# NRAP Task 4 - Developing a Risk-Based, Adaptive Monitoring Planning Tool


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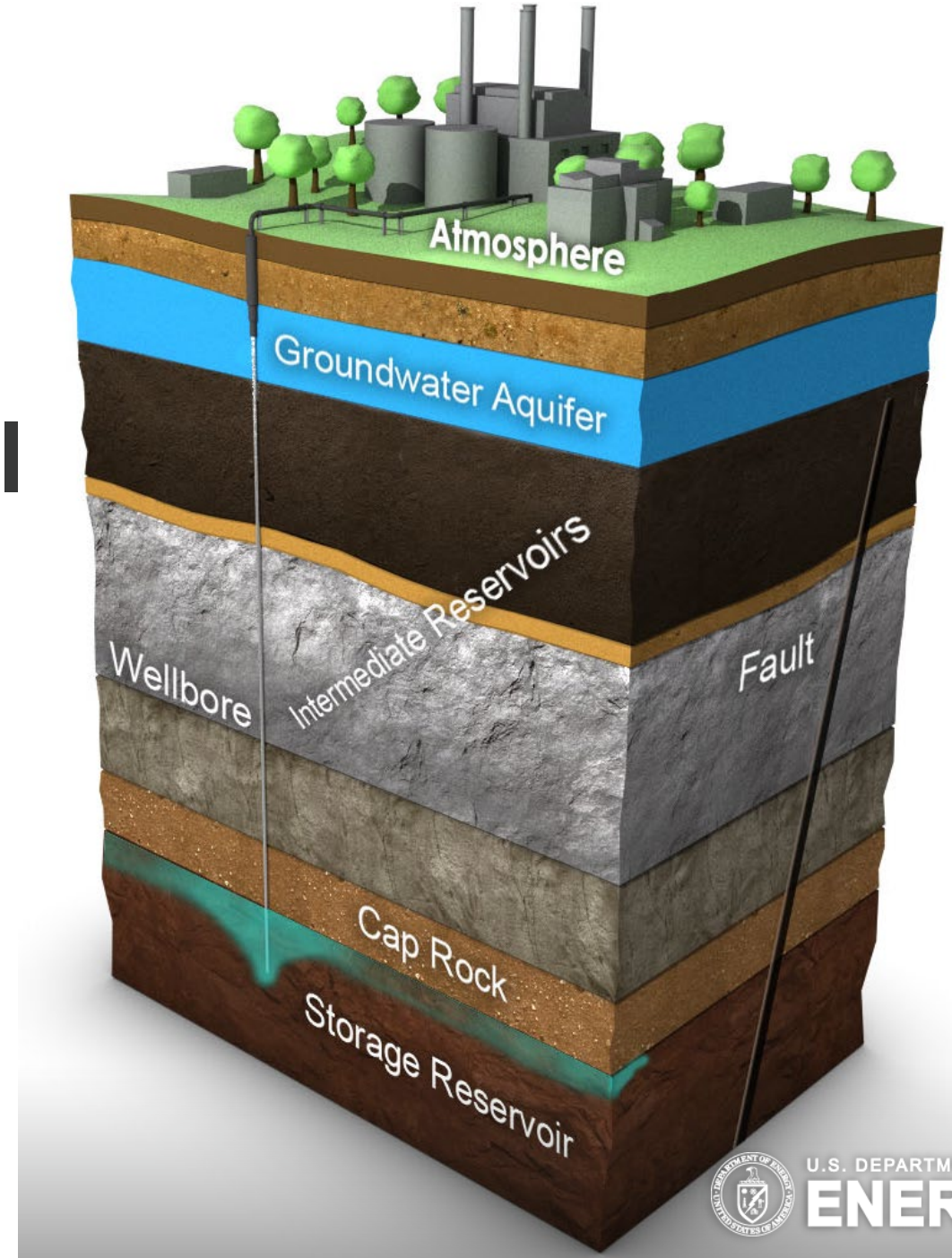
Lawrence Berkeley National Laboratory

**and Task 4 Team**



**2024 Carbon Management Research Project Review Meeting**
**August 8, 2024**

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# Research Team

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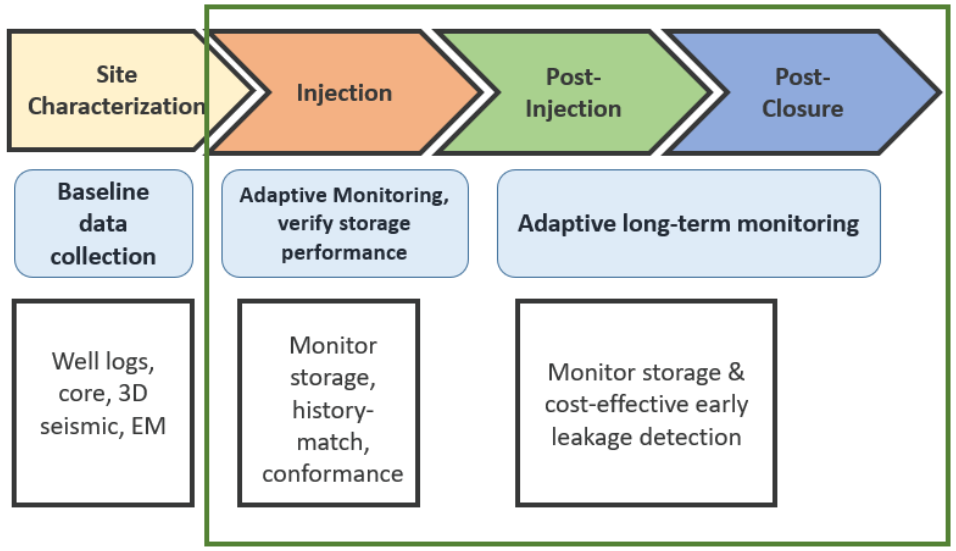
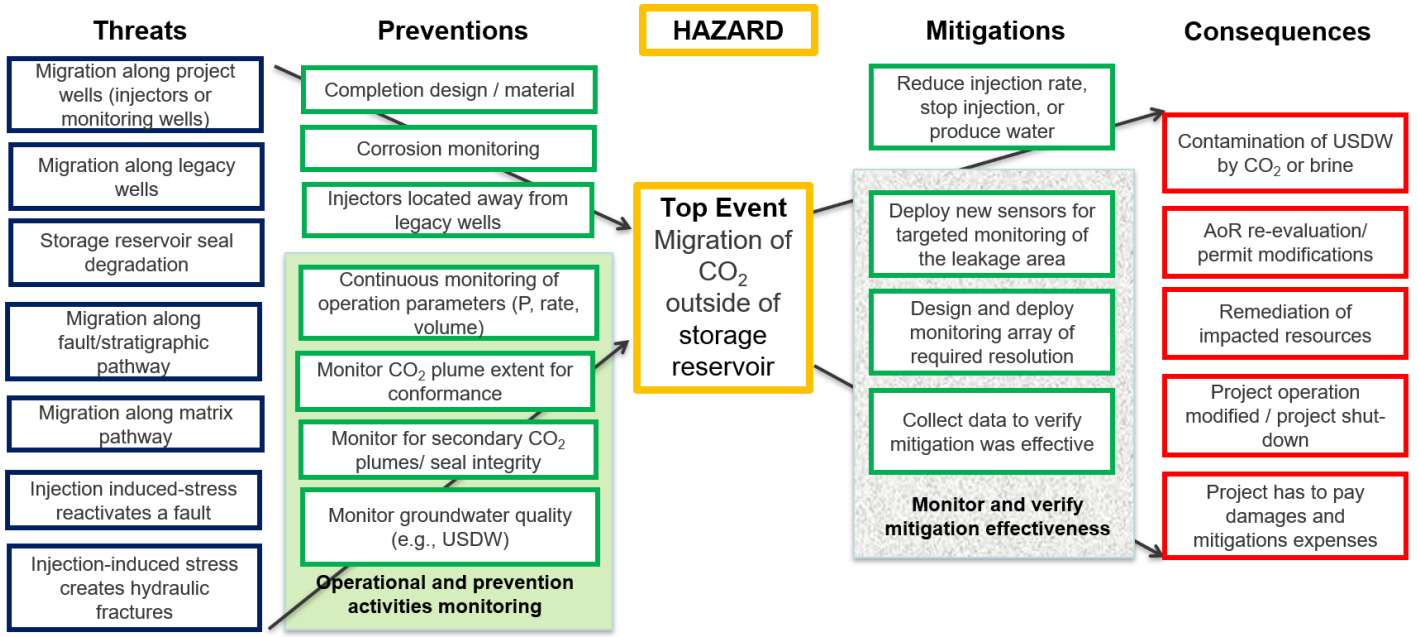
**PNNL:** Alex Hanna, Ashton Kirol, Delphine Appriou

