NRAP Task 3 - Induced Seismicity Risk Management

Kayla Kroll, Christopher Sherman, Gina Geffers, Dennise Templeton (LLNL); Jeff Burghardt, Marissa, Fichera, Delphine Appriou, Julia de Toledo Camargo (PNNL); Yves Gugliemi, Jonny Rutqvist, Corinne Layland-Bachman (LBNL); Ting Chen (LANL)

FECM/NETL Carbon Management Research Project Review Meeting
Thursday, August 31, 2023

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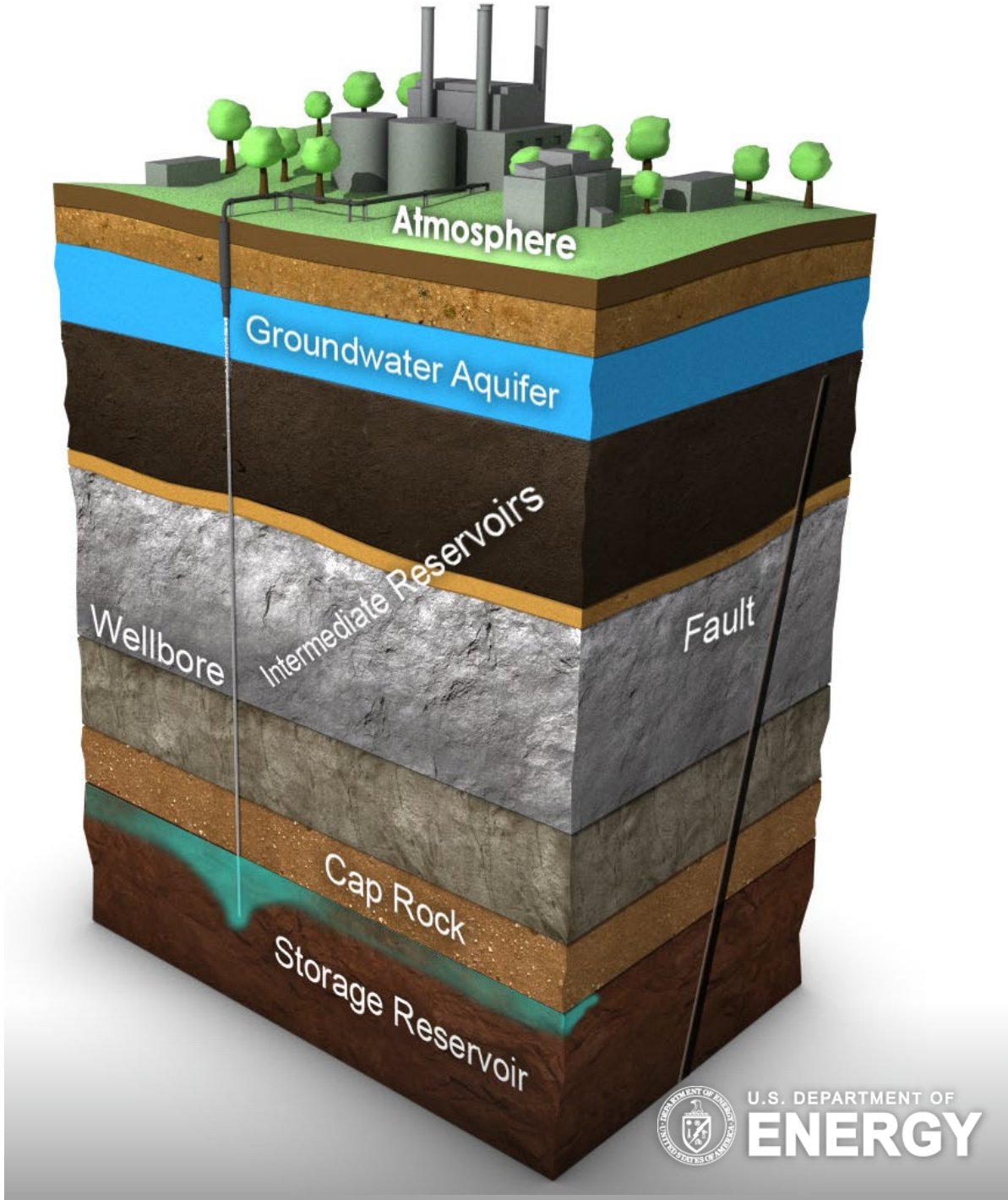

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Project Overview

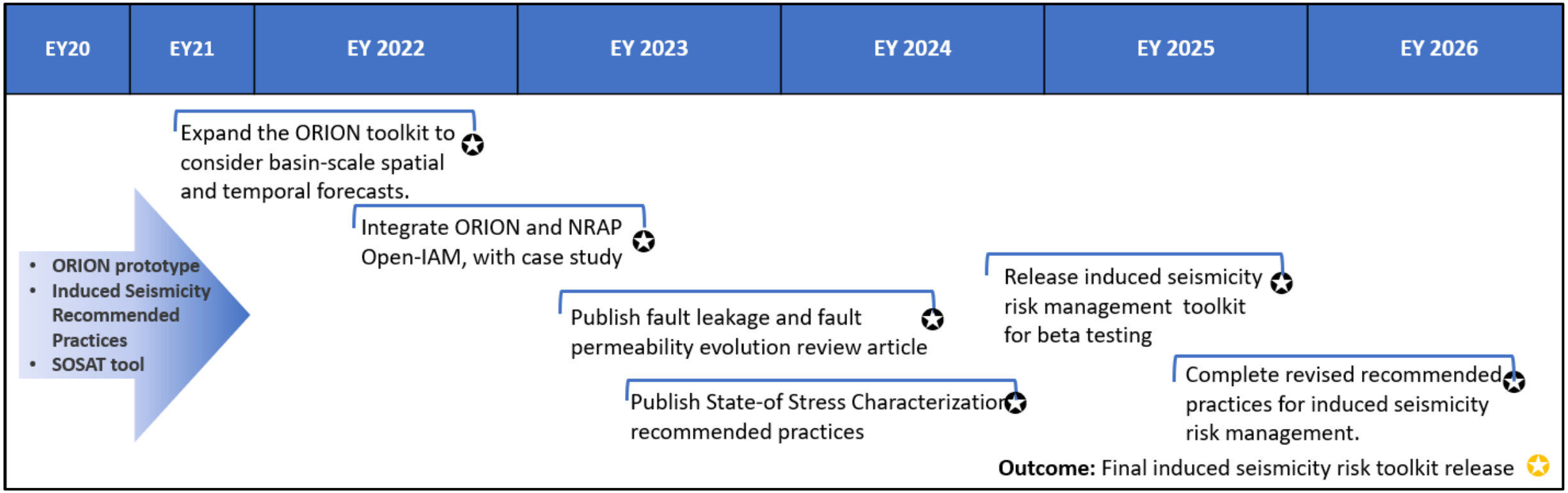
Key Project participants

LLNL	PNNL	LBNL	LANL
• Kayla Kroll • Chris Sherman • Gina Geffers • Dennise Templeton	• Jeff Burghardt • Julia de Toledo Camargo • Delphine Appriou • Marissa Fichsera	• Yves Gugliemi • Jonny Rutqvist • Corinne Layland-Bachmann	• Ting Chen

