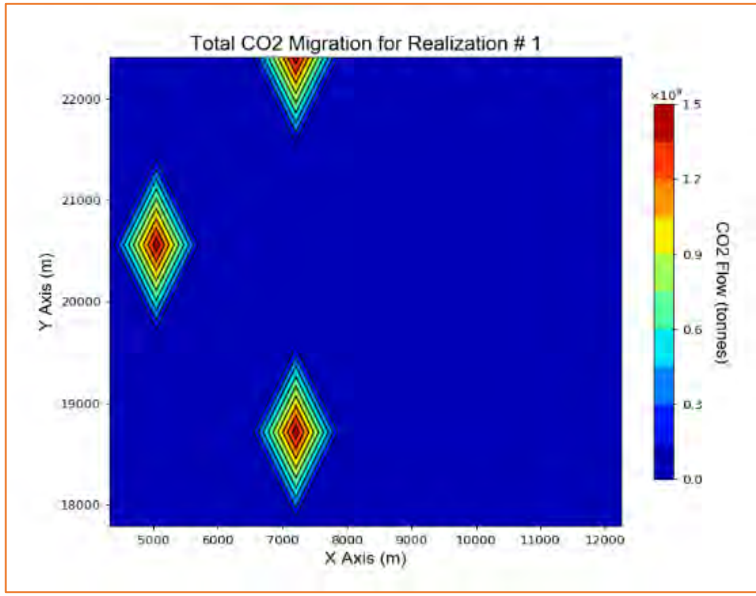
Seal_Risk ROM

Ernest Lindner, NETL

- For CO_2 Leakage through a Barrier Layer
- Features Include:
  - Two-phase Flow with Temperature & Pressure Dependence
  - Time-dependent CO_2 Reaction with Shale
  - Random and Heterogeneous Permeability
  - Variable Grid and Vertical Layers
  - Being Developed in Python
- Currently -> Basic Structure Established and Simple Time-Effect (S-Curve) Model Created

