National Risk Assessment Partnership - Strategic Monitoring for Uncertainty Reduction

Erika Gasperikova[1], Michael Commer[1], Quanlin Zhou[1], Thomas Daley[1], Delphine Appriou[2], Alain Bonneville[2], Xianjin Yang[3], Thomas Buscheck[3], Kayyum Mansoor[3], Susan Carroll[3], Kai Gao[4], Lianjie Huang[4], Yu Chen[4], Ting Chen[4], Zheng Zhou[4], Youzuo Lin[4], Zhongping Zhang[4], Yue Wu[4], George Guthrie[4], Zan Wang[5], Robert Dilmore[5], Grant Bromhal[5], William Harbert[5], Catherine Yonkofski[2], Jonathan Whiting[2], Diana Bacon[2], Jeffrey Burghardt[2]

[1]LBNL, [2]PNNL, [3]LLNL, [4]LANL, [5]NETL

U.S. Department of Energy

National Energy Technology Laboratory

Addressing the Nation's Energy Needs Through Technology Innovation – 2019 Carbon Capture, Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting

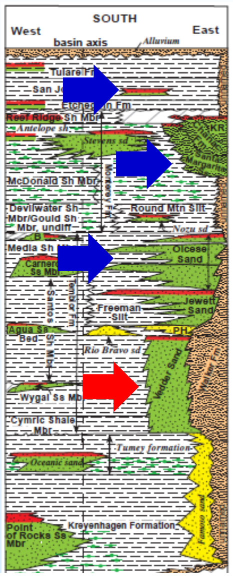
August 26-30, 2019

Presentation Outline

- Secondary CO_2 plume detection (Kimberlina 2: Leakage through a dipping fault)
  - Surface seismic, Electromagnetic, and Gravity methods
- Monitoring methods for detection of brine and CO_2 leakage (Kimberlina 1.2: Leakage through legacy wells)
  - Surface seismic, Magnetotellurics, Electrical resistivity tomography, Gravity, Downhole pressure, Chemical sampling
- Machine learning approaches for leakage detection
- Tools for optimal monitoring design
  - Microseismic Monitoring Network, DREAM
- Summary

Surface seismic and EM methods for CO_2 plumes detection (1)

Gasperikova, E., Commer, M., Zhou, Q., Gao, K., Huang, L., Daley, T.



Secondary CO_2 zones:

Etchegoin (~500 m)

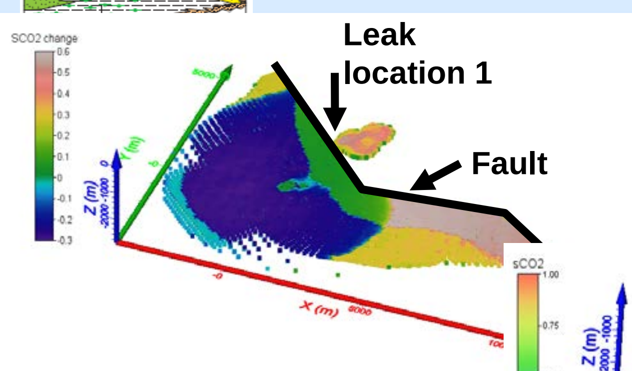
Santa Margarita (~1000 m)

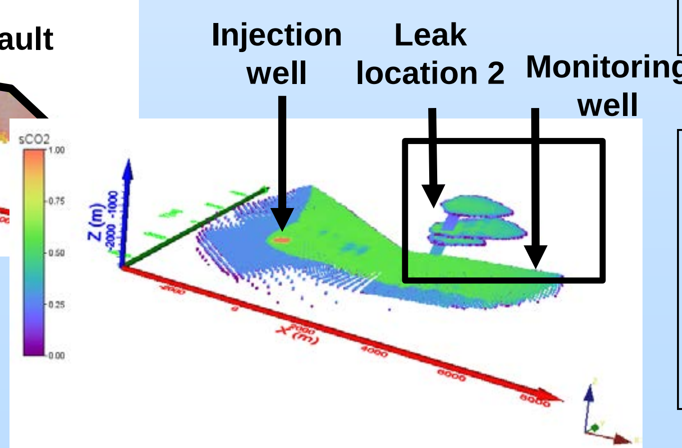
Olcese (~1500 m)

Injection Zone:

Vedder Sands (~2500 m)

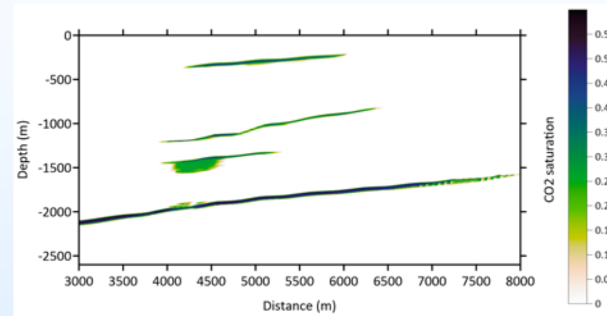
- Injection: 2.5 Mt/year for 60 years, total injected CO_2 mass is 150 Mt
- The fault (70˚ dip) is simulated as a barrier to the flow



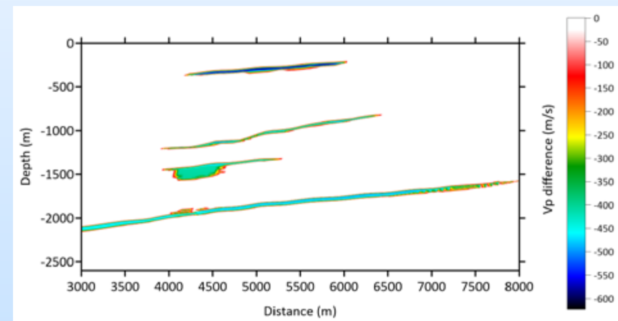


Time-lapse changes

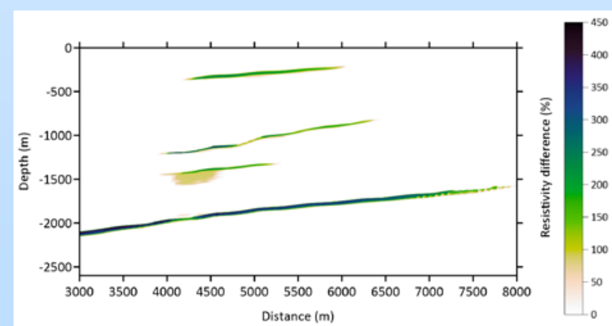
CO_2 saturation



Vp



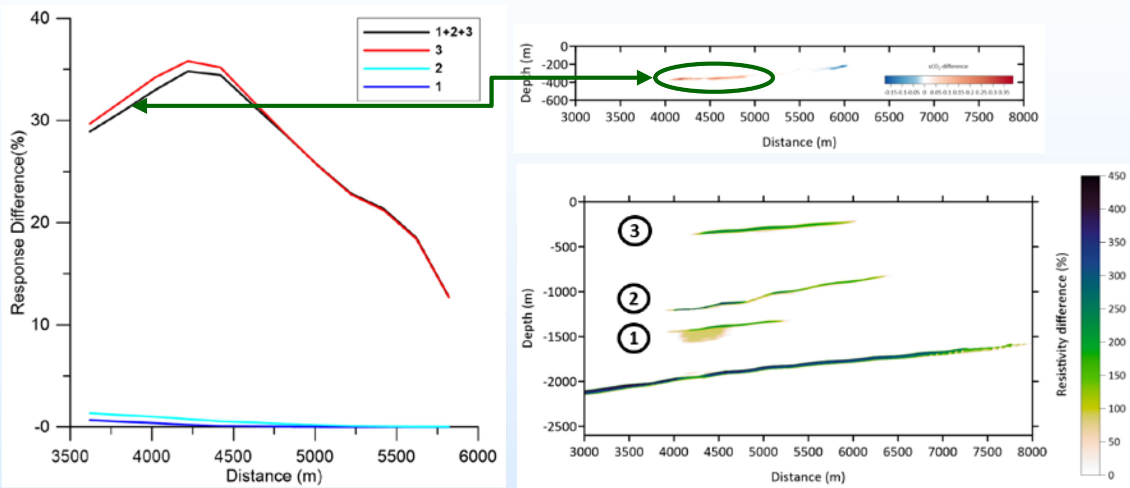
Resistivity



Surface seismic and EM methods for CO_2 plumes detection (2)