Task 3 Induced Seismicity Risk Management

Objectives

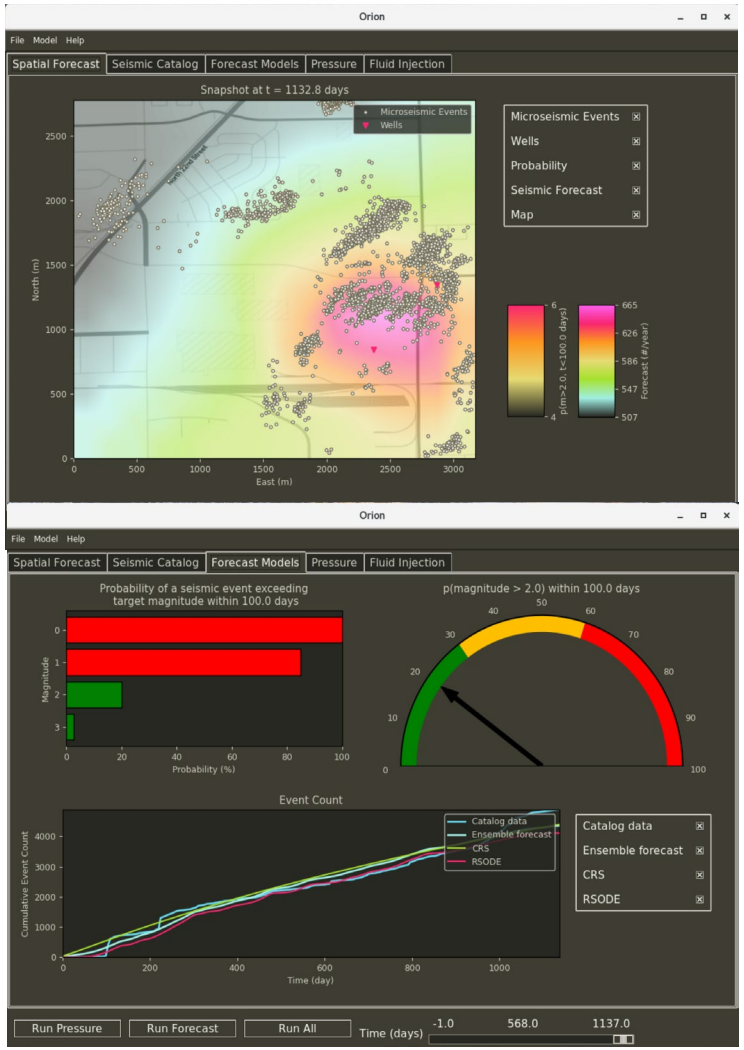
- To refine practical methods and tools to assess and manage induced seismicity risk associated with geologic carbon storage.
- To more explicitly link state-of-stress, hydraulic fracturing, potential fault activation and fault leakage risk with integrated risk assessment models.

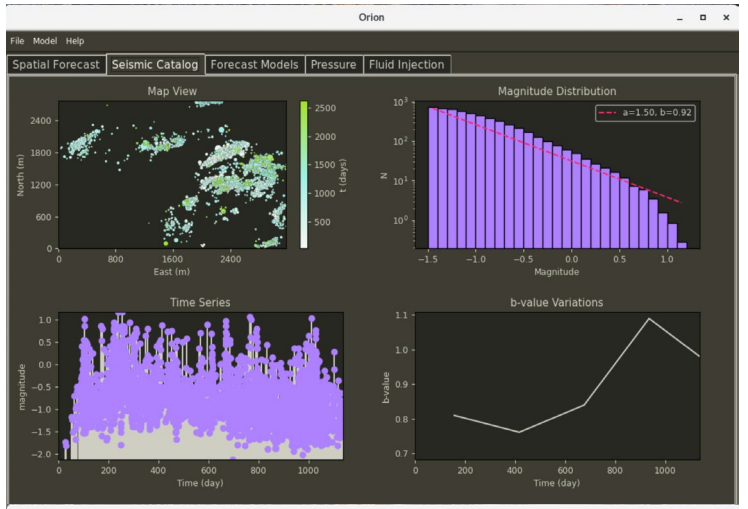


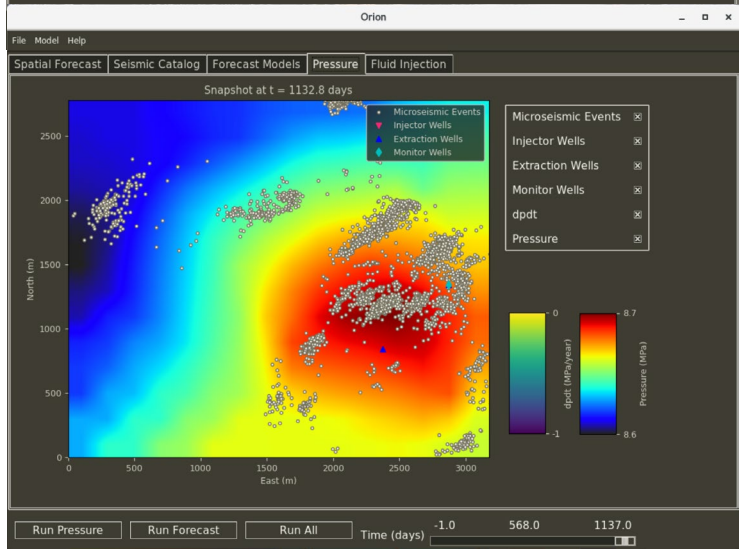
Basin Scale Spatio-temporal Forecasts

Subtask 3.1: ORION: Operational Forecasting of Induced Seismicity toolkit (Kayla Kroll, Chris Sherman, and Gina Geffers, LLNL)

- Import:
  - Well locations
  - Injection rates
  - Reservoir properties
  - Seismicity catalog
- Compute reservoir pressure and Coulomb stress changes
- Compute spatial and temporal seismicity forecast (via physics and statistical models)







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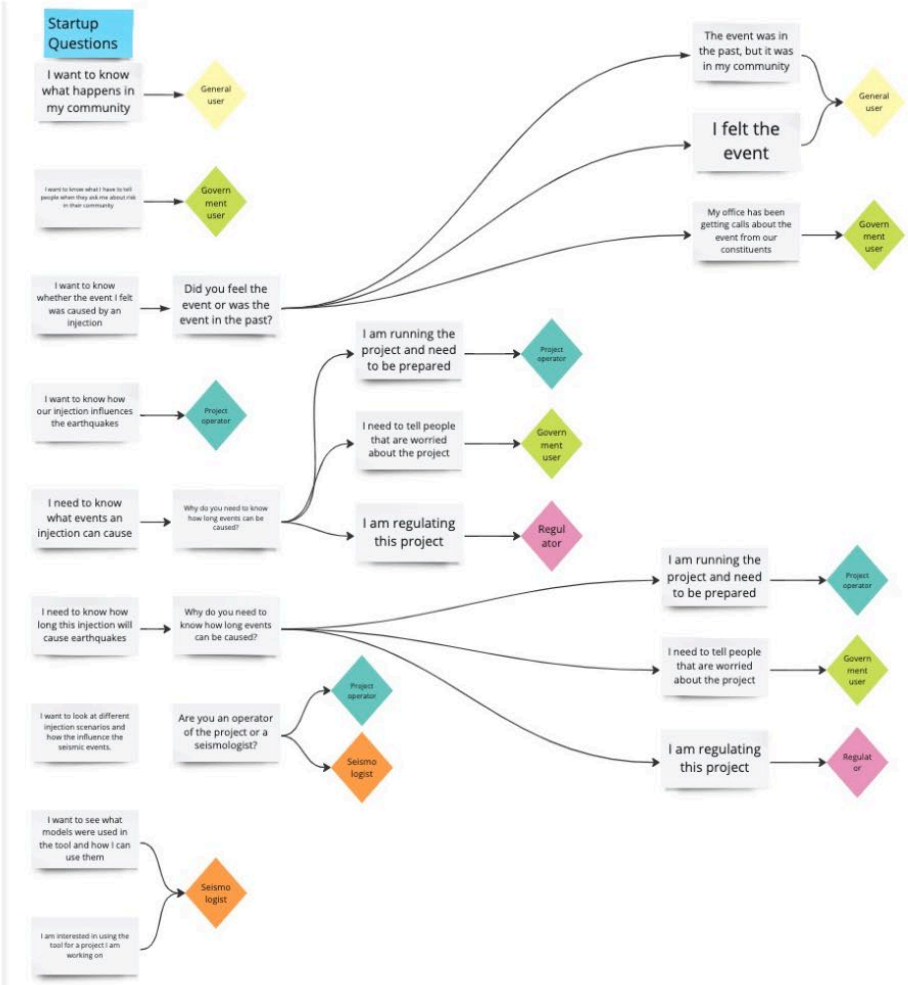
Basin Scale Spatio-temporal Forecasts