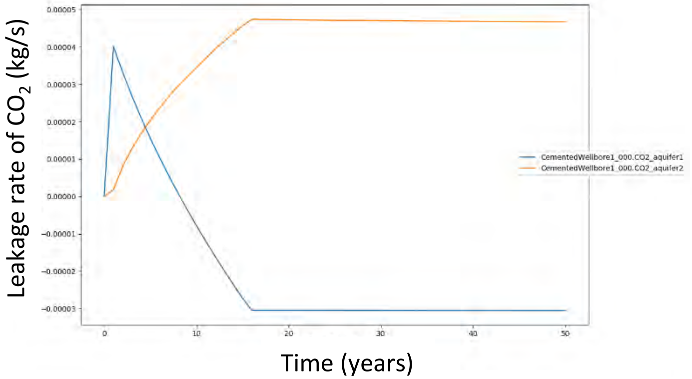


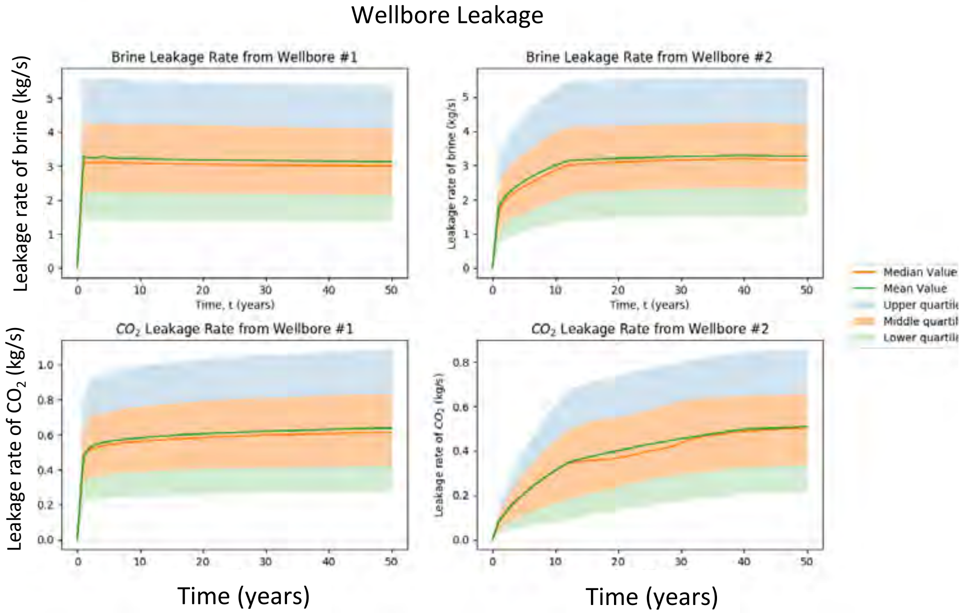


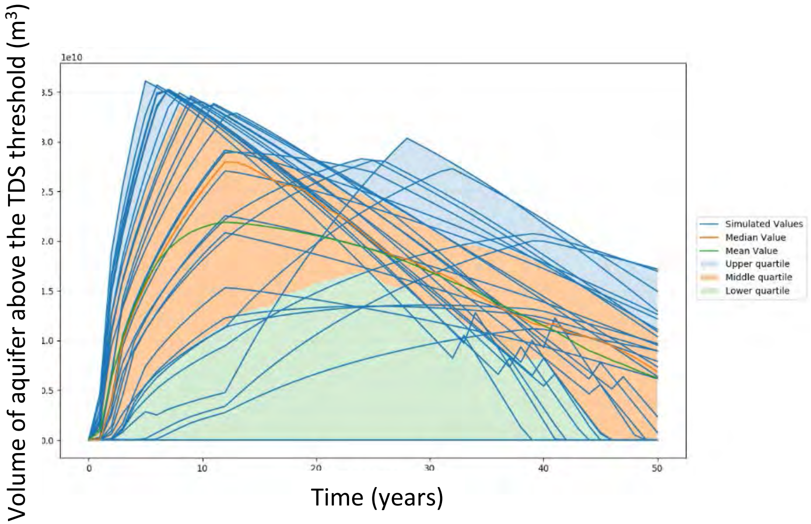


OpenIAM: Visualizing System Behavior

Probabilistic Analysis generates large amounts of data, good visualizations are key to quickly and easily understanding how the system is performing.







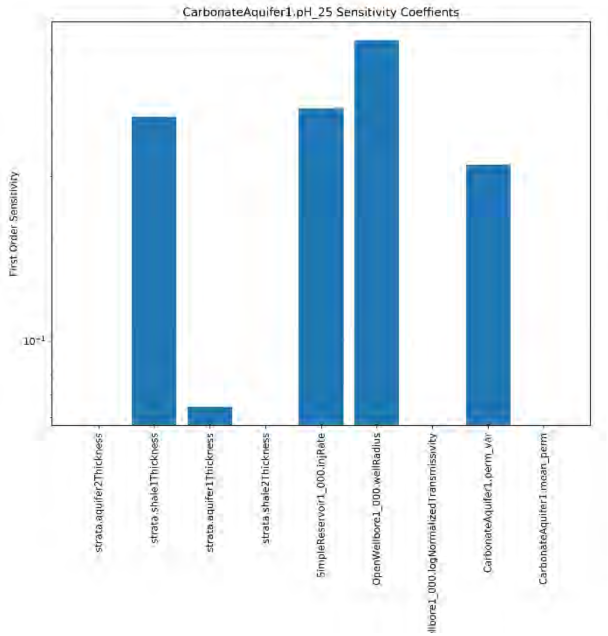
Results over time for deterministic simulation

Results over time shaded by quartile with mean and median for ensemble simulations

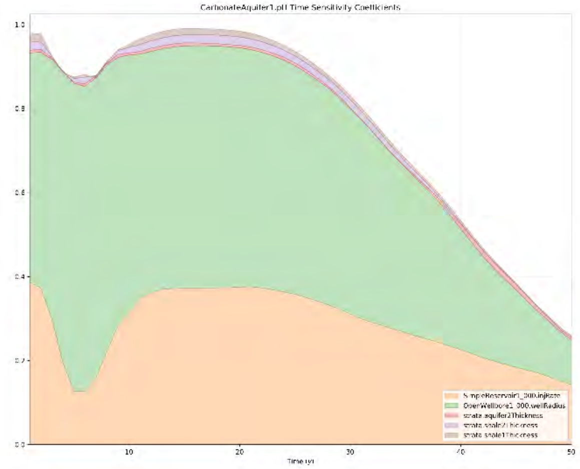
Quartile shading and realization results over time for ensemble simulations