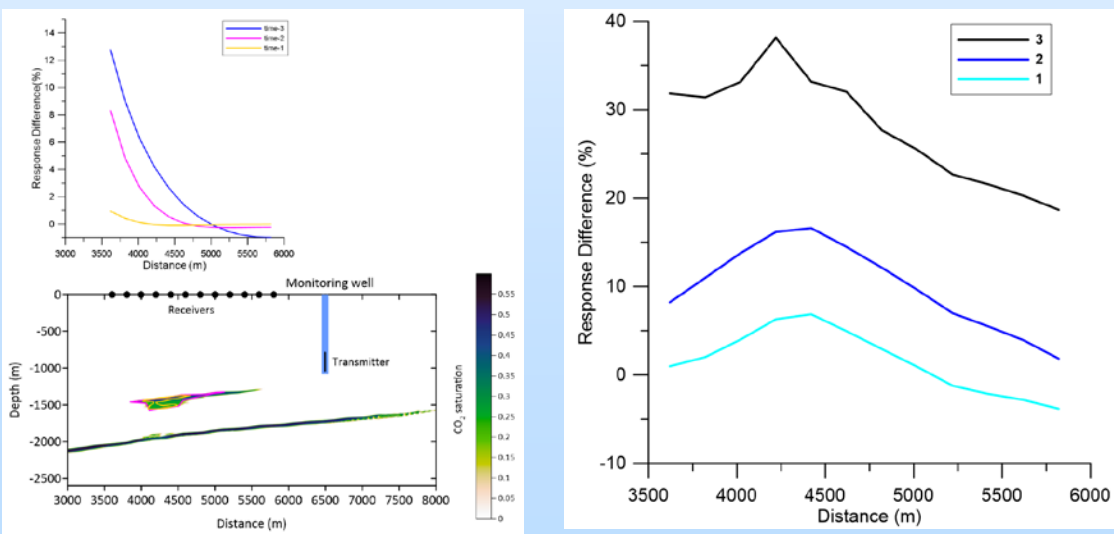
Gasperikova, E., Commer, M., Zhou, Q., Gao, K., Huang, L., Daley, T.

EM



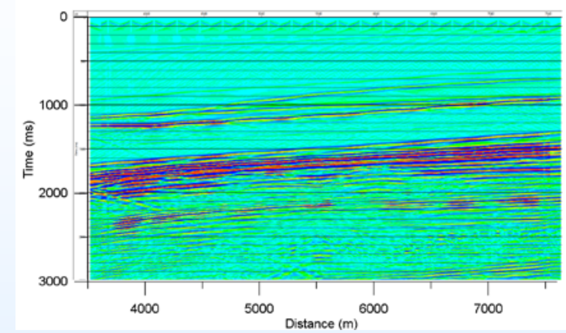
Surface EM

Time-lapse change in resistivity

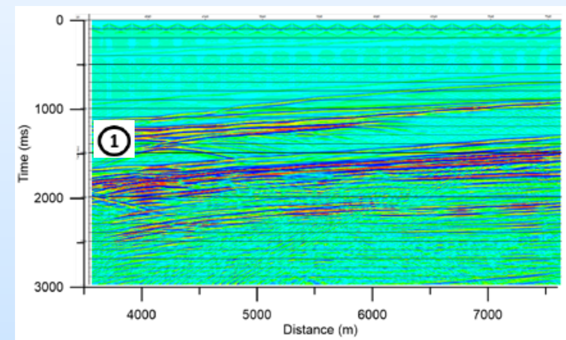


Borehole-to-surface EM

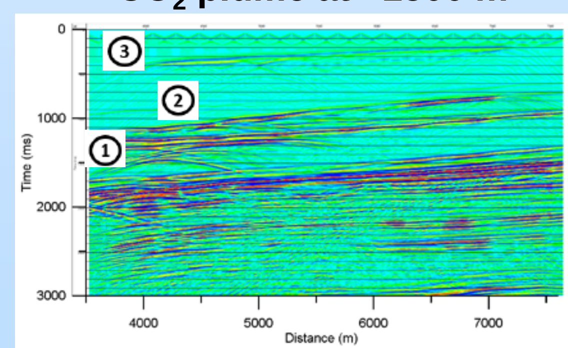
SEISMIC



Baseline



CO_2 plume at ~1500 m

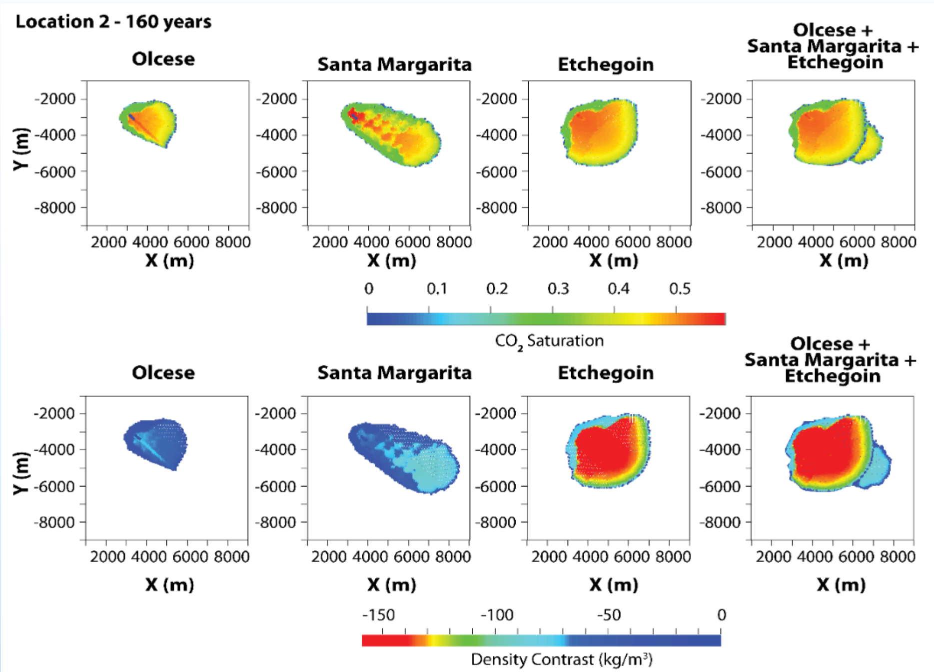


Three CO_2 plumes

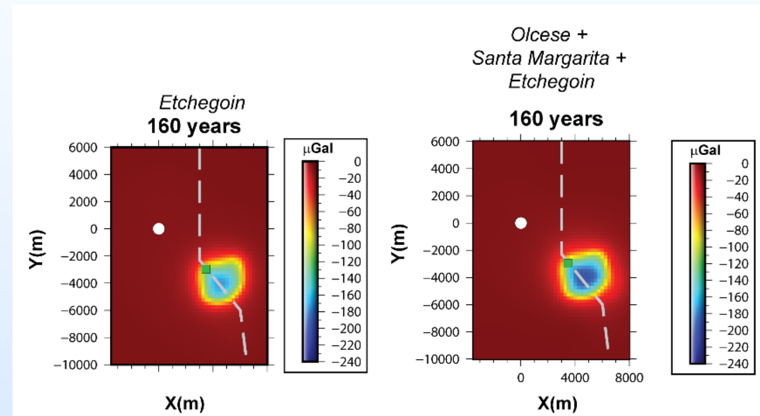
Gravity monitoring (1)

