NRAP Phase II: Managing Risks and Reducing Uncertainties

An Overview of Research Objectives and Accomplishments

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August 6, 2021

NRAP
National Risk Assessment Partnership

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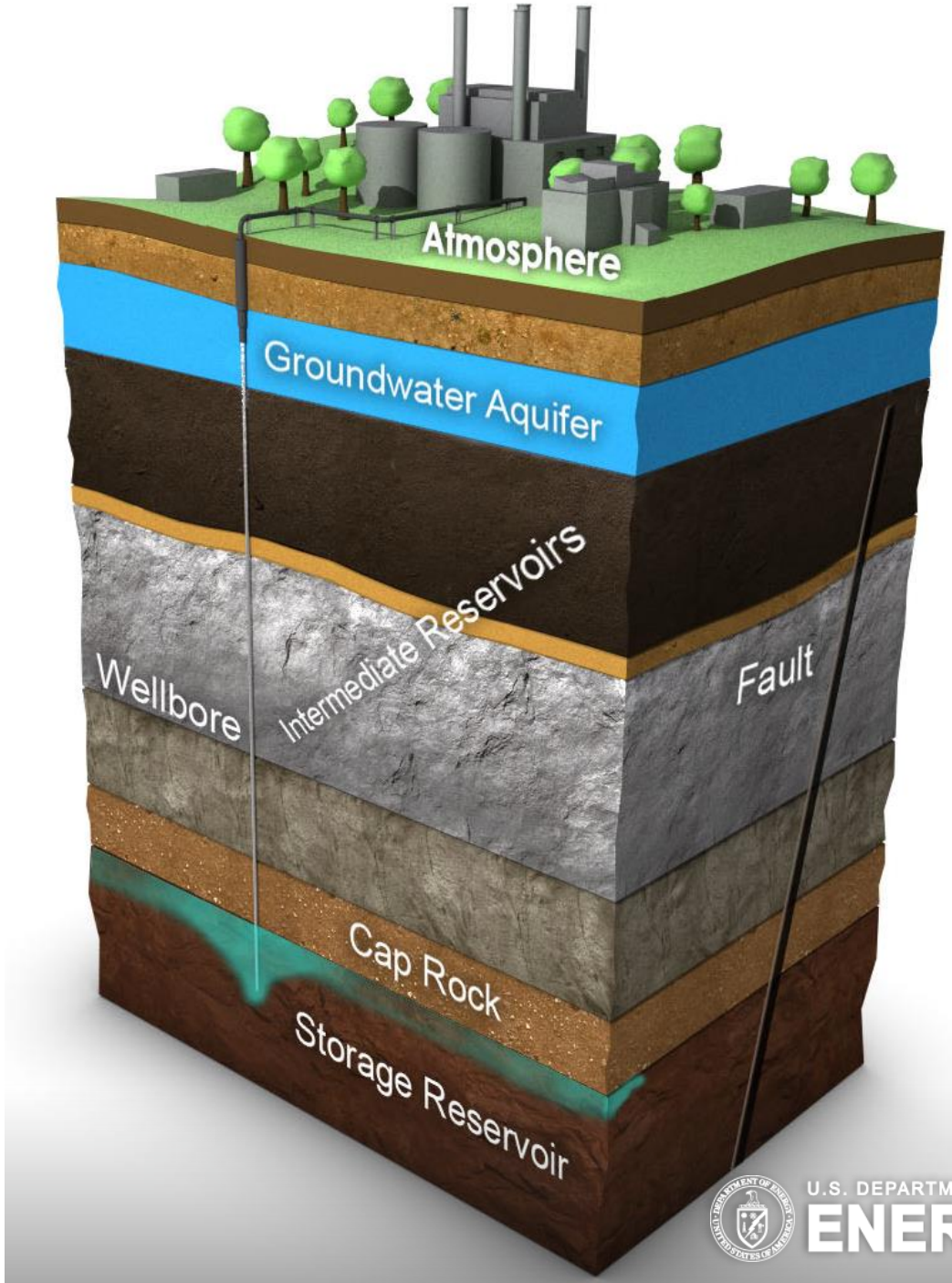
BERKELEY LAB

Los Alamos NATIONAL LABORATORY EST. 1943

Pacific Northwest NATIONAL LABORATORY



U.S. DEPARTMENT OF ENERGY

U.S. DOE's National Risk Assessment Partnership

NRAP
National Risk Assessment Partnership

NRAP leverages DOE's capabilities to quantitatively assess and manage long-term environmental risks amidst significant geologic uncertainty and variability.

Technical Team

NATIONAL ENERGY TECHNOLOGY LABORATORY

BERKELEY LAB
Lawrence Berkeley National Laboratory

Los Alamos
NATIONAL LABORATORY
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Pacific Northwest
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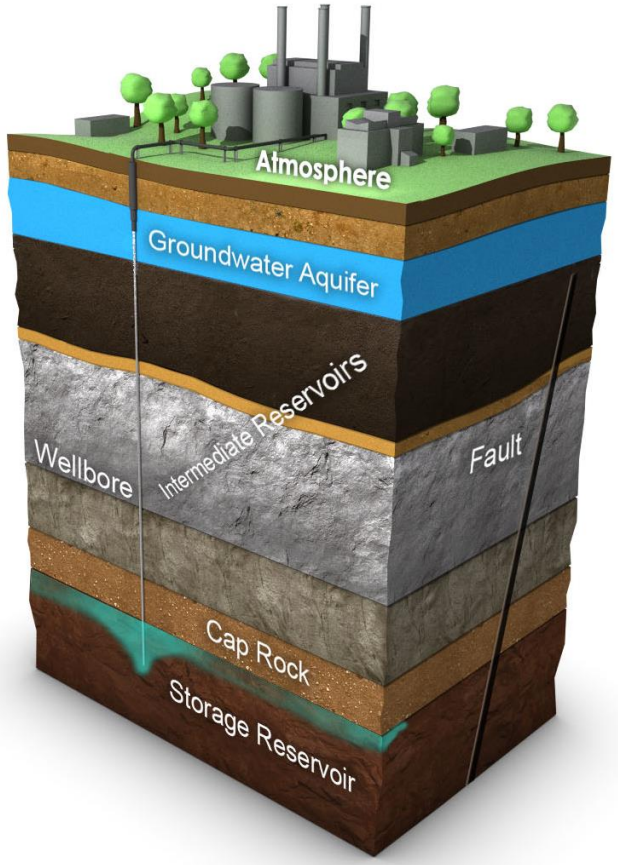

Stakeholder Group

PRINCETON UNIVERSITY

THE UNIVERSITY OF UTAH

ILLINOIS

BATTELLE

USGS
science for a changing world

bp

GLOBAL CCS INSTITUTE

Southern Company

ieaghg

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

CARBON SEQUESTRATION COUNCIL

NRDC

UNITED STATES Carbon Sequestration Council

U.S. DEPARTMENT OF ENERGY

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Integrated R&D Approach for Commercial-Scale Deployment

2017
Large Capture Pilots Initiated

2020
R&D Completed for Carbon Capture 2nd Generation Technologies

2025
Integrated CCS Projects initiated

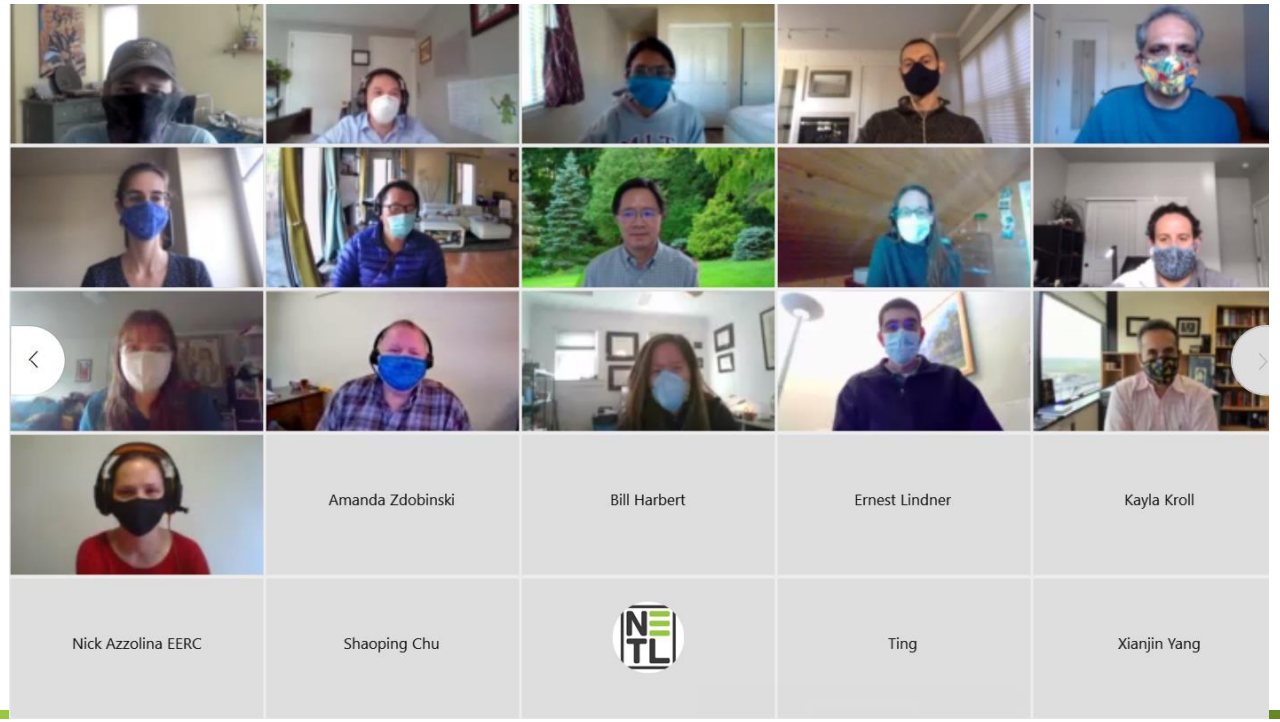
2030
Advanced technologies available for broad commercial-scale deployment

2017
Initiate Storage Feasibility for Integrated CCS

2022
Commercial-scale storage complexes characterized

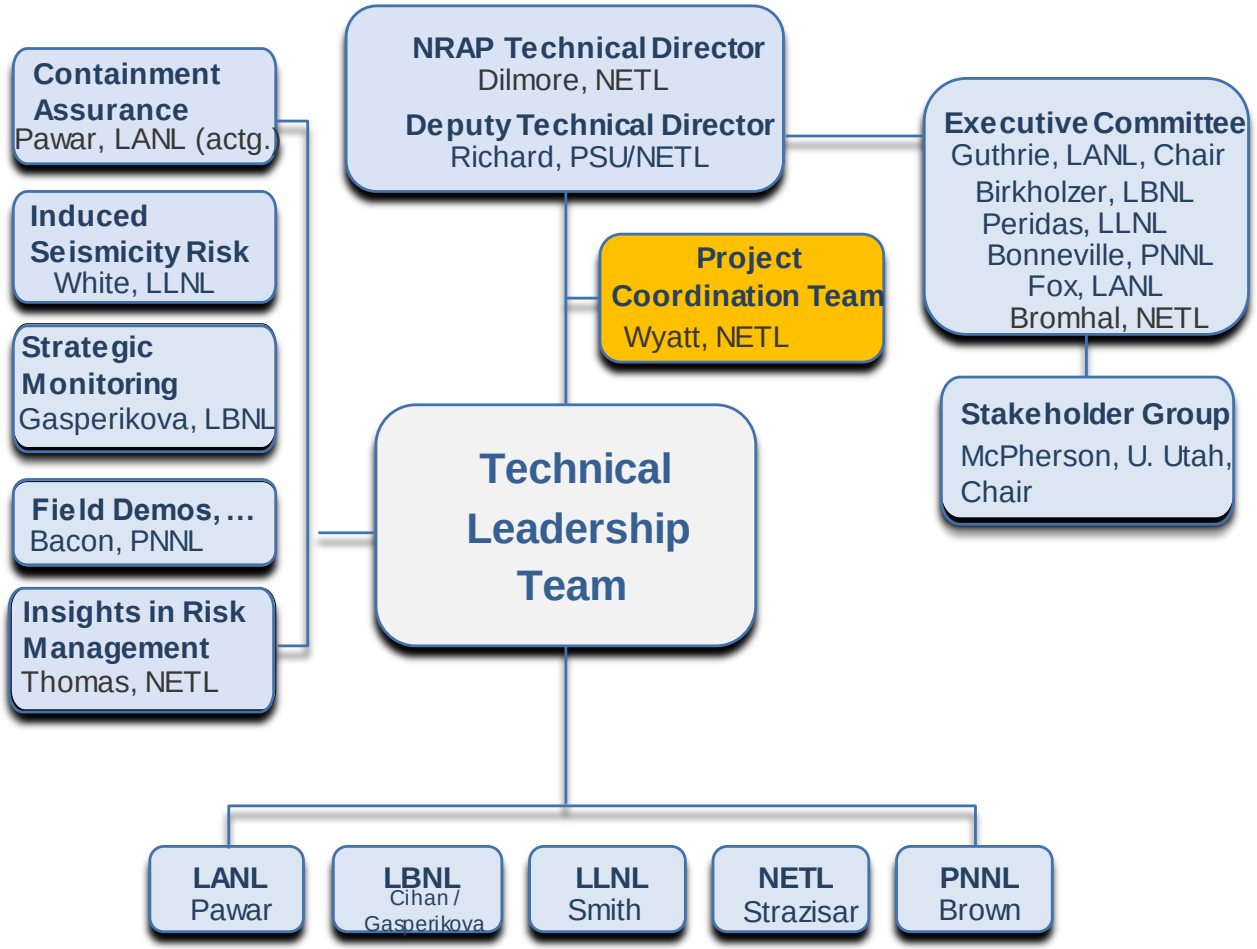
"New target for the United States to achieve a 50-52 percent reduction from 2005 levels in economy-wide net greenhouse gas pollution in 2030"
~ Biden Administration, 4/2021

The NRAP Team (2021)



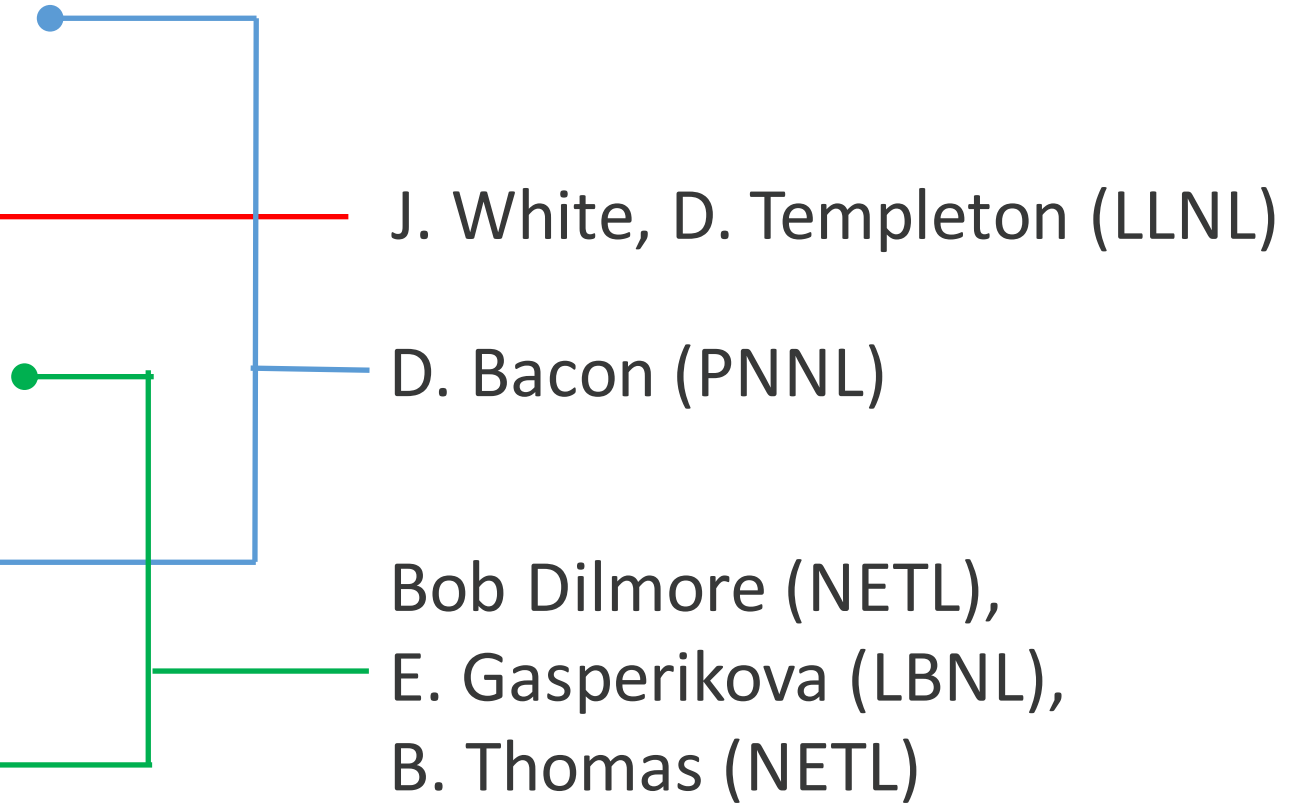
NRAP Phase II Technical Tasks and Org. Structure