OpenIAM: Statistical Analysis Visualization

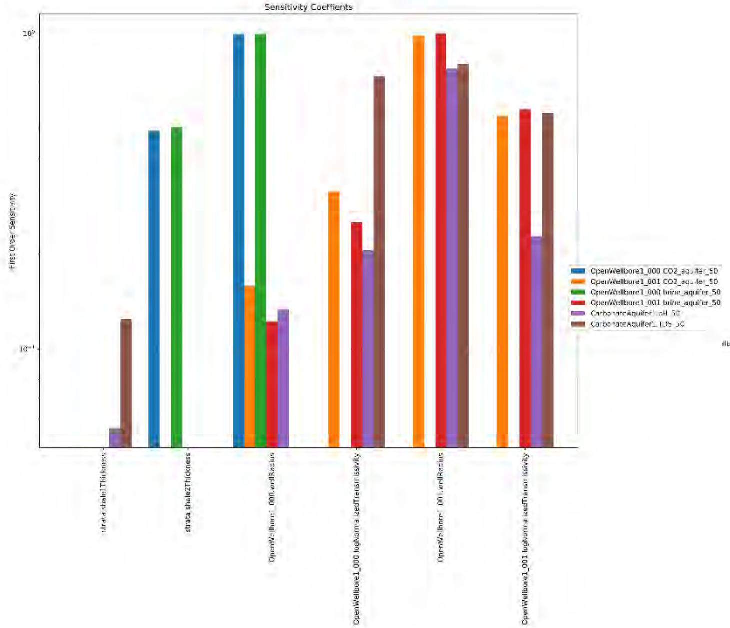
Correlation and Sensitivity Coefficients allow evaluation of model parameter impacts to system performance



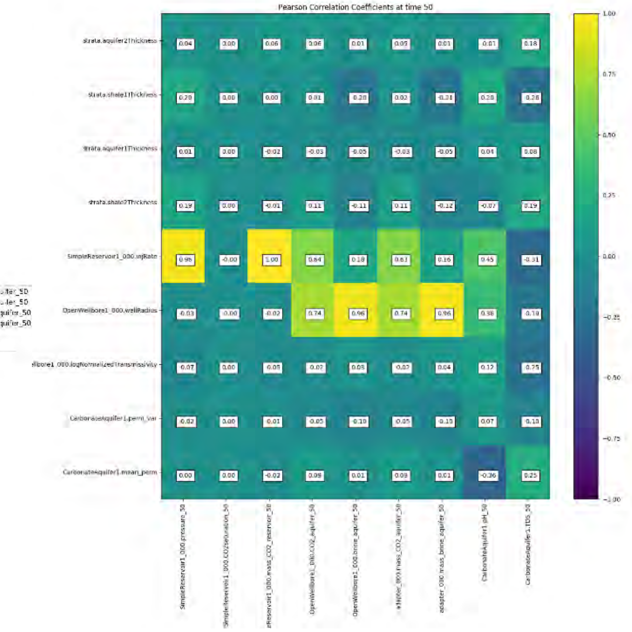
Sensitivity Coefficients for Aquifer Impact at a point in time



Sensitivity Coefficients for Aquifer Impact evolving through time



Sensitivity Coefficients of multiple parameters on multiple system performance metrics