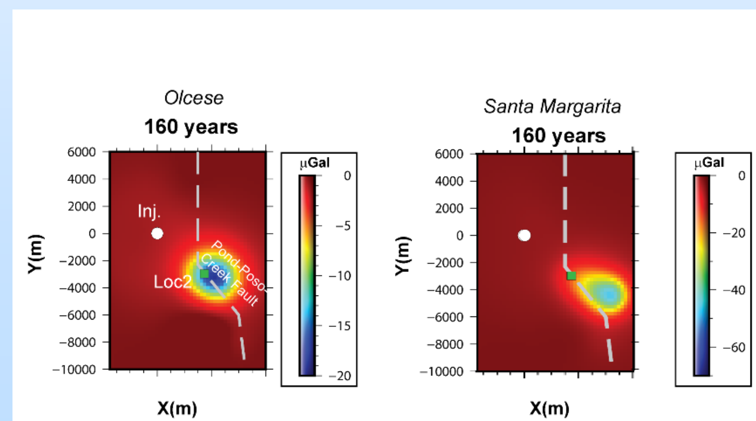
D. Appriou, A. Bonneville, Q. Zhou, E. Gasperikova

CO_2 saturation and density contrast



Surface gravity responses





<u>Surface monitoring:</u> detection strongly depends on 1) detection **threshold**, 2) **size** of the leak and 3) **depth** of the leak

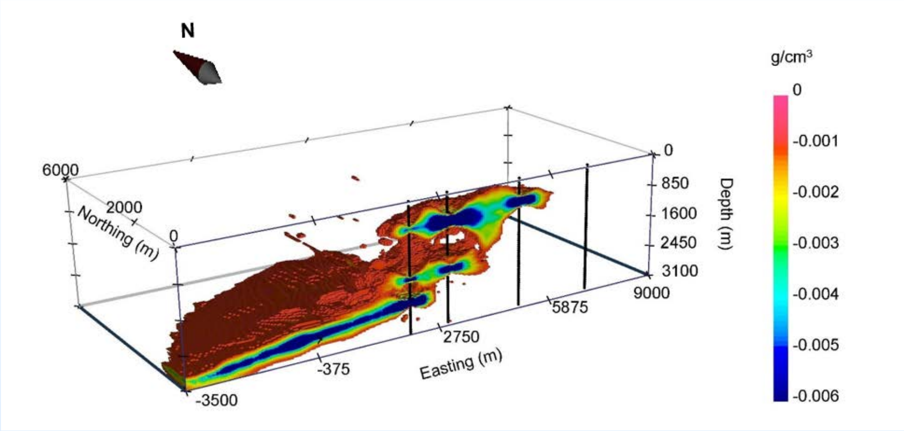
<u>Borehole monitoring</u>: time-lapse responses discriminate depth of leaks, but signal quickly decreases with the distance from a leak

Gravity monitoring (2)

D. Appriou, A. Bonneville, Q. Zhou, E. Gasperikova

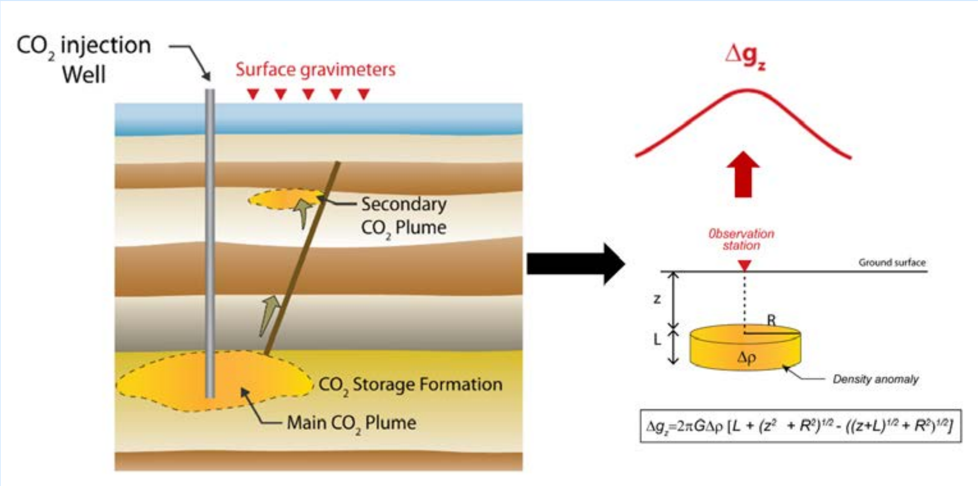
Gravity Inversion

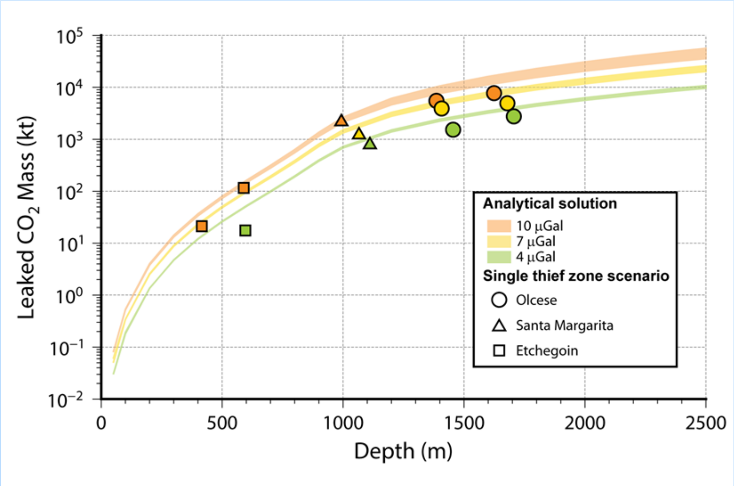
- **Best results** obtained by **joint** inversion of **borehole** and **surface** data with an a-priori background model
- The mass estimate is within 10 % to 20% of the actual mass of fluid displaced



Analytical Solution

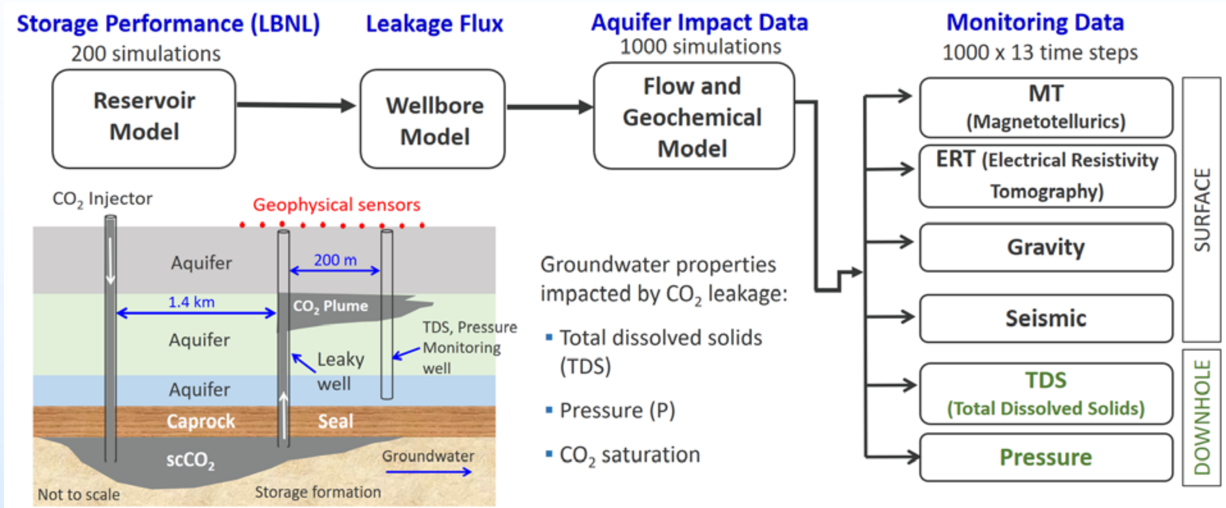
- First order agreement between multi-phase flow simulations and analytical solution
- Analytical solution can be used to estimate the gravity response expected at a CCS site