# CCS Site Monitoring

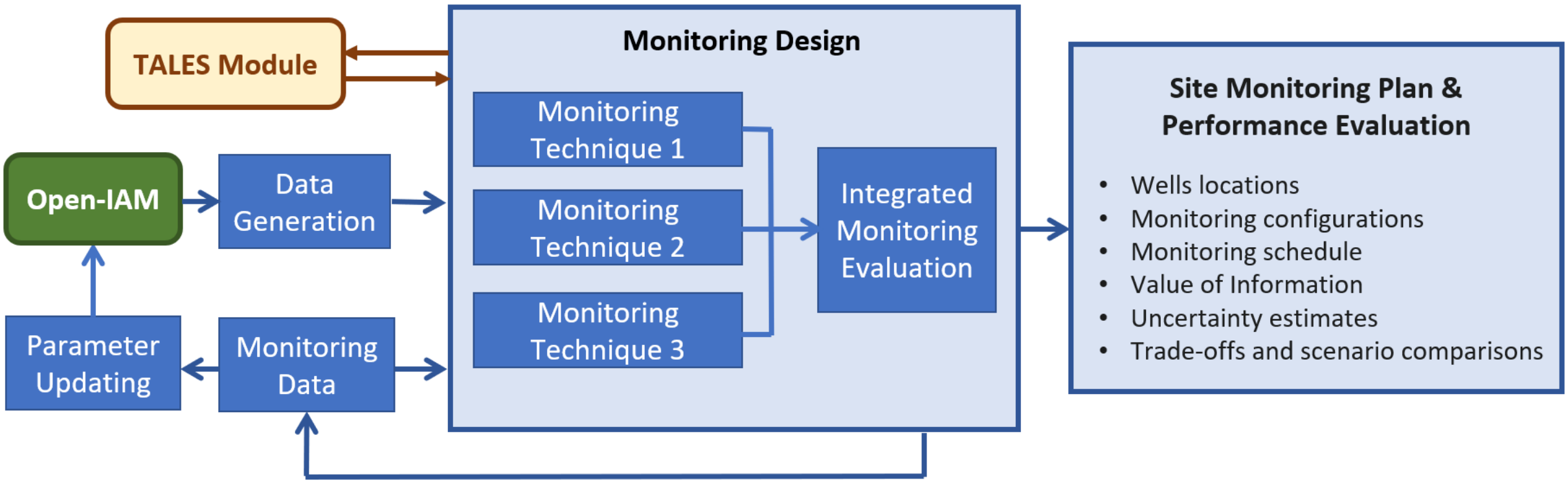



**Focus on monitoring objectives in injection and post-injection phases**

**Value of monitoring within a bowtie risk assessment framework**

# Risk-based Adaptive Monitoring Plan (RAMP)

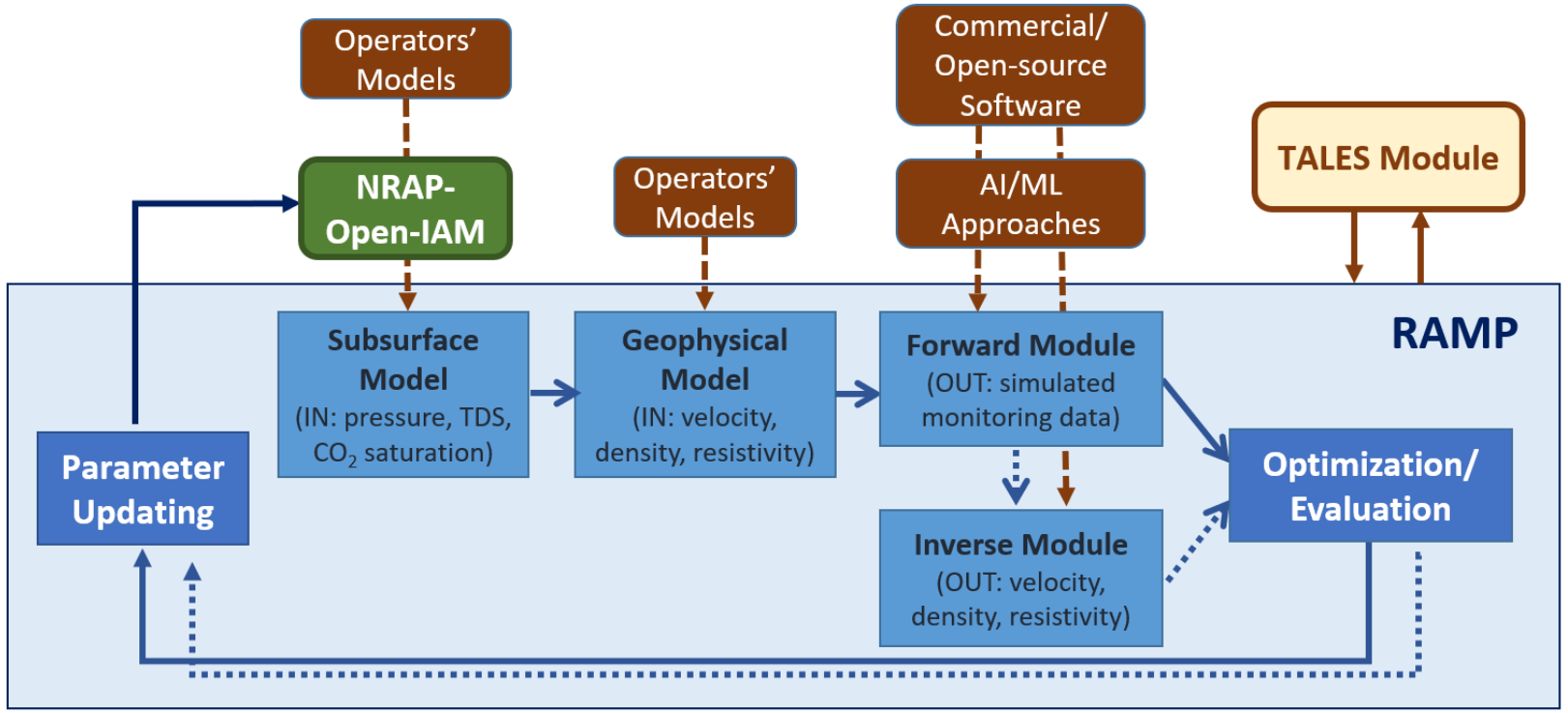



The user **can assess multiple monitoring technologies** (downhole pressure, fluid geochemical sampling, indirect methods – seismic, gravity, electrical/electromagnetic) and their **combinations**, **sensor configurations, and monitoring intervals**, and select an **optimal site monitoring plan** based on the **main project objectives**.

# RAMP

## Goals:

- Reduce risk
- Improve confidence

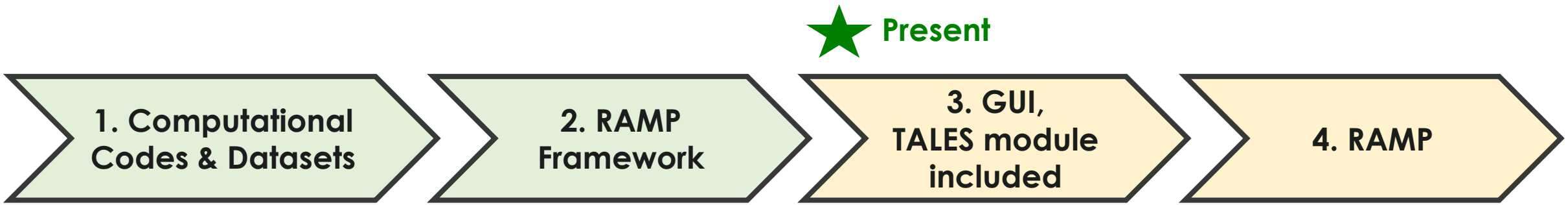



## Key features:

- Modular design
- Open-source programming environment
- Risk-based and adaptive with time
- Trade-offs between different monitoring scenarios