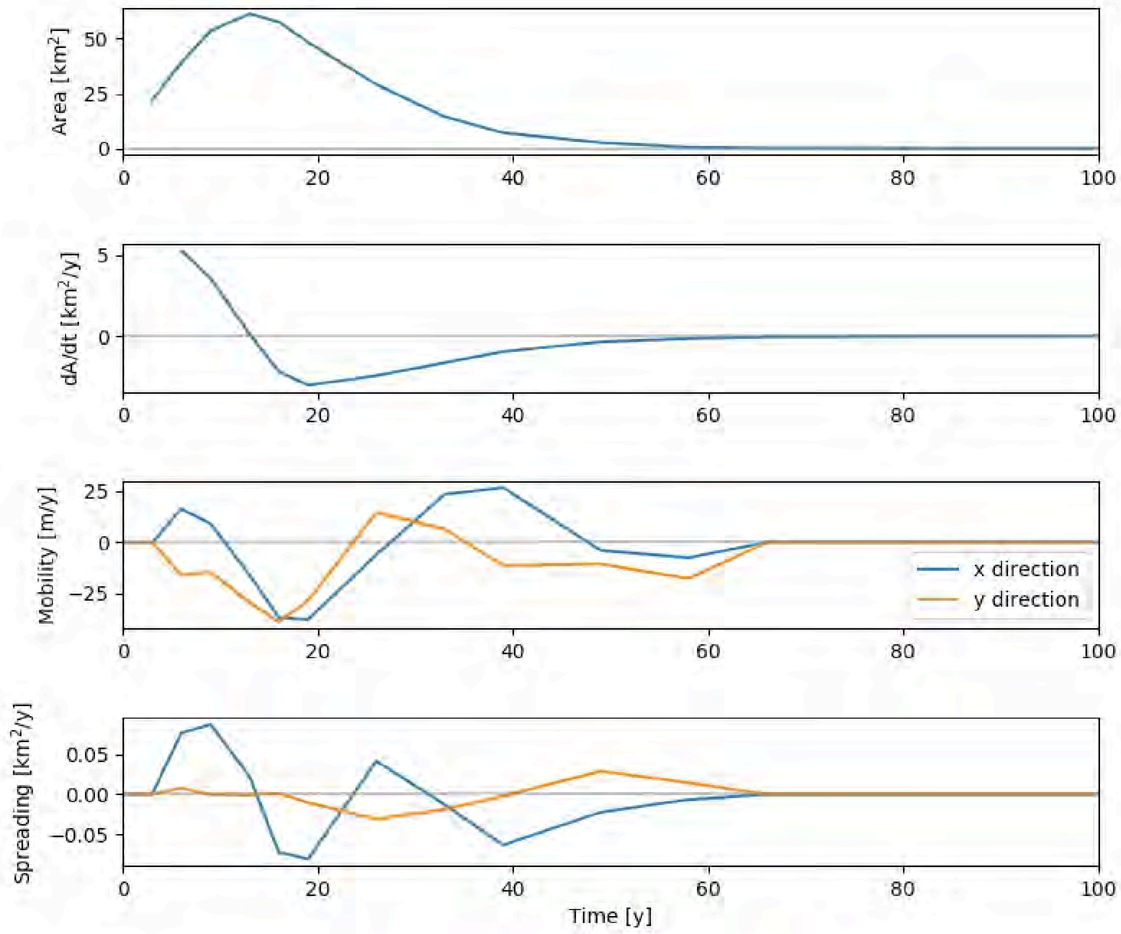


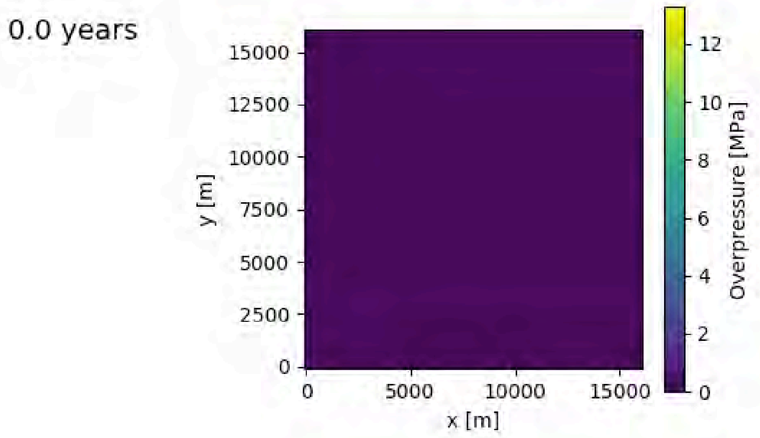
Pearson Correlation Coefficients can quickly show how input parameters affect model outputs

OpenIAM: Plume Stability Analysis

Example pressure plume stability analysis

- Based on moment analysis
- dA/dt – derivative of plume area with time
- Mobility – derivative of plume centroid with time
- Spreading – derivative of plume variance along characteristic axes with time.
- 10 years of injection
- 90 years of post-injection monitoring





