



# SMART tools for Geologic Carbon Storage Applications

Science-informed Machine Learning to Accelerate Real Time (SMART) Decisions in Subsurface Applications

**Task-6 team (PNNL, LLNL, and NETL)**

**Presenter (presentation and discussion):**

- **Eusebius Kutsienyo (PNNL)**

# Acknowledgments and disclaimers

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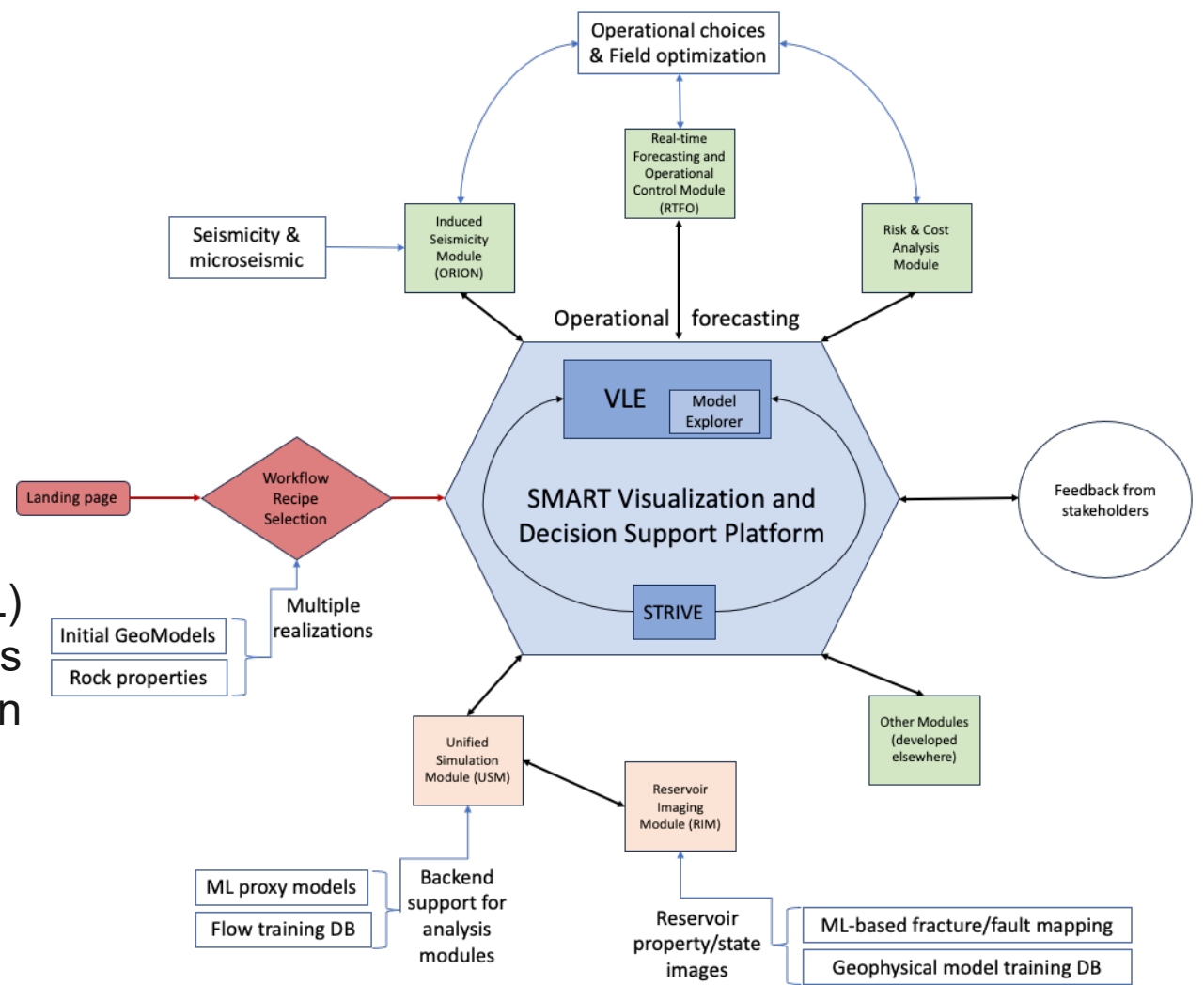
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# SMART Initiative