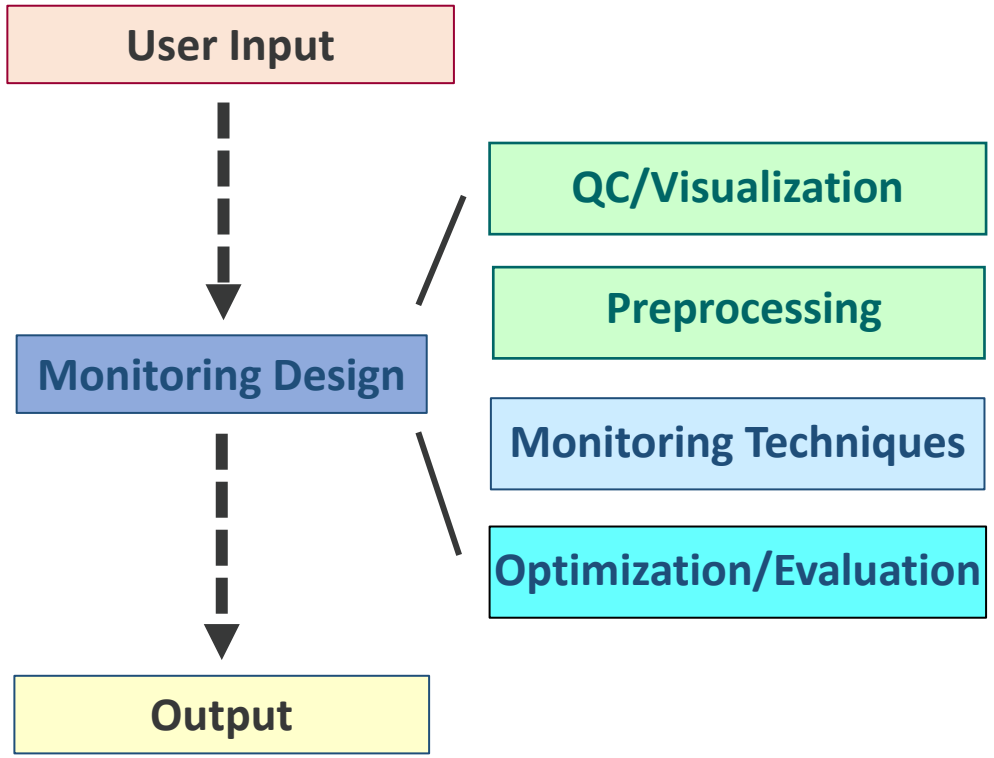
# RAMP - Timeline

- Year 1 – Identify and collect codes and data sets required for RAMP development
- Year 2 – Implement prototype RAMP framework and modify back-end codes
- Year 3 – Add GUI, link to TALES module (Task 5, NRAP/SMART Technoeconomic and Liability Evaluation for Storage Model)
- Year 4 – Complete RAMP tool

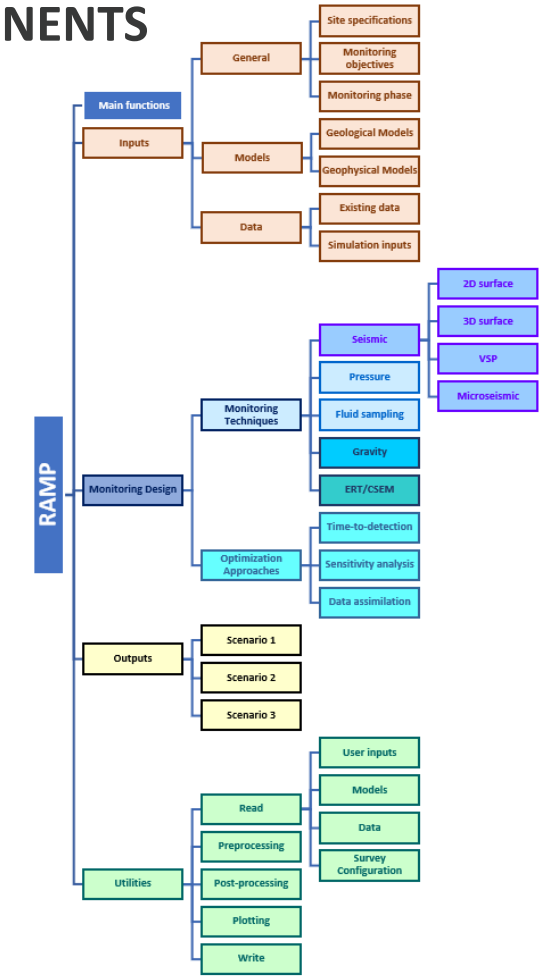


# RAMP Framework

## WORKFLOW

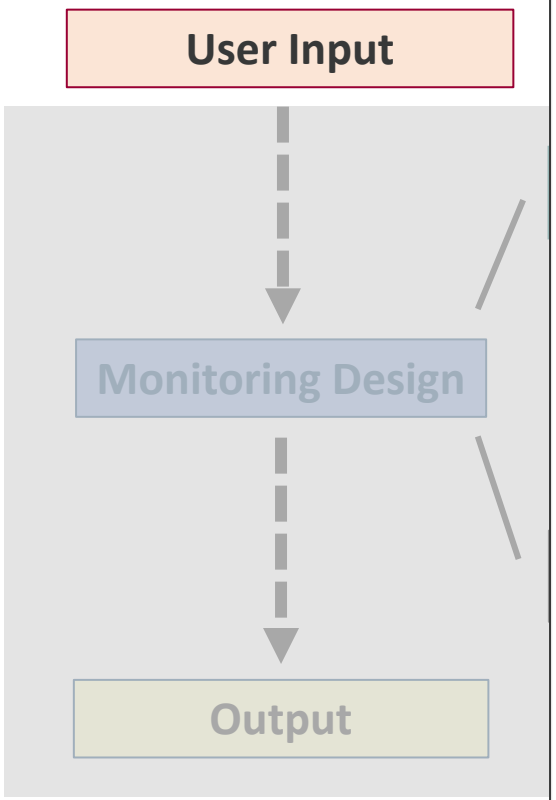



## COMPONENTS



# RAMP Framework

## WORKFLOW

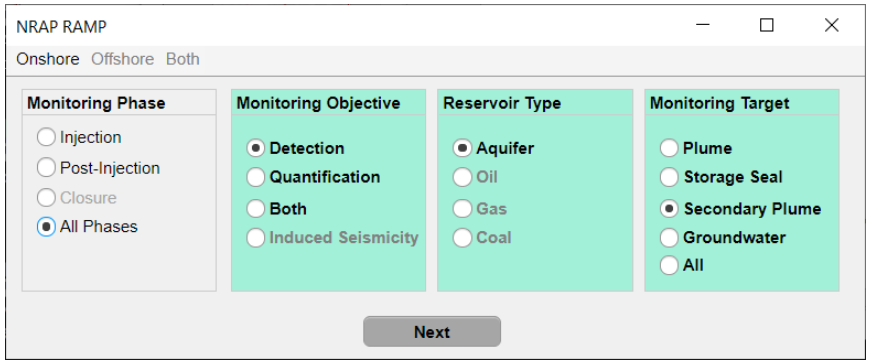


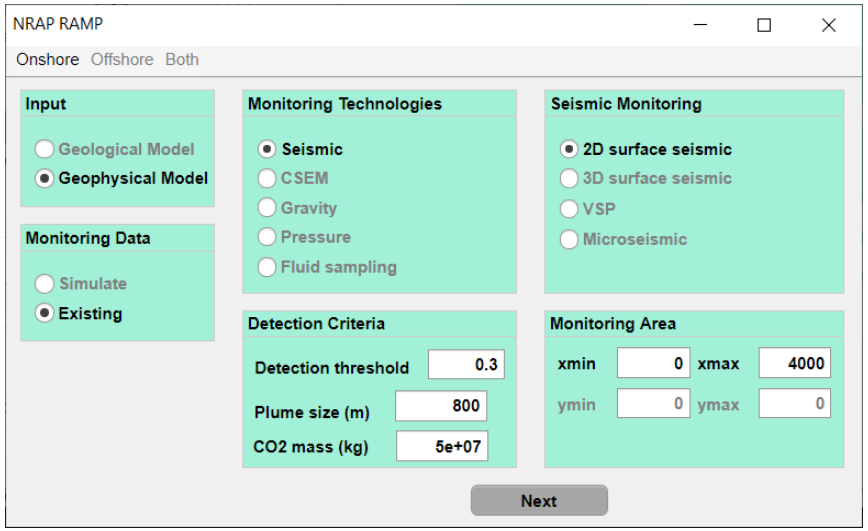

## Current version: Control File Interface

```yaml
ModelParams:
    TimePoints: [5, 10, 20, 30, 40, 50, 60, 80, 100, 120, 150, 200]
    OutputFilesDirectory: 'output/control_files/ex2a_{datetime}'
    OutputPlotsDirectory: 'output/control_files/ex2a_{datetime}/plots'
    Logging: 'Debug'
    Scenarios: '1-103'
    ScenariosToExclude: [8, 37, 92]
Workflow:
    Run: True
    Type: 'Evaluation'
    Setup: EvaluationSetup1
EvaluationSetup1:
    Analysis: 'Stochastic'
    Components: [MonitoringTechnology1]
MonitoringTechnology1:
    Type: 'InSitu'
    InputData:
        Source: 'Container'
        FileDirectory: 'data/user/Kimberlina_1.2/pressure'
        SetupFilename: 'pressure_setup_file.csv'
        TimePoints: [5, 10, 20, 30, 40, 50, 60, 80, 100, 120, 150, 200]
        Name: 'pressure'
        Baseline: False
        FileReader:
            Name: 'default_h5_file_reader'
            TimeIndex: True
            Arguments:
                obs_name: 'pressure'
    DataConfiguration:
        Name: 'pressure_setup'
        Type: 'Base'
        Points:
            nx: 40
            xmin: 4050.0
            xmax: 7950.0
            ny: 20
            ymin: 1550.0
            ymax: 3450.0
            z: [2.5, 7.5, 34.4, 83.1, 131.9, 180.6, 229.4, 278.1, 326.9,
                375.6, 424.4, 473.1, 521.9, 570.5, 619.0, 667.5, 716.0,
                764.5, 813.0, 861.5, 910.0, 958.5, 1007.0, 1055.5, 1104.0,
                1152.5, 1201.0, 1248.5, 1295.0, 1341.5, 1376.3, 1399.6]
    Parameters:
        threshold: 15.0  # pressure threshold
```