OpenIAM: Ensemble Plume Stability Analysis

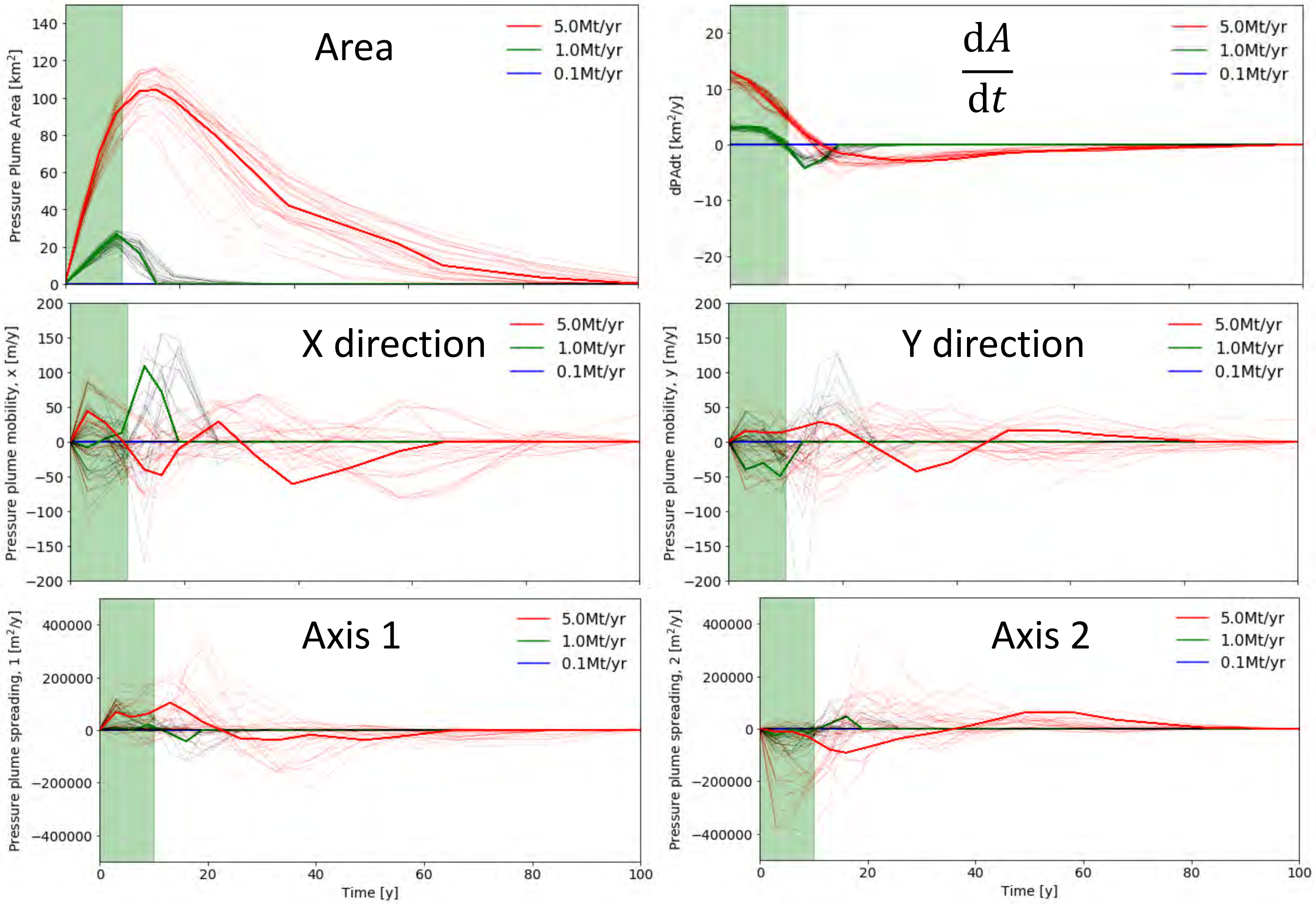
Extending to probabilistic ensemble analysis

