SMART-CS Initiative

Science-informed **M**achine Learning to **A**ccelerate **R**eal **T**ime (SMART) Decisions in Subsurface Applications

Task 3: Imaging Pressure and Stress

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U.S. DEPARTMENT OF ENERGY

Task 3: Imaging Pressure and Stress

Partnering Organizations

Batelle

Colorado School of Mines

Illinois State Geologic Survey (UIUC)

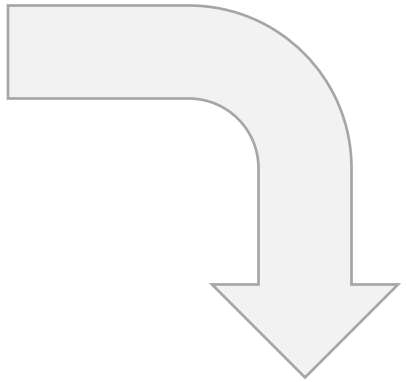
Lawrence Berkeley NL

Lawrence Livermore NL

Los Alamos NL

Oak Ridge NL

Pacific Northwest NL



Broad Expertise

Geophysics

Geology

Geomechanics

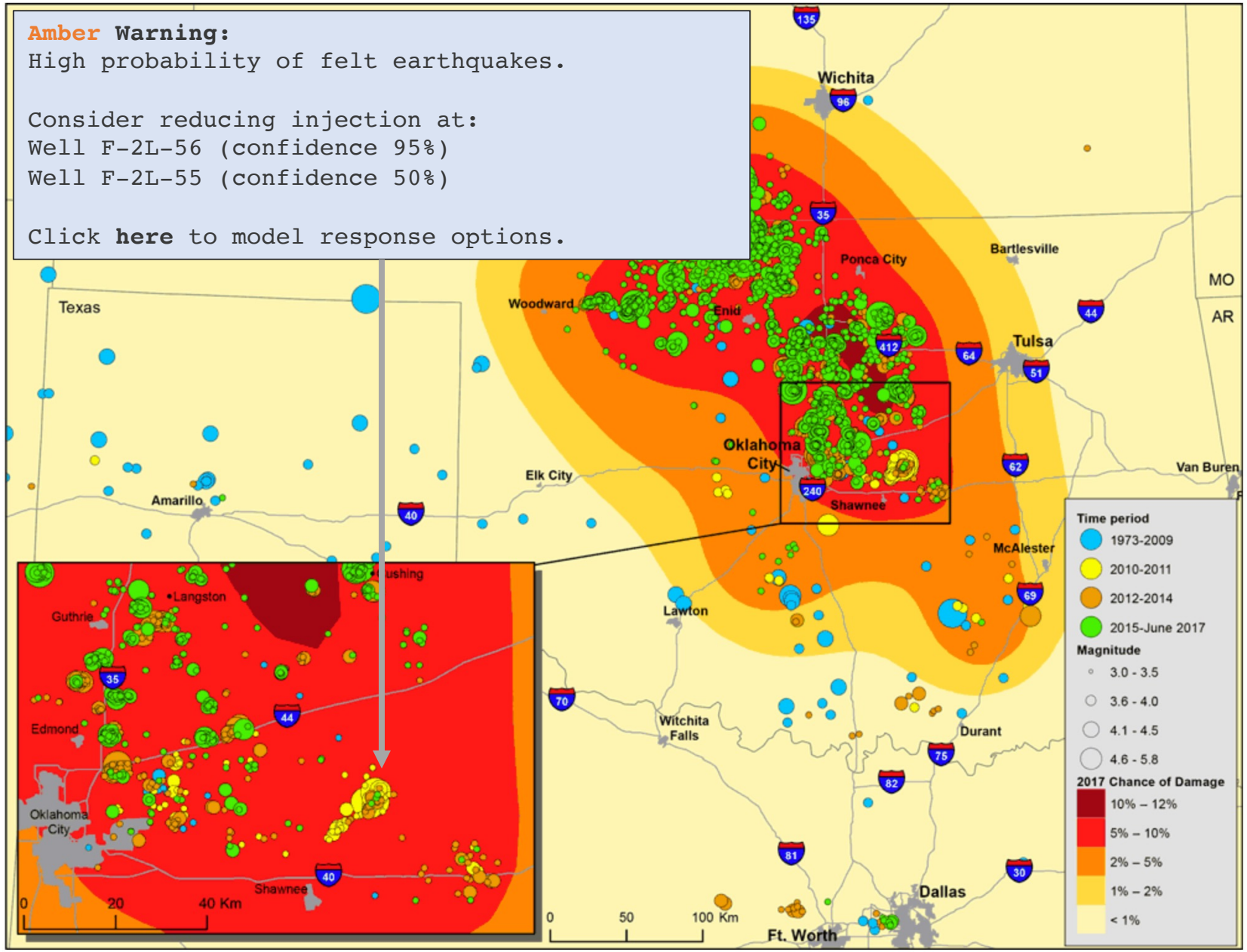
Reservoir Engineering

Data Science

HPC

Vision: What could next-gen subsurface "visualization" look like?

- Both regional & site-specific
- Updated in real time
- Provides automated anomaly detection
- Provides interface for rapid scenario exploration



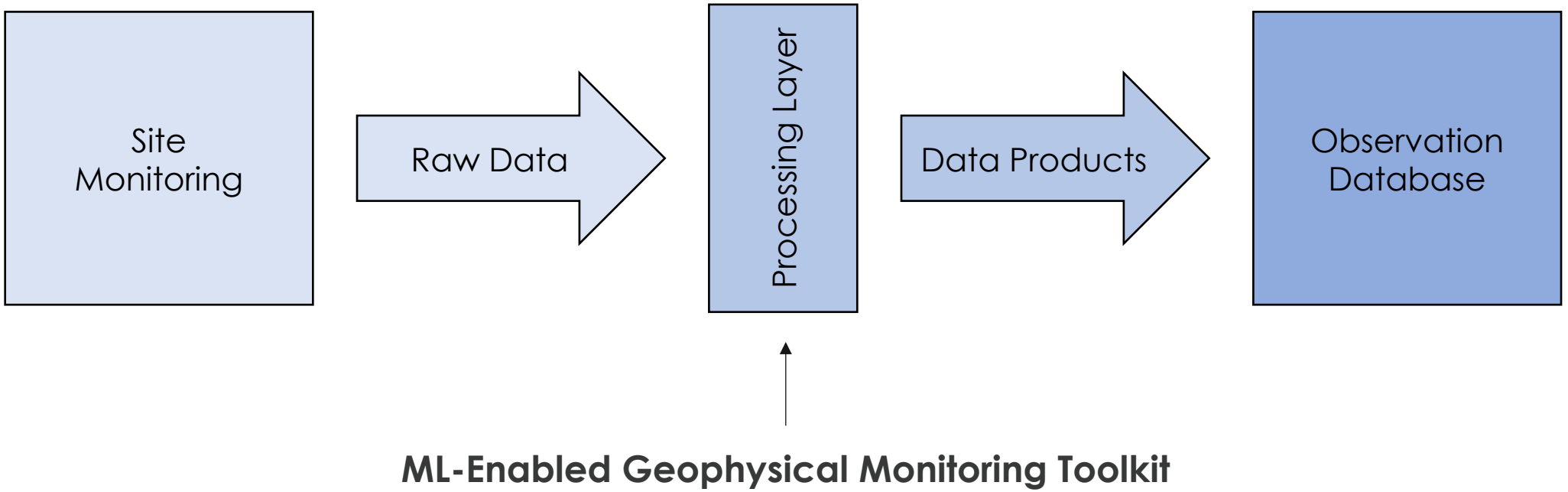
Modified 2017 USGS Oklahoma Hazard Map, for illustration purposes only