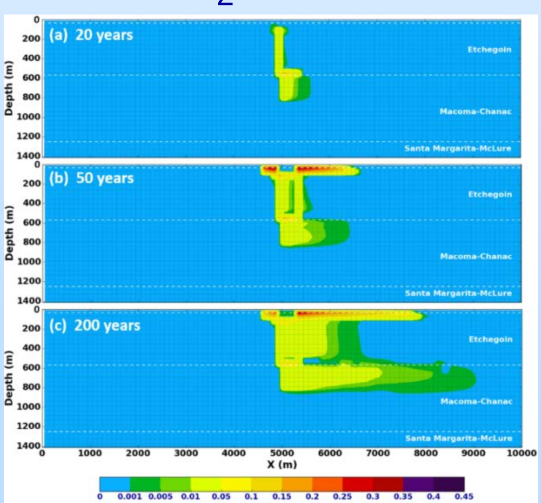


Monitoring Methods for Detection of Brine and CO_2 Leakage (1)

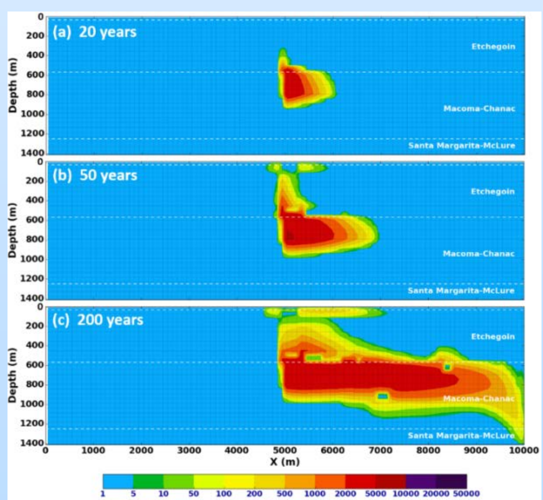
Yang, X., Buscheck, T., Mansoor, K., Wang, Z., Gao, K., Huang, L., Appriou, D., Carroll, S.



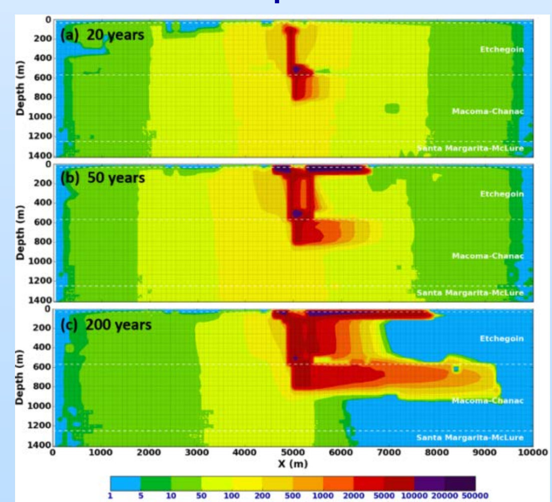
CO_2 saturation



TDS concentration

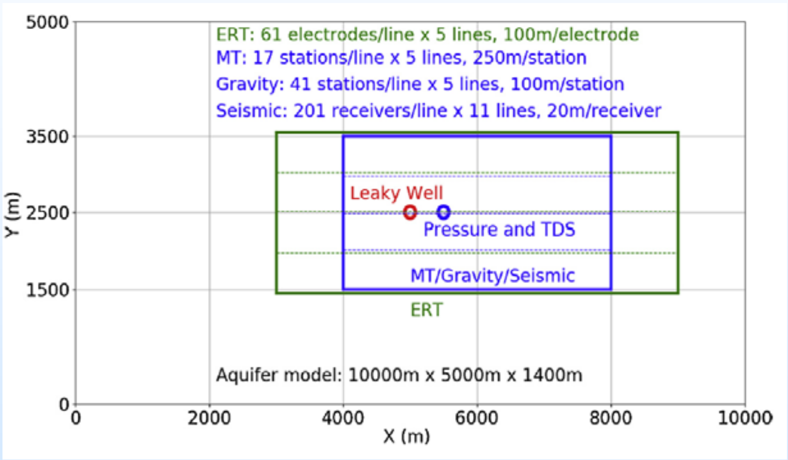


Overpressure

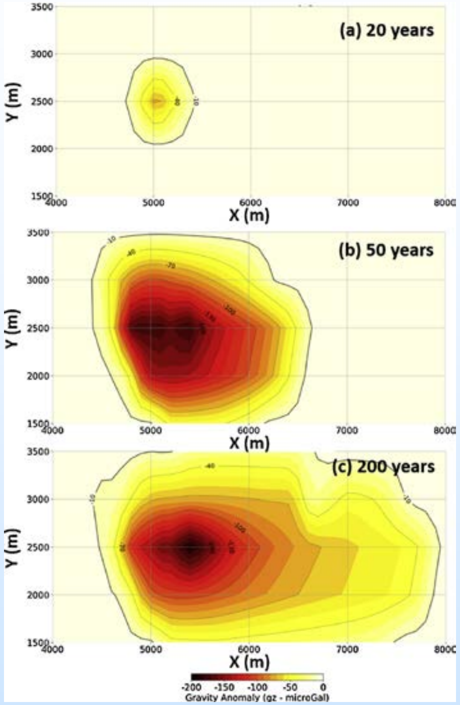


Monitoring Methods for Detection of Brine and CO_2 Leakage (2)

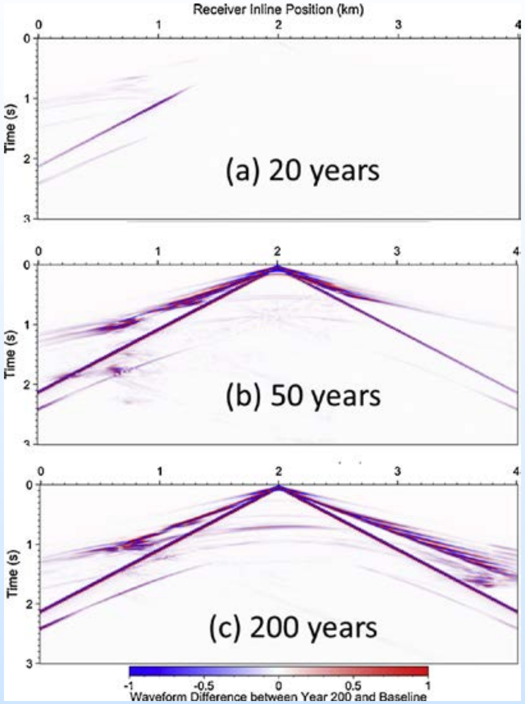
Yang, X., Buscheck, T., Mansoor, K., Wang, Z., Gao, K., Huang, L., Appriou, D., Carroll, S.