- Task 2: Containment assurance / leakage risk management
- Task 3: Induced seismicity risk management
- Task 4: Strategic monitoring for Uncertainty Reduction
- Task 5: Validating NRAP tools and approaches
- Task 6: Addressing critical risk-related questions



Today's Presentations

- Task 2: Containment assurance / leakage risk management
- Task 3: Induced seismicity risk management
- Task 4: Strategic monitoring for Uncertainty Reduction
- Task 5: Validating NRAP tools and approaches
- Task 6: Addressing critical risk-related questions

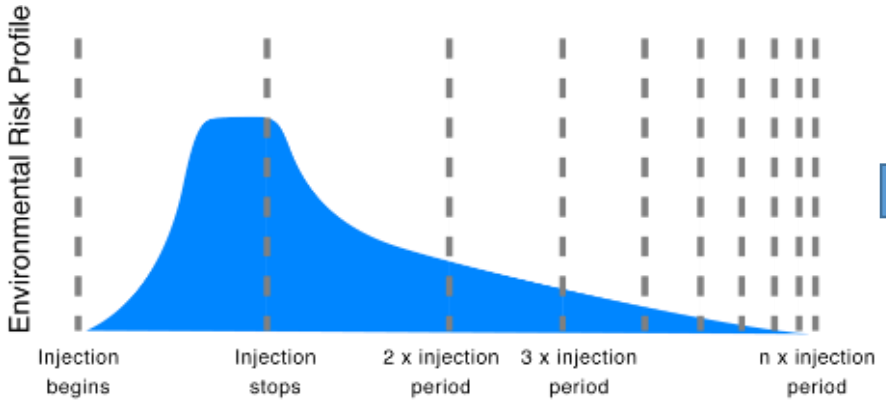


NRAP Phase I (2010 – 2016)

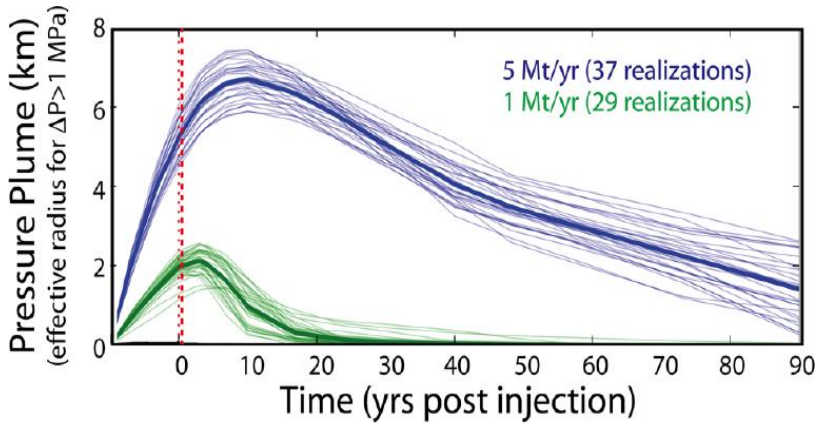
Risk Assessment & Uncertainty Quantification

How big might the risks be from a GCS operation?

- Pioneered hybrid methods for quantifying complex systems (physics coupled to empirical, e.g., machine learning)
- Developed computational tools for quantifying storage post injection
- Developed foundation for strategic (risk-based) monitoring (e.g., DREAM tool; no-impact thresholds)

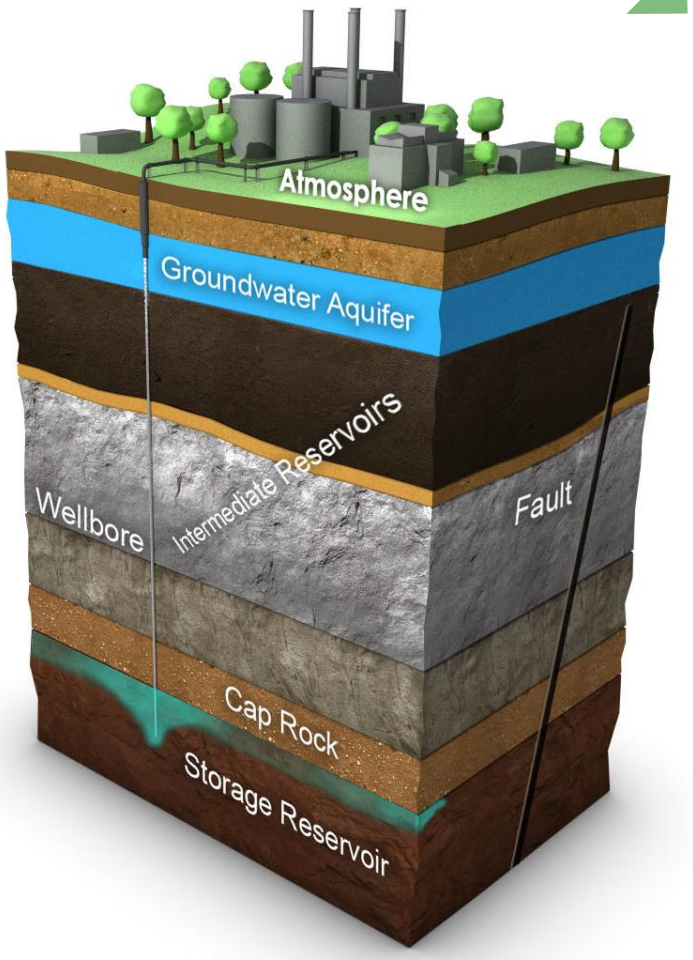


(Benson, 2007)

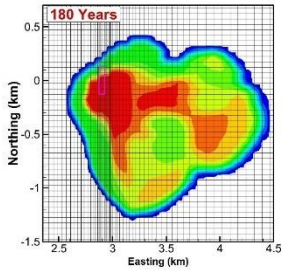


NRAP's approach for rapid prediction of whole-system risk performance

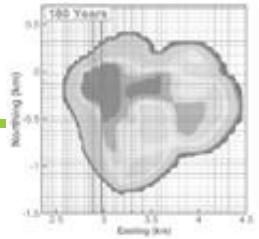
A. Divide system into discrete components



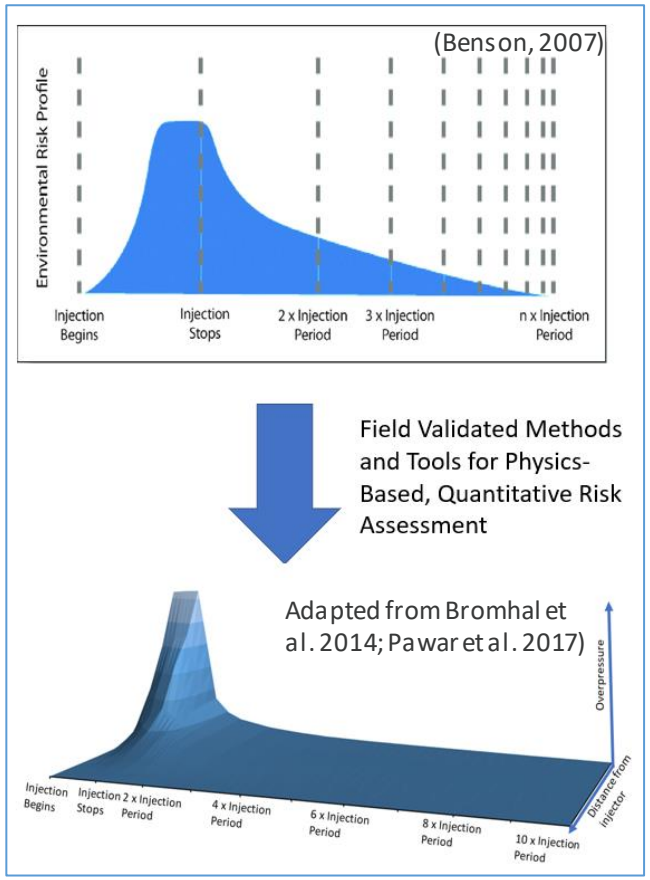
B. Develop detailed component models that are validated against lab/field data



C. Develop reduced-order models (ROMs) that rapidly reproduce component model predictions

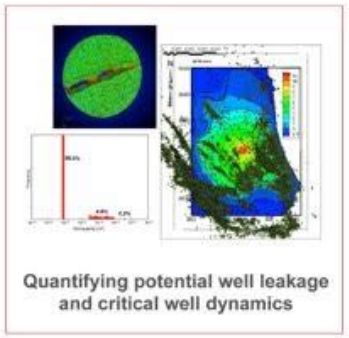


D. Link ROMs via integrated assessment models (IAMs) to predict system performance

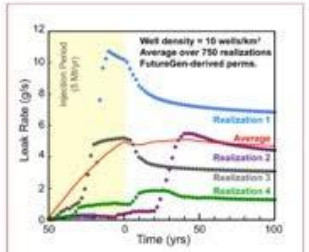


E. Exercise whole system model to explore risk performance

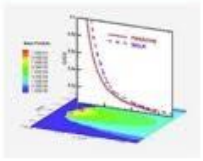
NRAP Phase I Accomplishments



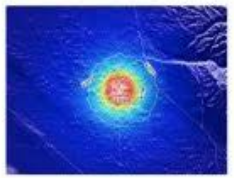
Quantifying potential well leakage and critical well dynamics



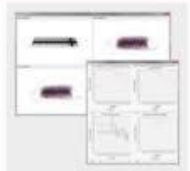
Probabilistic assessment of whole-system containment and leakage risk



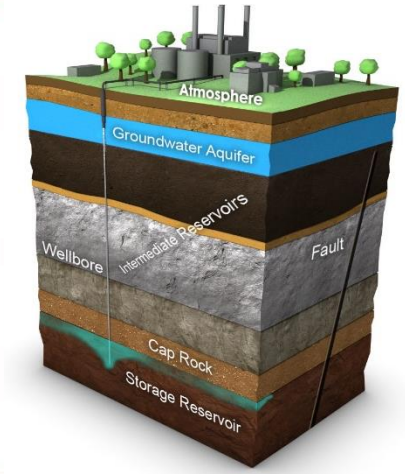
Rapid estimation of atmospheric dispersion

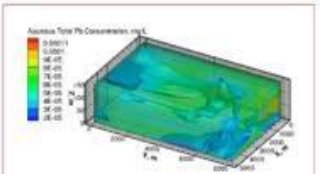


Estimating ground motion response from potential induced seismicity



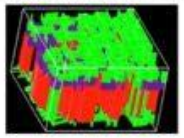
Prototype design approaches for strategic monitoring

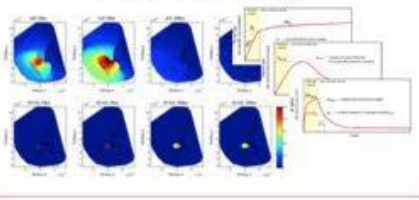




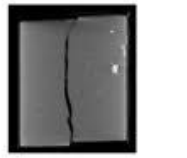
Predicting groundwater impacts from potential leakage

Estimating containment effectiveness of fractured seals

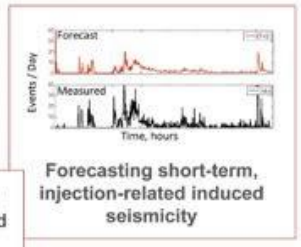




Identify critical reservoir storage/risk relationships



Reducing uncertainty in fault/fracture slip-induced permeability changes



Forecasting short-term, injection-related induced seismicity

R&D 100 55 Years of Invention

carbon sequestration leadership forum

IJGGC Virtual Special Issue (August, 2016)

NRAP National Risk Assessment Partnership

U.S. DEPARTMENT OF ENERGY

NRAP Tools Available at: www.edx.netl.doe.gov/nrap

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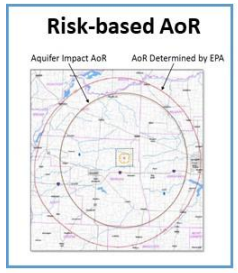
NRAP Phase II (2017–2021)

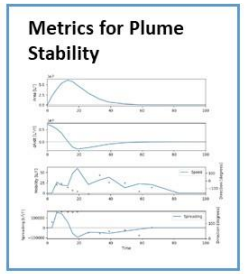
Risk Management and Uncertainty Reducdtion

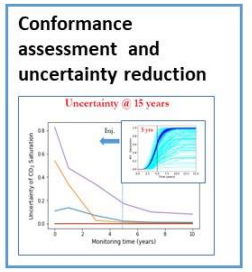
- **How can risks be managed at a GCS site?**
- **How can a risk-based approach help inform stakeholder decision making?**

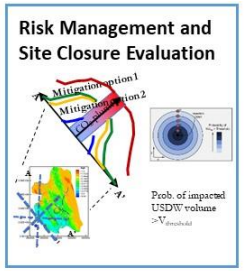
Supporting risk-based decisions at GCS sites