## Our objectives:

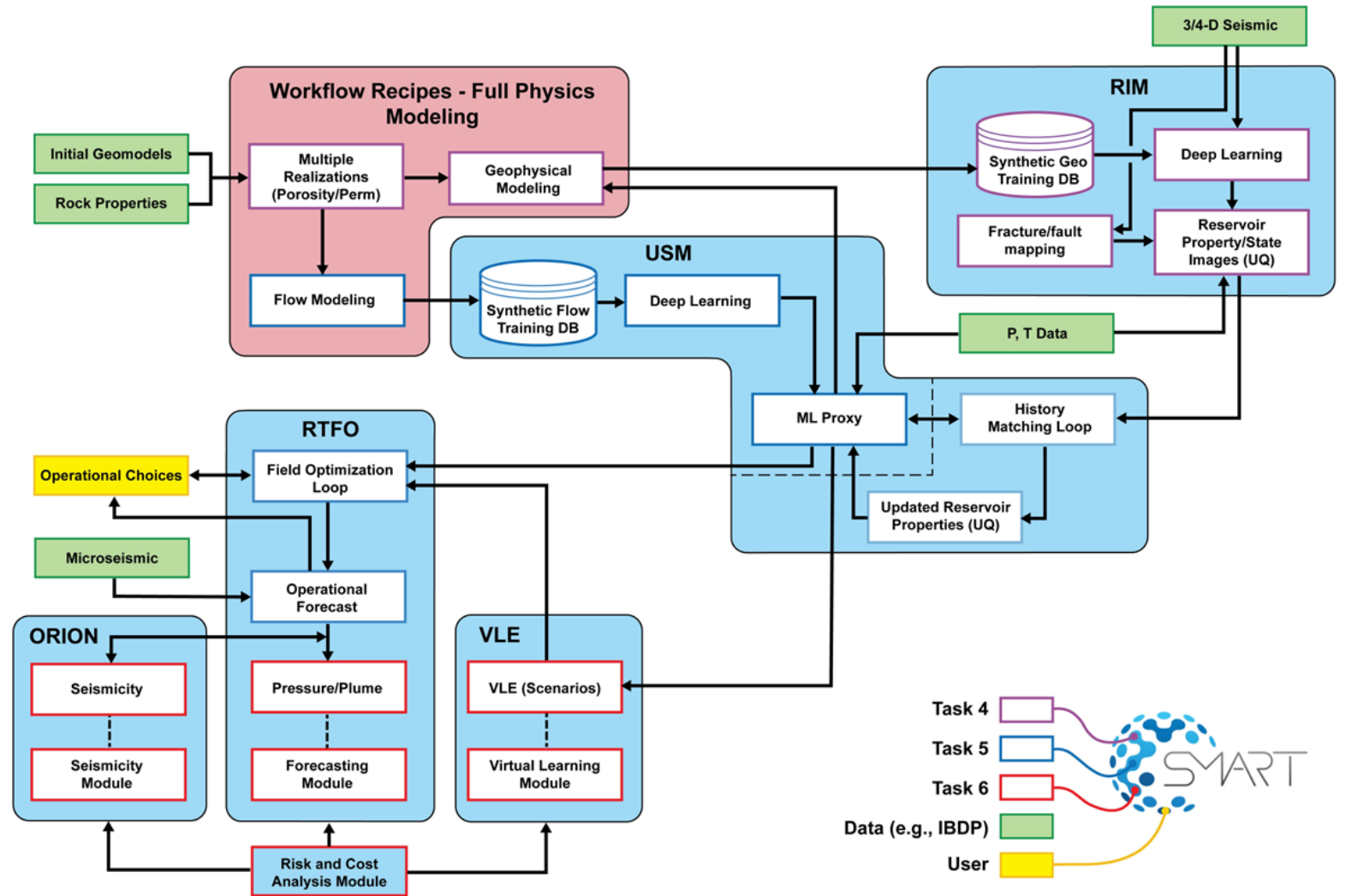
Showcase how the utilization of Machine learning (ML) can significantly improve efficiency and effectiveness of field-scale commercial carbon storage operations in three main areas:

- Real-time visualization
- Real-time forecasting
- Virtual learning



# SMART Modules Cross-talk

**Summary:** The platform is a suite of integrated tools or modules developed within SMART initiative to make better and informed decisions related to the geologic carbon storage through real-time visualization, forecasting, and virtual learning.



Workflow recipes of SMART modules and tools interaction

# Functionality of the SMART tools


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## SMART tools deployment in commercial-scale GCS projects

- Enabling dramatic improvements in the visualization of key subsurface features and flows,
  - Creating a computer-based experiential learning environment to improve field development and monitoring strategies, and
  - Transforming storage reservoir management by rapid analysis of real-time data and rapid forward prediction under uncertainty to inform operational decisions.
- **Outcome**
    - Successfully deployed tools: Awaiting feedback from CCS stakeholders - incorporating feedbacks into SMART module development

# SMART platform and its graphical user interface (EY24 early version)

## Welcome to the SMART Platform



Task 4  
Task 5  
Task 6  
Data (e.g., IROP)  
User

Wiring Diagram

Integrated SMART Network

Workflow and Tools



ORION

Explore induced Seismicity factors

Workflow and Tools



VIRGO

Forecasting simulation processes.


Workflow and Tools



Workflow Recipes

Explore different workflow recipes.

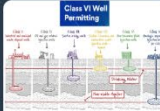
Workflow and Tools



ModelExplorer

Class VI permitting analysis.

Workflow and Tools



RIM

Reservoir Imaging Model

Workflow and Tools



Risk & Cost Analysis Module

Risk Analysis

Operational risks and costs.

Workflow and Tools



RTFO

Forecast and Operation Control.

Workflow and Tools



TALES

Economic and Liability Evaluation

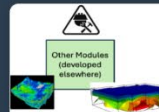
Workflow and Tools



Legacy Code

Predictions of simulation processes.

Workflow and Tools



Other Modules (developed elsewhere)