Task 3: Imaging Pressure and Stress

Ten-year vision will require three enabling technologies:

1. Rapid and autonomous geophysical monitoring
2. Real-time modeling and data assimilation tools
3. Visualization and decision-support frameworks

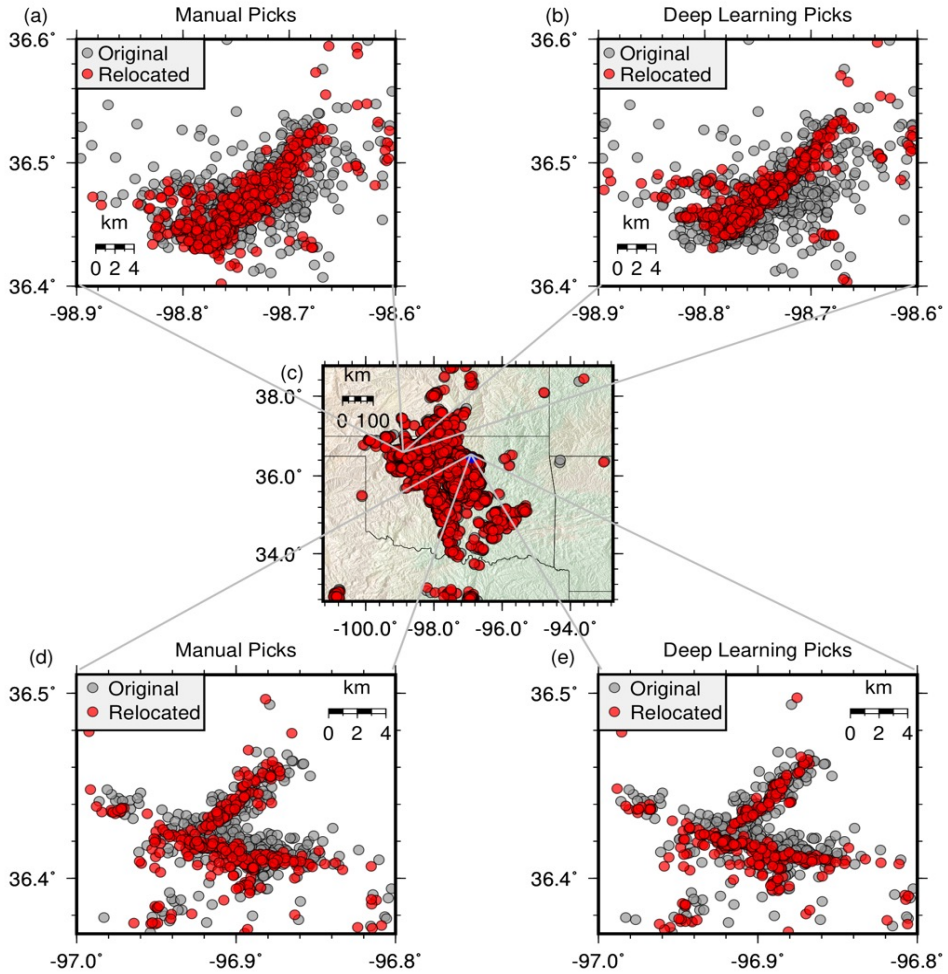
Enabling Technology 1: **Rapid Geophysical Monitoring**