**(RAMPEnv) C:/RAMP > python *ramp1.py control_file_interface.yaml***

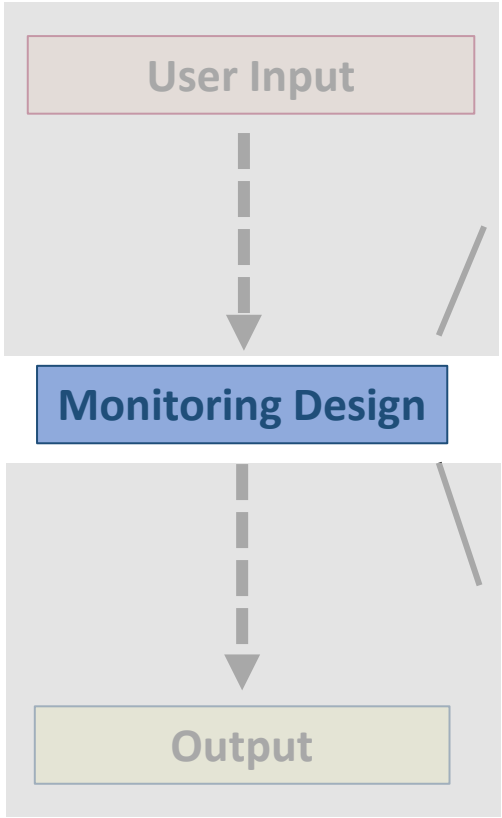
## Final version: GUI



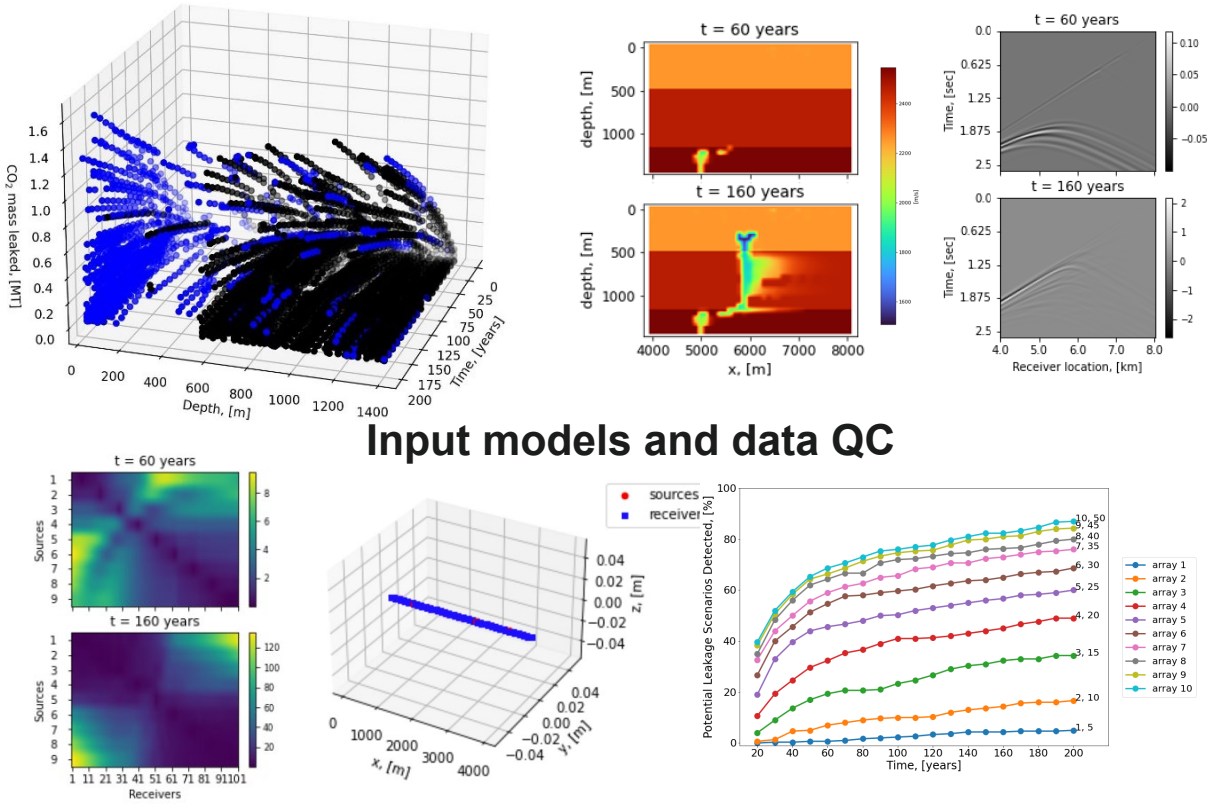



# RAMP Framework

**WORKFLOW**




- QC/Visualization
- Preprocessing
- Monitoring Techniques
- Optimization/Evaluation