Leakage Risk Management and Containment Assurance

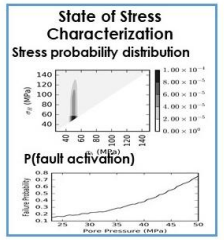


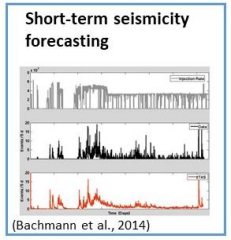


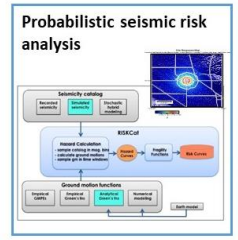




Induced Seismicity Risk Management

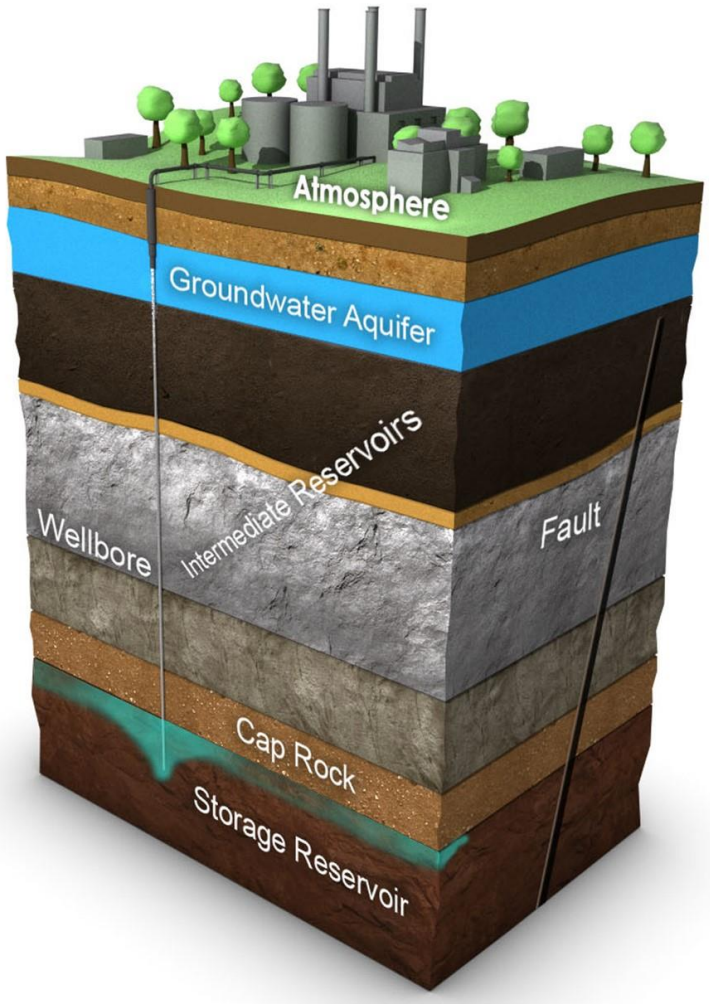






Risk-Based Monitoring Network Design

Site-specific, Physics-Based Risk Assessment

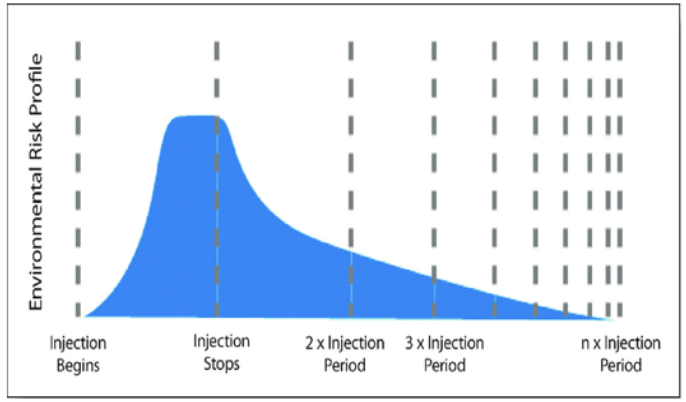


Receptors of Concern
- Groundwater aquifers
- Atmosphere

Potential Migration Pathways
- Wells and boreholes
- Fractures and faults
- Intermediate reservoirs

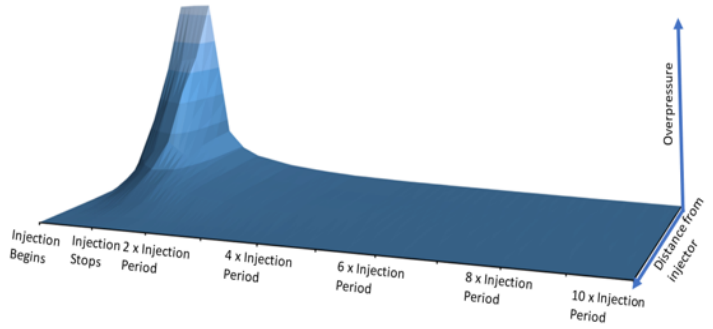
Storage System
- Storage reservoir
- Cap rock

Qualitative, Generalized Representation of Geologic Storage Risks (Benson, 2007)



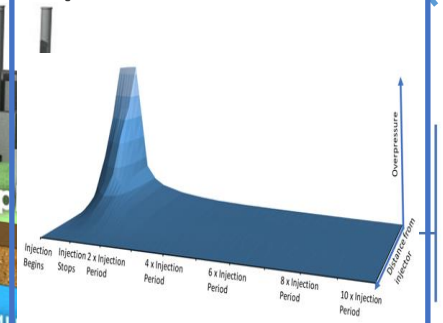
Field Validated Methods and Tools for Physics-Based, Quantitative Risk Assessment

Decay rate for leakage risk at CO_2 storage sites is strongly correlated to reservoir pressure and decreases much more rapid than previously thought (modified from Bromhal et al. 2014 and Pawar et al., 2017)

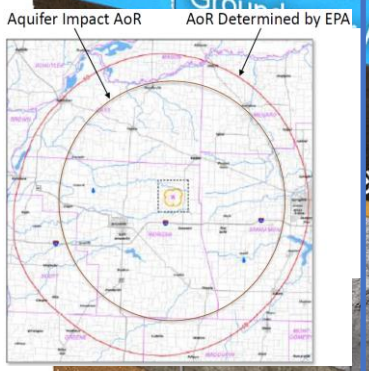


Integrated Decision Support for GCS Site Risk Mgmt

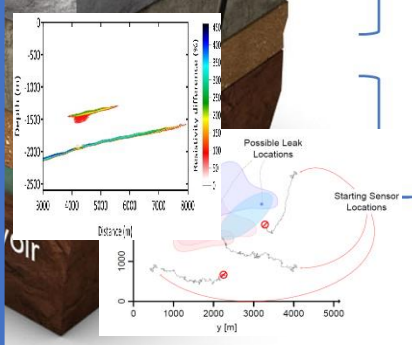
Quantitative, Site-Specific Risk Profiles



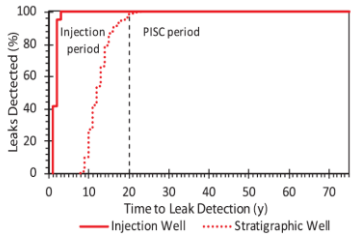
Risk-based AoR



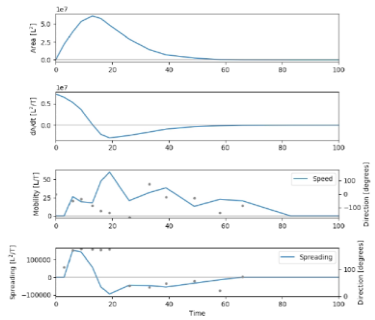
Monitoring Design Evaluation



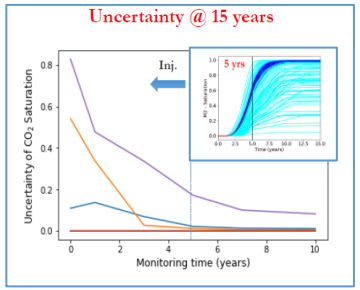
Performance-based Closure Assessment



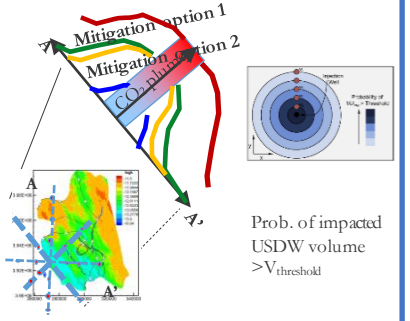
Metrics for Plume Stability



Conformance assessment and uncertainty reduction

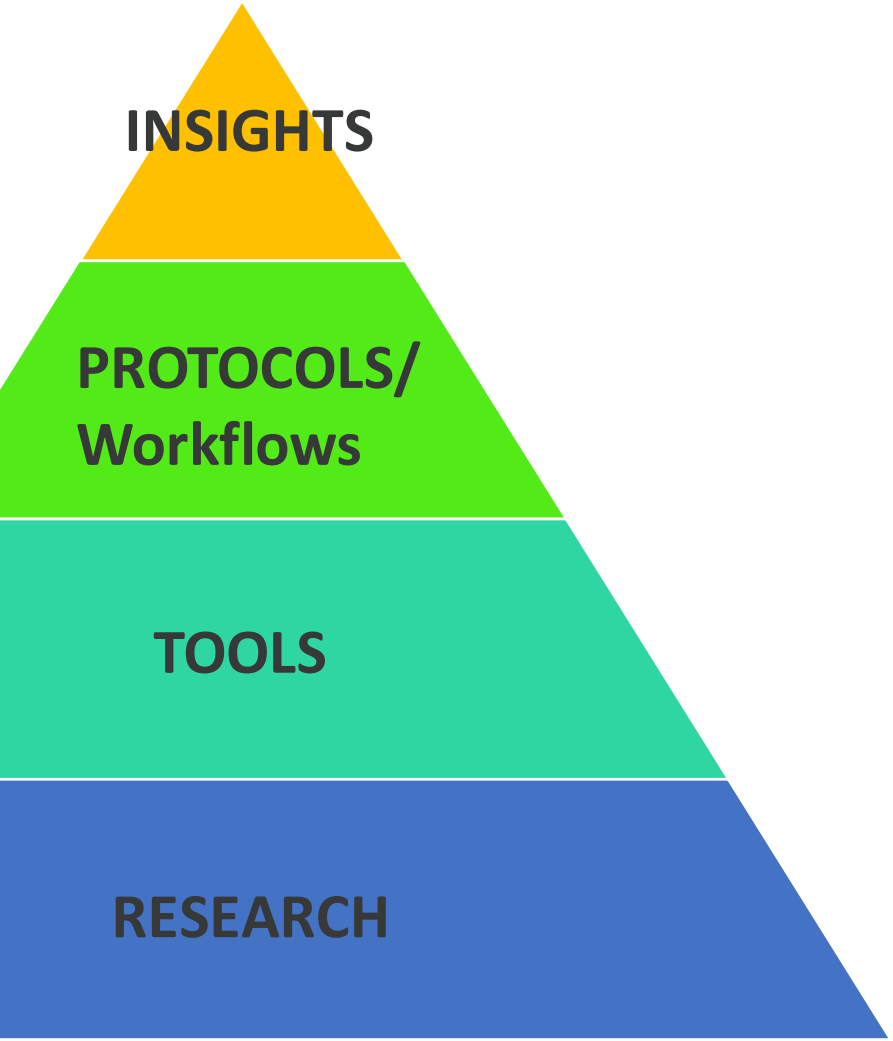


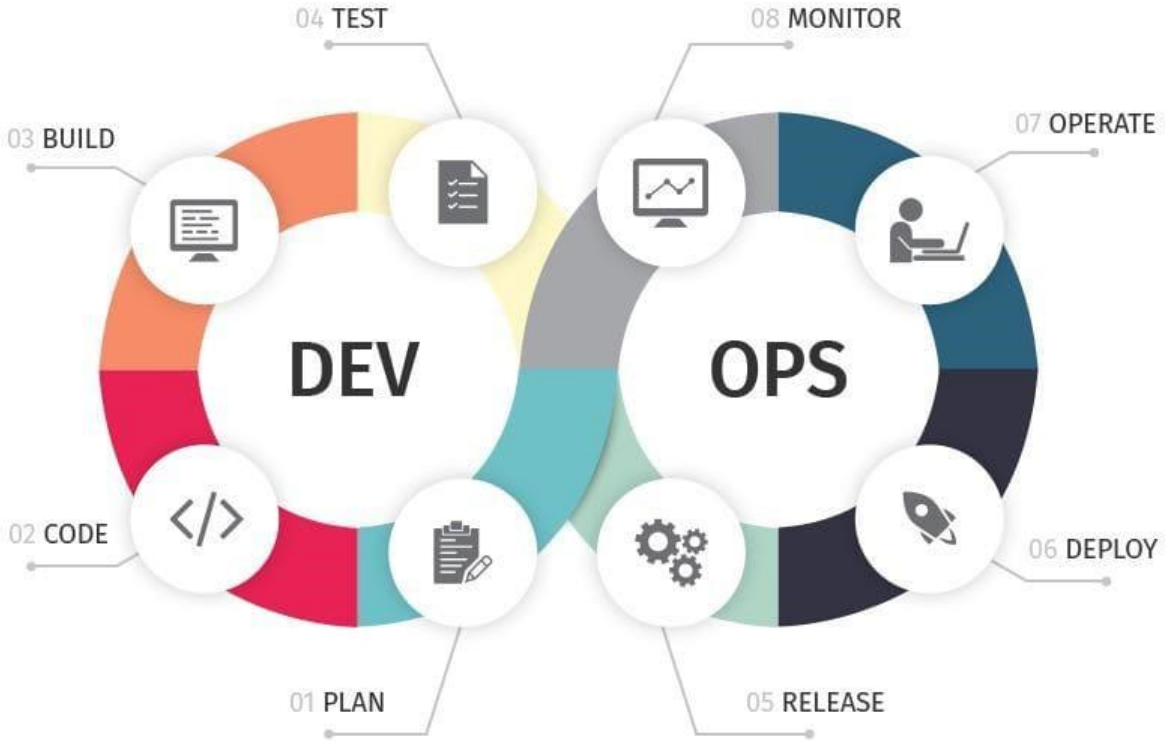
Risk Management and Site Closure Evaluation



https://gitlab.com/NRAP/OpenIAM

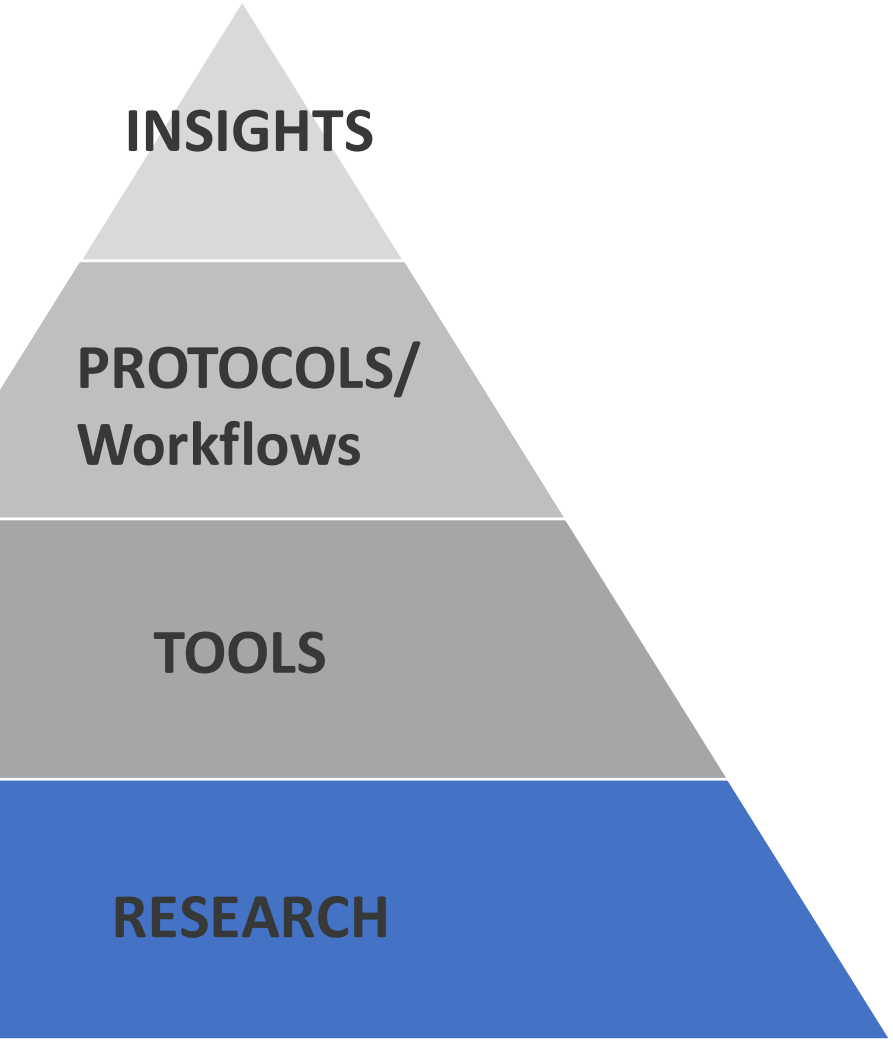
NRAP Products and Stakeholder Engagement





DEV-OPS Image SOURCE: https://res.cloudinary.com/practicaldev/image/fetch/s--dbl8WY9--/c_limit%2Cf_auto%2Cfl_progressive%2Cq_auto%2Cw_880/http://aisaac.io/content/images/2018/11/DevOps.jpg