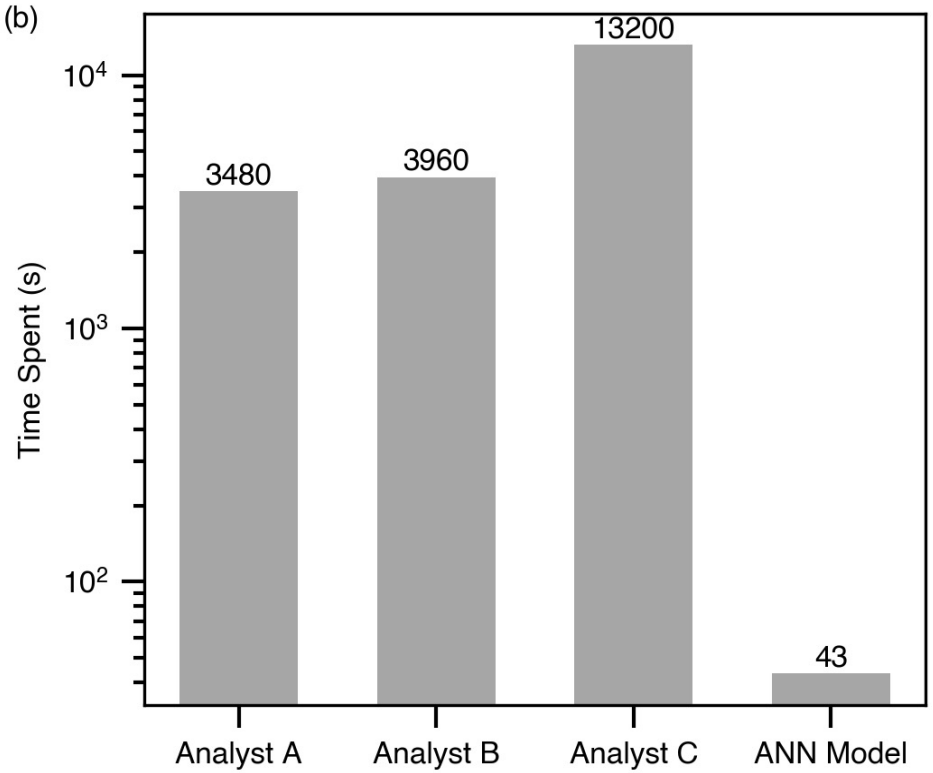


Passive Seismic Imaging

POC: Chengping Chai

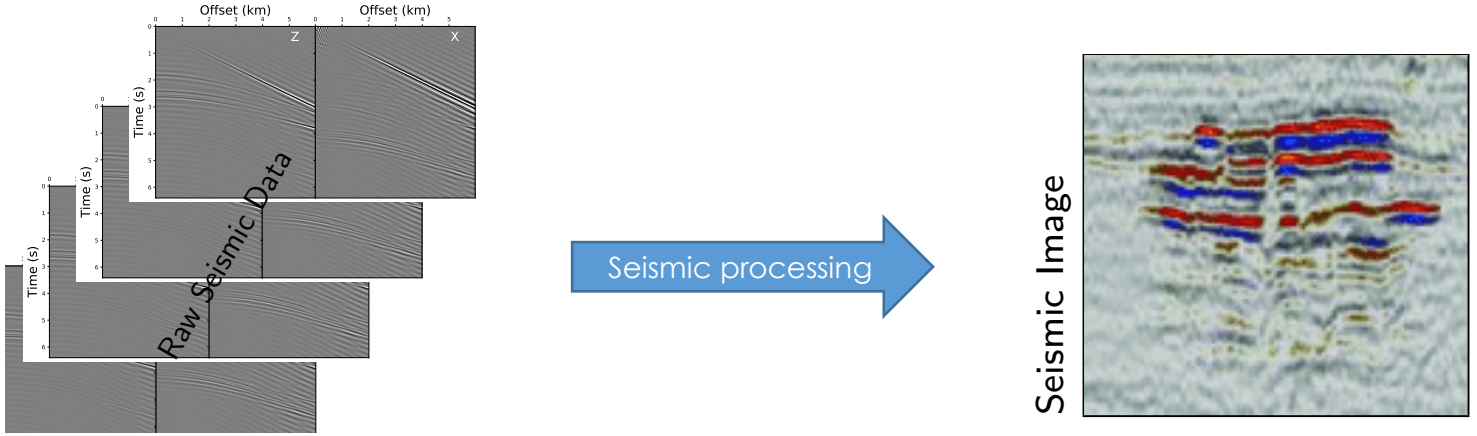
ML can provide better picks, locations, and tomography .... at orders of magnitude less cost.





Active Seismic Imaging

POC: Jyoti Behura



Challenge:

4D seismic processing is time-consuming and very expensive

Opportunity:

Use trained CNNs as a rapid seismic processor

Active Seismic Imaging

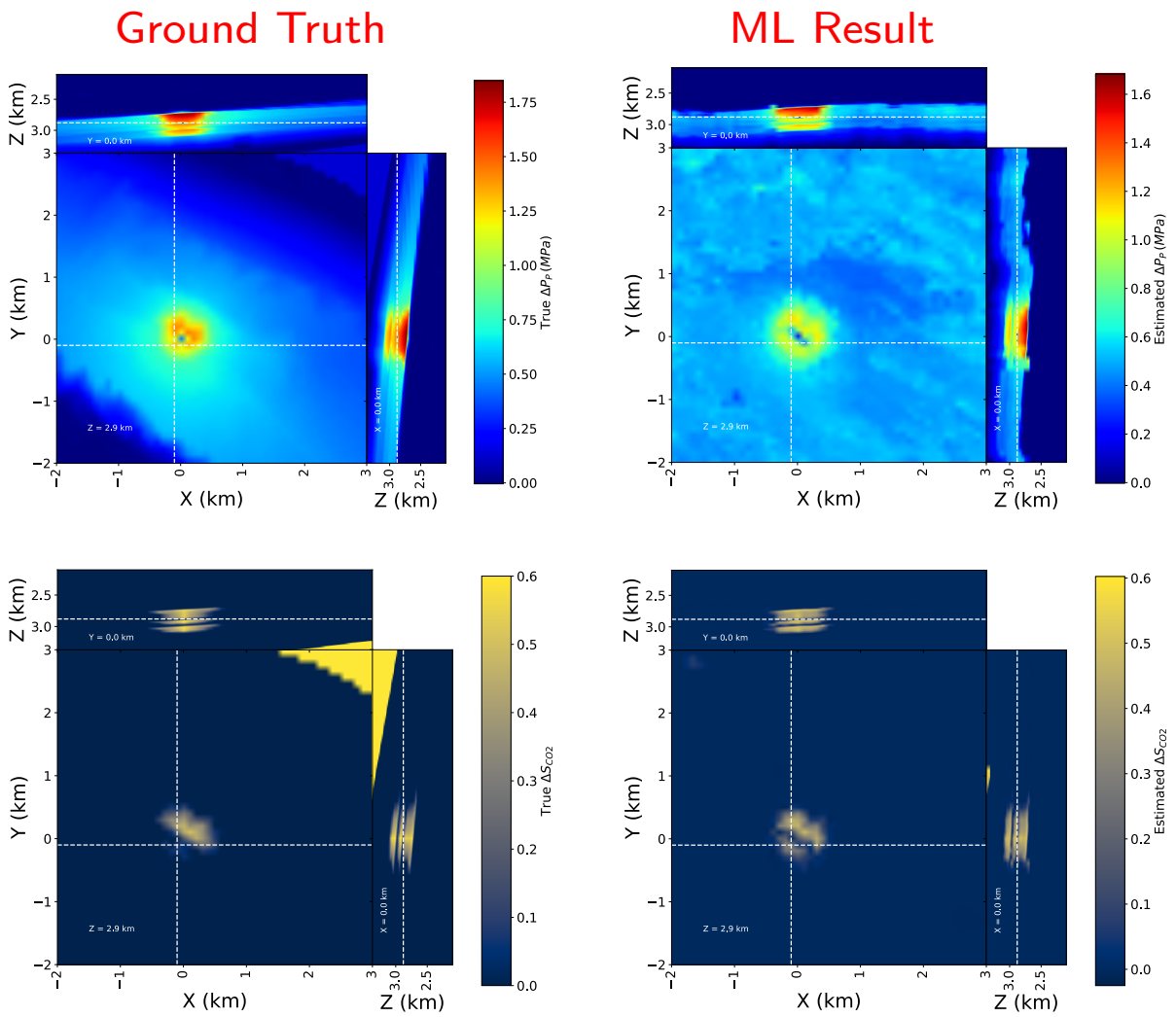
POC: Jyoti Behura

Methodology

- CNN trained using 400 shot-gathers from year 0 and year 1 seismic surveys
- Years 2 to 5 predicted