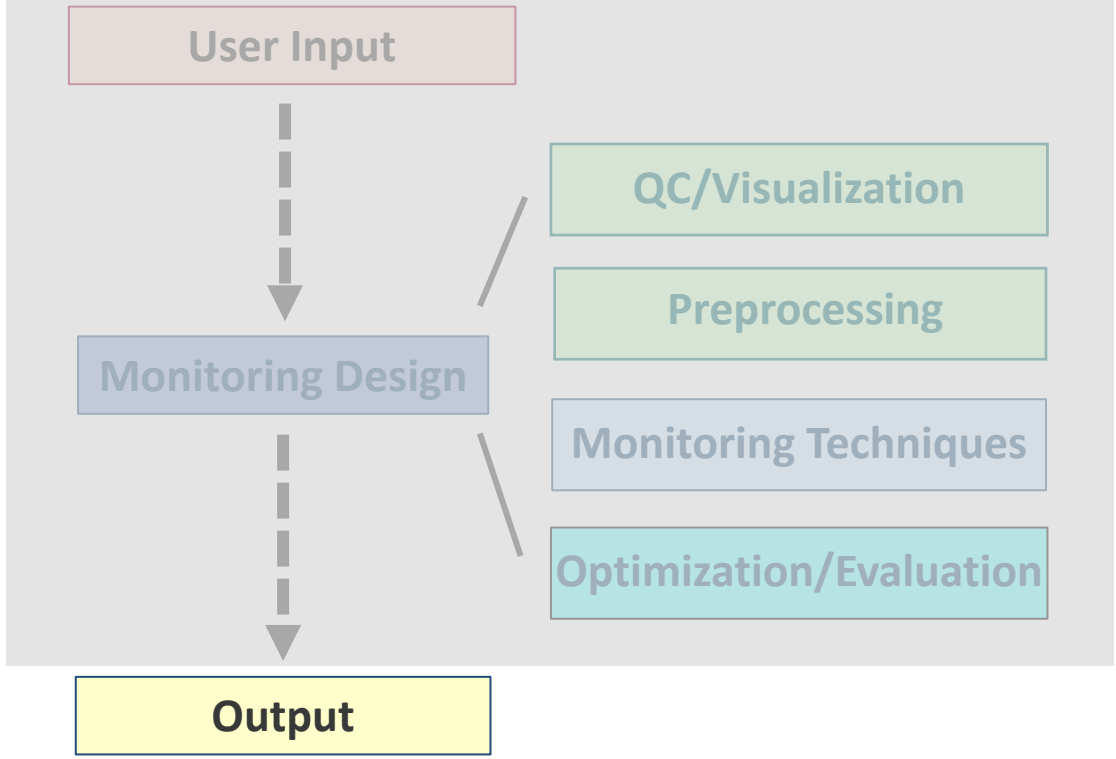

**Input models and data QC**

**Pre-processing** **Monitoring Configurations Evaluation**

**Options tailored to the user level:**
**(1) basic, (2) intermediate, and (3) expert**

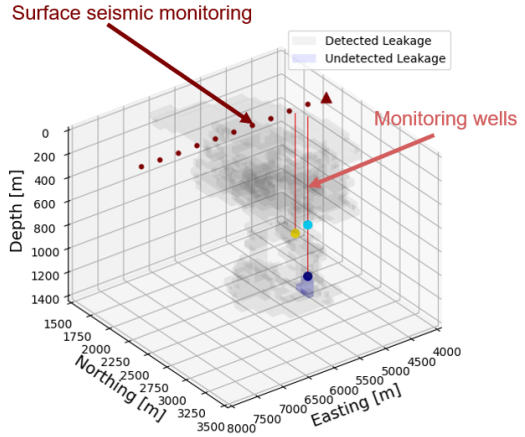
# RAMP Framework

## WORKFLOW

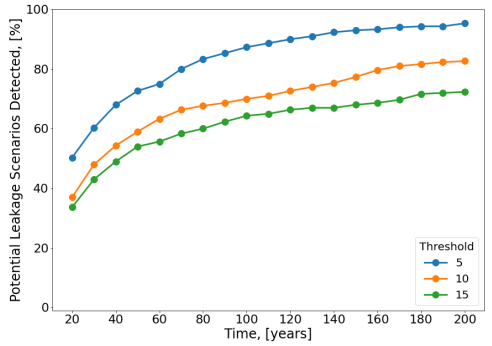




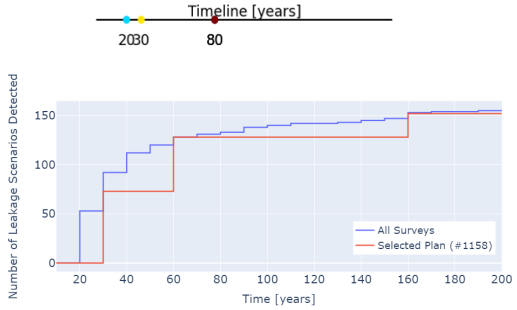
**Output file formats**




**Monitoring arrays**




**Monitoring performance tradeoffs**

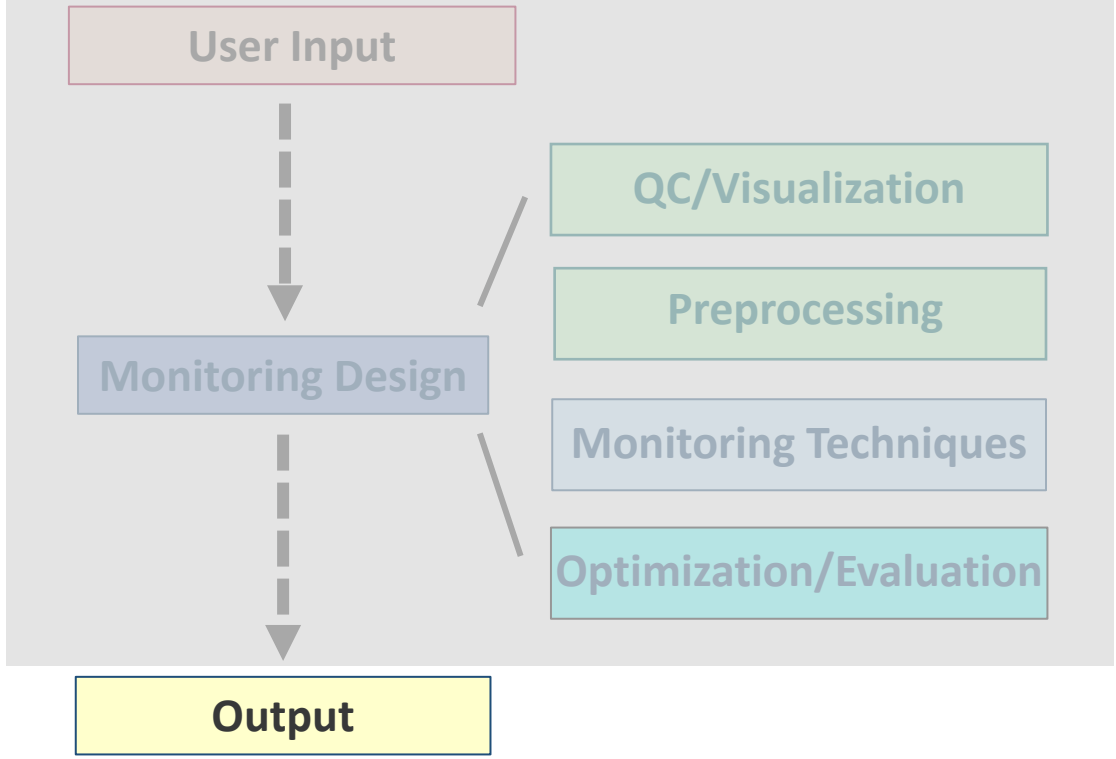



**Scenario's comparison**

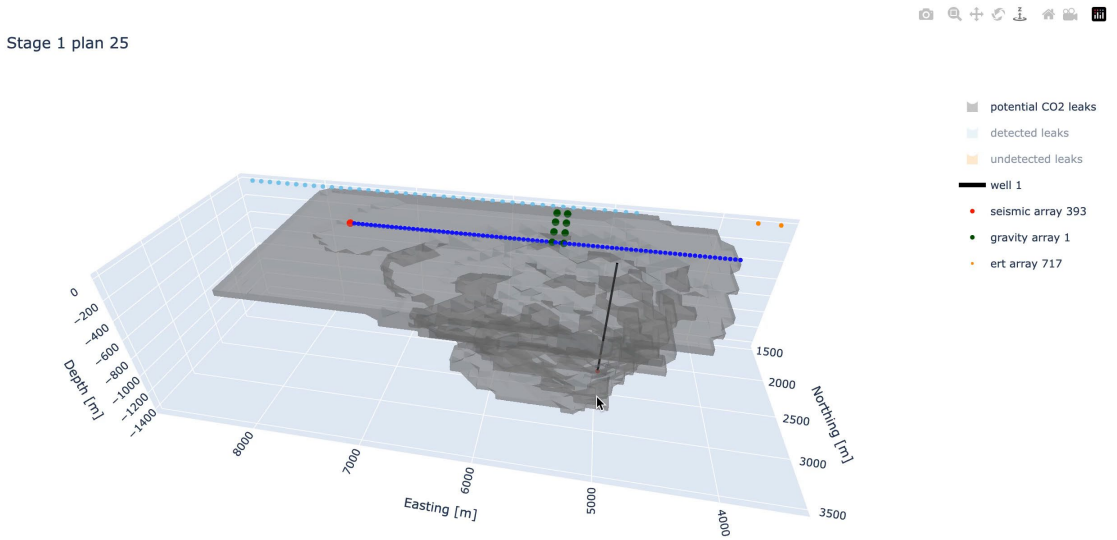
**Outputs tailored to the user level**

# RAMP Framework

## WORKFLOW



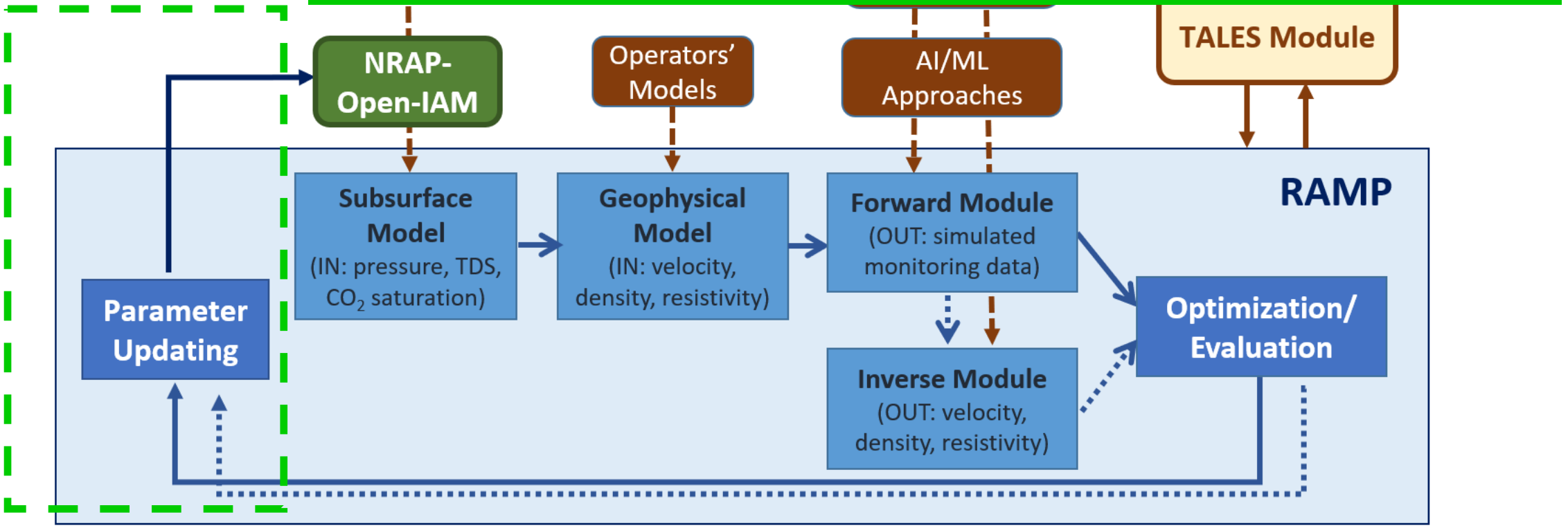

## Interactive plots



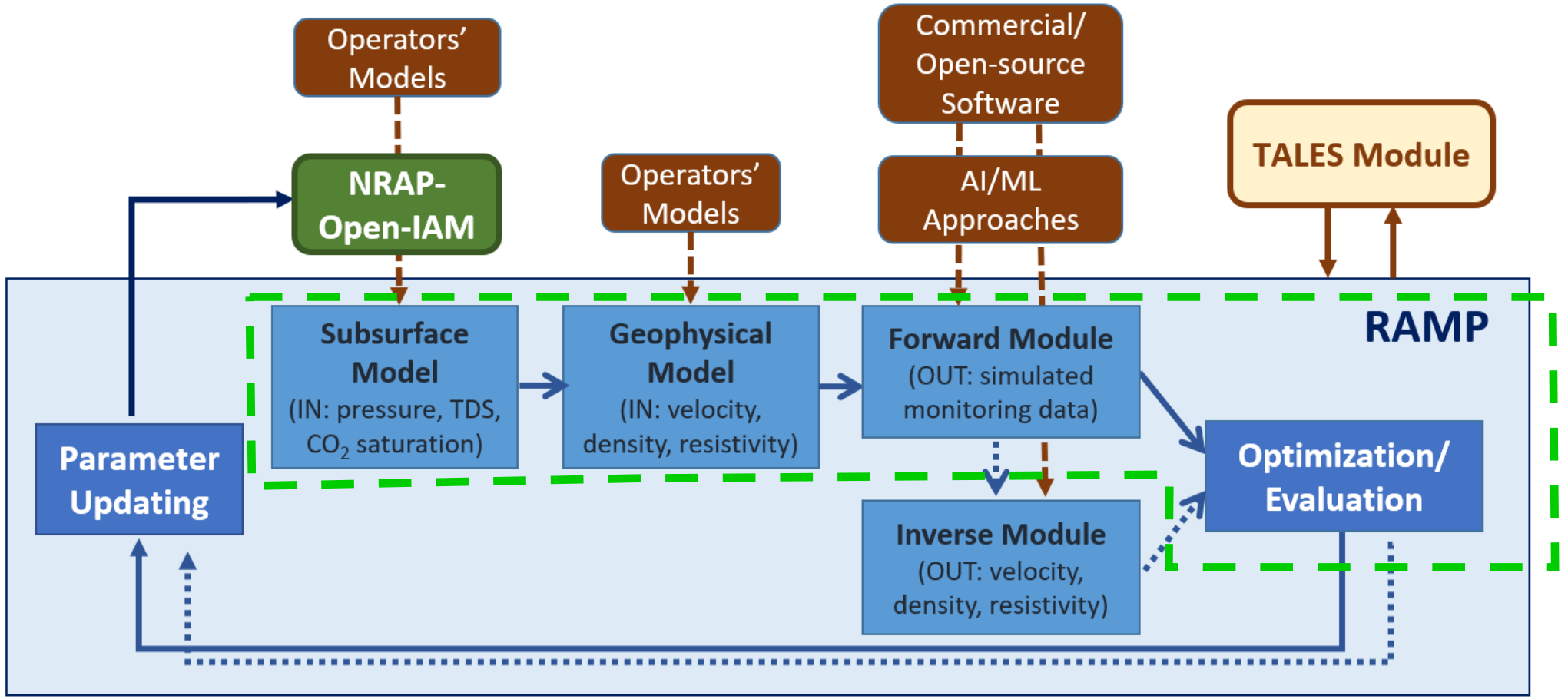

**Outputs tailored to the user level**

# A Module for Model Updating and Dynamic Risk Assessment by Assimilating Monitoring Data

Poster: A Module for Model Updating and Dynamic Risk Assessment by Assimilating Monitoring Data in the NRAP-RAMP Tool by M. Velasco-Lozano, M. Ma, V. Vasylkivska, E. Gasperikova, and B. Chen



# Monitoring Optimization and Evaluation Workflows



# NRAP Recommended Practices for Containment Assurance and Leakage Risk Quantification

| | |
|---|---|
| Step 1 | Characterize the site and develop a priori subsurface model |
| Step 2 | Develop GCS dynamic storage system performance forecasts |
| Step 3 | Define conditions to detect (failure, threats) or conformance and $CO_2$ accounting |
| Step 4 | Select candidate monitoring technologies, including their specifications, monitoring area, intervals, etc. |
| Step 5 | Evaluate the detectability of the condition of interest |
| Step 6 | Define threshold criteria. Identify the amount of change that needs to be detected to inform stakeholder decisions. |
| Step 7 | Design the adaptive site monitoring network and evaluate its performance |
| Step 8 | Modify and/or optimize the network as needed to ensure detectability of the conditions of interest |
| Step 9 | Use monitoring plan/detectability to inform decision-making. |

(Thomas et al., 2022)

# Monitoring Optimization and Evaluation Workflows

**Monitoring Objective**

| Detection | Quantification/ Conformance | Induced Seismicity |