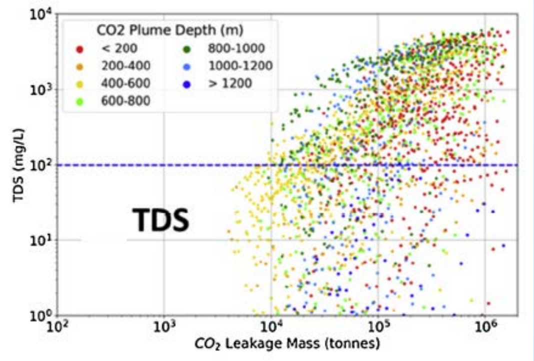
Monitoring layout

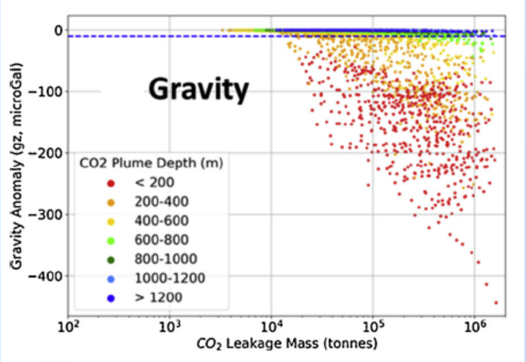


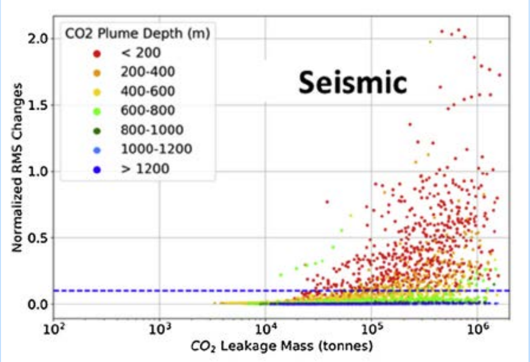
Gravity response change



Seismic amplitude change

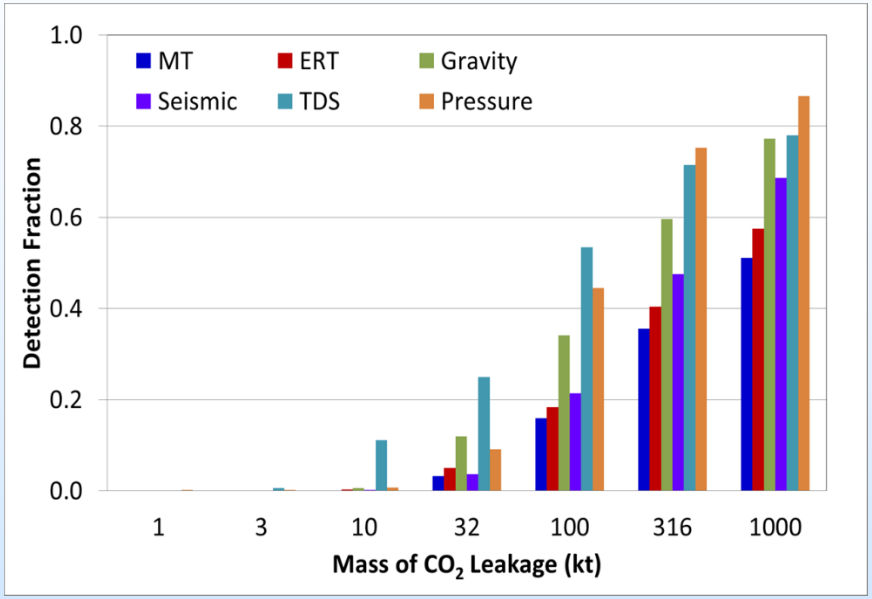


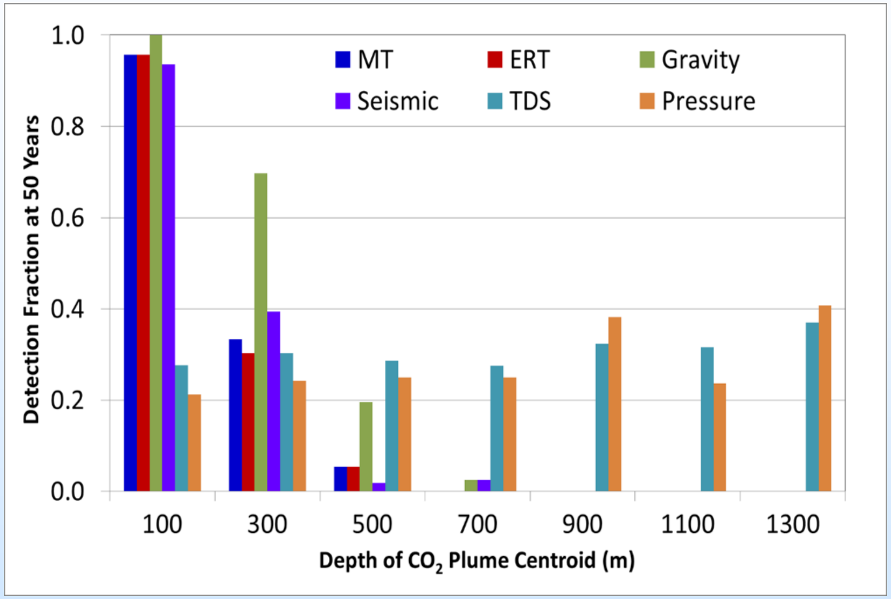




Monitoring Methods for Detection of Brine and CO_2 Leakage (3)

Yang, X., Buscheck, T., Mansoor, K., Wang, Z., Gao, K., Huang, L., Appriou, D., Carroll, S.



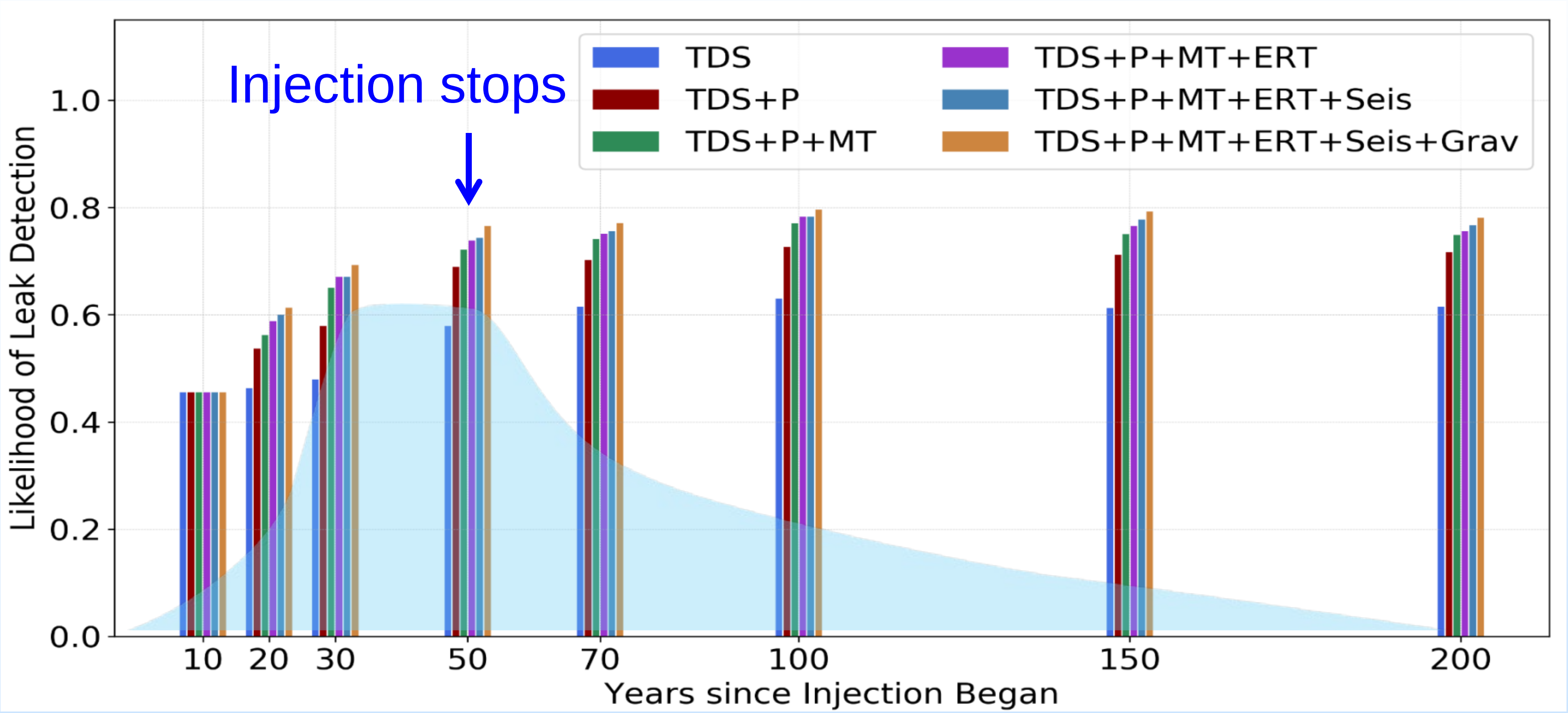


TDS monitoring is the only method that detects a small leak of less than 10,000 tonnes of CO_2 leakage

Effectiveness of downhole monitoring depends on the number and location of the monitoring wells and monitoring sensors

Monitoring Methods for Detection of Brine and CO_2 Leakage (4)

Yang, X., Buscheck, T., Mansoor, K., Wang, Z., Gao, K., Huang, L., Appriou, D., Carroll, S.