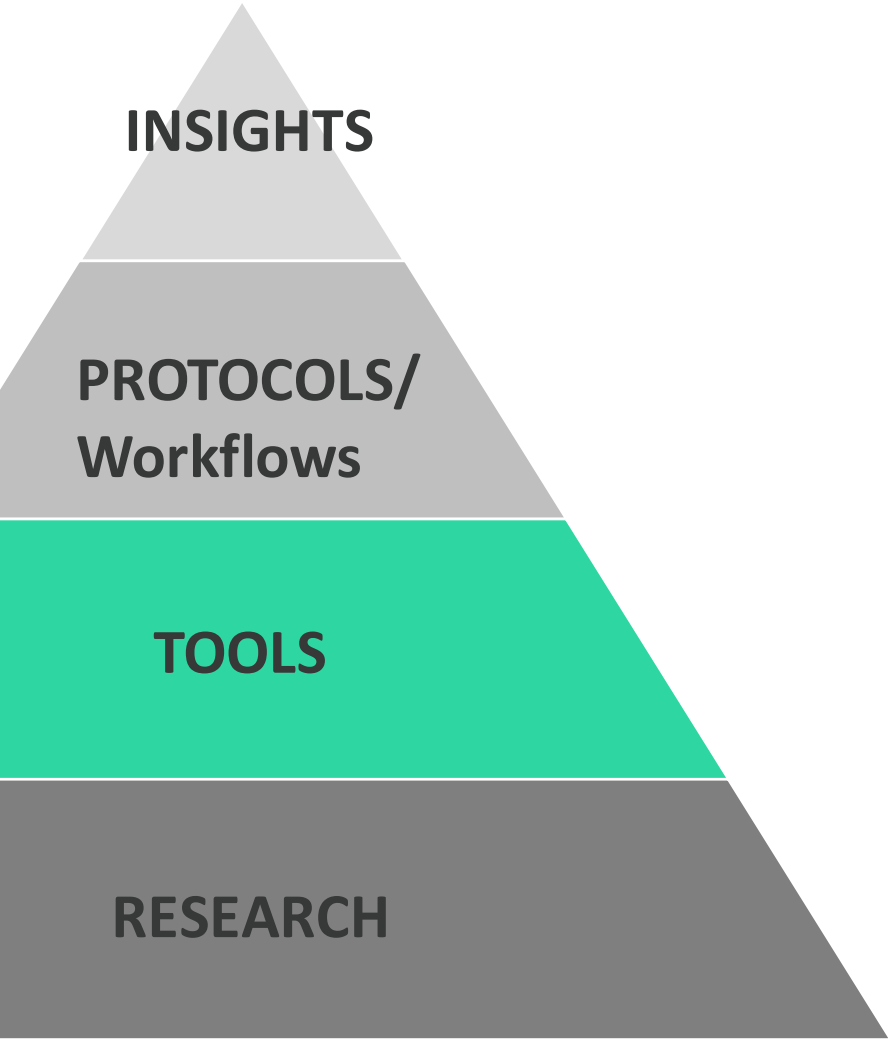
NRAP Foundational Research and Community Data



- **NRAP Phase II - Virtual Special Issue *International Journal of Greenhouse Gas Control* - (September 2020)**
- **Community Datasets**
  - Kimberlina (**initial release March 2020**)
  - FutureGen 2.0 (**initial release October 2020**)
- **https://www.osti.gov/**

~450 publications, 13,650 citations; h-index 65

NRAP Phase II Tools



Leakage Risk/Containment Assurance

- NRAP Open-Source Integrated Assessment Model (NRAP-Open-IAM) - **Beta Release May 2020**

Induced Seismicity Risk

- Short-term Seismic Forecasting Tool (STSF) – **Revision Expected 12/2021**
- State of Stress Analysis Tool (SoSAT) – **Beta release October 2018**
- Probabilistic Seismic Risk Assessment Tool (RiskCat) - **Beta release April 2020**

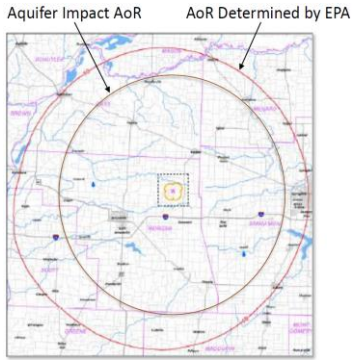
Monitoring Design and Optimization

- Designs for Risk Evaluation and Management (DREAM 2.0) - **Beta Release March 2020**
- Microseismic monitoring design optimization tool – **Beta release October 2020**

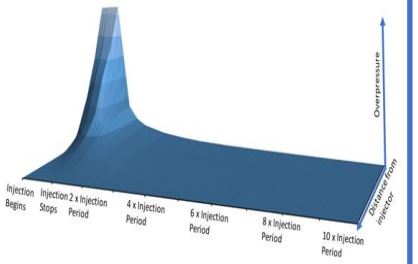
NRAP Tools Available at:
https://edx.netl.doe.gov/nrap/tools-main/

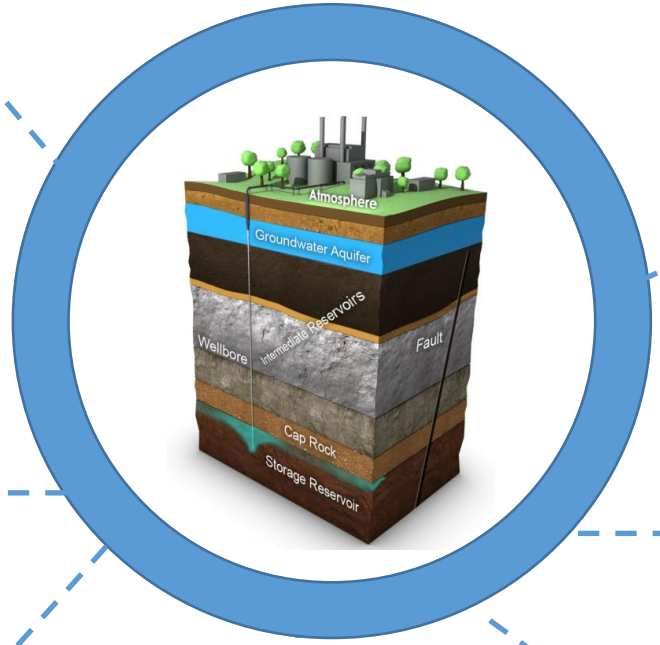
NRAP Open-Source Integrated Assessment Model (NRAP-Open-IAM)

Risk-based AoR



Quantitative, Site-Specific Risk Profiles





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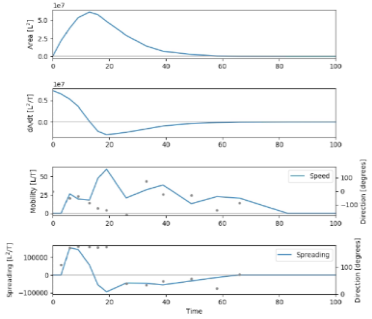

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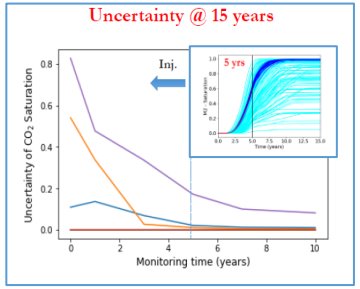
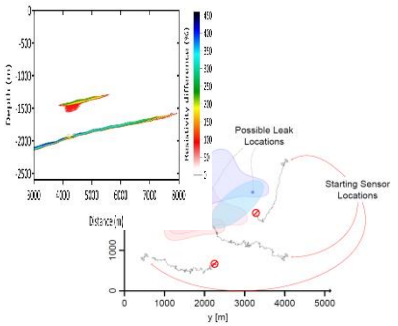
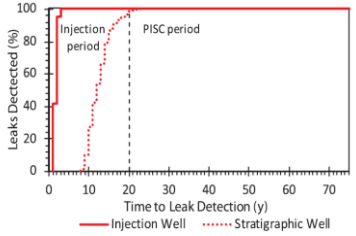


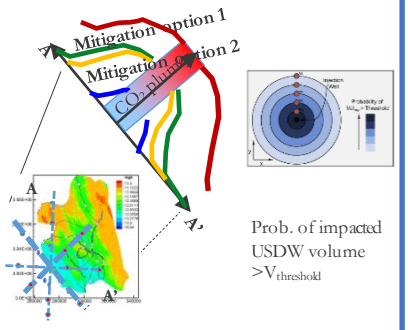
Monitoring Design Evaluation



Performance-based Closure Assessment



Risk Management and Site Closure Evaluation



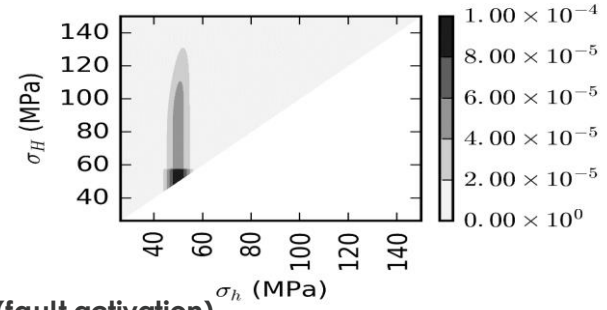
Prob. of impacted USDW volume >$V_{threshold}$

(Vasylkivska et al., forthcoming)
https://gitlab.com/NRAP/OpenIAM

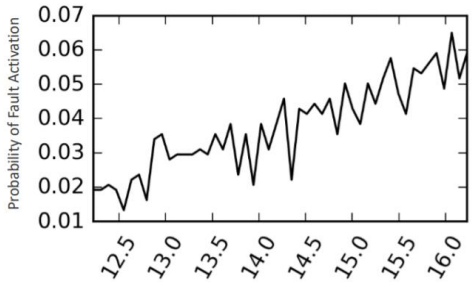
NRAP Induced Seismicity Risk Assessment and Management Tools

State of Stress Analysis Tool (SOSAT)

Stress probability distribution



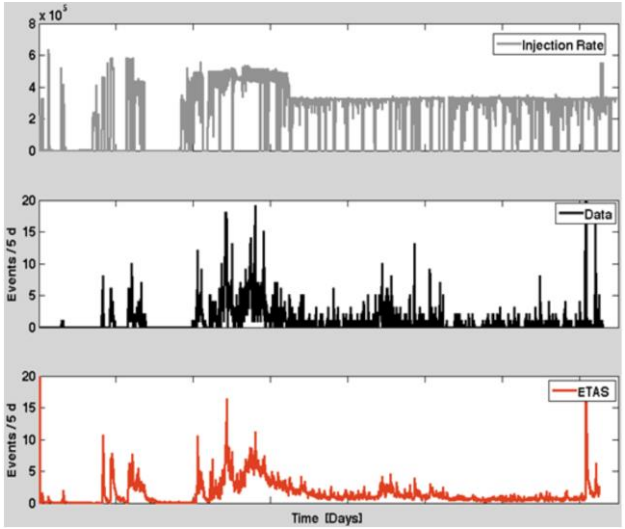
P(fault activation)



(Burghardt, 2018)

Beta tool available at: www.edx.netl.doe.gov/nrap

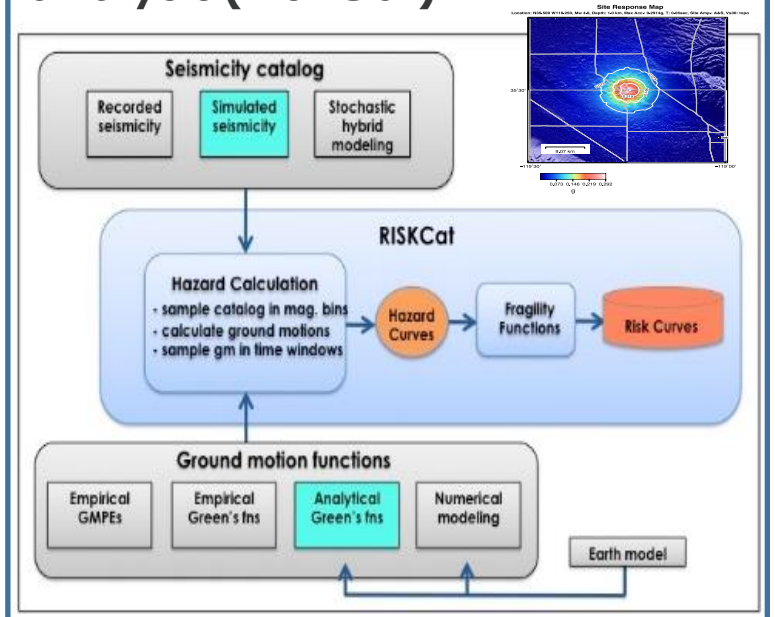
Short-term seismicity forecasting (STSF)



(Bachmann et al., 2014)

Beta tool available at: www.edx.netl.doe.gov/nrap

Probabilistic seismic risk analysis (RiskCat)

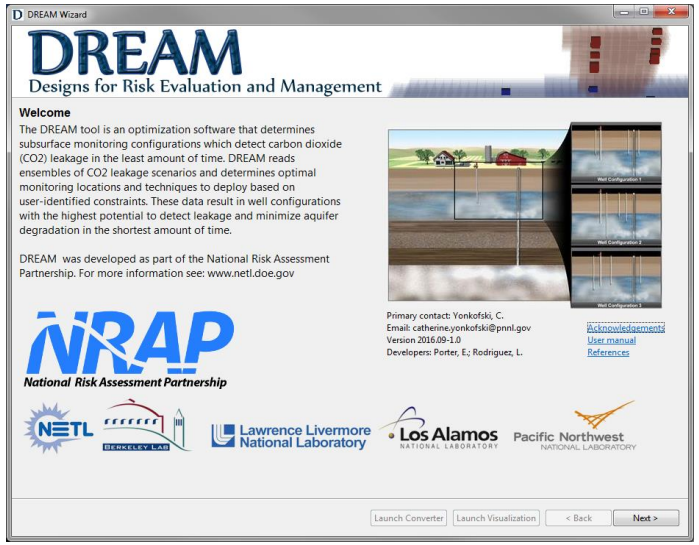


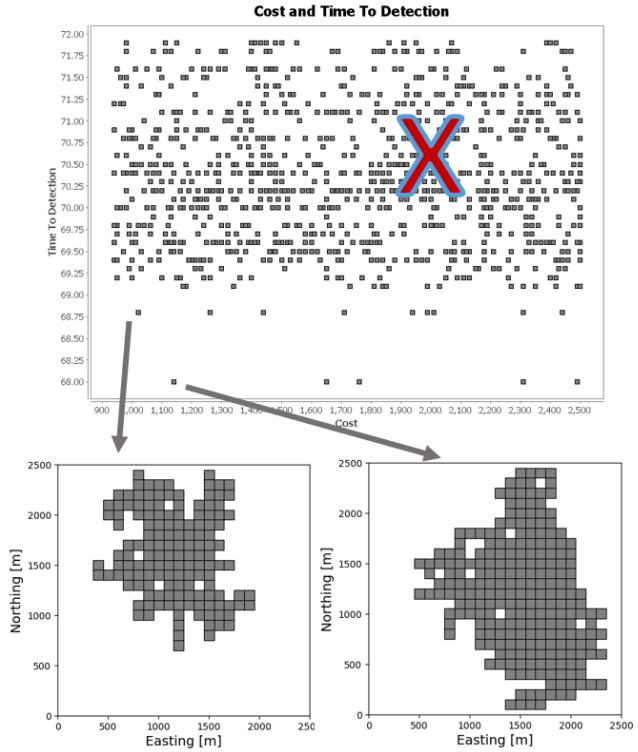
(Savy and Foxall, 2018)

Beta tool available at: https://gitlab.com/NRAP/RiskCat

Monitoring Design and Optimization Tools

Design for Risk Evaluation and Management (DREAM)