|---|---|---|
| • Workflow 1<br>• Workflow 2<br>• Workflow 3<br>• Workflow 4 | • Workflow 1<br>• Workflow 2<br>• Workflow 4 | • Workflow 5 |

| | |
|---|---|
| **Workflow 1** | Evaluation workflow |
| **Workflow 2** | Deterministic optimization workflow |
| **Workflow 3** | Pareto optimization workflow |
| **Workflow 4** | Seismic elastic-wave sensitivities optimization workflow (Poster on Tuesday) |
| **Workflow 5** | Passive seismic monitoring tool (PSMT) |

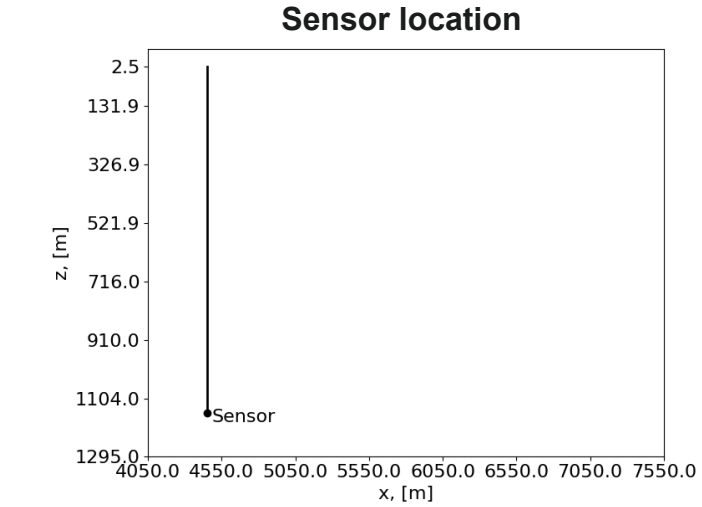
# Evaluation Workflow

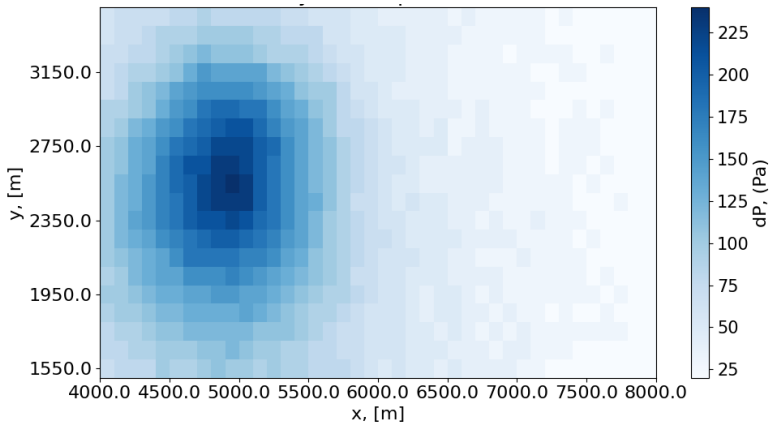
User Input

```yaml
ModelParams:
    TimePoints: [5, 10, 20, 30, 40, 50, 60, 80, 100, 120, 150, 200]
    OutputFilesDirectory: 'output/control_files/ex2a_{datetime}'
    OutputPlotsDirectory: 'output/control_files/ex2a_{datetime}/plots'
    Logging: 'Debug'
    Scenarios: '1-103'
    ScenariosToExclude: [8, 37, 92]
Workflow:
    Run: True
    Type: 'Evaluation'
    Setup: EvaluationSetup1
EvaluationSetup1:
    Analysis: 'Stochastic'
    Components: [MonitoringTechnology1]
MonitoringTechnology1:
    Type: 'InSitu'
    InputData:
        Source: 'Container'
        FileDirectory: 'data/user/Kimberlina_1.2/pressure'
        SetupFilename: 'pressure_setup_file.csv'
        TimePoints: [5, 10, 20, 30, 40, 50, 60, 80, 100, 120, 150, 200]
        Name: 'pressure'
        Baseline: False
        FileReader:
            Name: 'default_h5_file_reader'
            TimeIndex: True
            Arguments:
                obs_name: 'pressure'
    DataConfiguration:
        Name: 'pressure_setup'
        Type: 'Base'
        Points:
            nx: 40
            xmin: 4050.0
            xmax: 7950.0
            ny: 20
            ymin: 1550.0
            ymax: 3450.0
            z: [2.5, 7.5, 34.4, 83.1, 131.9, 180.6, 229.4, 278.1, 326.9,
                375.6, 424.4, 473.1, 521.9, 570.5, 619.0, 667.5, 716.0,
                764.5, 813.0, 861.5, 910.0, 958.5, 1007.0, 1055.5, 1104.0,
                1152.5, 1201.0, 1248.5, 1295.0, 1341.5, 1376.3, 1399.6]
    TechnologyConfiguration:
        Name: 'config1'
        Type: 'sensors'
        sensors:
            s1: (4, 10, 25)
```