Tailoring forecasting capabilities to various end-users:

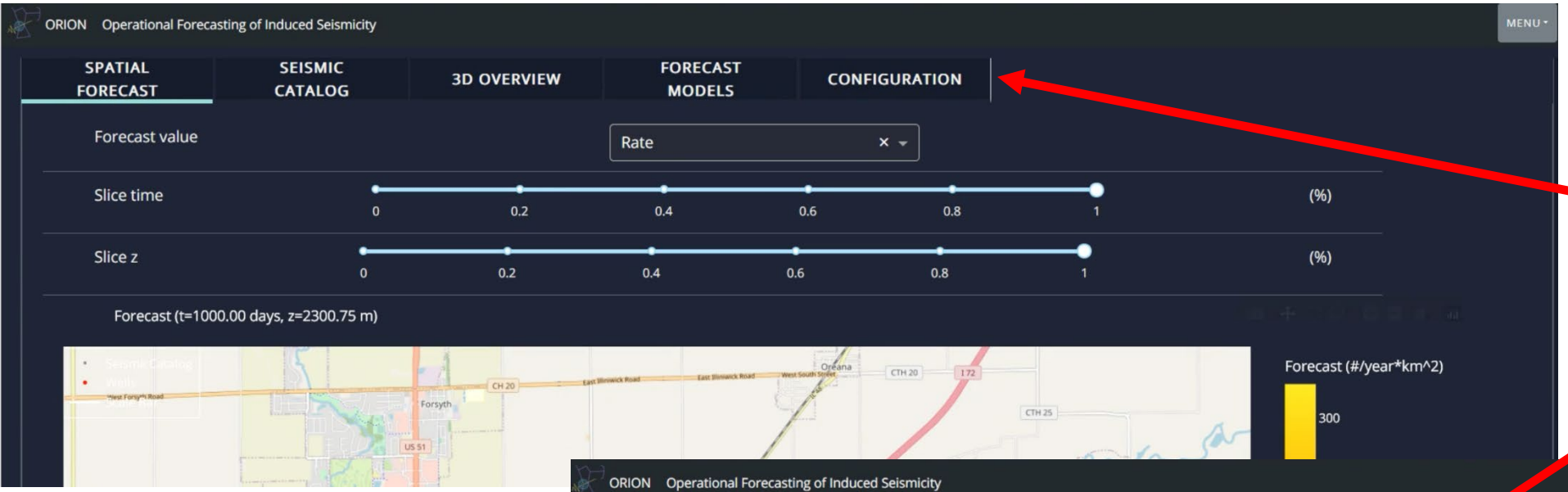
Start up questionnaire

- Define user groups / stakeholders
  - Define access each group will have
  - Define use cases for each group
- Start with set of simple questions
  - Answer lead to different groups
    - Refine questions to get more specific / distinguish different groups
- Do not overcomplicate it
  - Max three to four layers

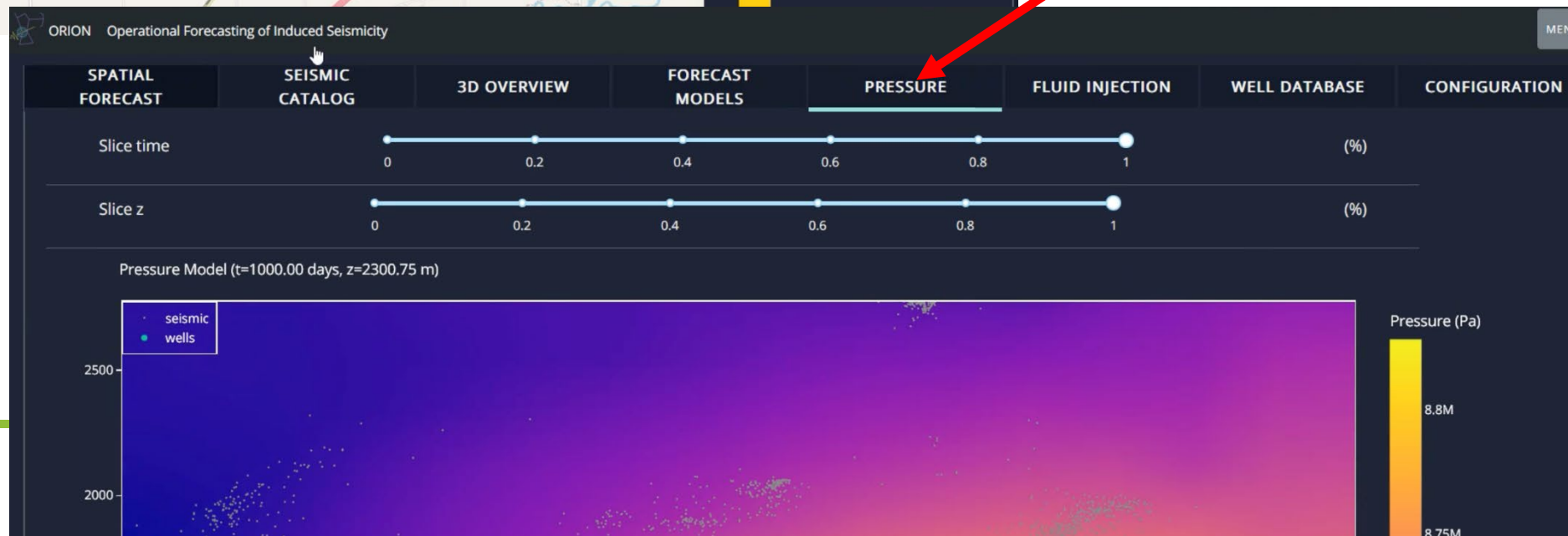


Basin Scale Spatio-temporal Forecasts

Tailoring forecasting capabilities to various end-users:

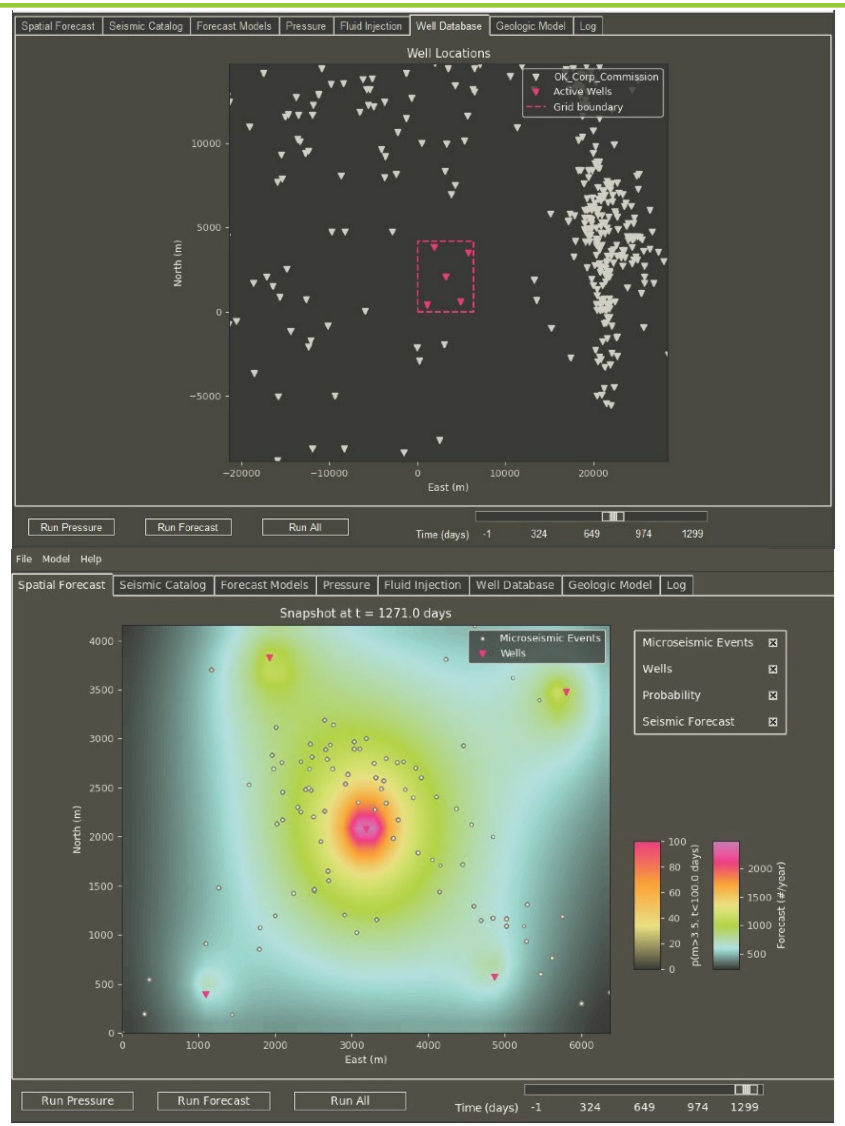


Change in number of Interactive capabilities



Basin Scale Spatio-temporal Forecasts

- Incorporate state-wide injection data and compute pressurization rates for interacting wells
- Compute seismic forecast in space and time
- Challenges
  - Forecasts in cells with $N_{eq} < 2$ & $\dot{p} != 0$ || $N_{eq} > 2$ & $\dot{p} == 0$
  - Injection data reporting deferred by 6 months
  - Basins contain multiple operations



Basin Scale Spatio-temporal Forecasts

Subtask 3.1: Improved seismic hazard forecasts (Gina Geffers and Kayla Kroll, LLNL)

INTRODUCING SPATIAL HETEROGENEITY IN SEISMIC FORECASTS

Gina-Maria Geffers[1], Kayla A. Kroll[1], Christopher S. Sherman[1] & Chaoyi Wang[1]
[1]Lawrence Livermore National Laboratory, Livermore, CA

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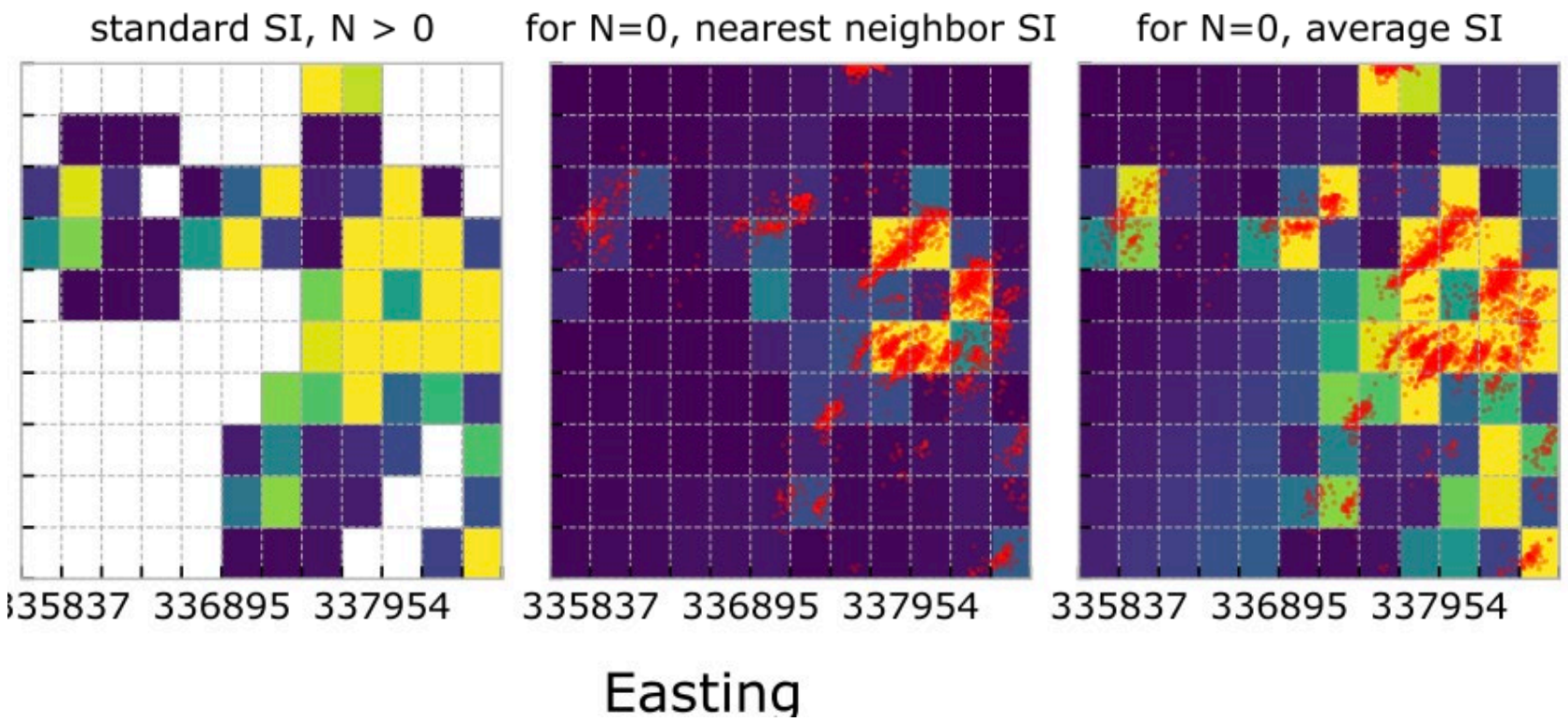
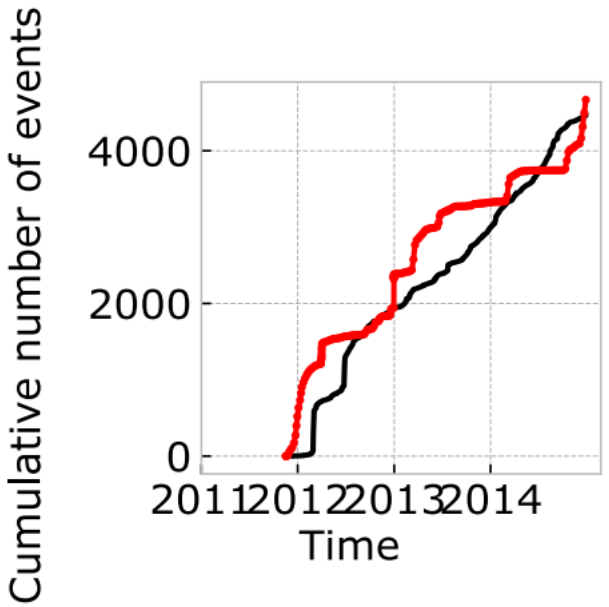