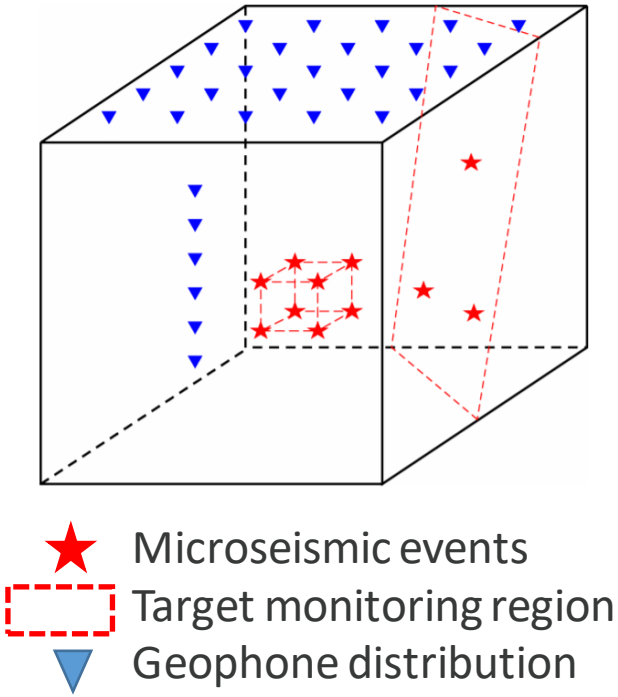




(Yonkofski et al., 2016)

https://edx.netl.doe.gov/workspace/resources/nrap-tools

Passive Seismic Monitoring Tool



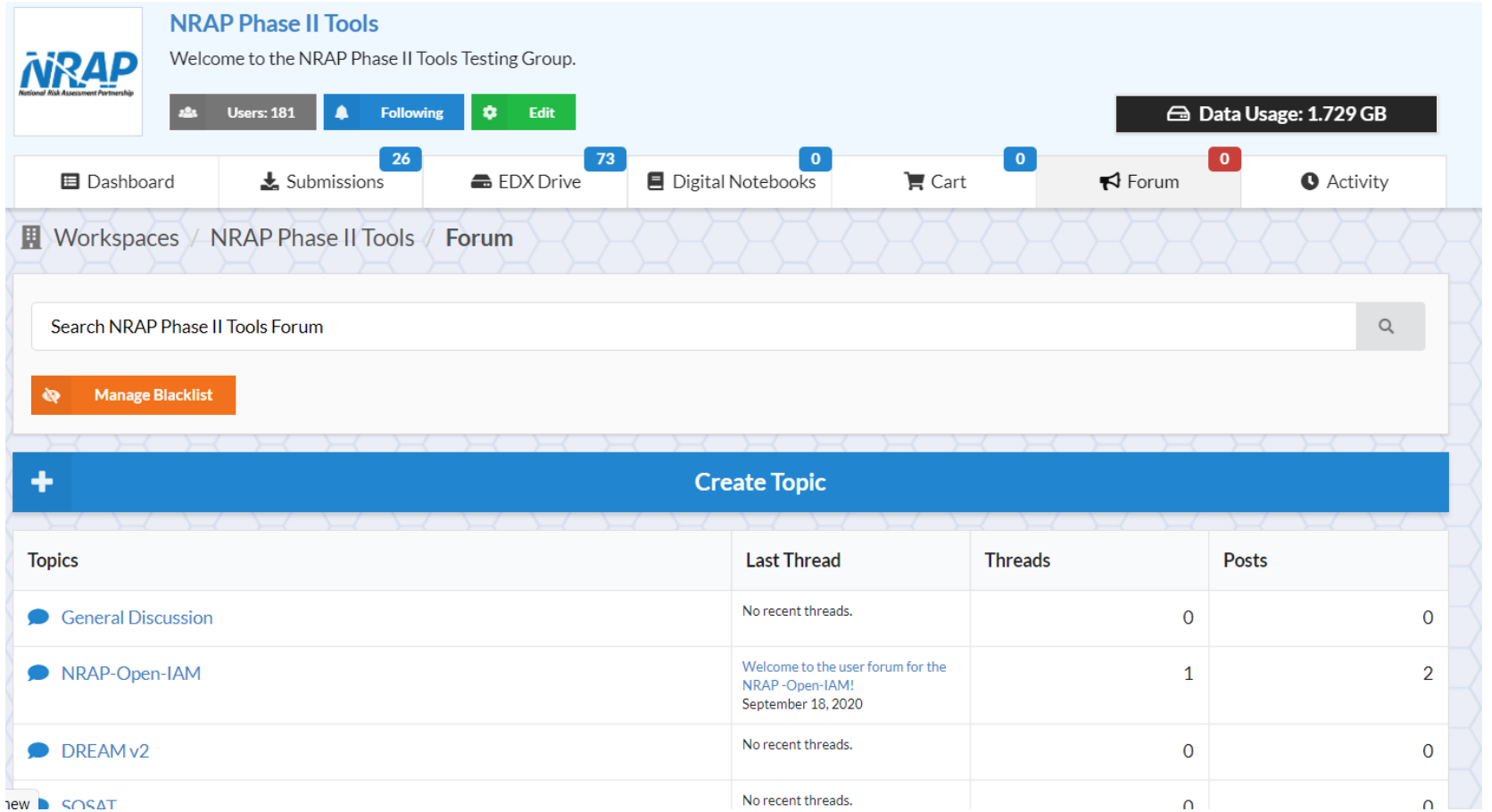
(Chen and Huang, 2020)

https://edx.netl.doe.gov/nrap/passive-seismic-monitoring-tool-psmt/

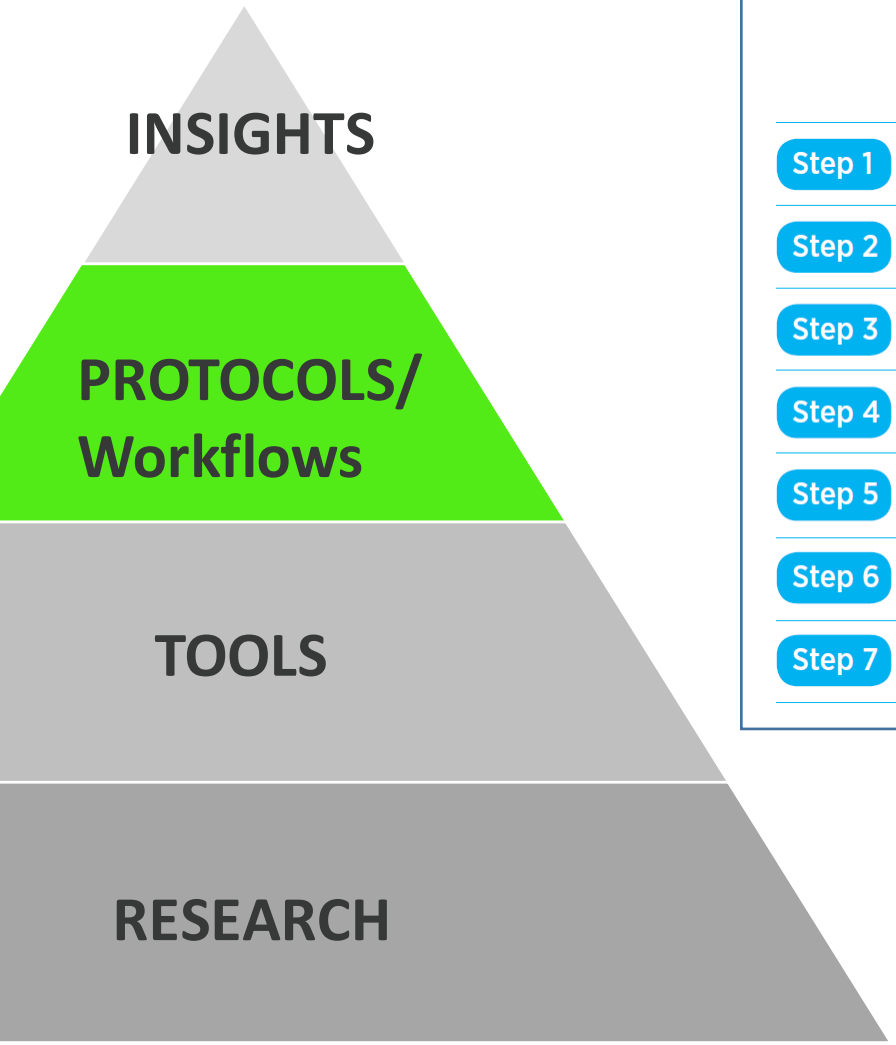
New NRAP Phase II Tools User Forum on EDX

https://edx.netl.doe.gov/workspace/forum/nrap-tools

Requires EDX account and permission to access NRAP tools workspace



Recommended Practices for Risk Management

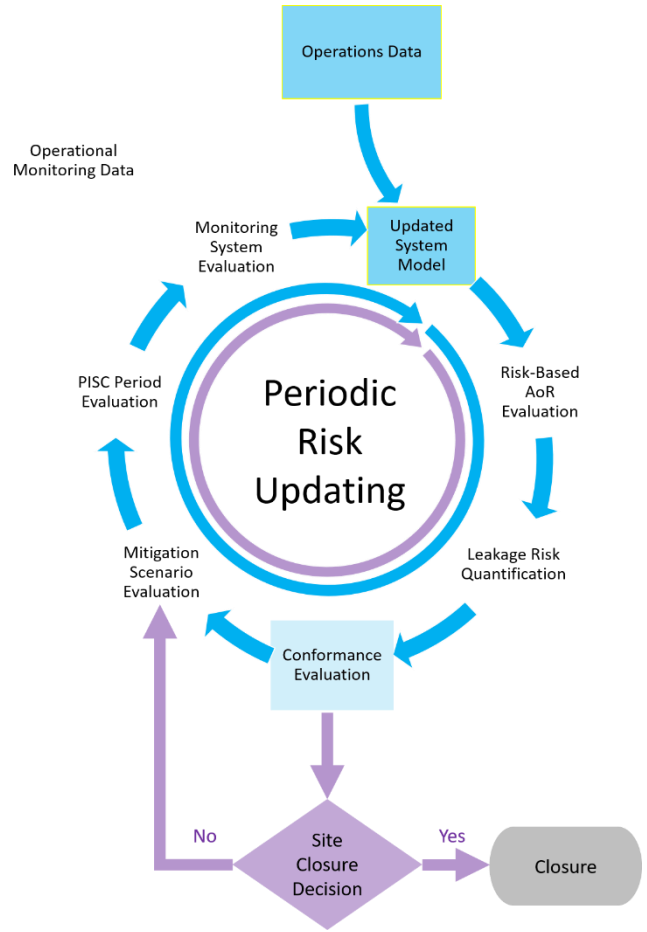


Induced Seismicity Risk Management

Step 1	Perform a preliminary screening evaluation.
Step 2	Implement an outreach and communication program.
Step 3	Review and select criteria for ground vibration and noise.
Step 4	Establish seismic monitoring.
Step 5	Quantify the hazard from natural and induced seismic events.
Step 6	Characterize the risk of induced seismic events.
Step 7	Develop risk-based mitigation plan.

Drafts Released March 8, 2021
Feedback still being accepted
Comments to: NRAP@netl.doe.gov

Leakage Risk Management and Containment Assurance



NRAP Tasks 4 and 6 Contributors

Task 4– Strategic Monitoring for Uncertainty Reduction

Task Lead: Erika Gasperikova (LBNL)

- Delphine Appriou (PNNL)
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Task 6 – Addressing critical risk-related questions

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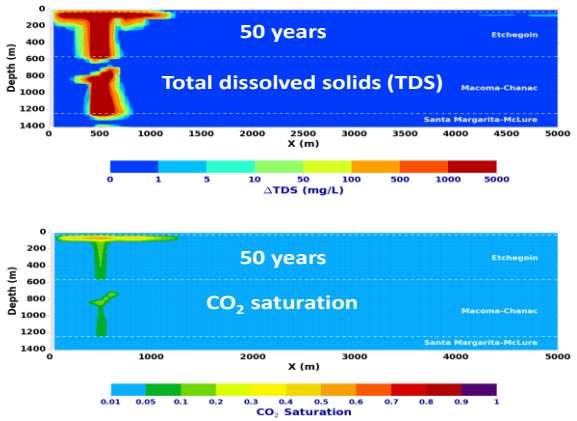
- Megan Smith (LLNL)
- Robert Van Voorhees (NETL)
- Veronika Vasylkivaka (NETL)
- Josh White (LLNL)

Task 4. Strategic Monitoring for Uncertainty Reduction

Estimating Leak Detection Thresholds of Monitoring Techniques

Stochastic Leakage Simulations



Monitoring Technology

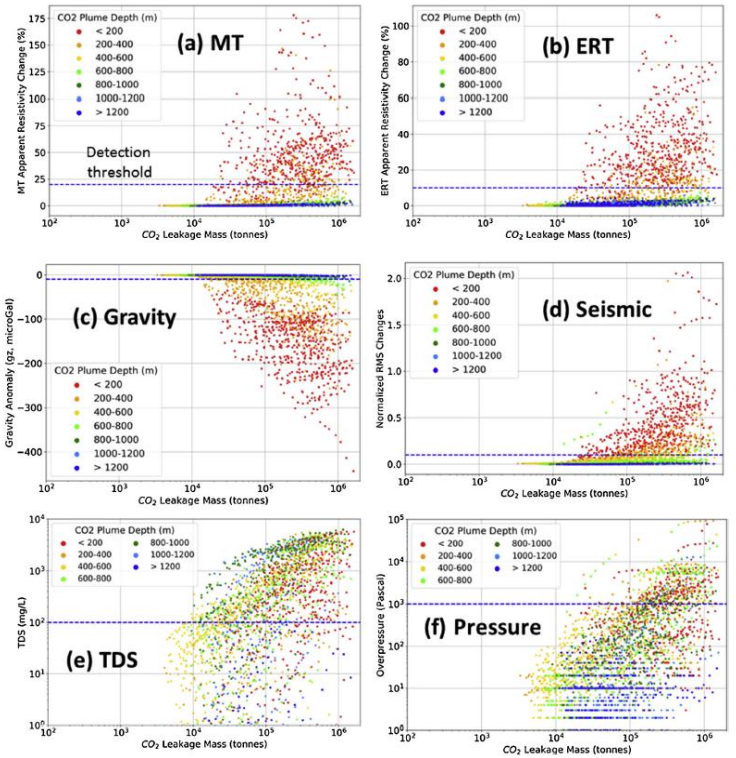
- MT (Magnetotellurics)
- ERT (Electrical Resistivity Tomography)
- Gravity
- Seismic

SURFACE

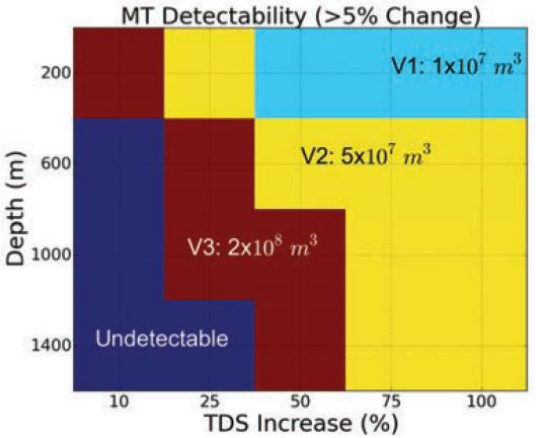
- TDS (Total Dissolved Solids)
- Pressure

DOWNHOLE

Model Geophysical Monitoring



Estimate Leak Detectability

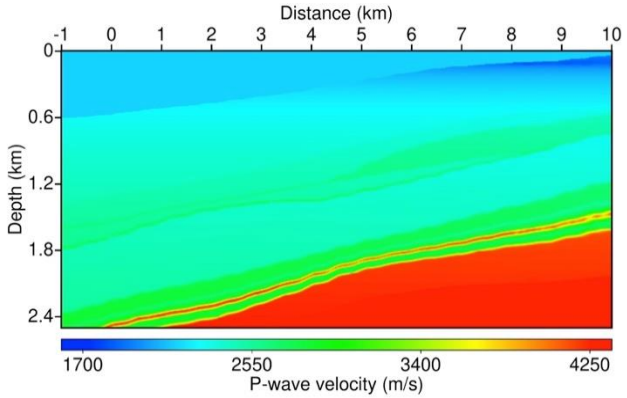


Gasperikova, E.; Daley, T.; Appriou, D.; Bonneville, A.; Feng, Z.; Huang, L.; Yang, X.; Wang, Z.; Dilmore, R.; Gao, K. Detection Thresholds and Sensitivities of Geophysical Techniques for CO2 Plume Monitoring; NRAP-TRS-I-001-2020; DOE.NETL-2021.2638; NRAP Technical Report Series; U.S. Department of Energy, National Energy Technology Laboratory: Pittsburgh, PA, 2020; p 64. DOI: 10.2172/1735331.