**(RAMPEnv) C:/RAMP > python**
***ramp1.py control_file_interface.yaml***

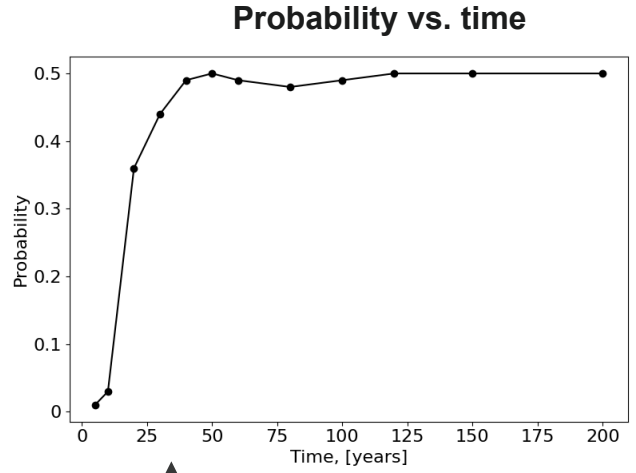
Configuration and Data

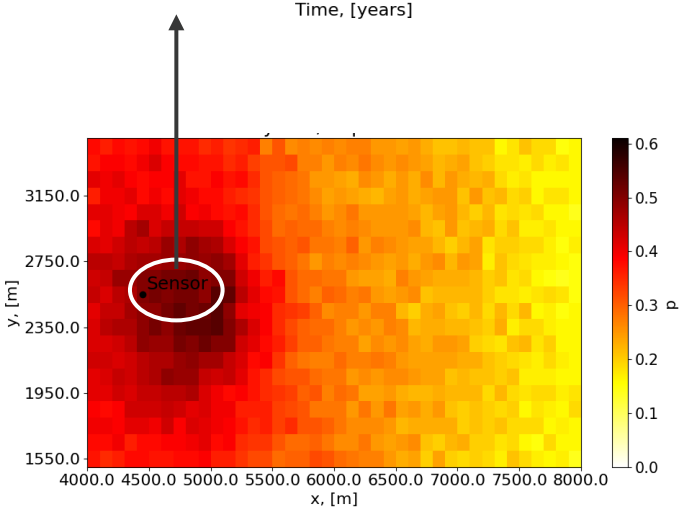



Change in pressure

Outputs




Probability of detection

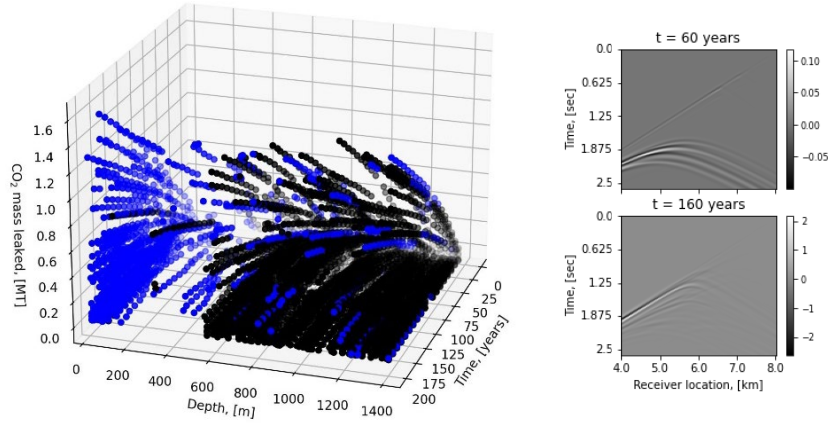
# Pareto Optimization Workflow

User Input

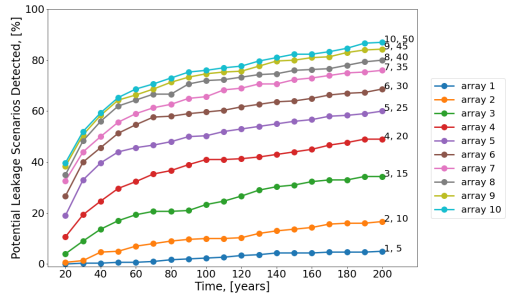
```yaml
ModelParams:
    TimePoints: 'data/user/Kimberlina_1.2/seismic/time_points_complete.csv'
    OutputFilesDirectory: 'output/control_files/ex6a_{datetime}'
    OutputPlotsDirectory: 'output/control_files/ex6a_{datetime}/plots'
    Logging: 'Debug'
    Scenarios: '1-400'
    ScenariosToExclude: [8, 37, 92, 118, 120, 127, 136, 150, 182, 197, 211,
                         245, 397, 449, 518, 590, 598, 686, 749, 863, 935,
                         937, 970]
Workflow:
    Run: True
    Type: 'ParetoOptimization'
    Setup: OptimizationSetup1
OptimizationSetup1:
    Analysis: 'Stochastic'
    Components: [MonitoringTechnology1, MonitoringTechnology2,
                 MonitoringTechnology3, MonitoringTechnology4,
                 MonitoringTechnology5]
    NumberProposals: 3
    MonitoringPlan:
        fixed_wells: None
        max_wells: 5
        stages: [0, 40]
MonitoringTechnology1:
    Type: 'Seismic'
    InputData:
        Source: 'Container'
        FileDirectory: 'data/user/Kimberlina_1.2/seismic'
        SetupFilename: 'seismic_setup_file.csv'
        TimePoints: 'time_points.csv'
        Name: 'seismic'
        Baseline: True
        FileReader:
            Name: 'default_bin_file_reader'
            Arguments:
                data_shape: (1251, 101, 9)
                move_axis_destination: [-1, -2, -3]
    taConfiguration:
        Name: 'SeismicSurvey'
        Type: 'Seismic'
        Sources:
            xyz: 'sources_coords.csv'
        Receivers:
            xyz: 'receivers_coords.csv'
```