Other Simulators

Pressure, Saturation, and AOR Evaluation

Workflow and Tools



Other Modules

Analytical-based GCS Estimation

Workflow and Tools

# STRIVE-based Virtual Learning Environment (VLE) Module

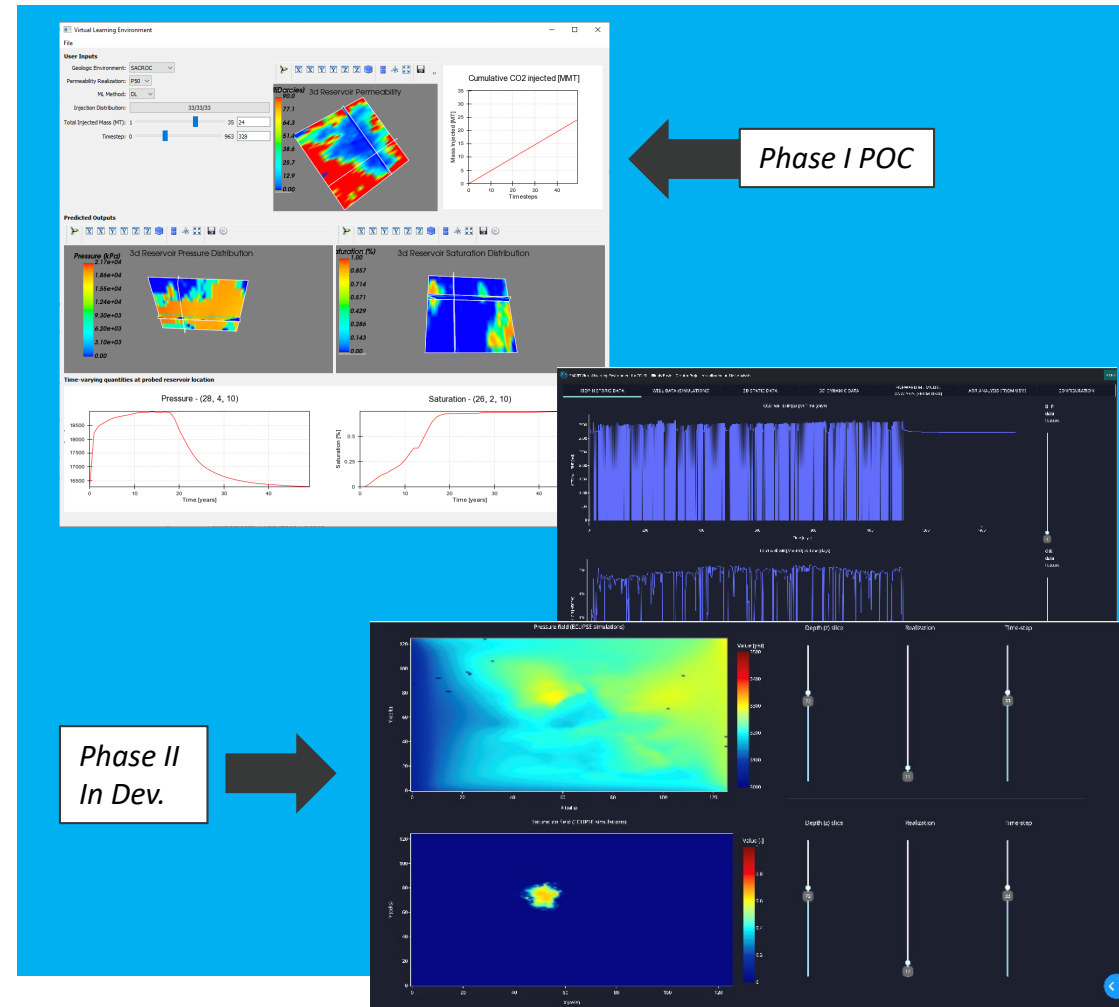
The **Virtual Learning Environment (VLE)** is an exploratory module which uses ML predictions to rapidly inform an end user of how a given reservoir simulation would likely change in response to altered inputs (i.e., “What-if” scenarios)

Phase II development utilizing STRIVE progress includes:

- Encompass Phase I behavior
  - Explore *predicted* changes in pressure and saturation over time given injection rate and rock property profile
  - Additional framing data (AoR) is integrated
  - ML model analysis and visualizations
- Be migrated to an online environment
- Import ML data from Unified Simulation Module (USM)
- Exploring the during and post-injection scenarios

Benefit to CCS industry:

- **Virtual learning:** Computer-based experiential learning environment to improve field development and monitoring strategies
- **Real-time visualization:** Visuals of key subsurface features and flows by exploiting ML to substantially increase speed and enhance detail



# Model Explorer

## Accelerate the Class-VI permitting process:

- Allows for quick visualization of the model inputs, output, and other types of data integration, where multiple sets of technical information (e.g., site characterization data and modeling input) can be visualized and evaluated in an integrated fashion.
- Calculates and maps Area of Review (AoR) in real-time in response to model inputs.
  - Displays the evolution and maximum predicted extent of the supercritical CO<sub>2</sub> plume, pressure front, and the combined AoR.
- AoR calculation is based on a pressure-front that can be user defined or determined using the suggested EPA methods.