Year 2 - Year 0 Perturbation in Pore - pressure

Year 2 - Year 0 Perturbation in CO_2 Saturation



Active Seismic Imaging

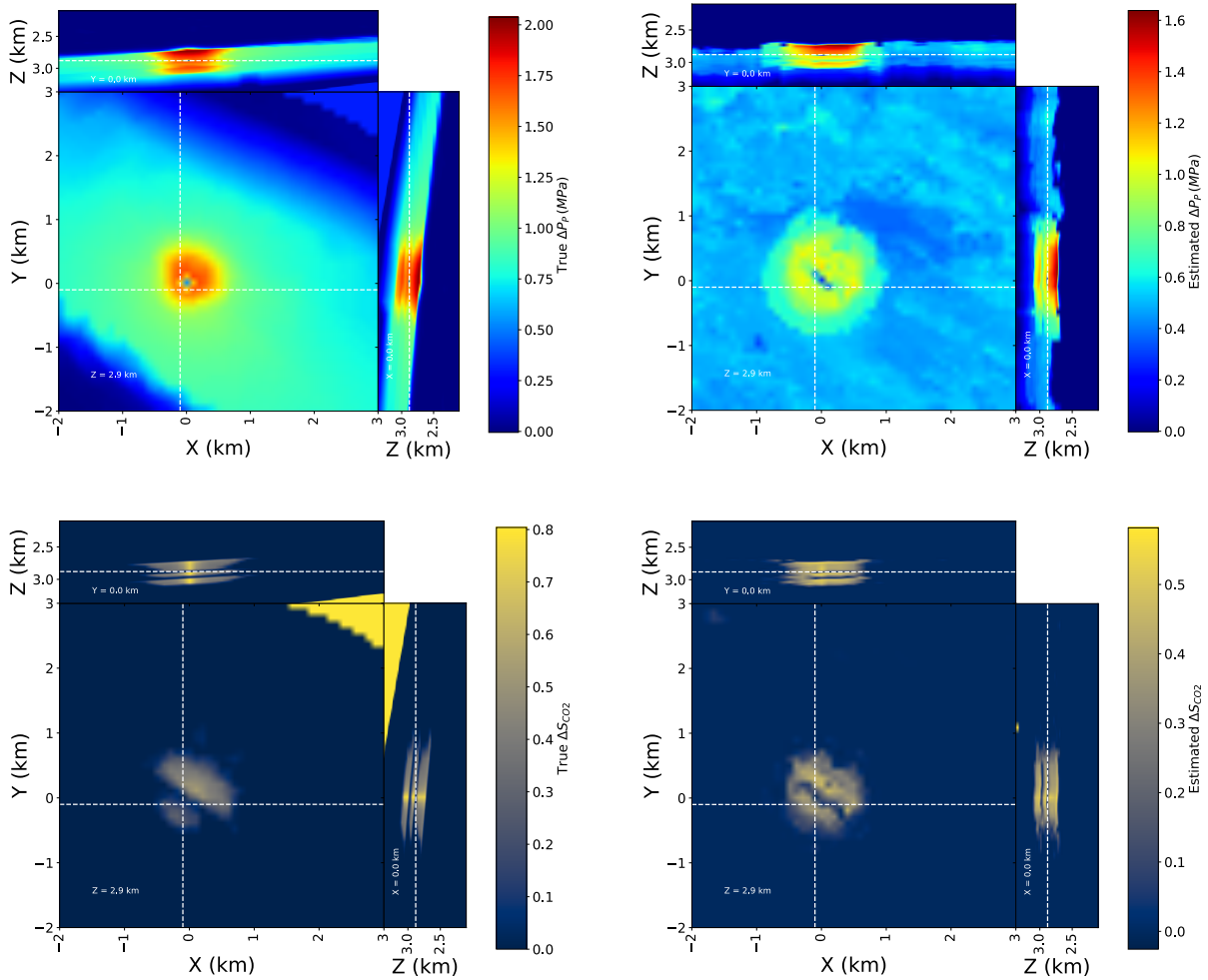
POC: Jyoti Behura

Year 5 - Year 0 Perturbation in Pore - pressure

Year 5 - Year 0 Perturbation in CO_2 Saturation

Ground Truth

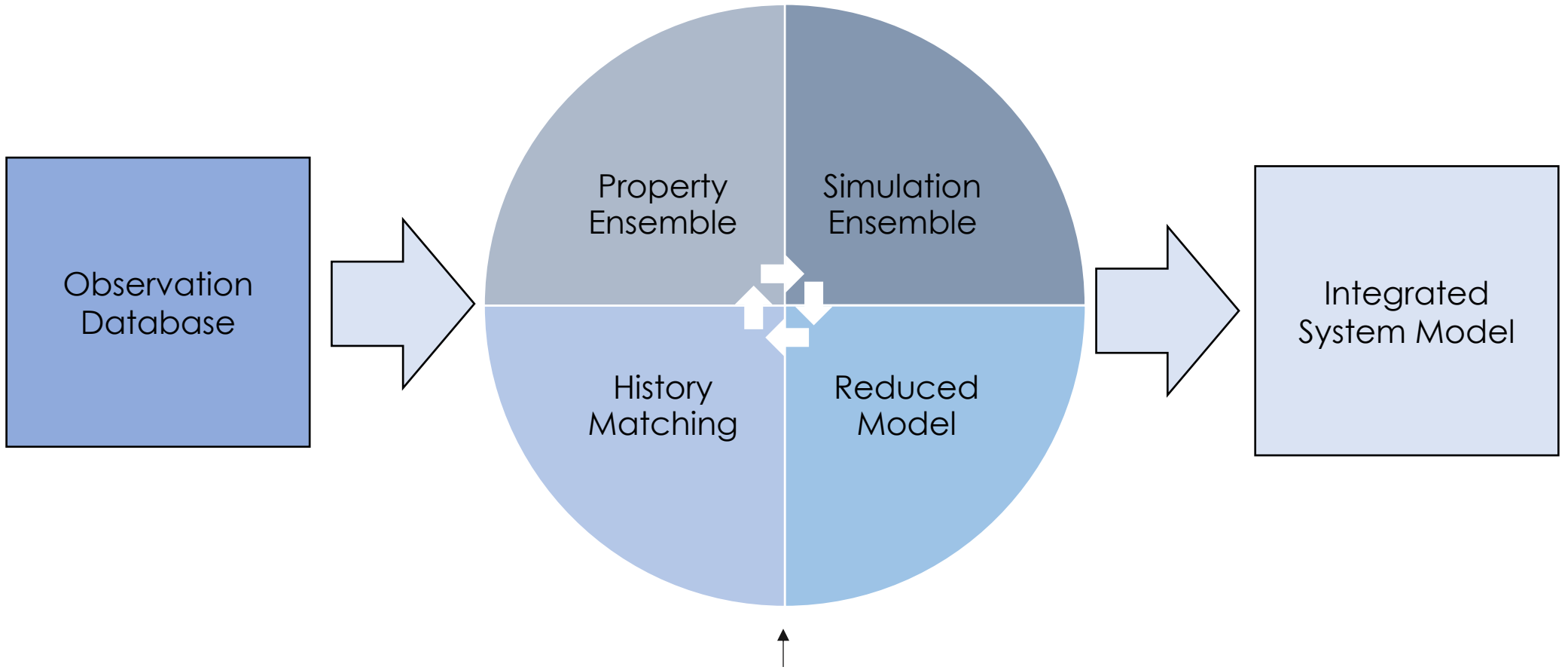
ML Result



Could open up whole new imaging workflows:

- Use rapid NN for quick-look results while awaiting more time-intensive processing
- Combining high-resolution and low-resolution surveys to lower monitoring costs

Enabling Technology 2: **Real-Time Modeling & Data Assimilation**



Autonomous Inversion of Deformation Data

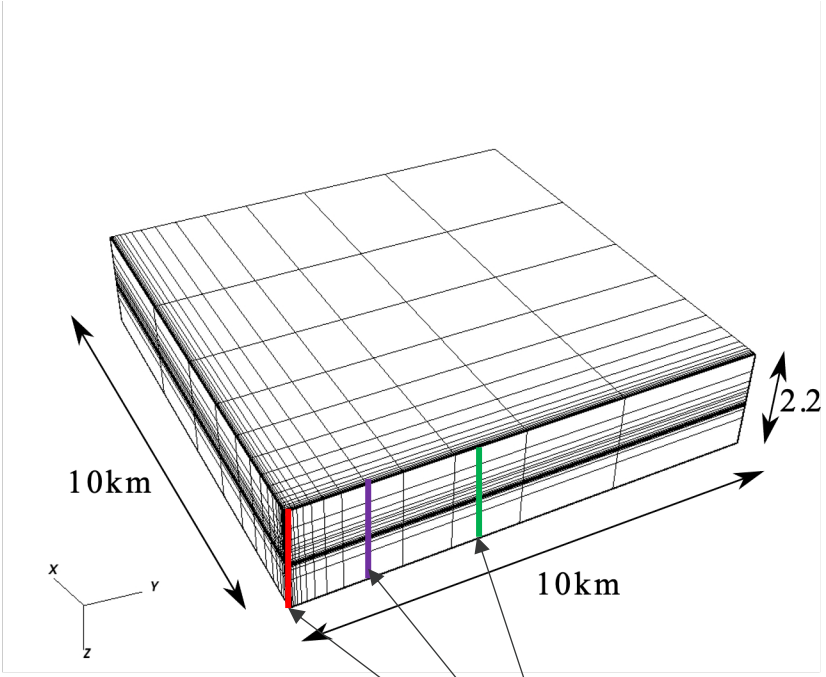
POC: Jeff Burghardt

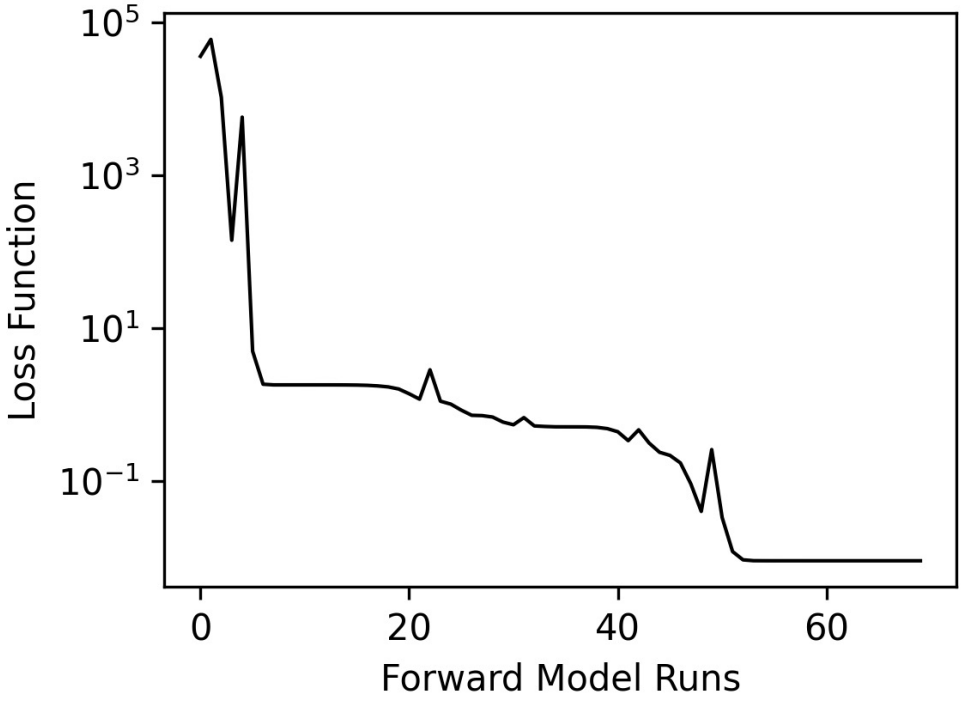
Challenge:

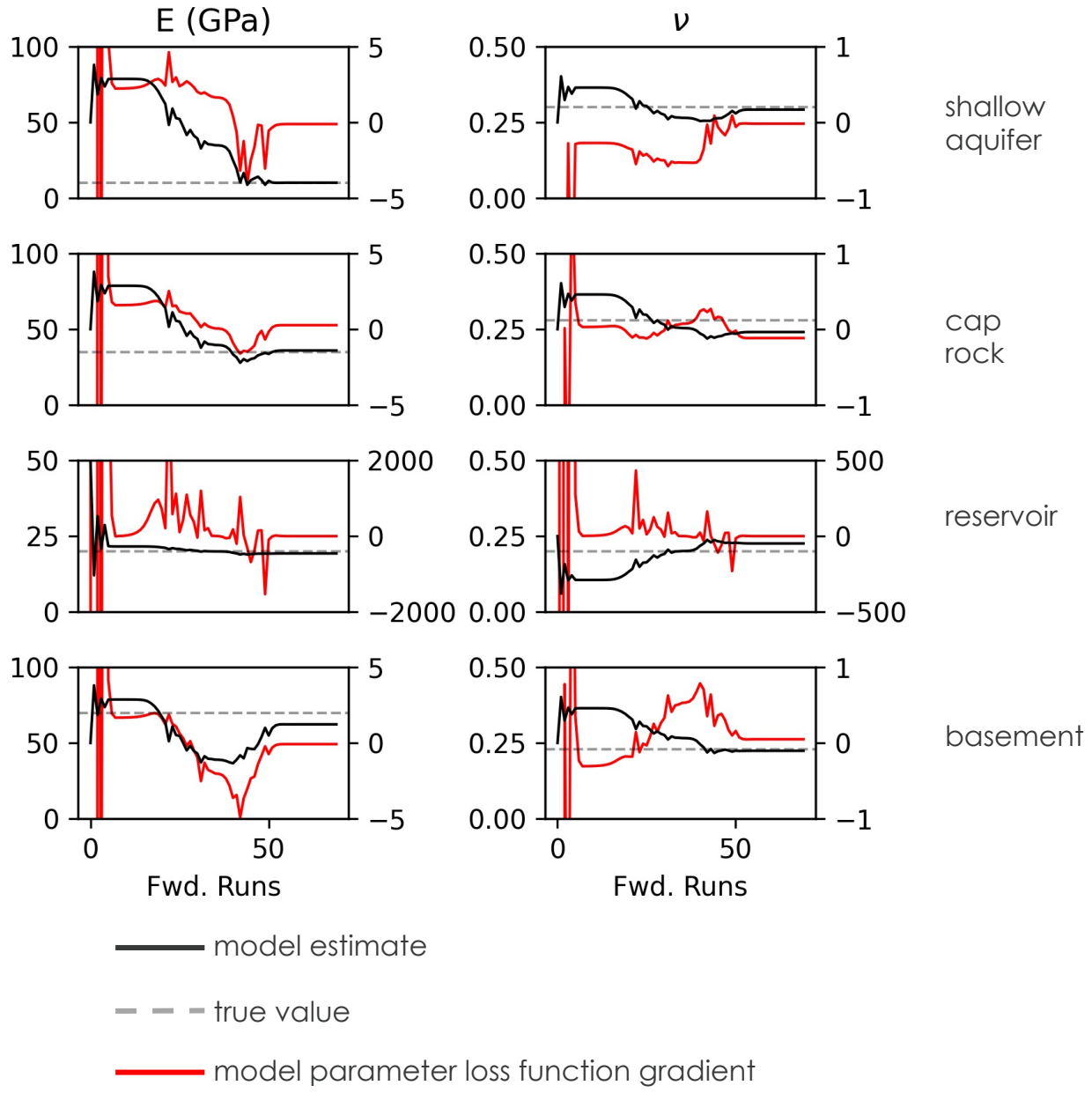
Workflows for determining rock properties and state-of-stress are often slow and clunky.

Proposed Approach:

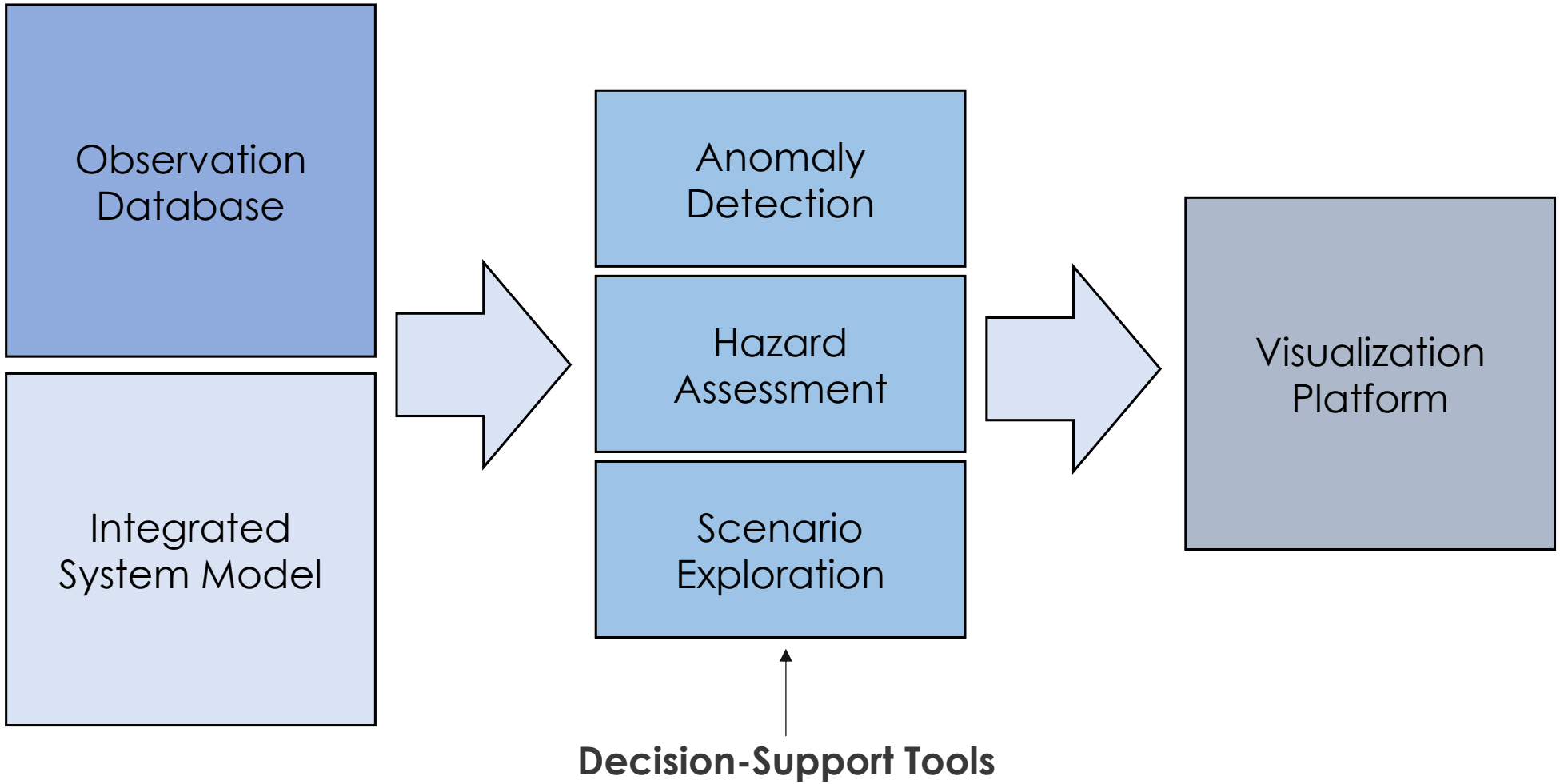
Combine NNs, a physics-based finite element model, and a gradient-based inversion algorithm to rapidly estimate elastic properties from sparse strain measurements.