A leak is defined as a plume that has

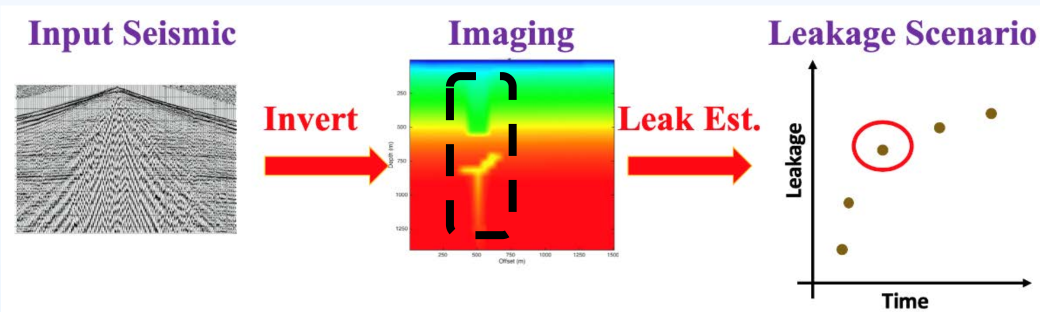
- Leakage mass > 20,000 tonnes
- TDS > 100 mg/l
- CO_2 saturation > 1%

Geophysical monitoring methods complement downhole monitoring and improve the likelihood of leak detection

A New ML Detection Method: Non-Imaging Leakage Detection

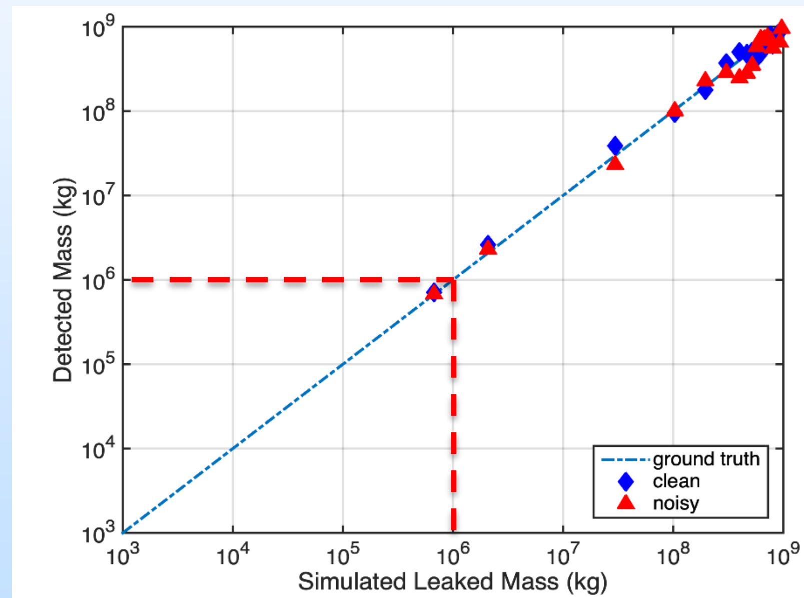
Z. Zhou, Y. Lin, Z. Zhang, Y. Wu, Z. Wang, R. Dilmore, G. Guthrie

Conventional Detection – Seismic Imaging



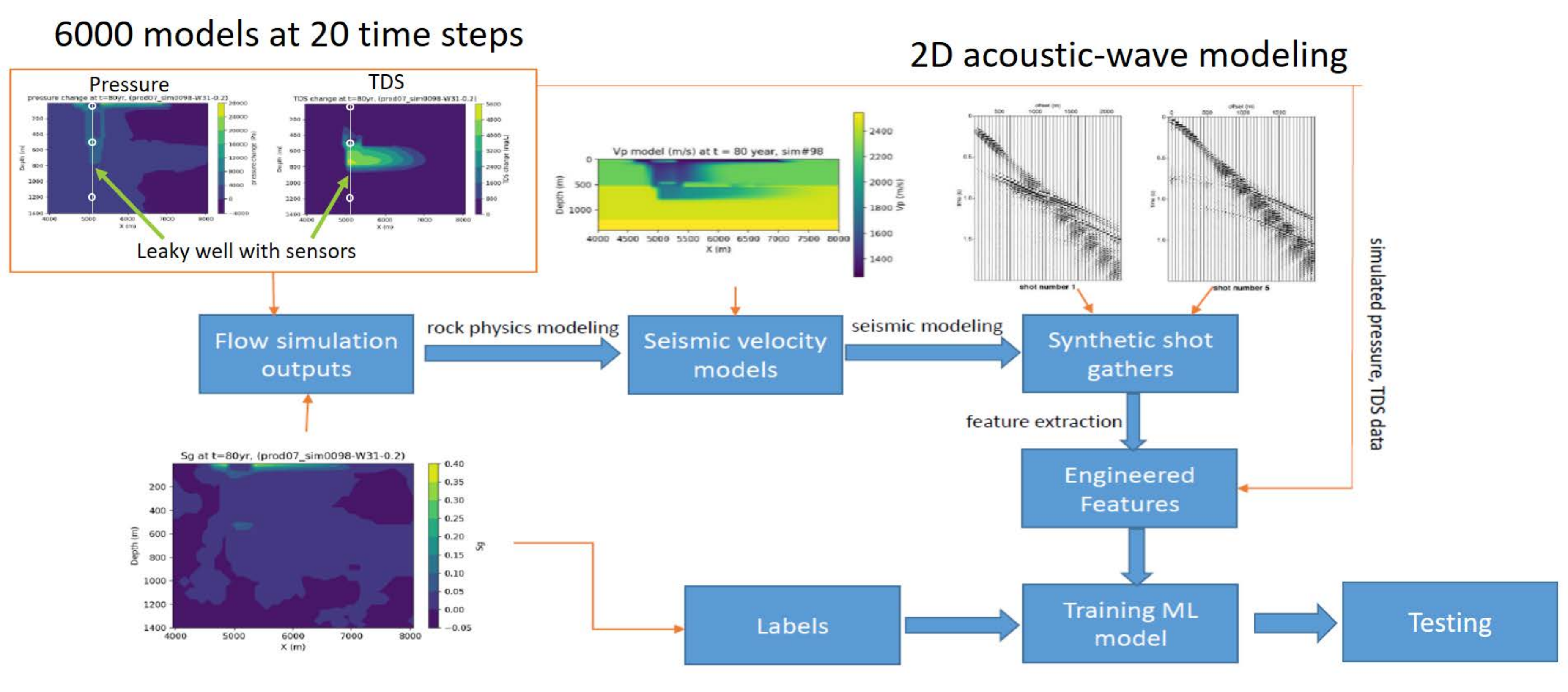
Machine Learning Detection – Seismic (Non) Imaging

Detection Results



Inferring CO_2 saturation from surface seismic and downhole pressure and TDS data using ML

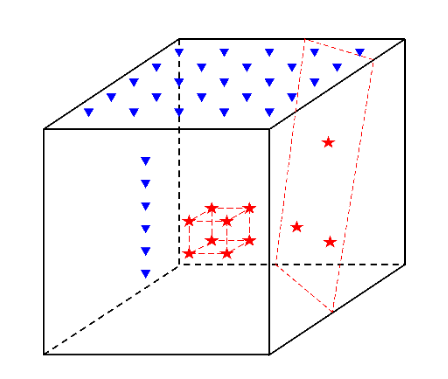
Wang, Z., Dilmore, R., Bromhal, G., Harbert, W.