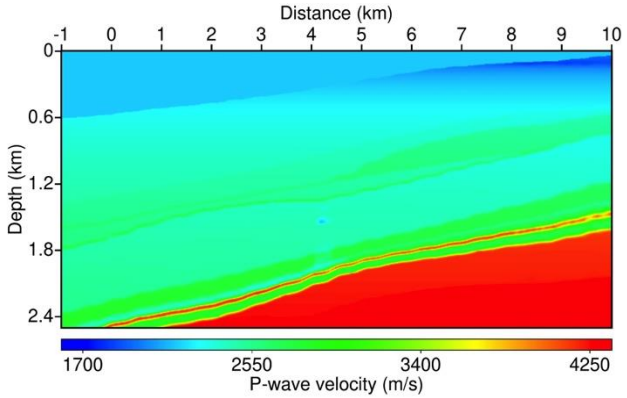
Seismic imaging of CO_2 plumes using Kimberlina 2 models with realistic seismic noise

Zongcai Feng, Lianjie Huang, Kai Gao, Erika Gasperikova

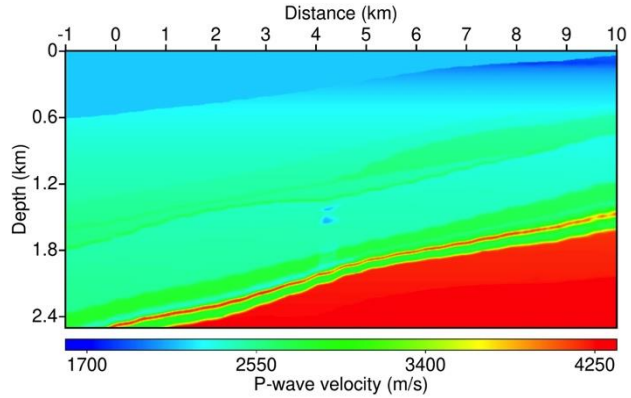
baseline: t0



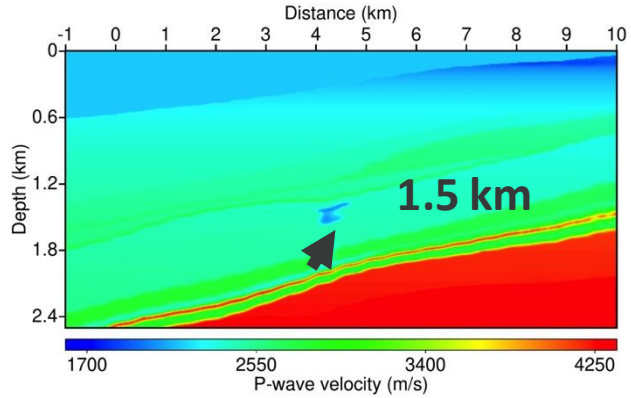
deep plume: t1



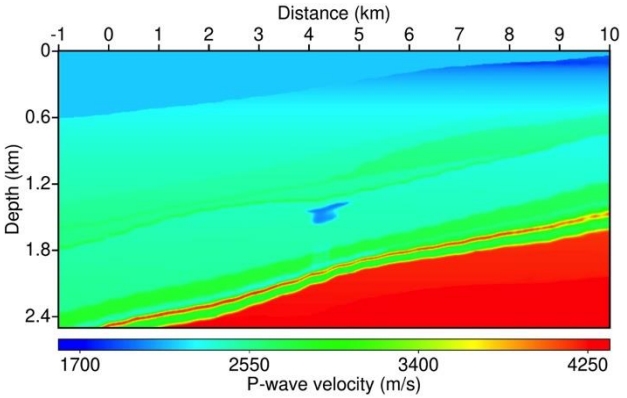
deep plume: t1+2yr



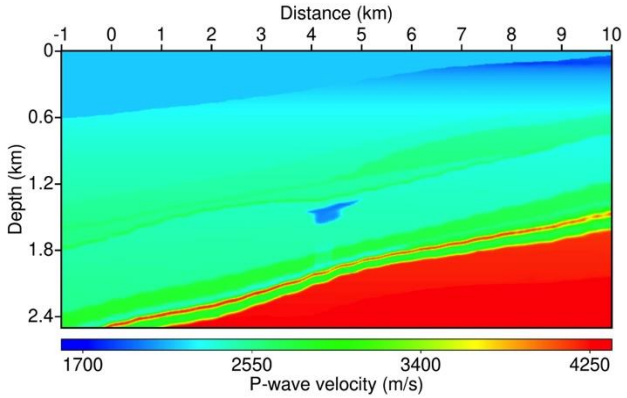
deep plume: t1+7yr



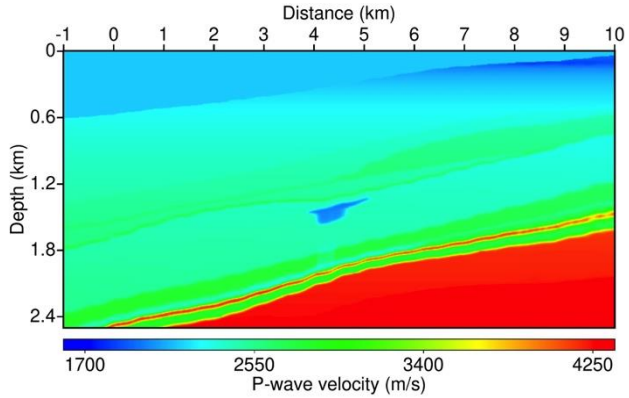
deep plume: t1+12yr



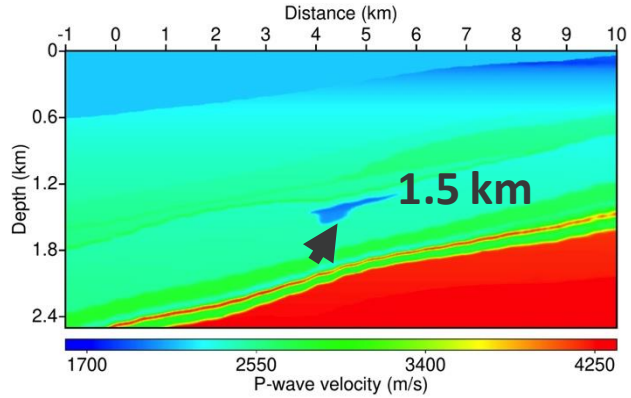
deep plume: t1+17yr



deep plume: t1+22yr



deep plumes: t1+47yr

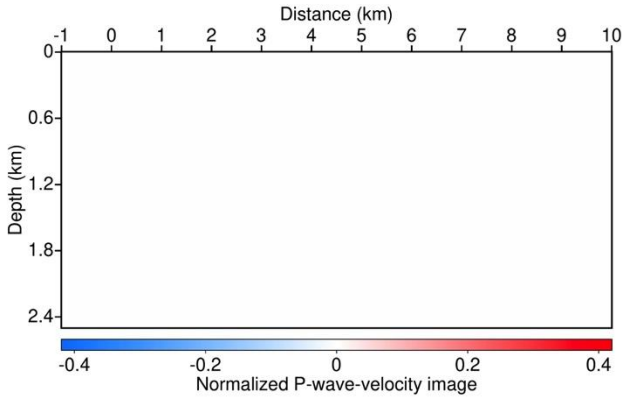


Seismic imaging of CO_2 plumes using Kimberlina 2 models with realistic seismic noise

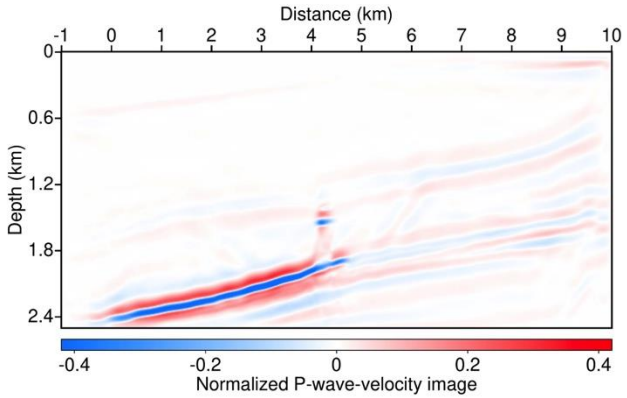
Zongcai Feng, Lianjie Huang, Kai Gao, Erika Gasperikova

Noise free data

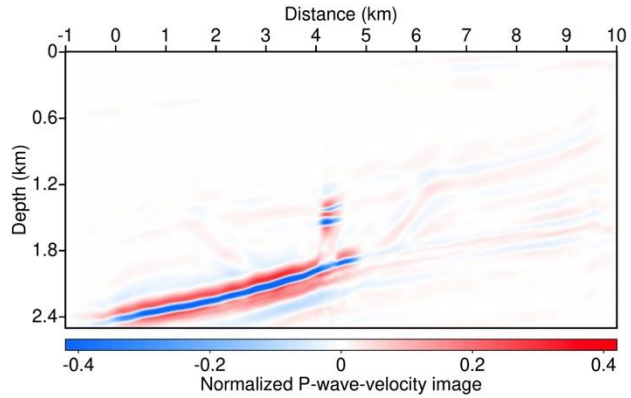
baseline: t0



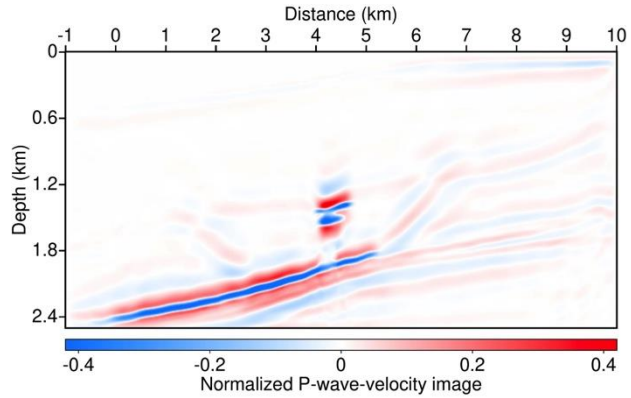
deep plume: t1



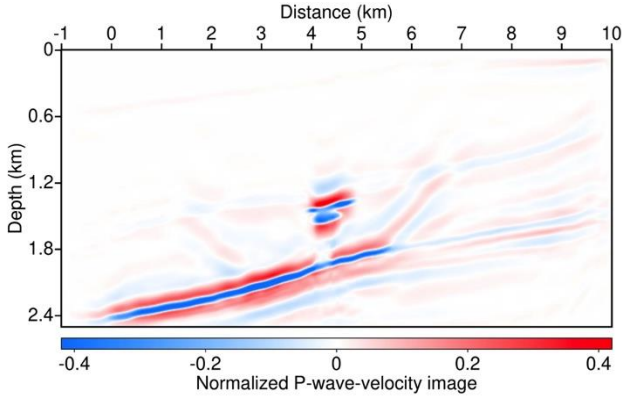
deep plume: t1+2yr



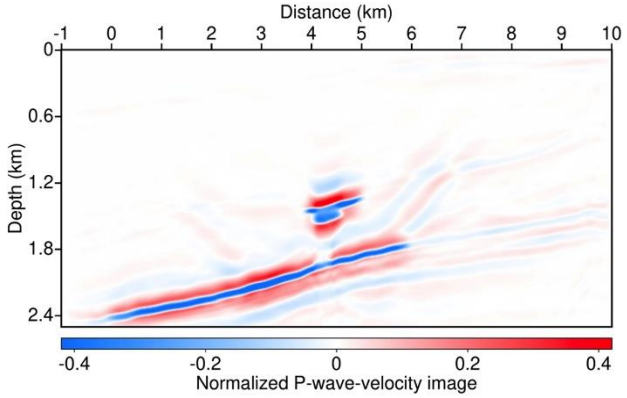
deep plume: t1+7yr



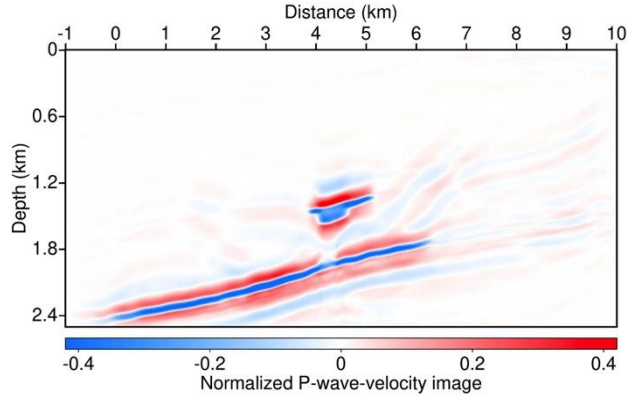
deep plume: t1+12yr



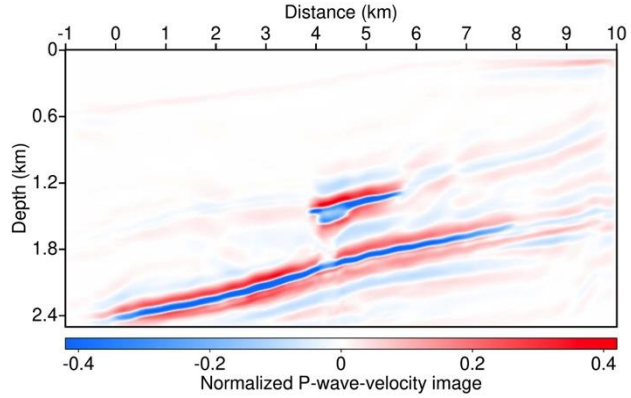
deep plume: t1+17yr



deep plume: t1+22yr



deep plumes: t1+47yr

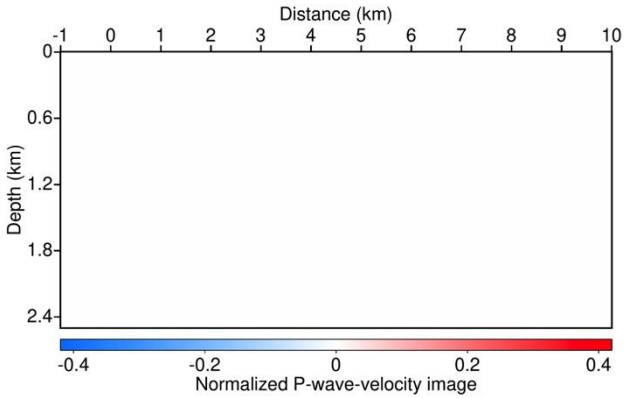


Seismic imaging of CO_2 plumes using Kimberlina 2 models with realistic seismic noise

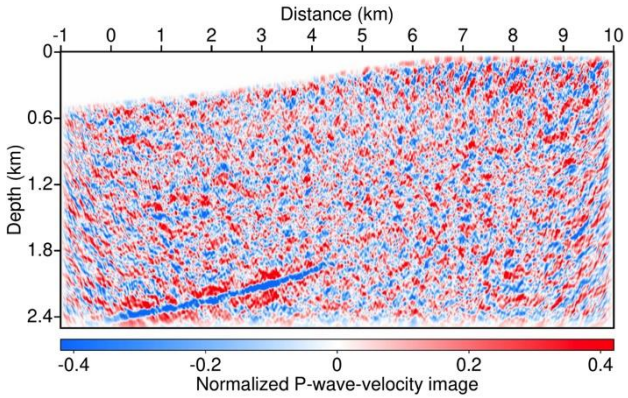
Zongcai Feng, Lianjie Huang, Kai Gao, Erika Gasperikova