Loss Function
10^5
10^3
10^1
10^{-1}
0
20
40
60
Forward Model Runs

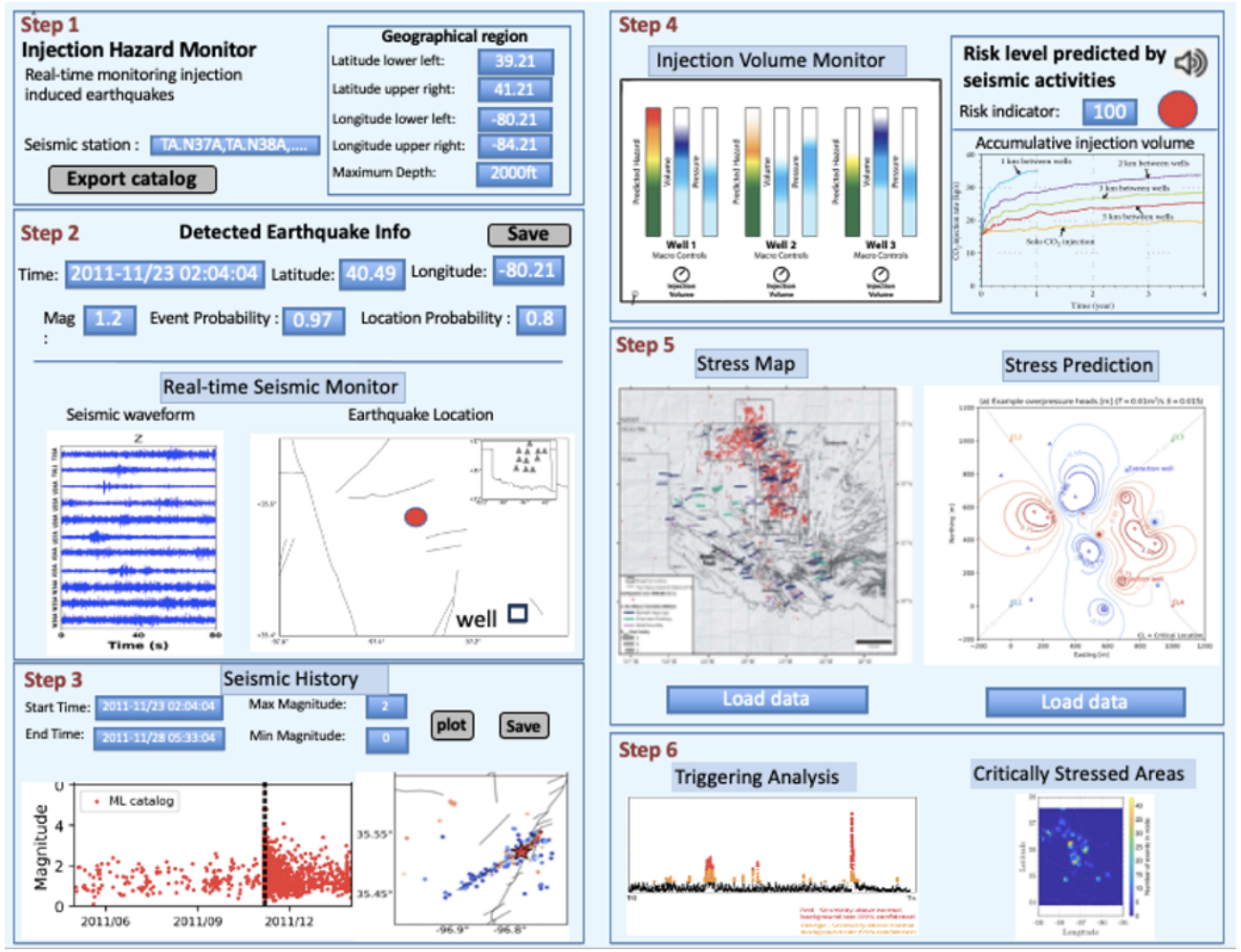

E (GPa)
ν
shallow aquifer
cap rock
reservoir
basement
Fwd. Runs
Fwd. Runs
model estimate
true value
model parameter loss function gradient

Enabling Technology 3: **Visualization & Decision Support**



Seismicity Hazard Forecasting & Operator Support

POC: David Coblentz / Chris Sherman



Goals:

- Co-visualize relevant P-T-S data in real time
- Provide hazard estimates and forecasting
- Think carefully about the human-machine interface