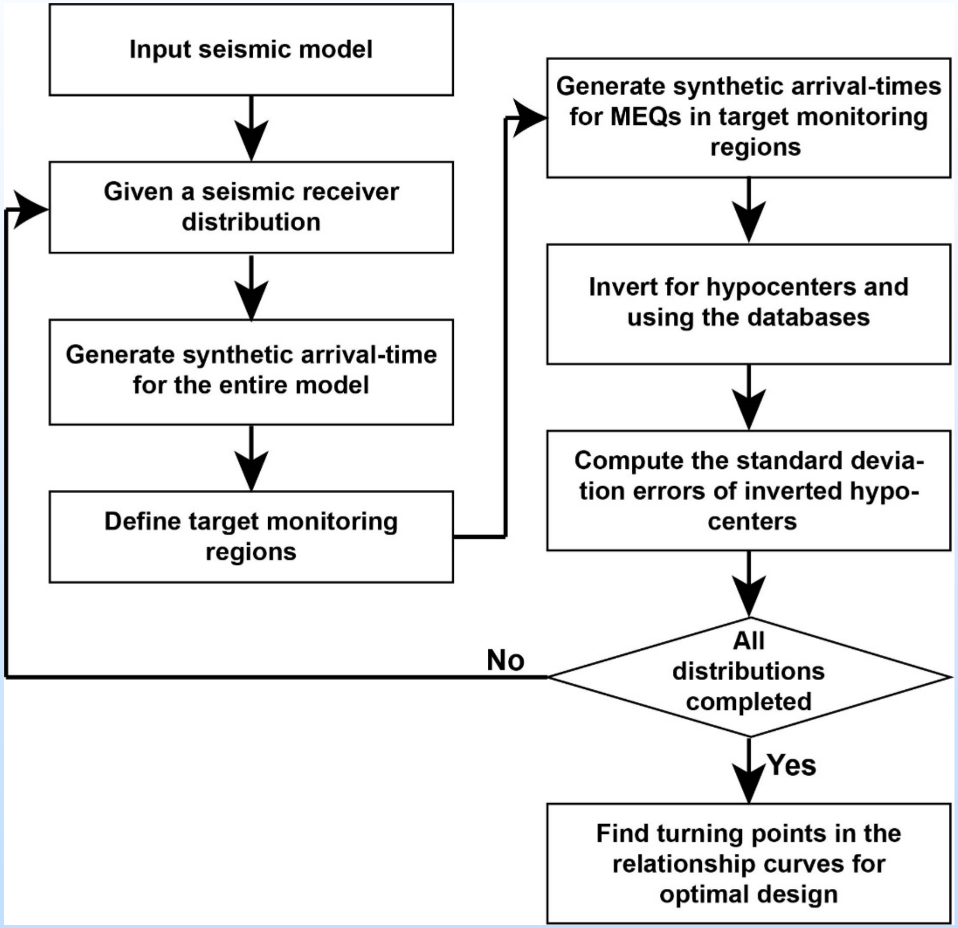


Tool for Optimal Design of Microseismic Monitoring Network (1)

Chen, Y., Chen, T., Gao, K., Huang, L.

- Developed a tool to determine the relationship between the **hypocenter** uncertainty of microseismic events (**red stars**) within a target monitoring region (**red dashed box**) and the **geophone** distribution (**blue triangles**).
- Designed an optimal, cost-effective **microseismic monitoring network** using this relationship.





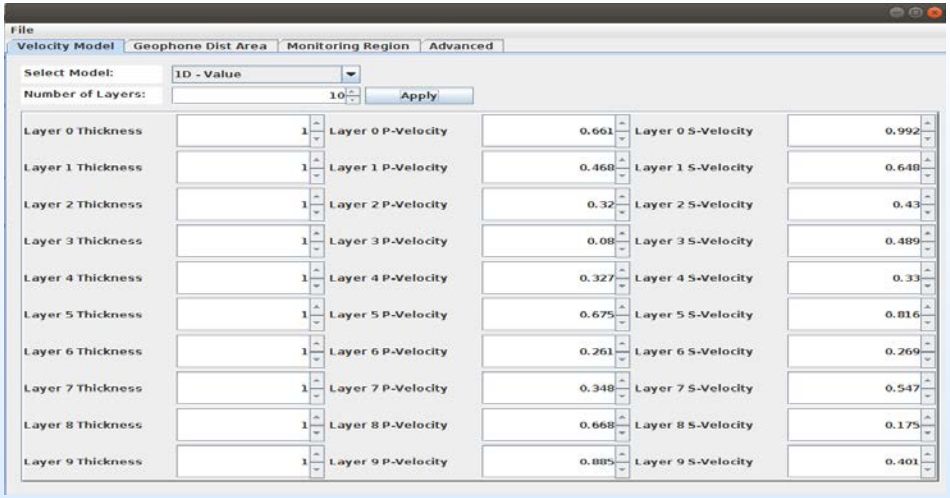
- Developed an Eikonal Solver algorithm to calculate P- and S-wave arrival times.
- Developed a simulated heat-annealing method to search the best hypocenters through minimizing the arrival-time misfit between data and synthetics.

Tool for Optimal Design of Microseismic Monitoring Network (2)

Chen, Y., Chen, T., Gao, K., Huang, L.

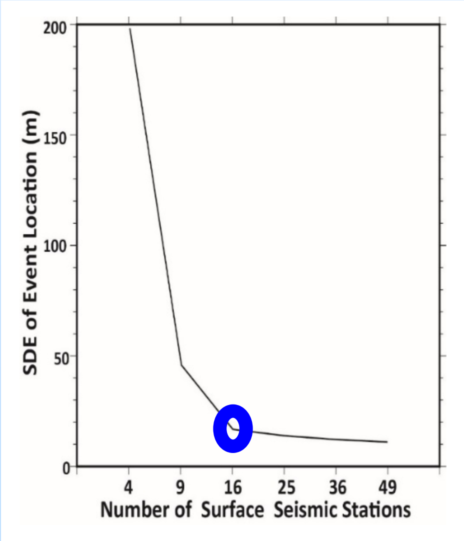
GUI Design

- Input velocity models, geophone distribution and target monitoring region in GUI.



Application

- Designed microseismic monitoring network for the Phase 4 of SWP at the Farnsworth CO2-EOR field.
- The turning point (blue circle) in the standard deviation error of microseismic event location vs the number of surface seismic stations indicates that 16 surface stations are needed for the optimal design.

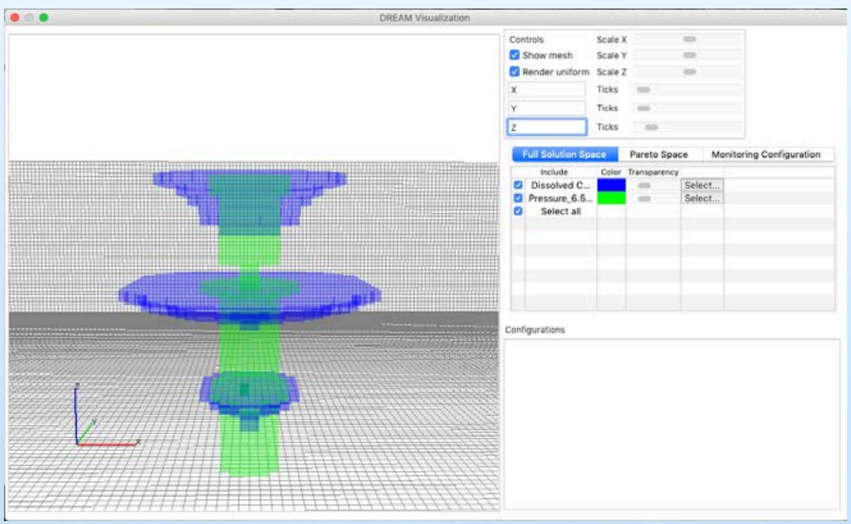


Risk-Based Monitoring Network Design Tools - DREAM

Yonkofski, C., Whiting, J., Bacon, D., Appriou, D. , Burghart, J.