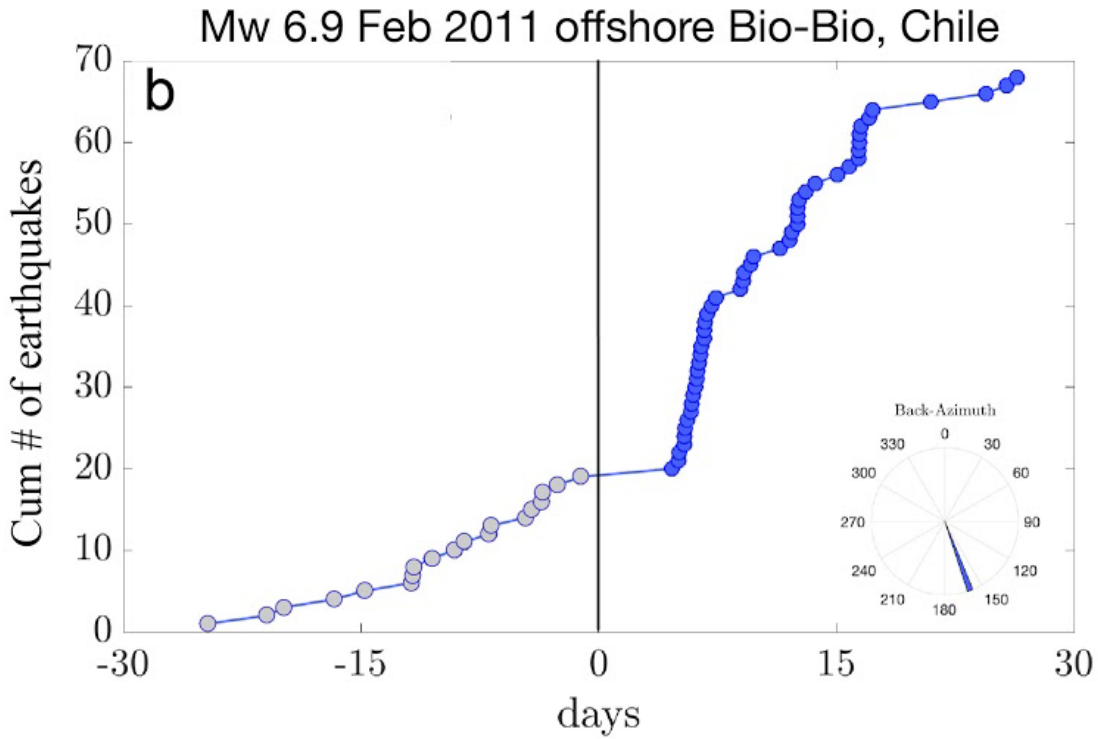


Basin Scale Spatio-temporal Forecasts

Subtask 3.1: Development of Advanced Traffic Light Procedures (Ting Chen, LANL)

- Goal:
  - Advance the Traffic Light System for induced seismicity risk mitigation
- Method:
  - Spatiotemporal analysis of seismicity, e.g., seismic response to stress perturbation such as seismic wave passage and tides
- Application:
  - Oklahoma

Dynamic triggering observed in Oklahoma, before 2011 Mw5.7 Prague earthquake, indicating critical fault state



Basin Scale Spatio-temporal Forecasts

Subtask 3.1: Assessment of operational management strategies (Kayla Kroll, LLNL, Elizabeth Cochran, USGS

High-Fidelity Simulations of Induced Earthquakes to Inform Operational Management Strategies

Kayla A. Kroll[1], Elizabeth S. Cochran[2], and Christopher S. Sherman[1]
kroll5@llnl.gov; ecochran@usgs.gov; sherman27@llnl.gov

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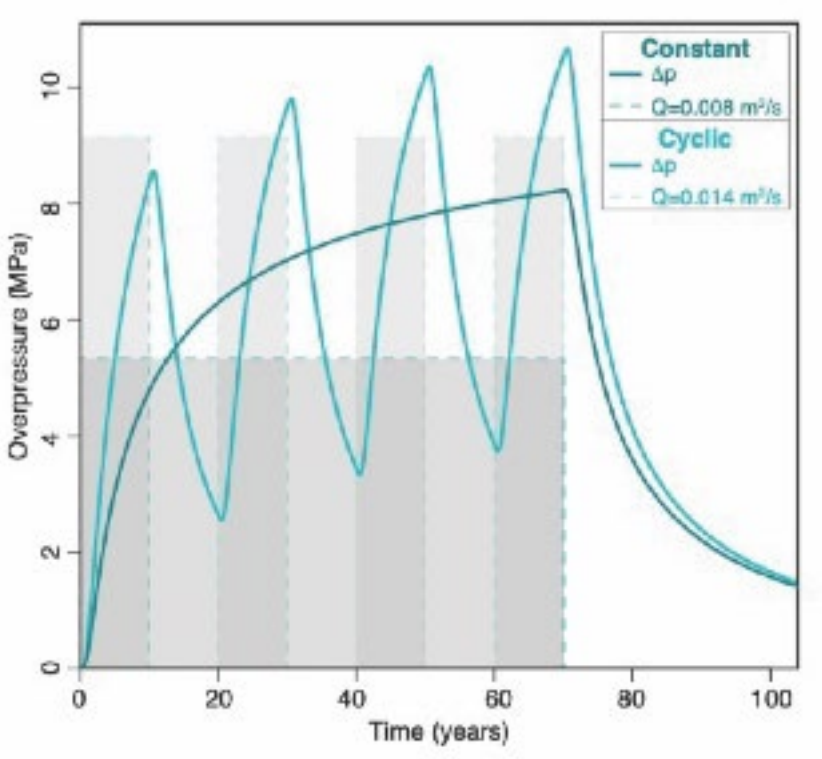