Seismic data with SNR = 2

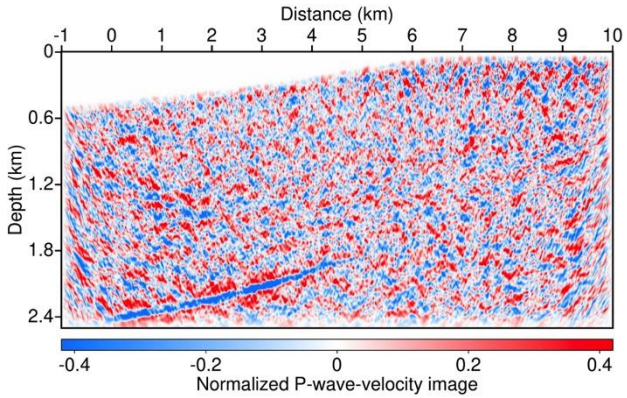
baseline: t0



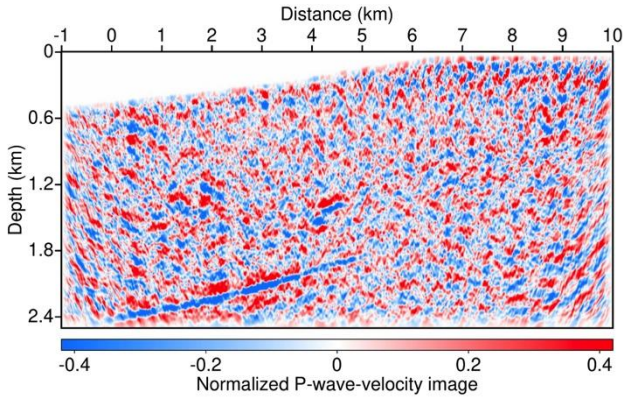
deep plume: t1



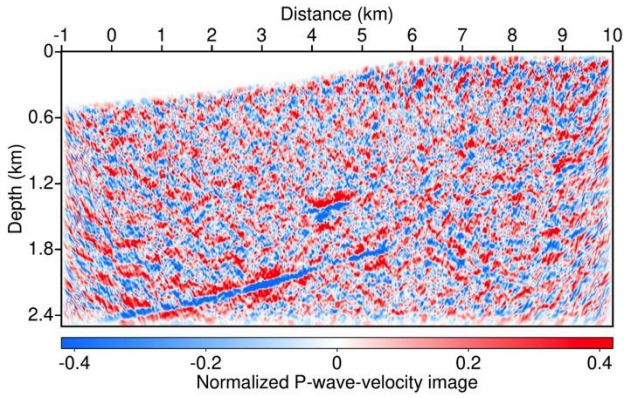
deep plume: t1+2yr



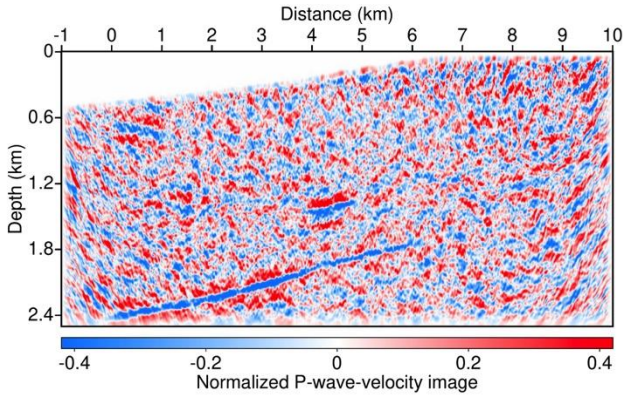
deep plume: t1+7yr



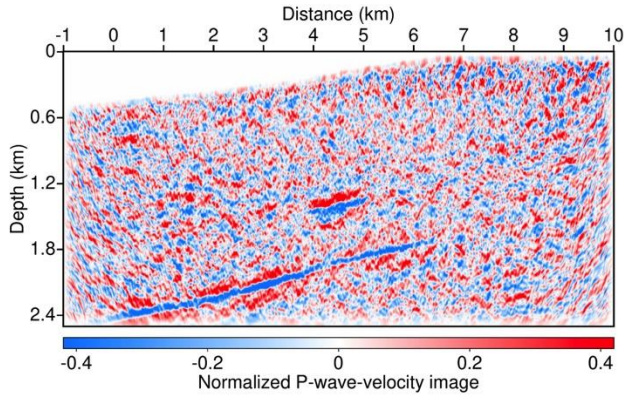
deep plume: t1+12yr



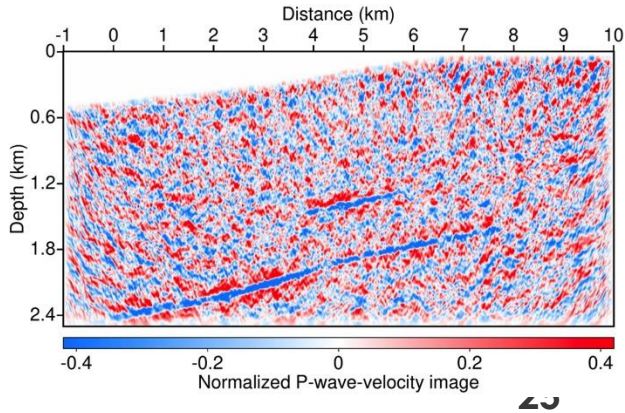
deep plume: t1+17yr



deep plume: t1+22yr



deep plumes: t1+47yr



Seismic noise was extracted from field seismic data recorded at Kevin Dome, MT

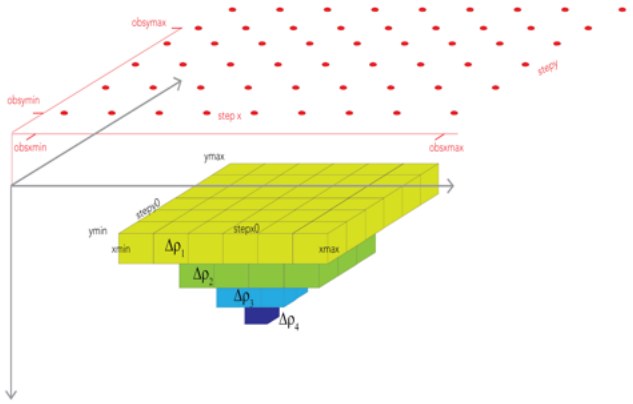
CO2Grav – reduced complexity gravity modeling of CO_2 migration

Delphine Appriou, Alain Bonneville

INPUT

Site-specific properties:
- Geothermal Gradient
  - Surface Temp.
  - Gradient
- Hydrostatic pressure gradient.

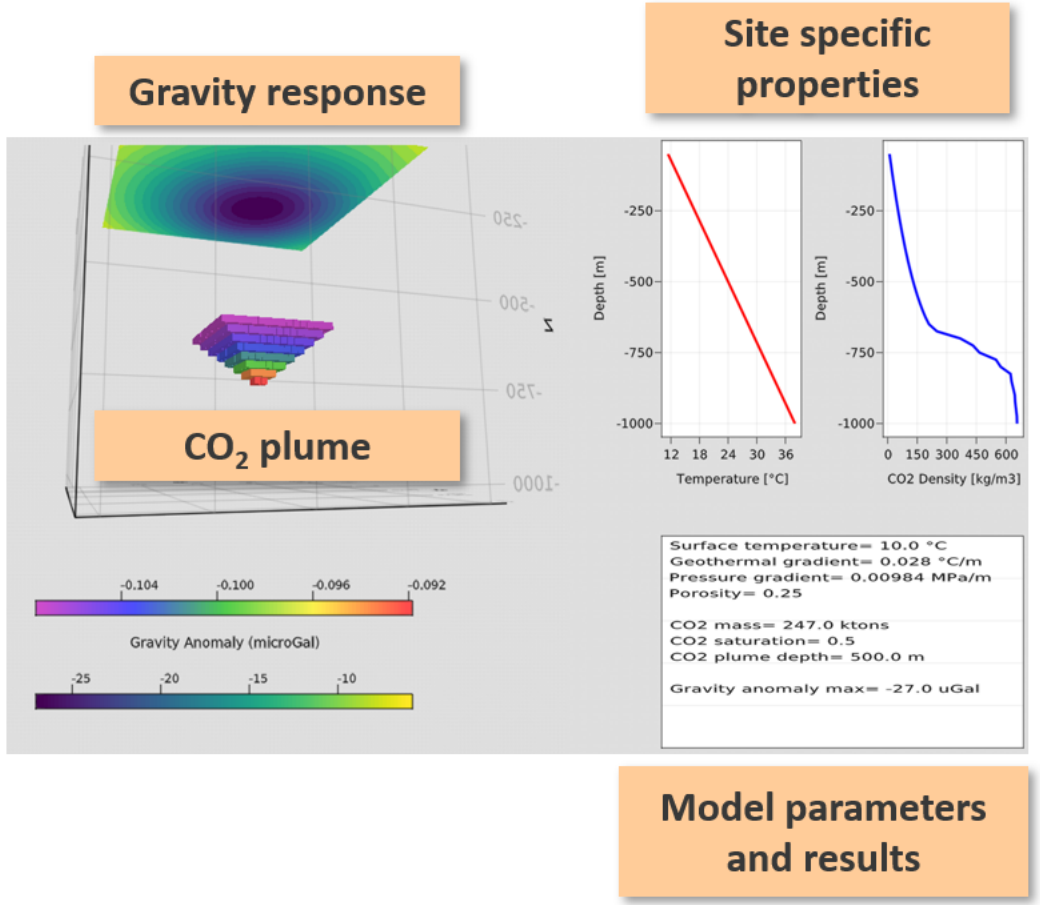
Observation point
- obsxmin/obsxmax/stepx
- obsymin/obsymax/stepy



CO_2 Plume properties:
- CO_2 Sat.
- Matrix Porosity

CO_2 Plume Dimensions
- xmin/xmax/stepx0
- ymin/ymax/ztepy0
- zmin/zmax/stepz0

OUTPUT

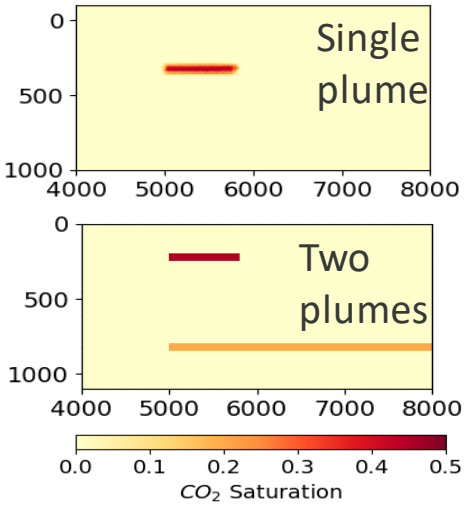


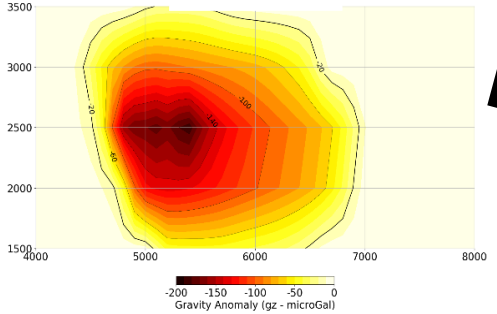
(forthcoming)

Deep learning inversion of gravity data for detection of CO_2 plumes in overlying aquifers (1)