## Model Explorer

Compute Resources    GCS Site    Load Geologic Models






### Login

Username

Password

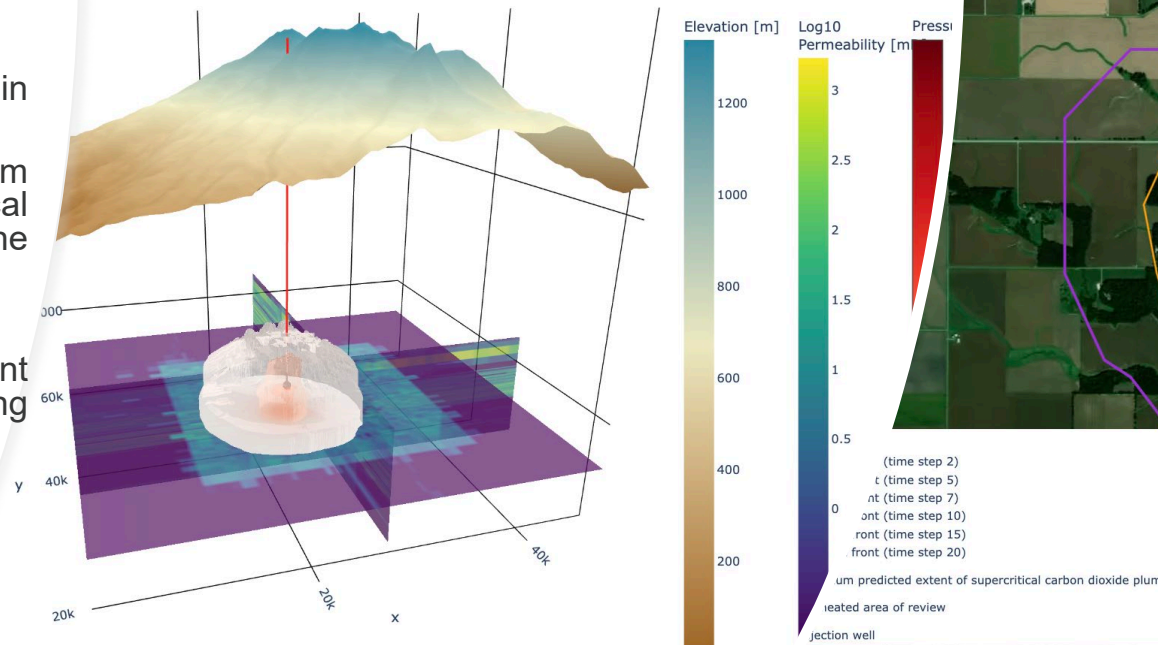
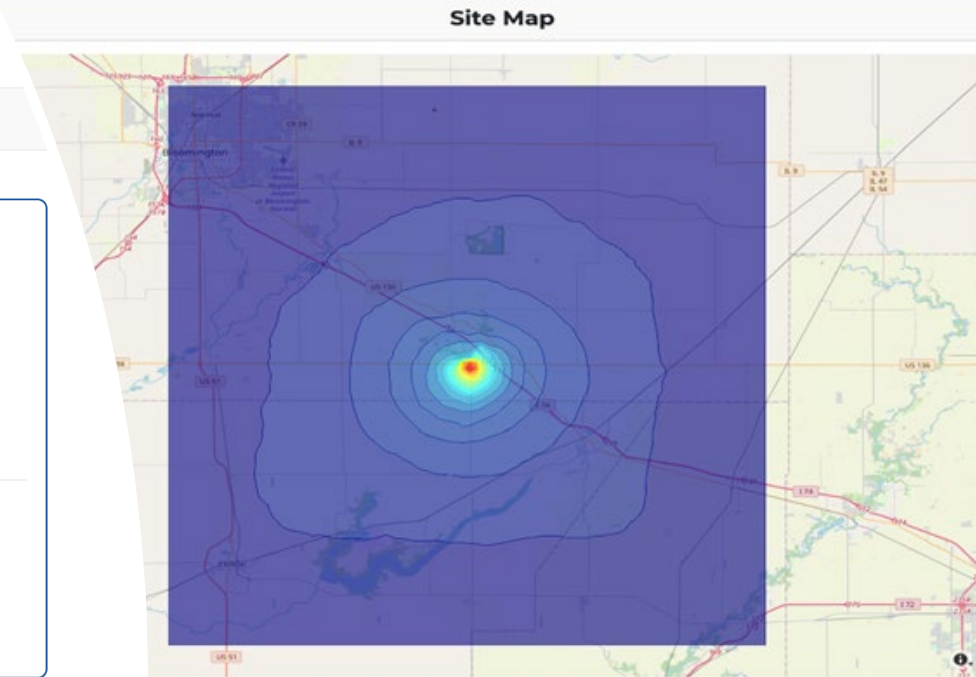
Login