Phase I Targets

Automated Monitoring & Characterization

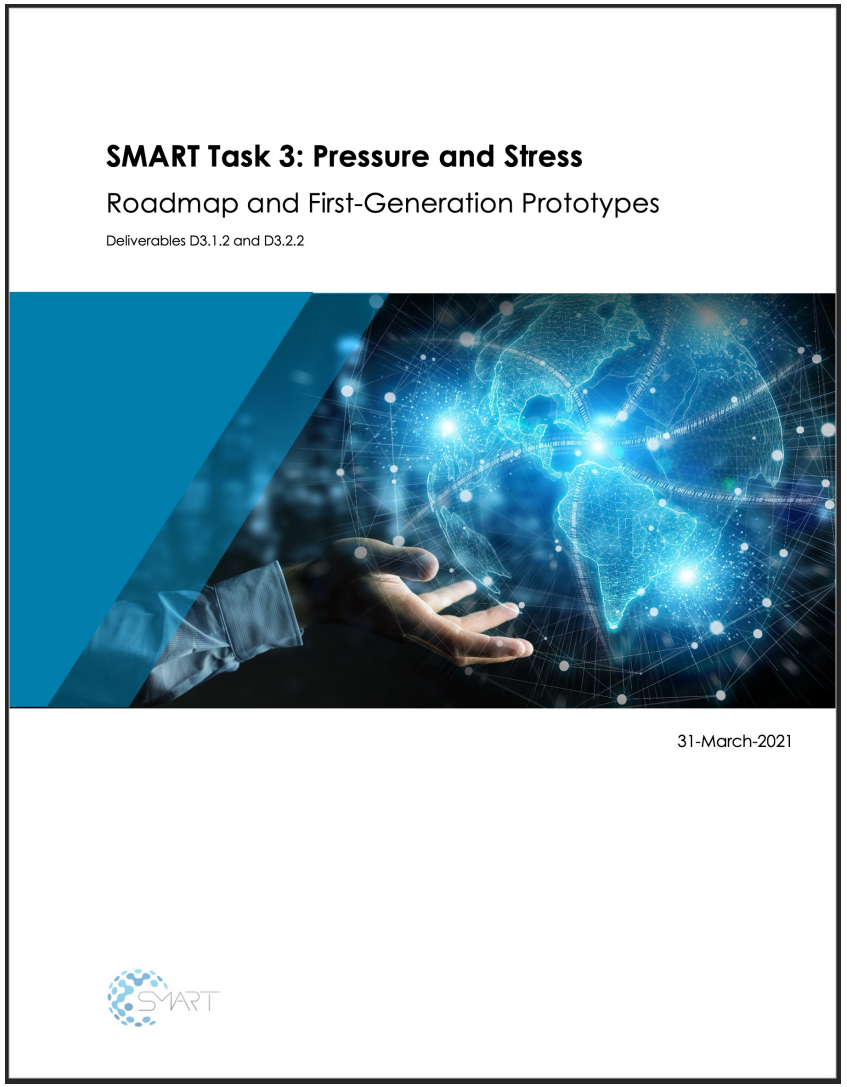
- *Study 1A:* Seismic event detection and source properties with machine learning
- *Study 1B:* Artificial intelligence enhanced body and surface wave tomography
- *Study 1C:* Using ambient noise to estimate stress orientation
- *Study 1D:* State of stress from triggered earthquakes
- *Study 1E:* Deep learning and anomaly detection applied to distributed acoustic sensing (DAS)
- *Study 1F:* Pre-injection characterization by transfer learning to identify features below active seismic resolution from induced events.

Real-Time Modeling & Data Assimilation

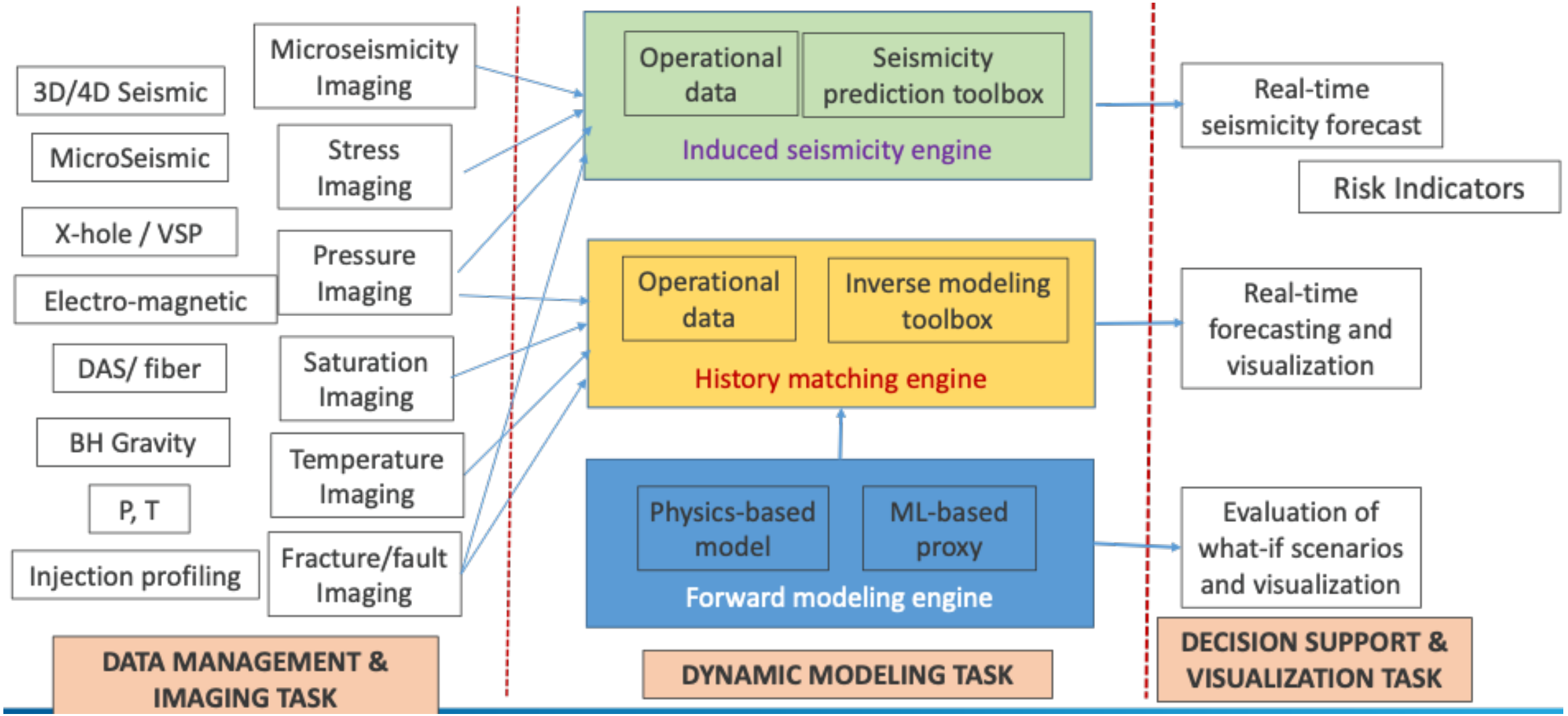
- *Study 2A:* Predictive analysis of pressure and temperature in carbonate reservoirs
- *Study 2B:* State of stress modeling from geophysical joint inversion
- *Study 2C:* Embedding deep learning models into finite element models to learn unknown physics directly from field monitoring data

Visualization & Decision Support

- *Study 3A:* Operational Forecasting of Induced Seismicity



Phase II Goals



Questions?

Thank you!

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