Xianjin Yang, Xiao Chen, Megan Smith

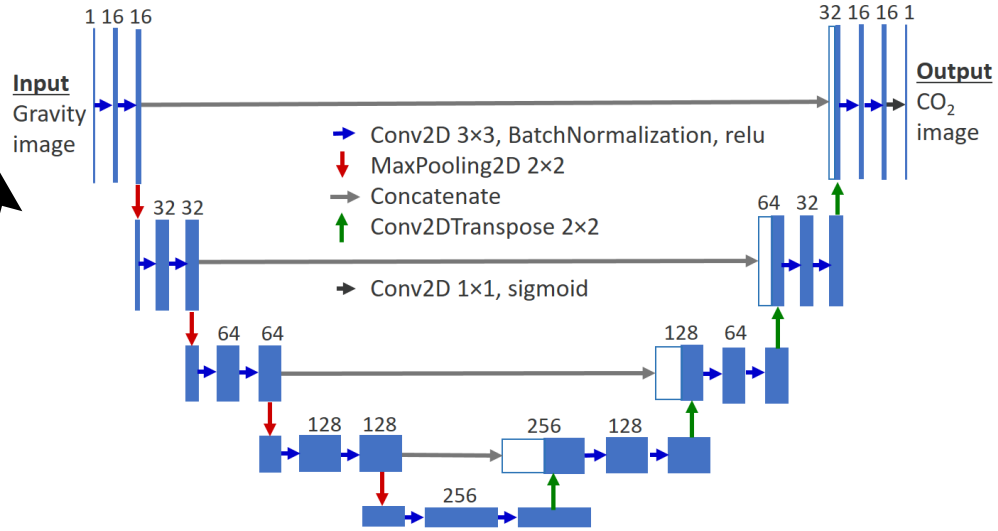
Density models





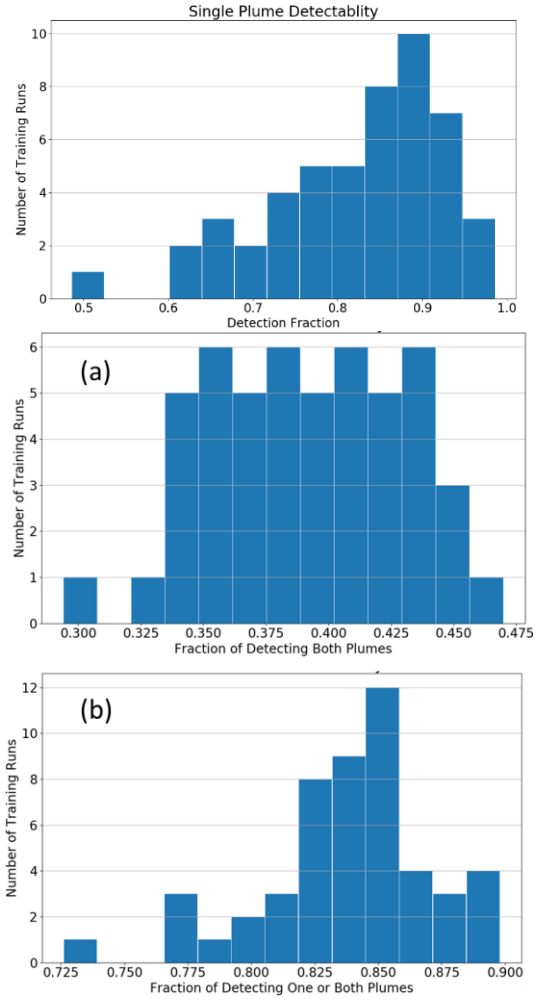
Surface gravity data

U-net network



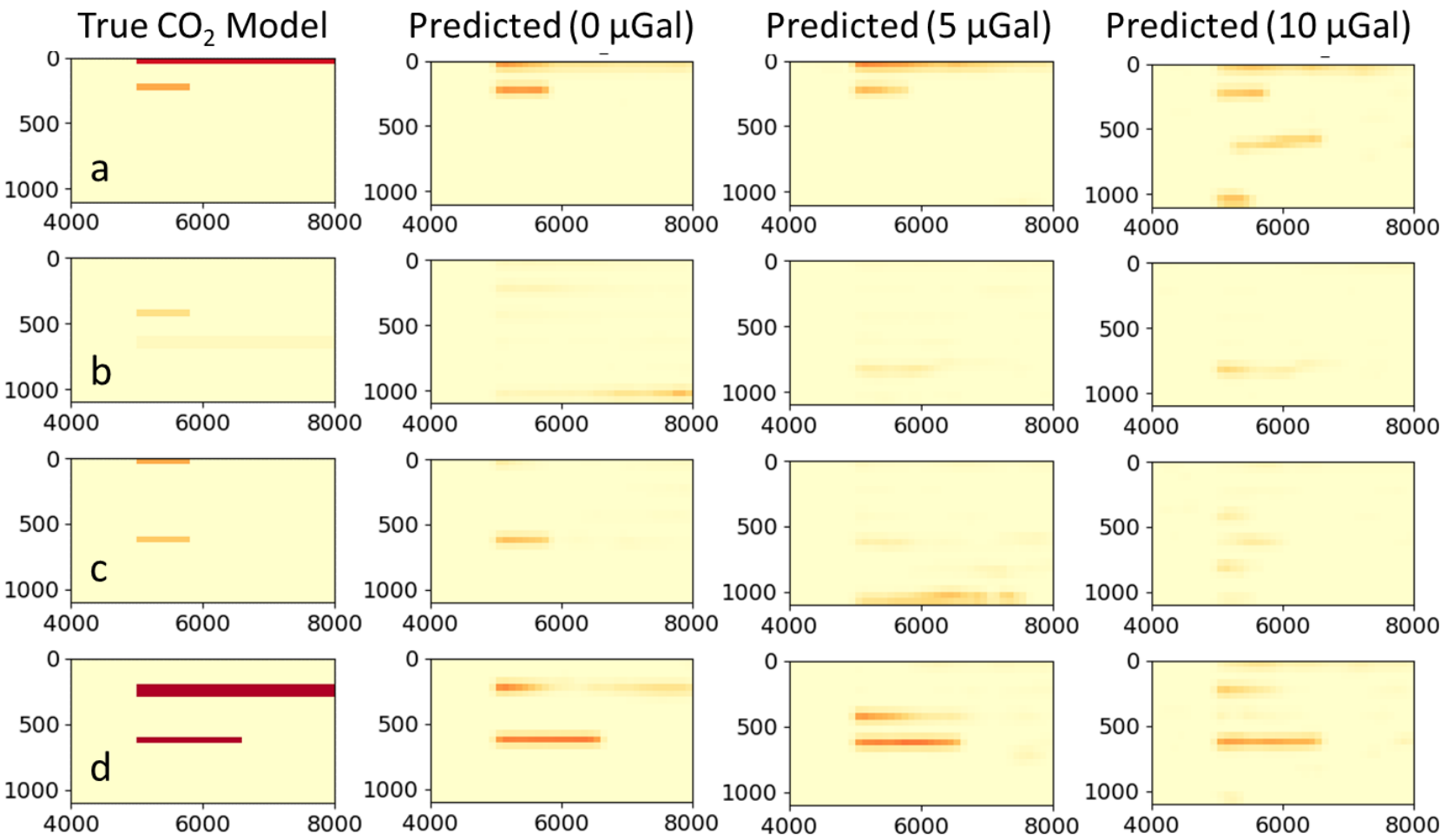
- Deep learning inversion can resolve single plume model accurately
- Undetected single plumes correspond to small gravity anomalies
- Detecting one of two plumes is possible, but detecting both plumes in the two-plume scenario is challenging

Results



Deep learning inversion of gravity data for detection of CO_2 plumes in overlying aquifers (2)

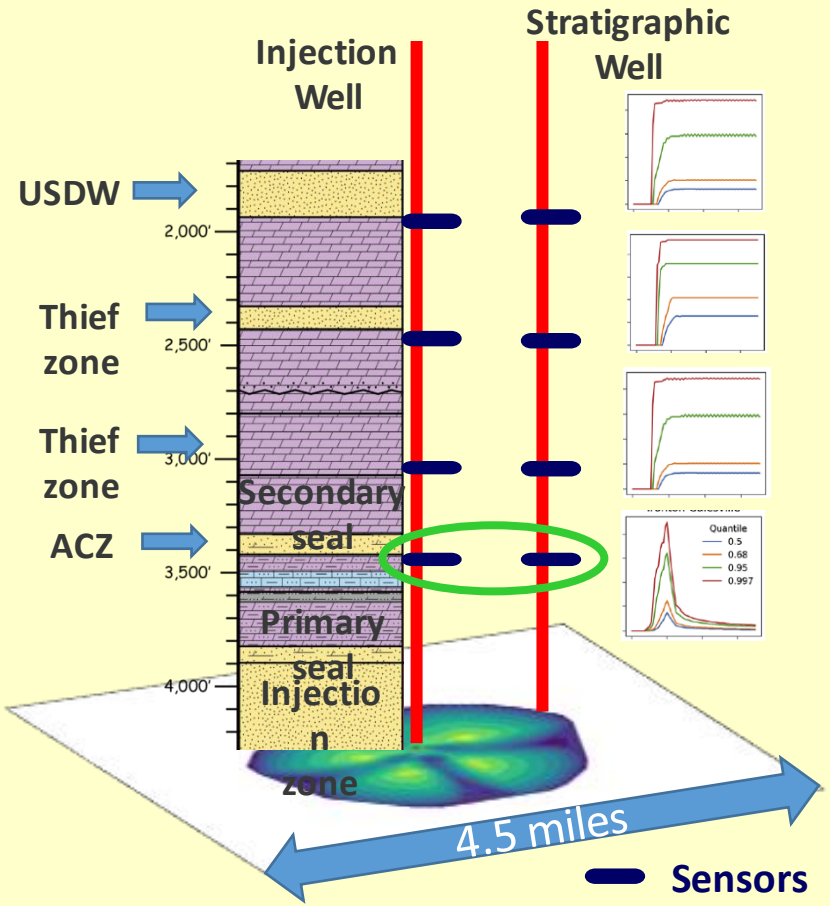
Xianjin Yang, Xiao Chen, Megan Smith



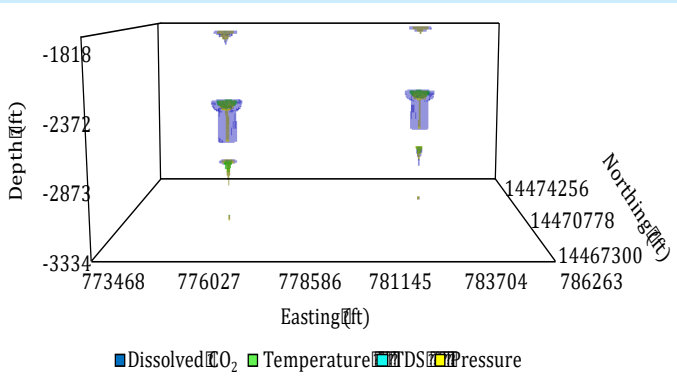
The deep learning inversion accurately detects >80% of single plumes, but more noise in the data lowers detection fraction

Monitoring Design and PISC Period Determination – FutureGen 2.0 case

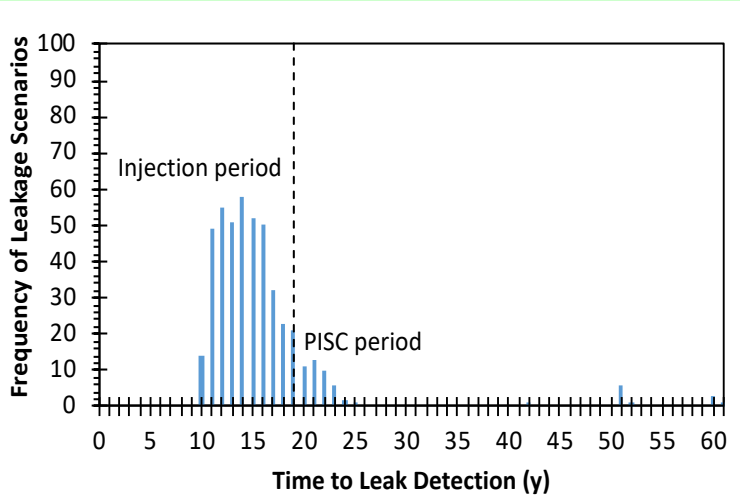
NRAP-Open-IAM simulations of Storage and Leakage



Optimization of monitoring design using **DREAM**



Decision support for monitoring design and PISC



Supports a net PISC period reduction of 40-years and a total cost reduction of~ $50M

Bacon DH, CM R Yonkofski, CF Brown, DI Demirkanli, and JM Whiting. 2019. "Risk-based post injection site care and monitoring for commercial-scale carbon storage: Reevaluation of the FutureGen 2.0 site using NRAP-Open-IAM and DREAM." *International Journal of Greenhouse Gas Control* 90:102784. 10.1016/j.ijggc.2019.102784.

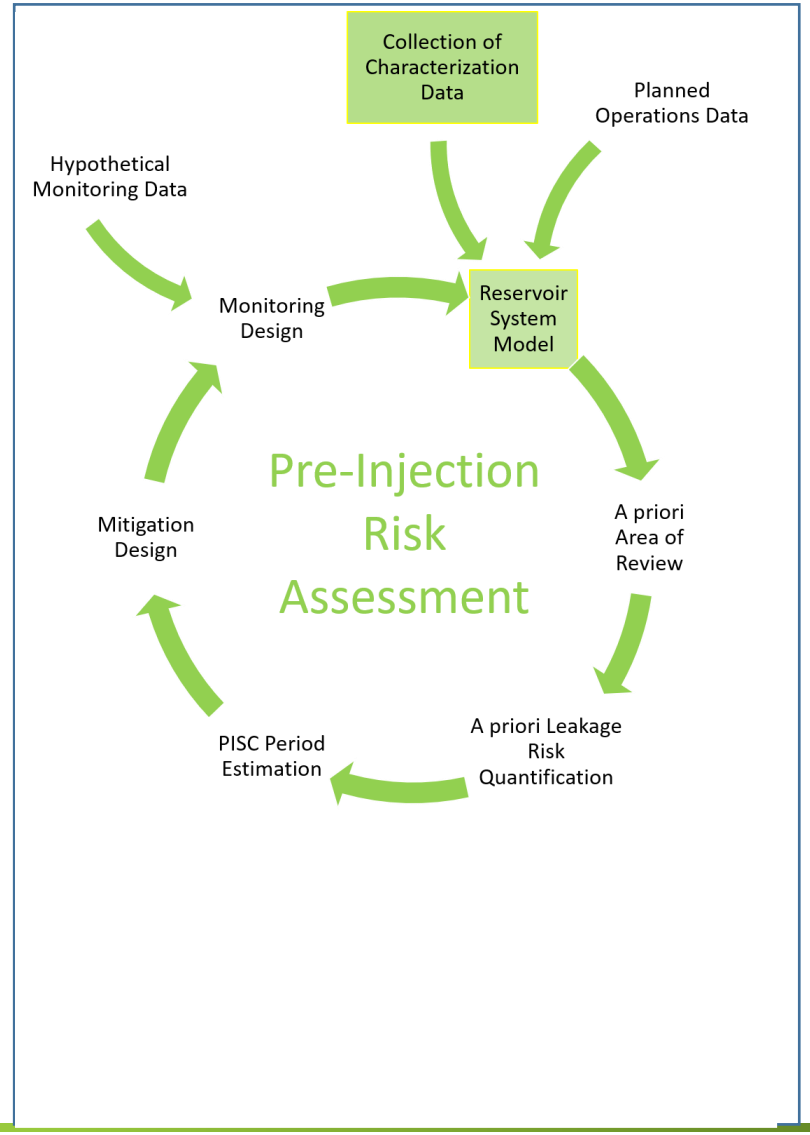
Task 6: Addressing critical risk-related questions

Recommended Practices Containment Assurance and Leakage Risk Management (Thomas et al., DRAFT)

- Planning and Execution of Risk-based GCS Site Characterization
- Characterization of State of Stress and Geomechanical Conditions
- Developing a Risk-based AOR
- Risk-based Strategic Monitoring
- Assessing GCS System Conformance
- Evaluating Mitigation Scenarios to Inform Risk Management Decisions (under development)
- Defining a Risk-based Period of Post-injection Site Care in Support of Site-Closure Decision-making

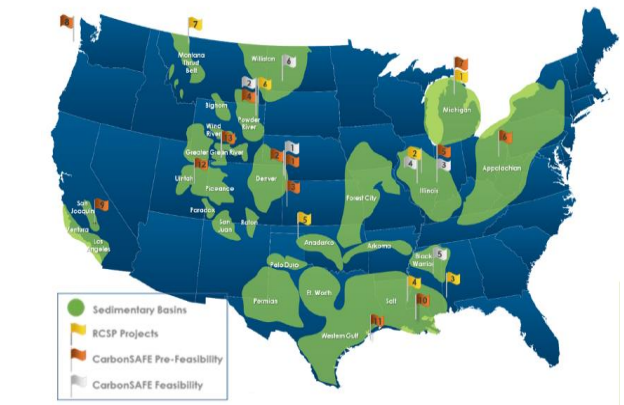
Draft Released March 8, 2021
Feedback still being accepted
Comments to: NRAP@netl.doe.gov

https://edx.netl.doe.gov/dataset/draft-nrap-recommended-practices-for-containment-assurance-and-leakage-risk-quantification



Engaging with Key Stakeholders

DOE CarbonSAFE

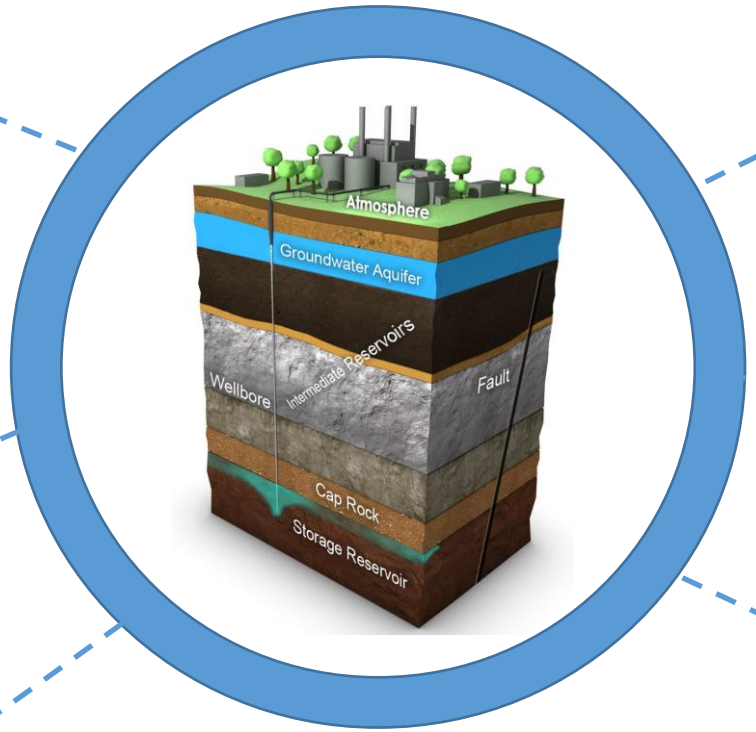


DOE-FE Regional Initiatives

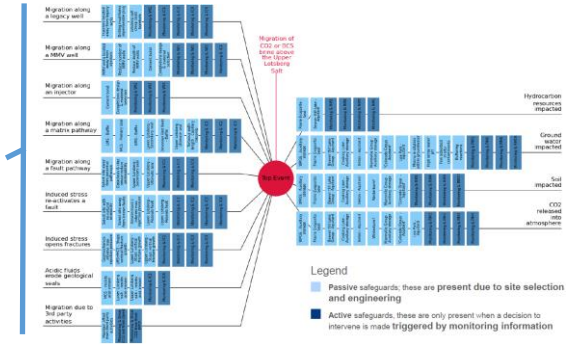
DOE-FE SMART Initiative

SMART

NRAP
National Risk Assessment Partnership



Industry Best Practices



Bourne et al., 2014

International CCUS RD&D Community

ieaghg

Regulatory Context

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

NORTH DAKOTA OIL AND GAS DIVISION

DEQ

NATIONAL ENERGY TECHNOLOGY LABORATORY
Los Alamos NATIONAL LABORATORY EST. 1943
Pacific Northwest NATIONAL LABORATORY

Thank you!

Comments and Questions:

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

Sign up for NETL EDX: https://edx.netl.doe.gov/user/register

NRAP Timeline and Milestones for Phase II Completion

- **NRAP Phase II Completion by March 2022**
  - Release of final NRAP Phase II toolset
  - Release of final recommended practices documents
  - Release of final NRAP applications catalog
  - Finalize NRAP community datasets
  - Accomplishments and key insights reporting