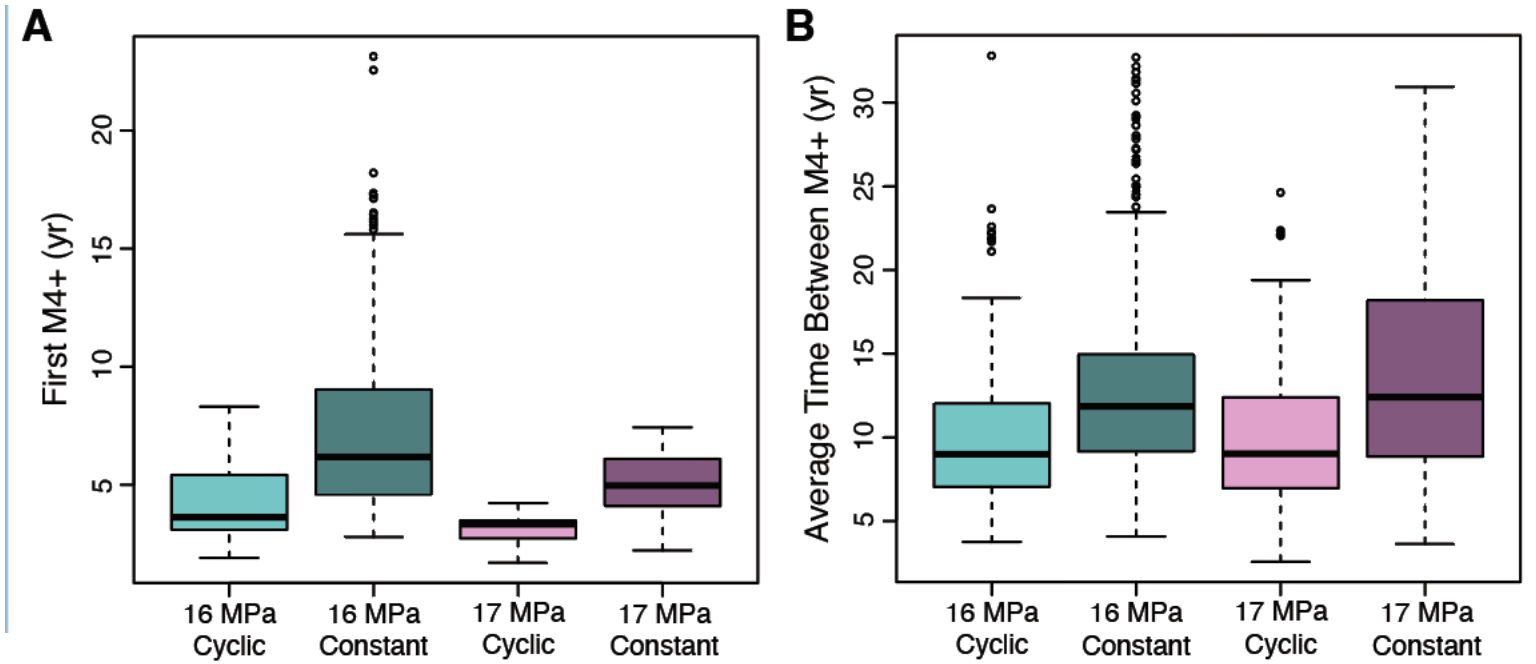

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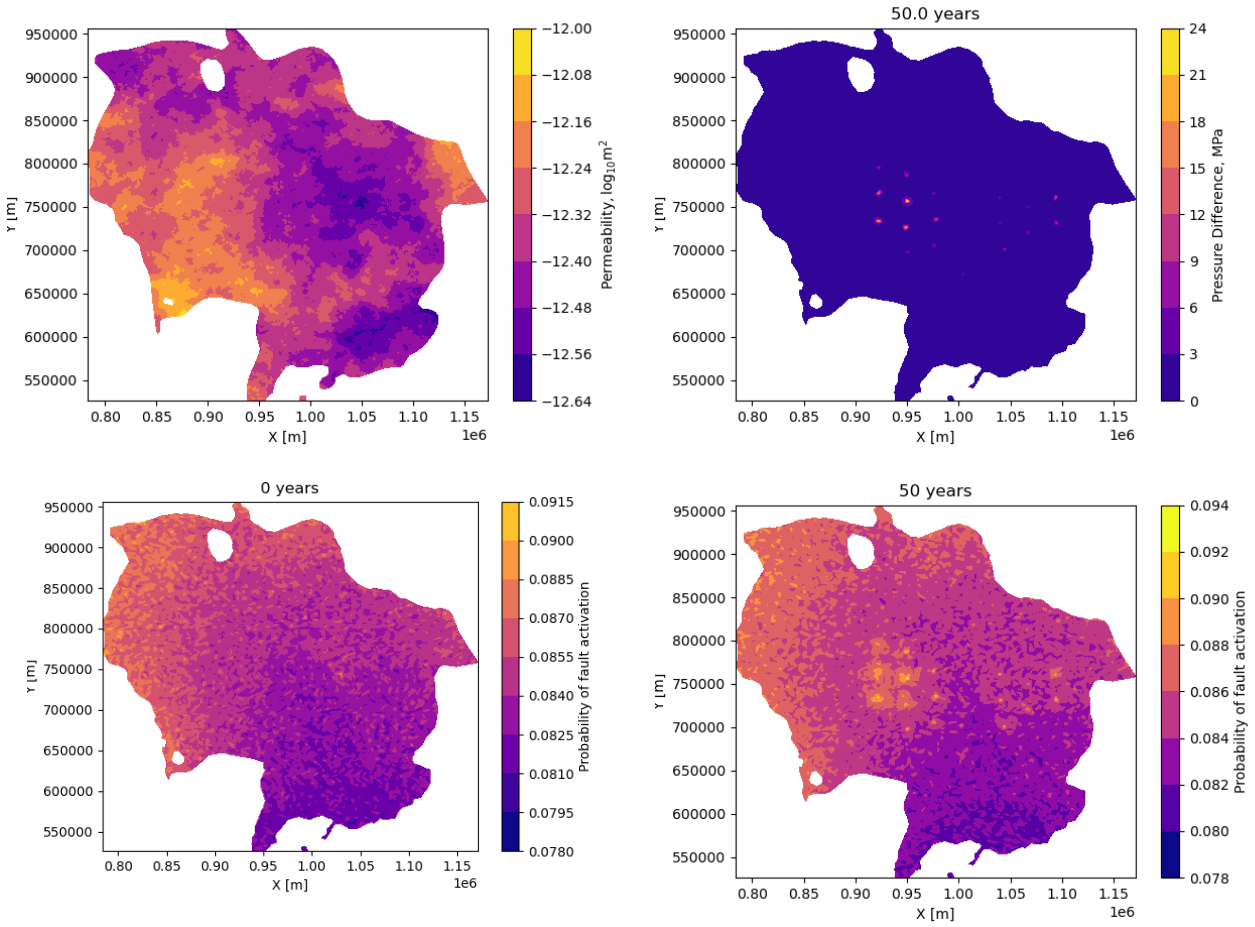
Geomechanical and Induced Seismicity Risk

Subtask 3.2: State of Stress Assessment Computational Tools, Jeff Burghardt (PNNL), Julia de Toledo Camargo, Delphine Appriou, and Melissa Fichera

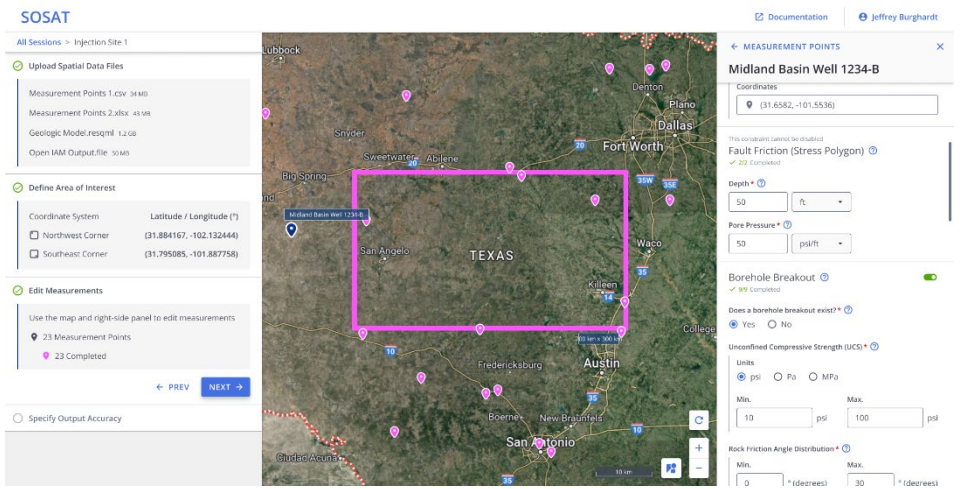
- SOSAT estimates initial stress state probability across area of interest (Illinois Basin in this case)
- Open IAM estimates overpressure caused by injection sites
- SOSAT estimates change in stress and risk of activating critically oriented fault over time

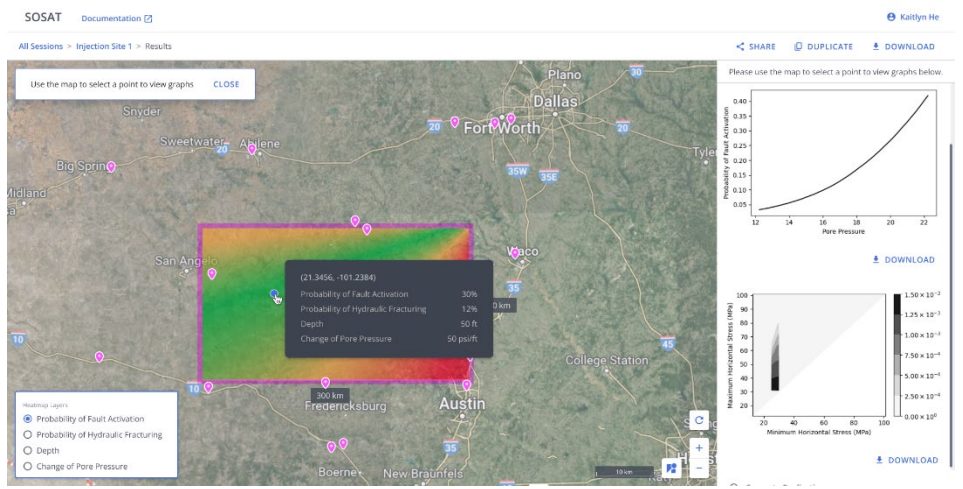


Geomechanical and Induced Seismicity Risk

Subtask 3.2: SoSAT Spatial Mapping Capabilities, Jeff Burghardt (PNNL), Julia de Toledo Camargo, Delphine Appriou, and Melissa Fichera

- This prototype is now being built into a new web interface for SOSAT
- The UX design is complete and implementation is underway
- The user will be able to specify their area of interest and automatically import publicly available stress data (World Stress Map)
- Users will be walked through entering stress measurement data and stress indicators to further constrain the state of stress
- User's can upload geologic information (formation depths, thickness, etc.)
- Open IAM or external reservoir models can be used to provide pore pressure distribution
- SOSAT will then evaluate the fault stability and risk of hydraulic fracturing across the area of interest