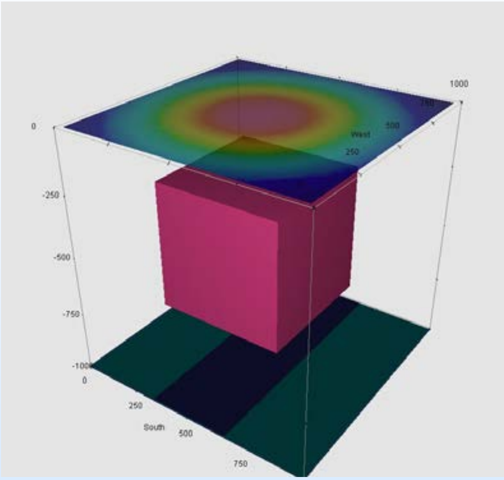
- Completed development of the DREAM tool interface to accommodate NRAP-Open-IAM input

DREAM/ NRAP-Open-IAM Input



NRAP-Open-IAM application to FutureGen 2.0

DREAM/Gravity testing



Density grid with a cubic domain representing a 0.2 g/cm^2 contrast

- Began DREAM/gravity integration
  - Completed validation of standalone gravity semi-analytical solutions.
- Continued evaluation of the ERT module
  - Modifications - consider more sensitive array configurations

Next Steps

– Integration of gravity module into DREAM
– Continued evaluation of ERT module in DREAM
– Compare effectiveness of monitoring technologies for leak detection at CO_2 storage sites
– Develop characterization of technical performance of monitoring technology detection thresholds, and attributes of spatial and temporal resolution
– Report and peer reviewed article on comparing effectiveness of monitoring technologies for leak detection at CO_2 storage sites

Accomplishments

- Release of DREAM tool with NRAP-Open-IAM input
- Tool for Optimal Design of Microseismic Monitoring Network
- Peer reviewed journal articles and presentations at scientific conferences

Synergy Opportunities

- Noise levels from actual field data could be incorporated into modeling and improve statistical estimates of derived parameters

- Field data sets from active experiments could be used to test and verify monitoring approaches

- Developed codes and methodologies will be shared with other projects

Appendix

Benefit to the Program

- To develop a science-based method for quantifying the risks (and associated potential liabilities) for CO_2 storage sites and to develop efficient, risk-based monitoring protocols. The work is based on detailed multi-physics process models, coupled with reduced order modeling to facilitate stochastic analysis of risk and uncertainty.

- The development of monitoring approaches and risk assessment methodologies will lead to more efficient use of monitoring resources with risk reduction as an optimization metric.

Project Overview

Goals and Objectives

- Assess the effectiveness of monitoring methods to detect leakage, develop optimized cost-effective monitoring designs, and integrate monitoring into the NRAP-Open-IAM to reduce risk and uncertainty in risk.

- The integration will include feedbacks that allow a monitoring protocol to be influenced or driven by the NRAP-Open-IAM assessment of risks, as well as allowing the risk profiles to be modified by monitoring and mitigation. The influence of monitoring will be in identifying the need for mitigation (i.e., identification of leakage) and then the monitoring of mitigation to assess its success.

Milestones and Deliverables

- D.4.B Decision Point: Propose a conceptual design for effectively integrating geophysical models/monitoring technology characterizations into a risk assessment framework. June 2019
- Presentation on NRAP Task 4.0 accomplishments at the Carbon Capture, Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting. August 2019
- M4.B Complete draft manuscript comparing effectiveness of monitoring technologies for leak detection. September 2019
- Briefing to NRAP Stakeholder Group on progress and status of strategic monitoring task. Fall 2019
- Report comparing effectiveness of monitoring technologies for leak detection at CO_2 storage sites. December 2019

Bibliography (1)

- Appriou D., A. Bonneville, E. Gasperikova, and Q. Zhou, 2018, Assessment of Time-Lapse Gravity Monitoring for Detecting Leakage from a Faulted CO_2 Subsurface Storage Complex, AGU, Washington D.C.
- Bacon, D.H., Yonkofski, C.M., Brown, C.F., Demirkanli, D.I. and Whiting, J.M., 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.
- Buscheck, T.A., K. Mansoor, X. Yang, H. M. Wainwright, and S. A. Carroll, 2019, Downhole Pressure and Chemical Monitoring for CO_2 and Brine Leak Detection in Aquifers Above a CO_2 Storage Reservoir, Int. J. of Greenhouse Gas Control, accepted.
- Daley, T.M., 2019, Rock Physics of CO_2 Storage Monitoring in Porous Media, in Geophysics and Geosequestration, Cambridge University Press. ISBN: 9781107137493
- Daley, T. M., and Harbert, W., 2019, Goals of CO_2 monitoring: Why and how to access the subsurface changes associated with CCS, in Geophysics and Geosequestration, Cambridge University Press. ISBN: 9781107137493
- Delaney, D., Purcell, C., Mur, A., Haljasmaa, I., Soong, Y., Crandall, D., and Harbert, W, 2019, Dynamic Moduli and Attenuation: Rhyolite and Carbonate Examples, AGU Book, in press.

Bibliography (2)

- Gasperikova, E., and M. Commer, 2019, Electrical and Electromagnetic Methods. In: Geophysics and Geosequestration, Editors: Davis, T. and Landro, M., Cambridge University Press, ISBN: 9781107137493.
- Gasperikova, E., and H.F. Morrison, 2019, Fundamentals of Electrical and Electromagnetic Techniques for CO2 Monitoring. In: Geophysical Monitoring for Geologic Carbon Storage and Utilization , Editor: Huang, L., AGU and Wiley book, in press.
- Huerta N., C. Brown, S. Carroll, R. Dilmore, E. Gasperikova, E. Keating, C. Oldenburg, R. Pawar, G. Bromhal, 2018, Using simulation case studies to assess how the level of risk informs monitoring requirements, GHGT-14, Melbourne, Australia,
- Shi, Z., Sun, L., Haljasmaa, I., Harbert, W., Sanguinito, S., Tkach, M., Goodman, A., Tsotsis, T. T., and Jessen, K., 2019, Impact of Brine/CO_2 Exposure on the Transport and Mechanical Properties of the Mt. Simon Sandstone, Journal of Petroleum Science and Engineering, 117, p. 295-305.
- Wang Z., Harbert W.P., Dilmore R.M., Huang L., 2018, Modeling of time-lapse seismic monitoring using CO2 leakage simulations for a model CO_2 storage site with realistic geology: Application in assessment of early leak-detection capabilities. International Journal of Greenhouse Gas Control, 76, 39-52.
- Wang Z., Dilmore R.M., Harbert W.P., 2019, Inferring CO_2 saturation from synthetic surface seismic and downhole monitoring data using machine learning for leakage detection at CO_2 sequestration sites. International Journal of Greenhouse Gas Control, in review.

Bibliography (3)

- Zhou, Z., Y. Lin, Z. Zhang, Y. Wu, Z. Wang, R. Dilmore, and G. Guthrie, 2019. A Data-Driven CO2 Leakage Detection Using Seismic Data and Spatial-Temporal Densely Connected Convolutional Neural Networks. International Journal of Greenhouse Gas Control, accepted.
- Zhou, Z., Y. Lin, Y. Wu., Z. Wang, R. Dilmore, and G. Guthrie, 2018, Spatial-Temporal Densely Connected Convolutional Networks: An Application to CO2 Leakage Detection. SEG Technical Program Expanded Abstracts: 2136-2140.
- Yang, X., T. A. Buscheck, K. Mansoor, Z. Wang, K. Gao, L. Huang, D. Appriou, and S. A. Carroll, 2018, Assessment of Multiple Monitoring Methods for Detection of Brine and CO_2 Leakage, presented at GHGT-14, 10/22 - 10/25, Melbourne, Australia.
- Yang, X., T. A. Buscheck, K. Mansoor, Z. Wang, K. Gao, L. Huang, D. Appriou, and S. A. Carroll, 2019, Assessment of Geophysical Monitoring Methods for Detection of Brine and CO_2 Leakage in Drinking Water Aquifers, Int. J. of Greenhouse Gas Control, 90, 102803, ISSN 1750-5836, https://doi.org/10.1016/j.ijggc.2019.102803.
- Yonkofski C., G.D. Tartakovsky, N.J. Huerta, A.M. Wentworth, and J.R. Sminchak, 2018, Risk Based Monitoring Designs for CO2 Leakage through Abandoned Wellbores: An application of NRAP's WLAT and DREAM tools. International Journal of Greenhouse Gas Control, accepted.