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Federated Authentication





# SMART-Model Explorer

## Status - Module Workflow – Area of Review Calculation

### 1. Pressure Front

- User defined threshold.
- EPA Method 1. Under-pressurized injection zone. Pressure front based on bringing injection zone and USDW to equivalent hydraulic heads.

$$P_{i,f} = P_u + \rho_i g \cdot (z_u - z_i)$$

- EPA Method 2. Hydrostatic injection zone. Pressure front based on displacing fluid initially present in the borehole.

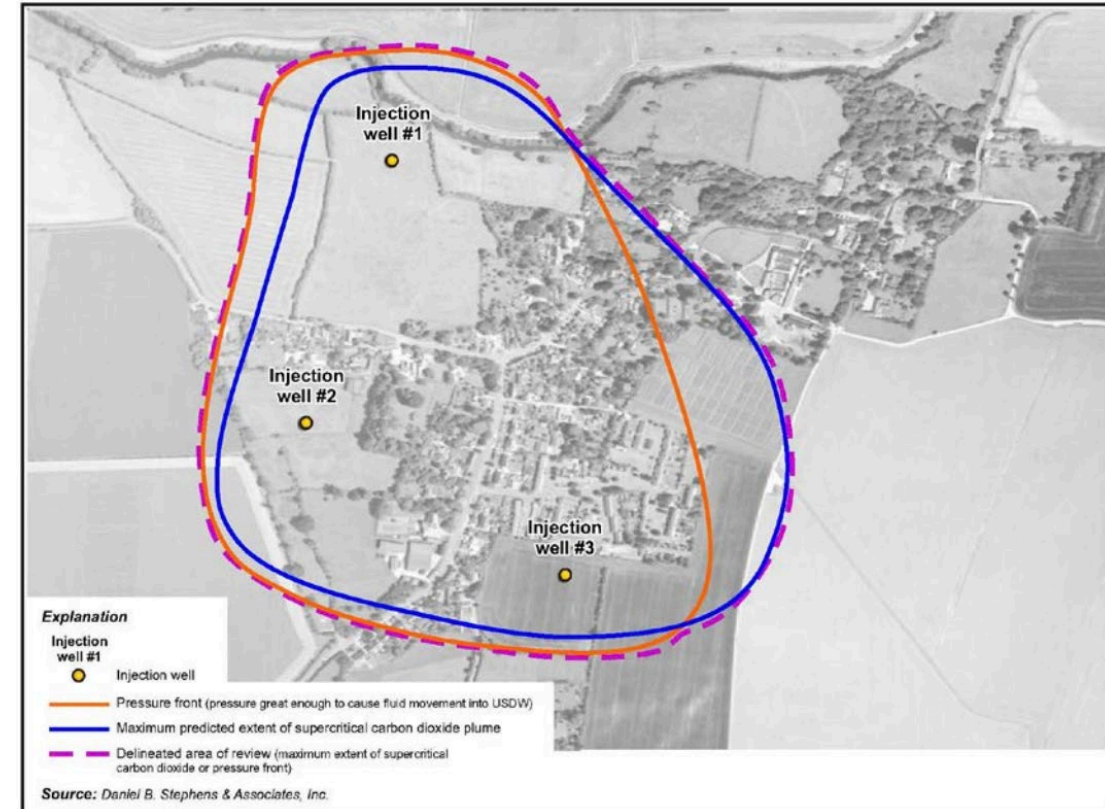
$$\Delta P_c = \frac{1}{2} \cdot g \cdot \xi \cdot (z_u - z_i)^2$$

### 2. Supercritical CO<sub>2</sub> Plume

- Maximum predicted extent of the separate-phase plume.