Geomechanical and Induced Seismicity Risk

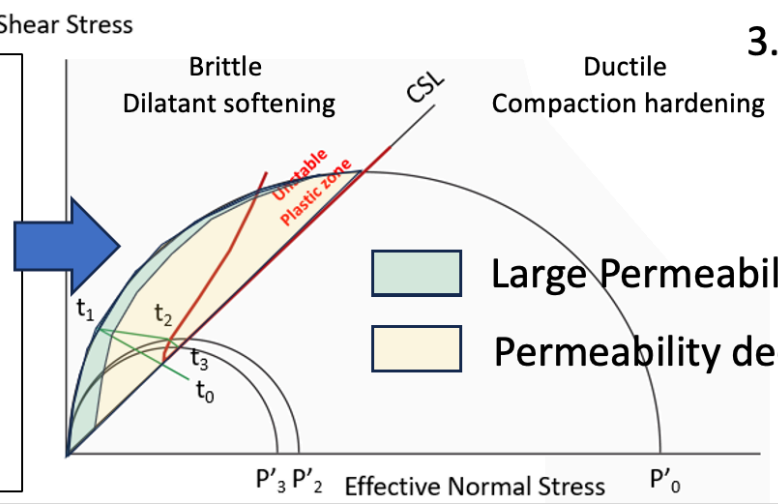
Subtask 3.3: Improved Fault Activation and Leakage Reduced Order Model, Yves Gugliemi, Jonny Rutqvist, and Corinne Layland-Bachmann (LBNL)

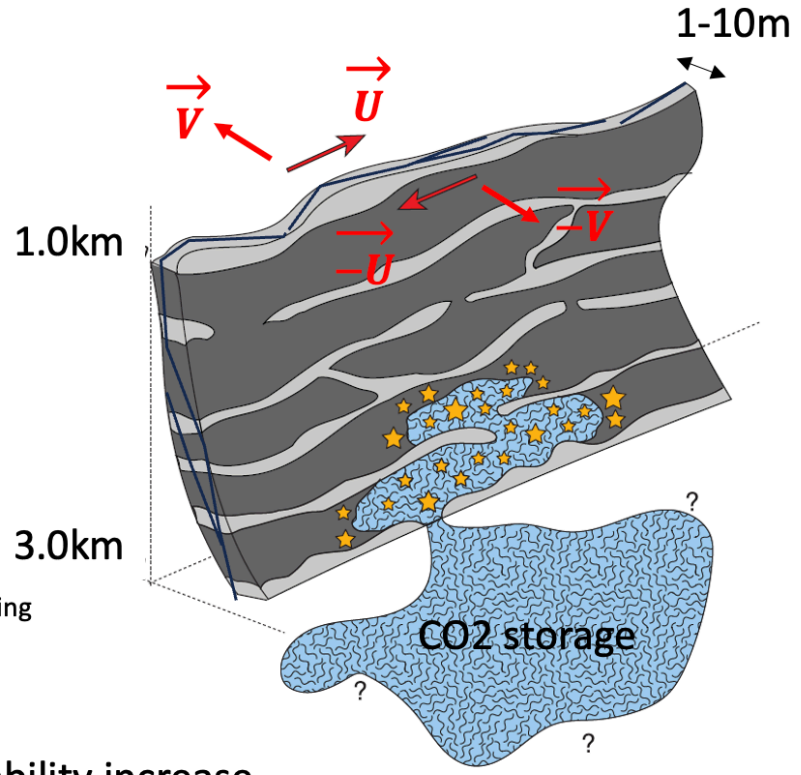
In NRAP-phase 2, LBNL conducted a bibliographic review highlighting that fault zone permeability variations depend on macro- to micro-scale hydromechanical processes in the fault zone :

- Several orders of permeability drop above 20% of clay content
- Coexistence of brittle and ductile processes that condition strain partitioning and flow paths developments
- Fast switch from ductile to brittle when fault pore pressure increases
- Potential 2-3 orders of magnitude decrease in permeability with increase in effective normal stress at slip and with the increase in the slip amount

In NRAP-phase 3, LBNL is developing a ROM to integrate this fault permeability change into an end-cap plastic failure criterion with a flow rule that accounts for brittle-to-ductile fault hydromechanical response – **Application to Caprock leakage and Induced Seismicity**

(modified from Maury et al., 2020)





Large Permeability increase

Permeability decrease

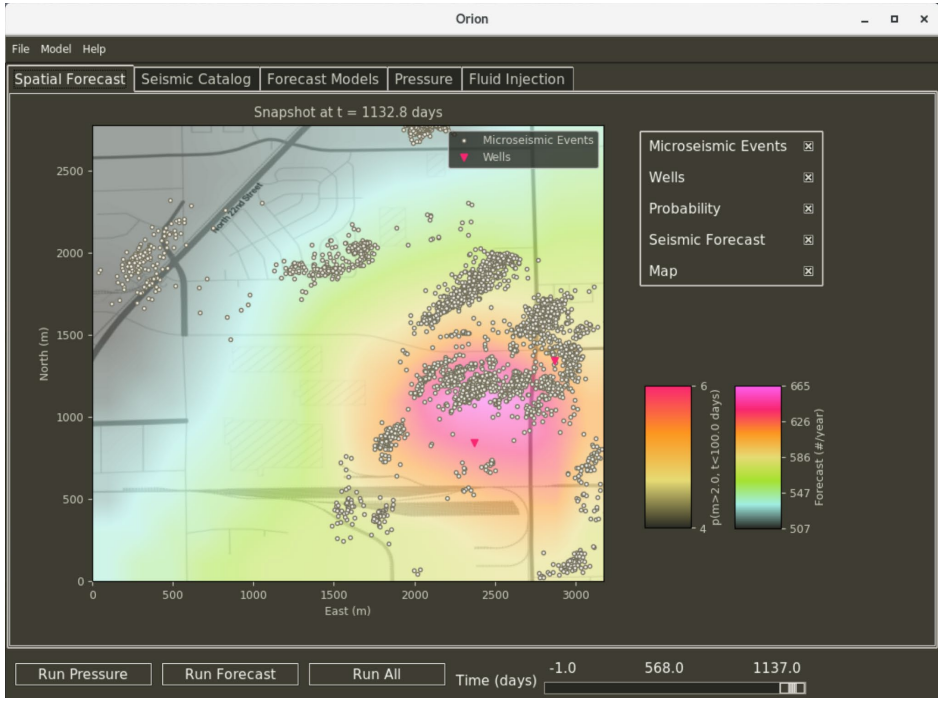
Modified from Ross et al. Science 368, 1357–1361 (2020)

Geomechanical and Induced Seismicity Risk

Subtask 3.4: Tool coupling and integration Chris Sherman, LLNL and Veronika Vasylkivska, NETL3

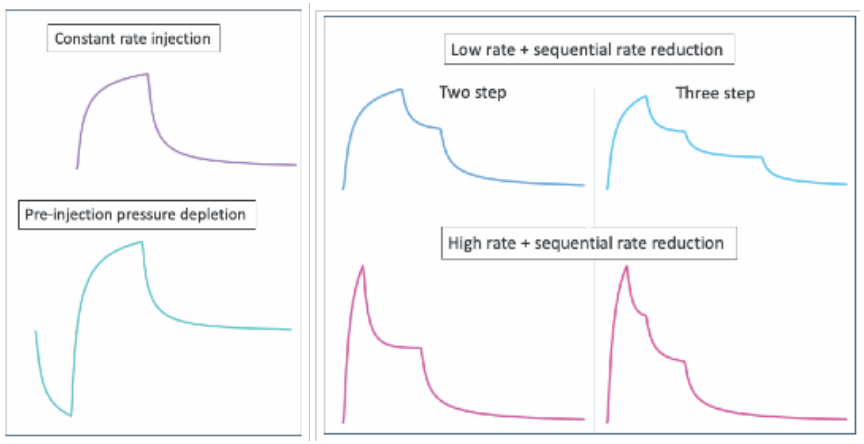
Coupling of NRAP-Open-IAM and ORION (in progress)