Pressure plume stability analysis

Area

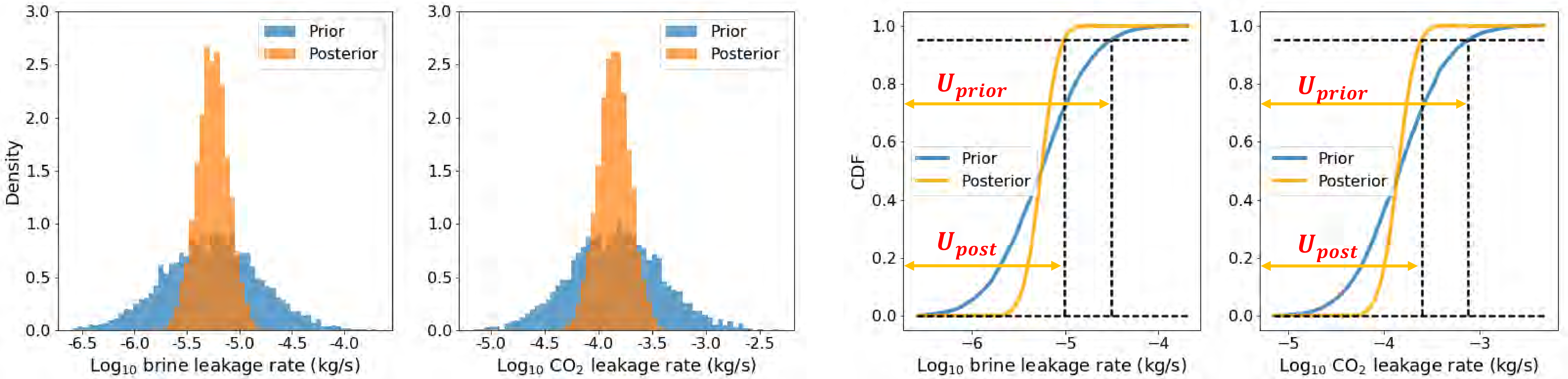
Mobility (Centroid)

Spreading



OpenIAM: Using Monitoring Data for Model Updating

- **Markov Chain Monte Carlo (MCMC) approach can be use to update applicable parameters**
- **Proof of concept case developed using synthetic storage reservoir monitoring data**