**(RAMPEnv) C:/RAMP > python**
***ramp_optimization1.py***
***control_file_interface.yaml***

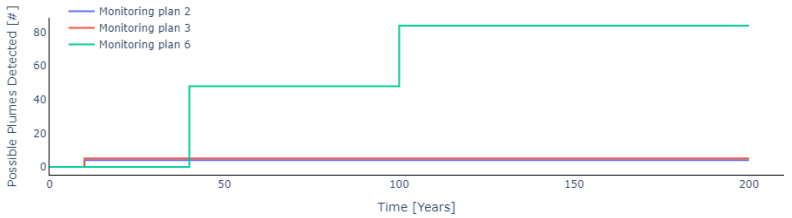
Monitoring Design/Optimization



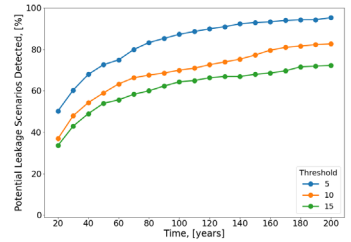

**Input models and data QC**




**Monitoring Arrays Evaluation**

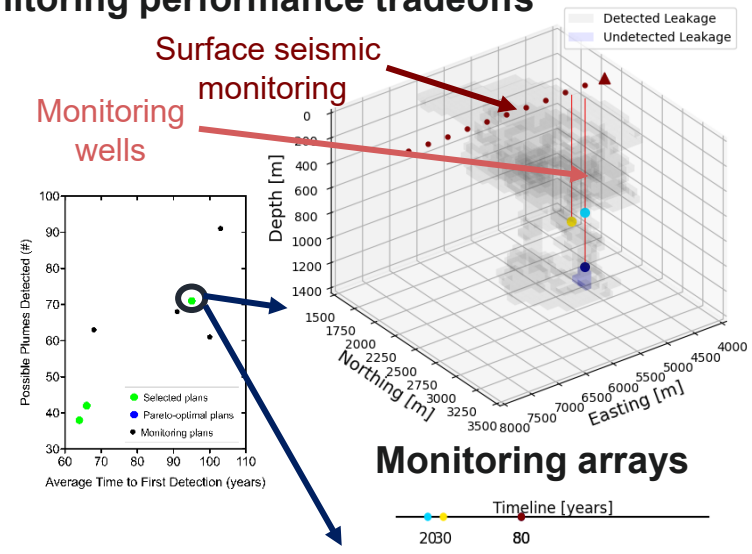



**Monitoring plans comparison**

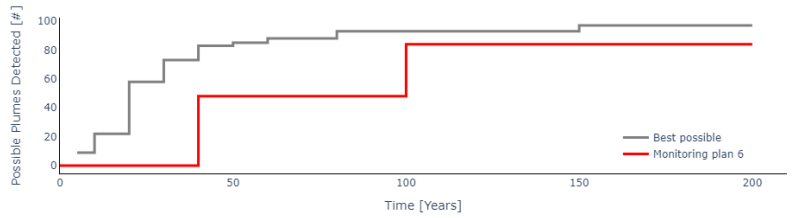



**Monitoring performance tradeoffs**

Outputs




**Monitoring arrays**




**Scenario's comparison**

# Deterministic Optimization Workflow

User Input

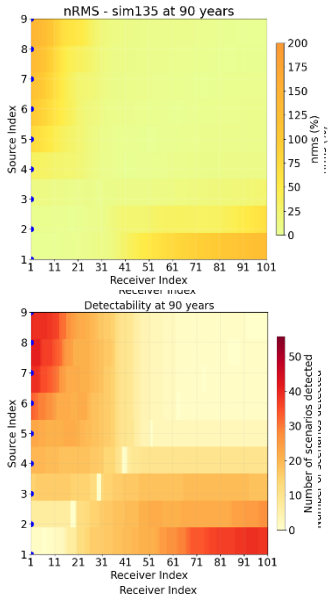
```
ModelParams:
    TimePoints: [5, 10, 20, 30, 40, 50, 60, 80, 100, 120, 150, 200]
    Scenarios: '1-1000'  # scenarios available
    SaturationDirectory: 'C:\RAMP\data\saturation'
    LeakyWellXY: [5000, 2500]
    SaturationThreshold: 0.02
    ScenariosExcluded: [8, 37, 92, 118, 120, 127, 136, 150, 182, 197, 211, 245,
                        397, 449, 518, 590, 598, 686, 749, 863, 935, 937, 970]
    MassCentroidFile: './data/vol_mass.csv'
    Analysis: 'Optimization'
    Components: ['MonitoringTechnology1', 'MonitoringTechnology2',
                 'MonitoringTechnology3', 'MonitoringTechnology4',
                 'MonitoringTechnology5', 'MonitoringTechnology6',
                 'MonitoringIntegration1']
    OutputFilesDirectory: 'C:\RAMP\output\{timestamp}\data'
    OutputPlotsDirectory: 'C:\RAMP\output\{timestamp}\plots'
    Logging: 'Error'   # Info, Warn, Debug, Error


MonitoringTechnology1:
    Type: 'InSituMonitoring'
    InputData:
        Name: 'pressure'
        Scenarios: '101-200'    #  Scenarios to use
        TimePoints: [ 5, 10, 20, 30, 40, 50, 60, 80, 100, 120, 150, 200 ]
        FileDirectory: 'C:\RAMP\data\pressure'
        FileReader:
            Name: h5_file_reader
            Arguments:
        Baseline: True
    DataConfiguration:
        nx: 40
        ny: 20
        nz: 32
        xmin: 4000
        xmax: 8000
        ymin: 1500
        ymax: 3500
        zmin: 0
        zmax: 1410.80
    OptimizationParameters:
        max_wells: 2
        well_xy: []
        min_spacing: 90
        min_sensors: 2
        max_sensors: 10
        threshold: 3000  # Pascal
        objective: 'MaxDetection'
    Output:
        Format: ['h5', 'csv', 'yaml']
```

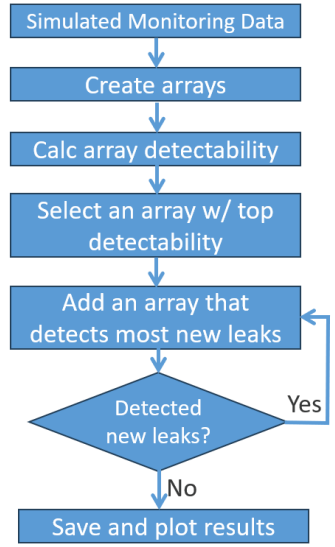
**(RAMPEnv) C:/RAMP > python *monitoring_integration.py control_file_interface.yaml***

Monitoring Design/Optimization

**Monitoring technologies:** pressure, total dissolved solids (TDS), $CO_2$ saturation, gravity, seismic, and electrical resistivity tomography (ERT).




**Pre-processing**

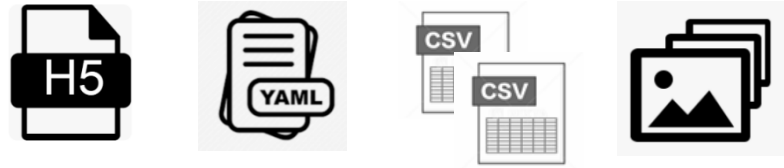



**Workflow**

An effective monitoring plan depends on:

a) Monitoring objective
b) Technology's ability to detect a plume of a defined size and depth
c) Monitoring technique costs

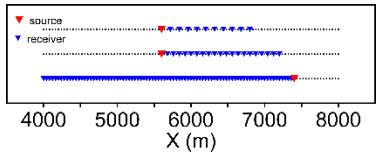
Outputs



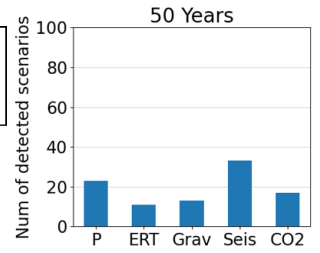


darker color = unique detection

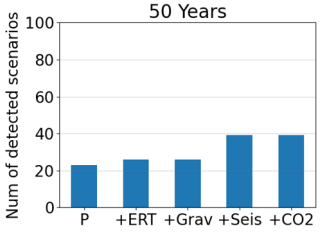
**Detection**




**Monitoring arrays**




| | P | ERT | Grav | Seis | CO2 |
|---|---|---|---|---|---|
| P | 0 | 24 | 15 | 8 | 20 |
| ERT | 0 | 0 | 0 | 0 | 1 |
| Grav | 1 | 10 | 0 | 1 | 10 |
| Seis | 7 | 23 | 14 | 0 | 20 |
| CO2 | 0 | 5 | 4 | 1 | 0 |

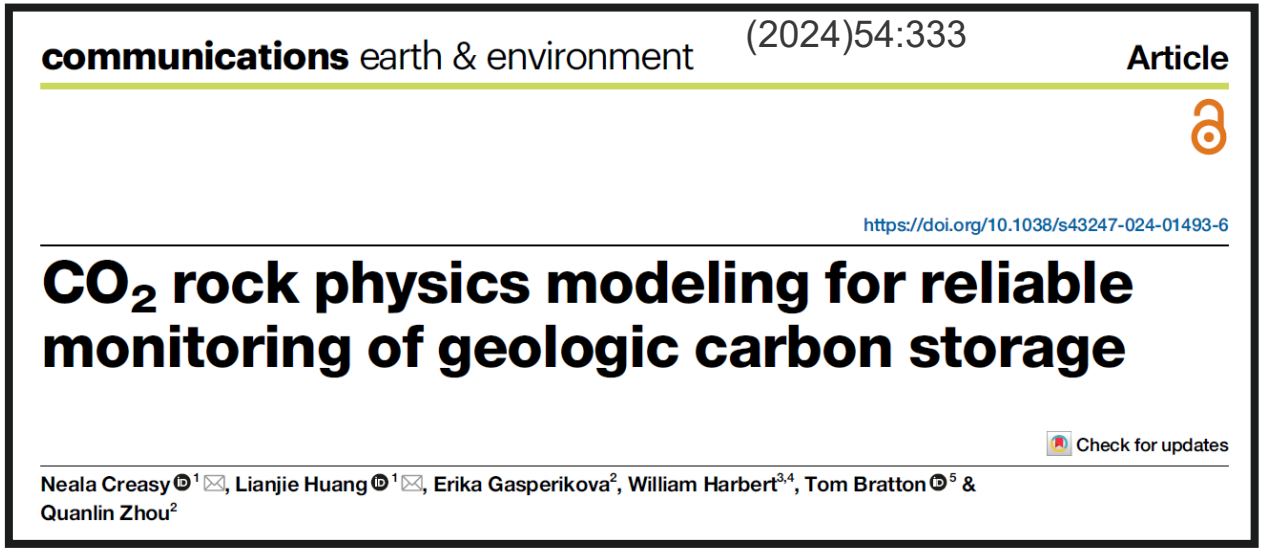



**Complementary detections**

# Future Additions

1) **Rock-physics Module:**

A rock-physics model that allows for subsurface parameter changes caused by compliant porosity and $CO_2$ weakening.



communications earth & environment (2024)54:333 Article

https://doi.org/10.1038/s43247-024-01493-6

**$CO_2$ rock physics modeling for reliable monitoring of geologic carbon storage**

Check for updates

Neala Creasy[1], Lianjie Huang[1], Erika Gasperikova[2], William Harbert[3,4], Tom Bratton[5] & Quanlin Zhou[2]

2) **AVO attributes and a Bayesian Network Model:**

Poster: "Assessing the value of seismic AVO attributes for $CO_2$ storage project using Bayesian network model for decision support" by J. Wang, A. Kumar, and W. Harbert

# Summary

- RAMP monitoring framework is risk-based and adaptive with time
- The tool addresses two goals: (a) risk reduction and (b) improved confidence in $CO_2$ storage
- Adaptive for injection and post-injection periods
- Ability to assess the effectiveness of a GCS monitoring plan
- RAMP enables evaluations of trade-offs between different monitoring scenarios
- Currently adding GUI and TALES (cost, financial risks, and liabilities) component
- Modular design and open-source programming environment allow for easy incorporation of existing tools and functionalities
- Feedback on needed features, outputs, and user interactions is welcomed

# Thank you!

## Comments and Questions:

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NRAP Website: https://edx.netl.doe.gov/sites/nrap/