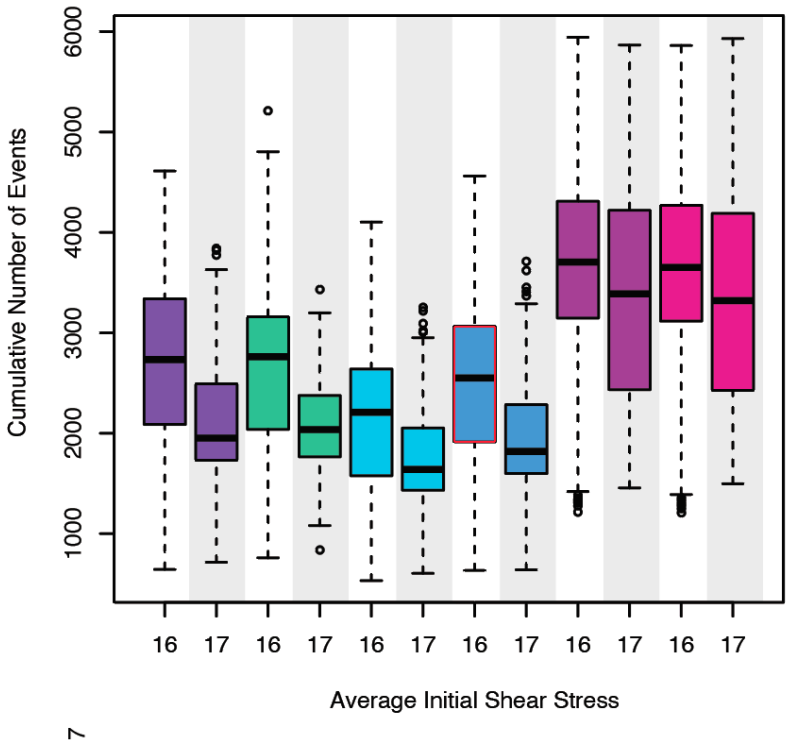
- Developed script with Lookup Table Reservoir component of NRAP-Open-IAM to create pressure data file in a format (hdf5) accepted by ORION
- Selected Decatur example distributed with ORION as test problem for coupling of the two tools: ORION needs both pressure data/pressure model and seismic catalog to run forecast prediction

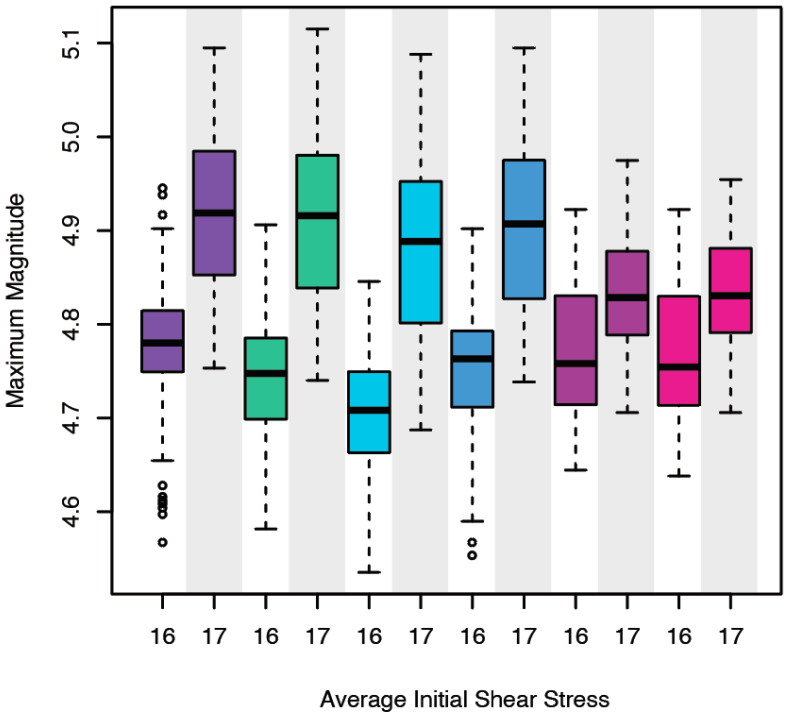


Next Steps

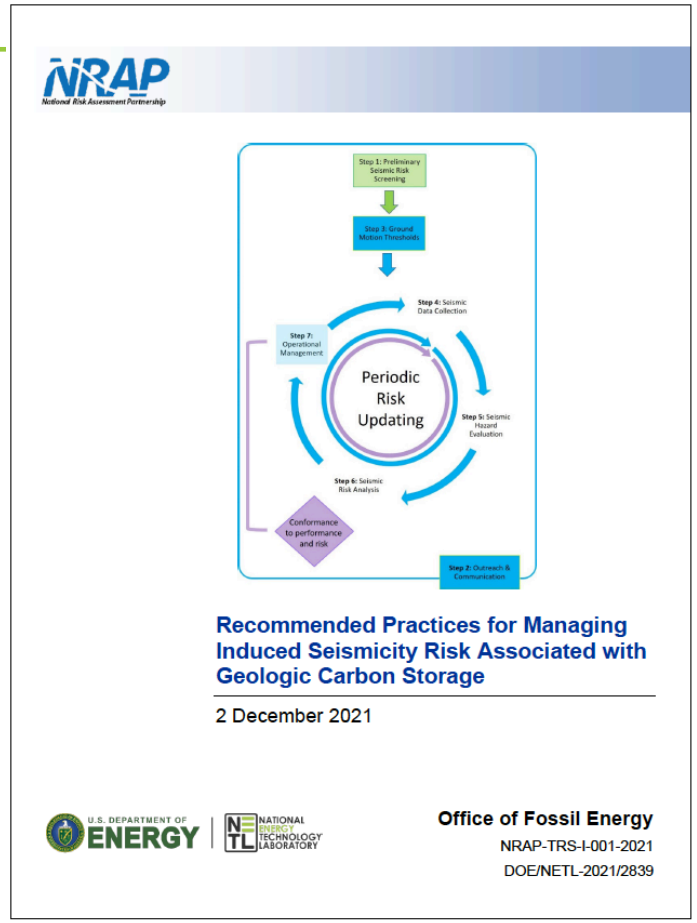
Explore seismic impact from larger variety of injection schedules

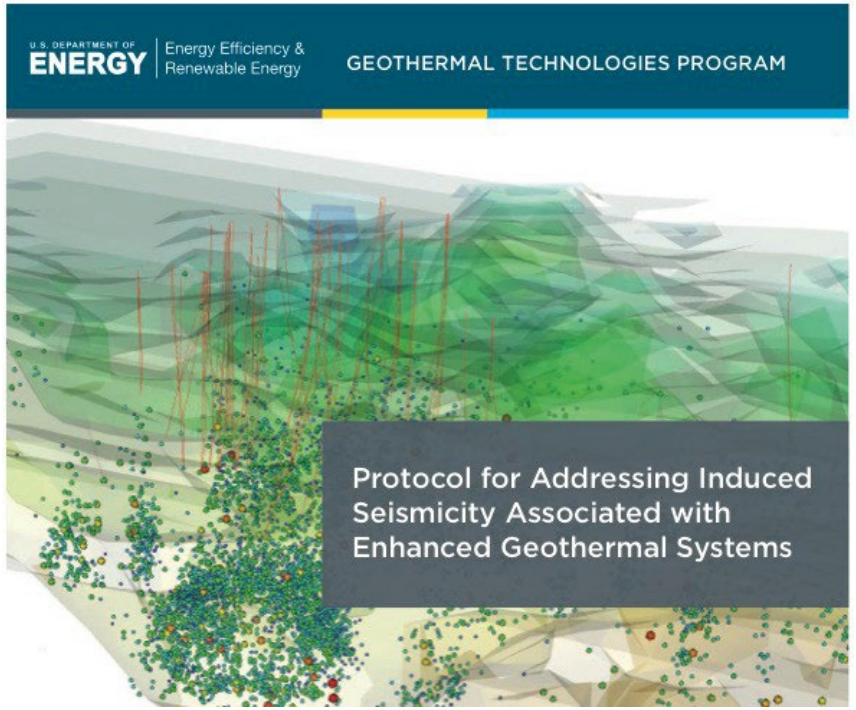






State-of-Stress Evaluation Recommended Practices





- **Starting Point:**
  - NRAP Induced Seismicity Recommended Practices
  - GTO Geothermal Seismicity Protocol (2012).
- **Goal:** Develop recommended practices guidelines relevant for stress state evaluation in carbon storage settings

Thank you!

Comments and Questions:

kroll5@llnl.gov

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