### 3. Area of Review

- Combined maximum extent of pressure front and supercritical CO<sub>2</sub> plume.



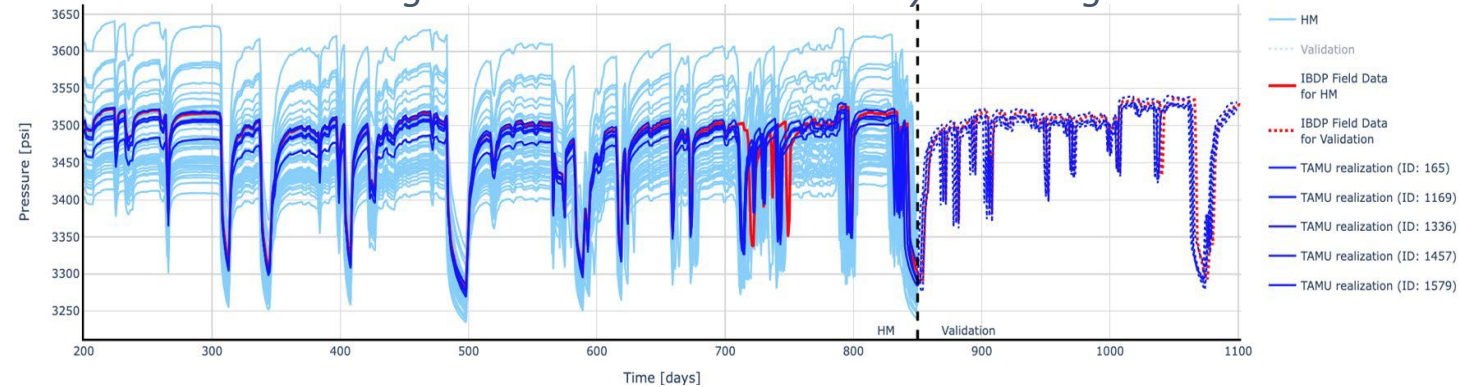
Example area of review contour

epa.gov

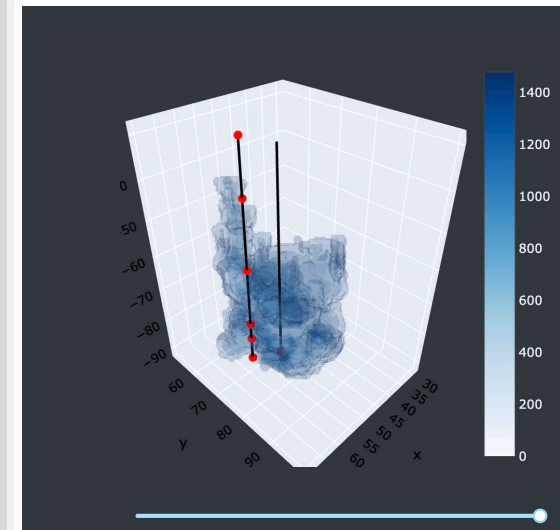
# RTFO module

- RTFO is integrated with advanced machine learning models, optimization algorithms, and interactive data visualization tools.
- RTFO provides a robust platform for managing and analyzing reservoir data.