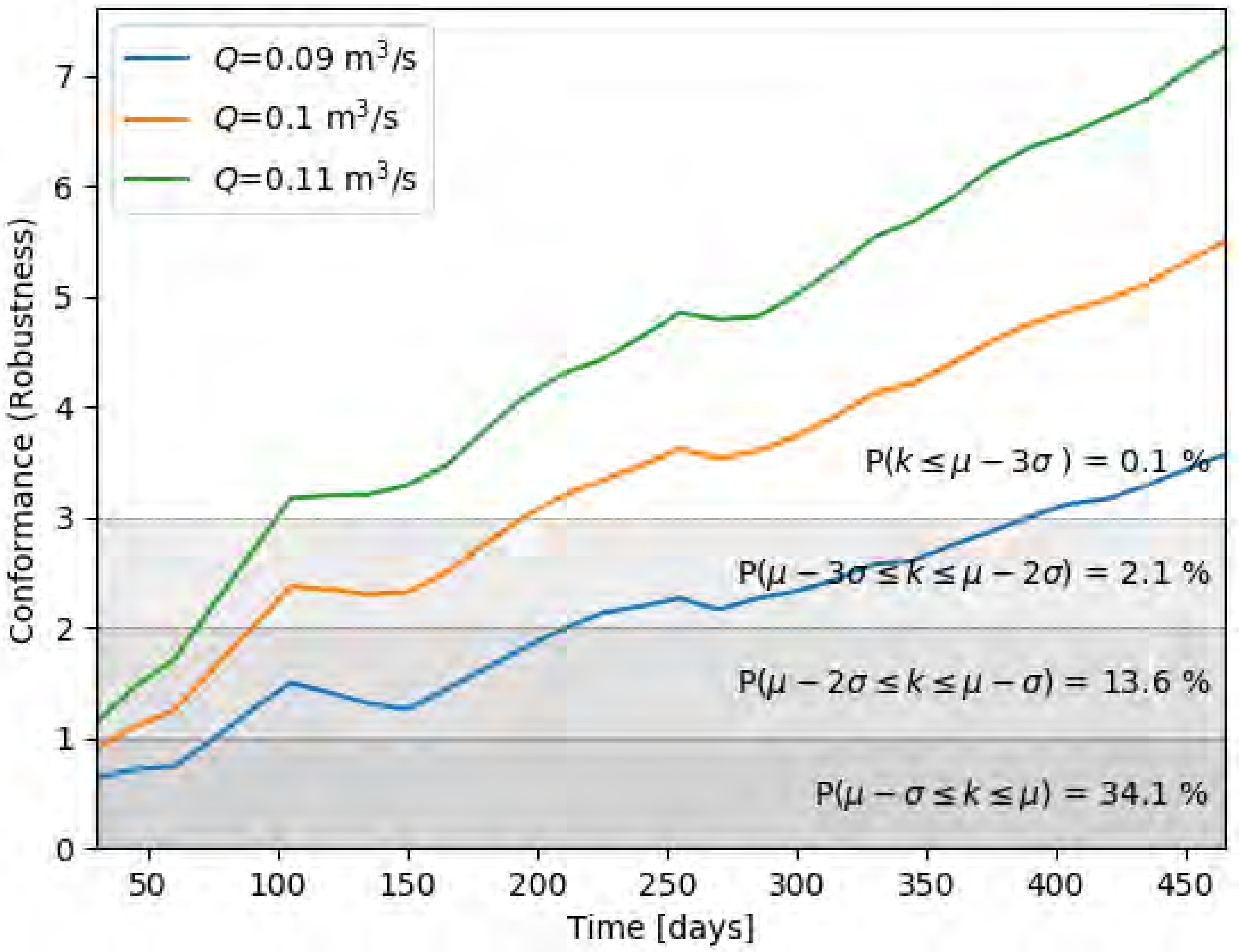


Observations → Data assimilation using MCMC → Uncertainty reduction in brine and CO_2 leakage rate

OpenIAM: Supporting designations of Conformance (*in Beta*)

Conformance – confidence that the GCS operation will meet performance criteria in the future

- *Conformance increases over time as more monitoring data becomes available.*



Thank You!

Acknowledgement: This work is funded by the United States Department of Energy Fossil Energy Office through the National Risk Assessment Partnership (NRAP) managed by the National Energy Technology Laboratory (NETL)

Outline

- **Task 2 (Containment Assurance) overview**
  - Task organization
  - Objectives