Figure 2: TAMU Pressure History Matching



IBDP CO<sub>2</sub> plume (3D view)



IBDP CO<sub>2</sub> plume (2D view)

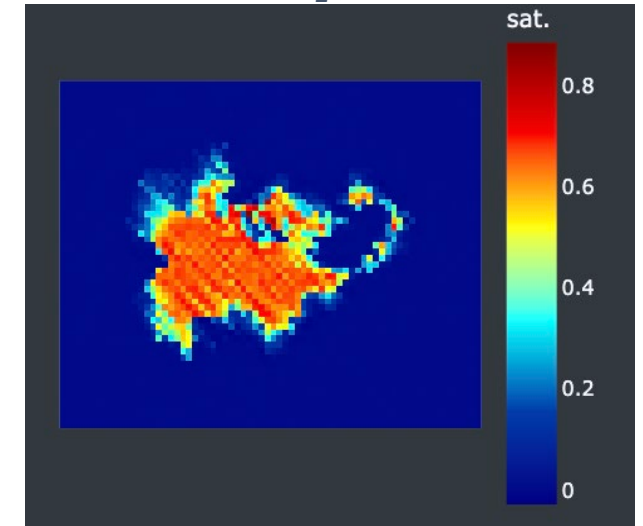


Figure 3: CO<sub>2</sub> plume in 3D and 2D

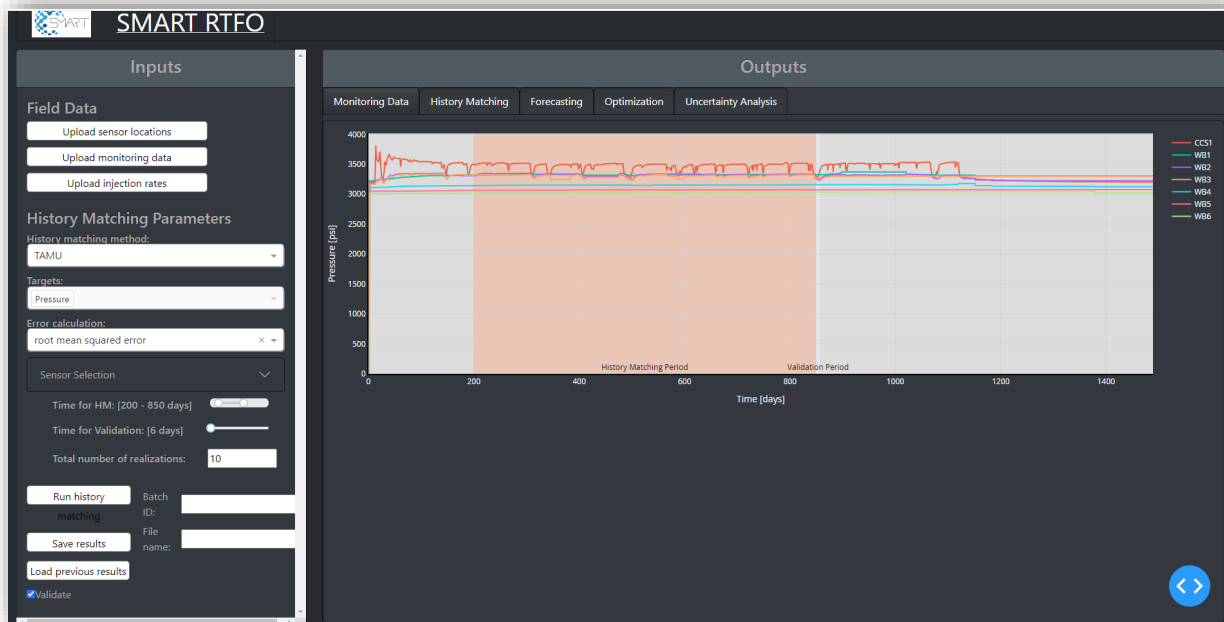


Figure 1: Interface of RTFO SMART Tool

# SMART Visualization and Decision Support Platform

Task-6 (EY23 and on-going EY24): Key Developers, Contributors, and Participants – PNNL, LLNL, NETL

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## Other contributors

- Derek Vikara
- David Morgan
- Diana Bacon
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**Questions?**

**Thank you!**

# SMART modules integration into overall platform (video)

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