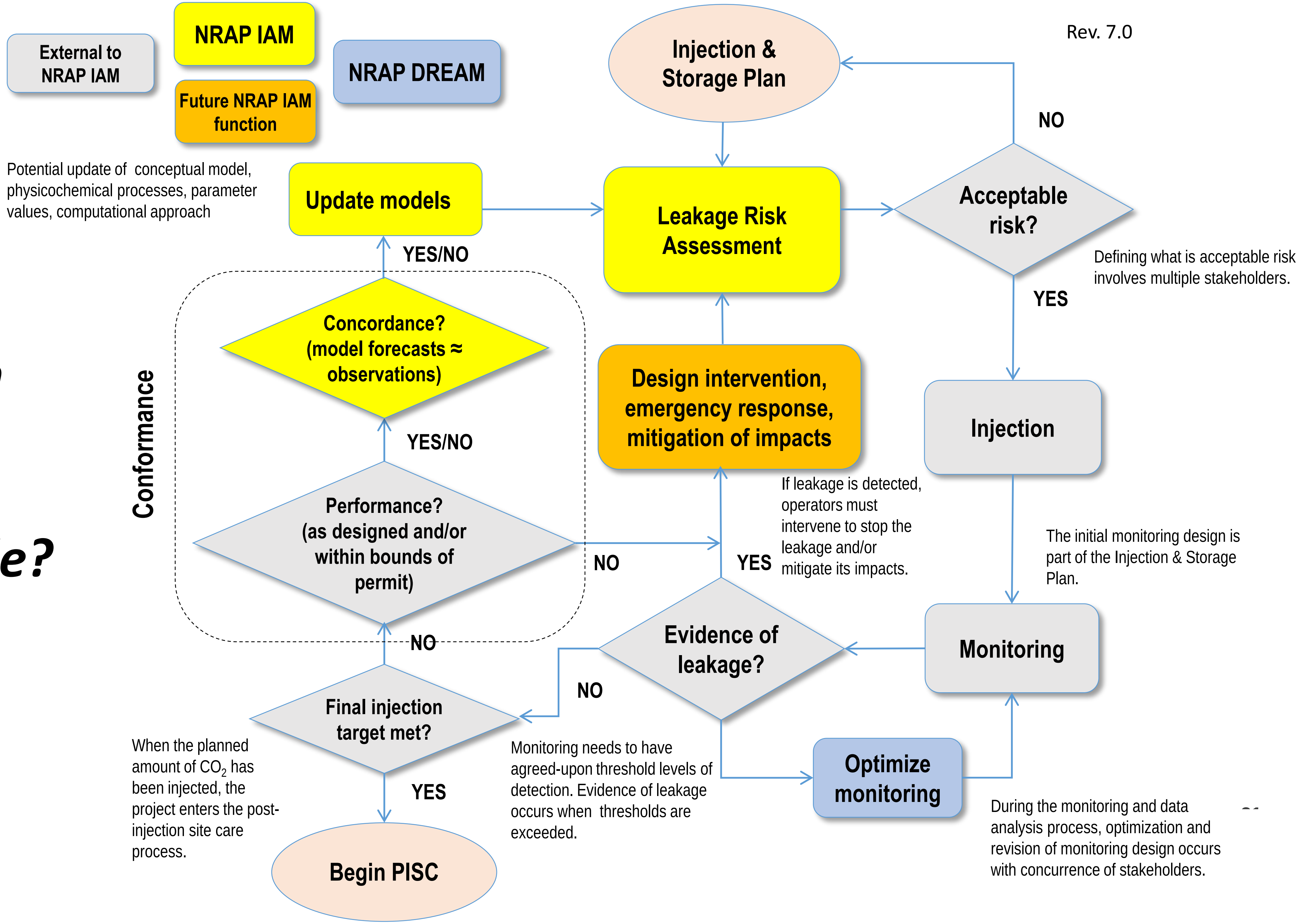
OpenIAM: Current Status

- **Alpha release for internal NRAP testing –** Posted on EDX and gitlab
- **7 component models –** 2 reservoir components, 3 wellbore components, 1 aquifer component, 1 atmospheric dispersion model (additional aquifer component in progress).
- **Modeling and parameter sampling –** Forward modeling, Monte-Carlo Modeling, Parameter Studies, MCMC, parameter estimation
- **Control File Interface –** Simple text file can be used to build and run the most common IAM problems, no python scripting is required from the User. GUI interface coming soon.
- **Text file observation output –** All observations are written to an output file for any user analysis desired.
- **Setup script –** Script to check that necessary libraries and programs are installed, compiles component models when needed, and run test suite to check that the IAM is properly working.
- **User's Guide –** Guide to describe functionality and uses of the OpenIAM.
- **Test Suite –** Ensures the OpenIAM is operating as expected.
- **Examples –** Simple examples to show off different functionality of the IAM to get user's started.
- **Analysis –** Correlation and Sensitivity Coefficient output for model analysis. Reservoir simulation plume stability analysis.
- **Visualizations** – Graphical output of model and analysis data.
- **Cross Platform and Parallel Operation –** Currently operational on Windows, Mac, and Linux. User can specify number of CPUs to use. Can be run on laptops, desktops, compute servers, or high performance clusters.

Task 2 Overview – Key science questions

- *What is the likelihood and impact of CO_2 leakage through damaged wells?*
- *How may fractured caprocks (i.e., seals) respond to stress and saturation changes, and what response may be expected in overlying strata?*
- *How can a probabilistic risk assessment framework be used to inform pressure and plume management at CO_2 storage sites?*
- *How can a quantitative risk assessment framework be used to inform assessment of plume conformance?*

Where does Containment Assurance fit in the CO2 sequestration project life-cycle?



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Containment Assurance task timeline

Milestones:

1. Complete OpenIAM design plan

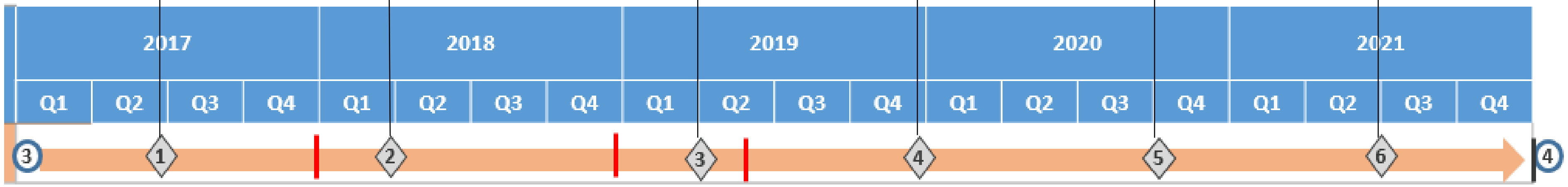
2. Internally release OpenIAM

3. External release of OpenIAM for beta testing

4. Complete conformance analysis

5. Complete draft manuscript on leakage risk management scenario

6. Develop protocols/ recommended practice for leakage risk management



Robustness over time for different critical pressures

- If the critical pressure is 10 MPa, the robustness does not increase over time.
- Less restrictive critical pressures lead to increasing robustness over time.