Task 4: Active Reservoir Management

(See FEW-0191)

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Presentation outline

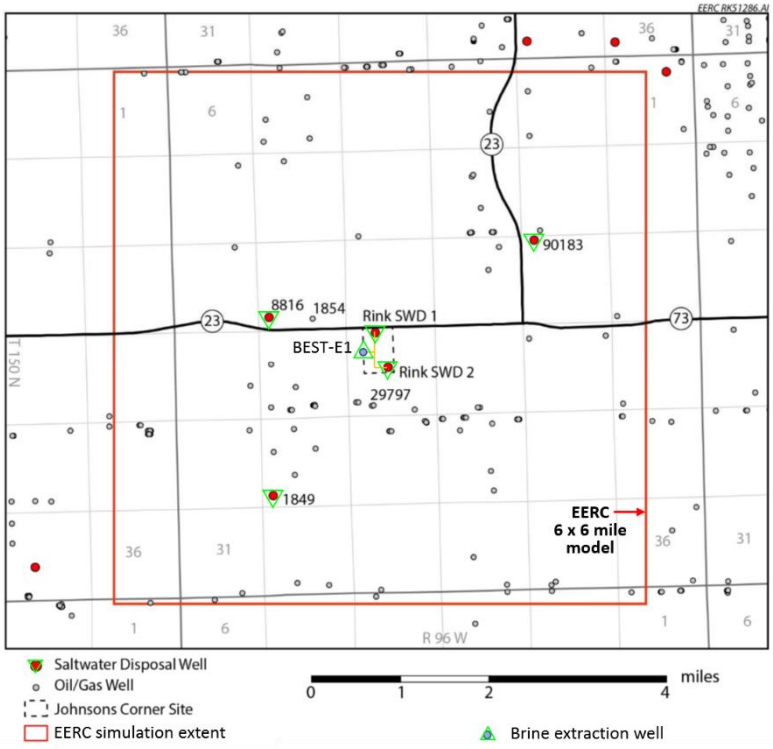
- Active reservoir management (ARM) of geologic CO_2 storage (GCS) in open reservoirs
  - managing reservoir pressure of adjoining GCS and saltwater disposal (SWD) operations, analyzed with model constrained with data from the Energy & Environmental Research Center (EERC) Brine Extraction Storage Test (TEST) site
- ARM analyses for a hypothetical GCS operation next to a SWD operation for a 10.5-year period when SWD data is available
- ARM analyses for the hypothetical GCS and SWD operations extended by 19.5 years for 30 years of operation
- Accomplishments to date
- Lessons learned
- Synergy opportunities
- Project summary

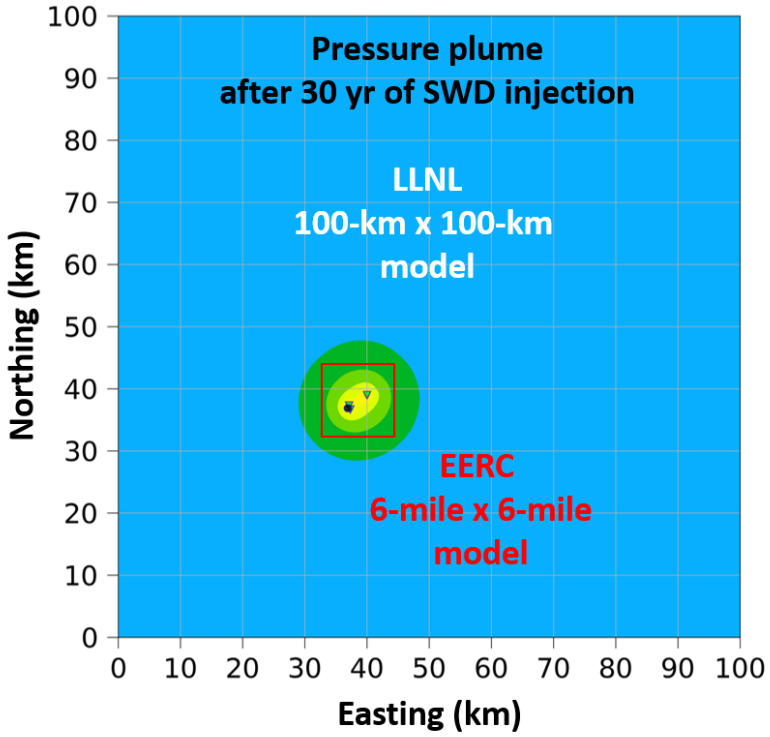
Technical Status: Active Reservoir Management (ARM) for GCS in open reservoirs

- EERC has provided LLNL geologic information and 58 years of well data for saltwater disposal (SWD) operations near the BEST site, located in the Inyan Kara Fm. in the Williston Basin
  - deep saline formation (DSF), is a large open reservoir underlying nearly all of North Dakota and large portions of neighboring states
  - > 700 SWD wells injecting > 400 million barrels during 2018, > 95% of SWD in ND, and is projected to reach 1 billion barrels per year by 2030
  - estimated CO_2 storage capacity of 20–80 billion tons (Glazewski et al, 2015) and recent unpublished analysis suggesting 2–5 times that
- Our focus has evolved into the use of ARM to leverage the advantages of open, large-capacity reservoirs through efficient integration of GCS with adjoining SWD operations
- We have extended our ARM analyses by an additional 19.5 years to consider a typical 30-year GCS project

Technical Status: Data-constrained model of the EERC BEST site

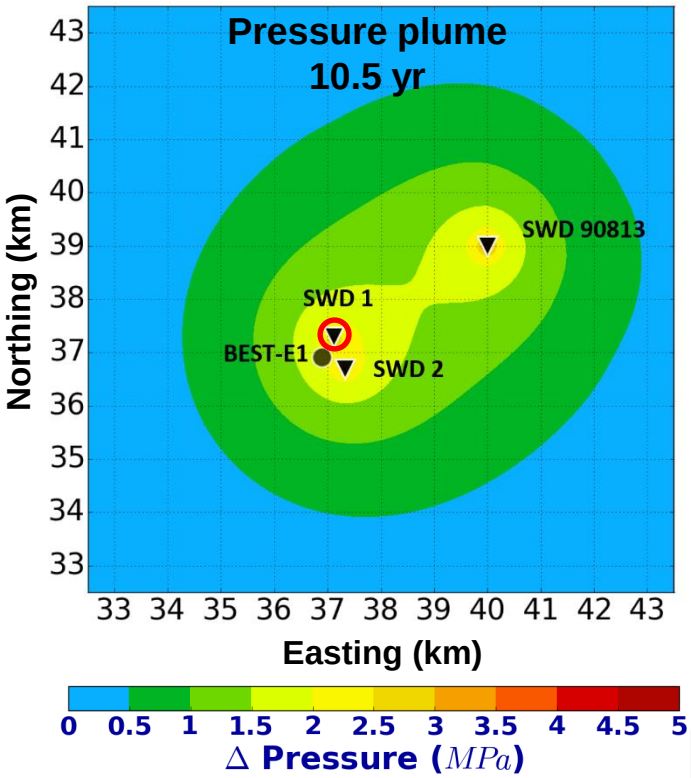
- The EERC BEST site has 5 SWD wells operating since 1961
- The EERC team has used a 6 x 6-mile reservoir model of this site
- Using a 100 x 100-km reservoir model, we confirmed that the Inyan Kara Fm. is an open reservoir

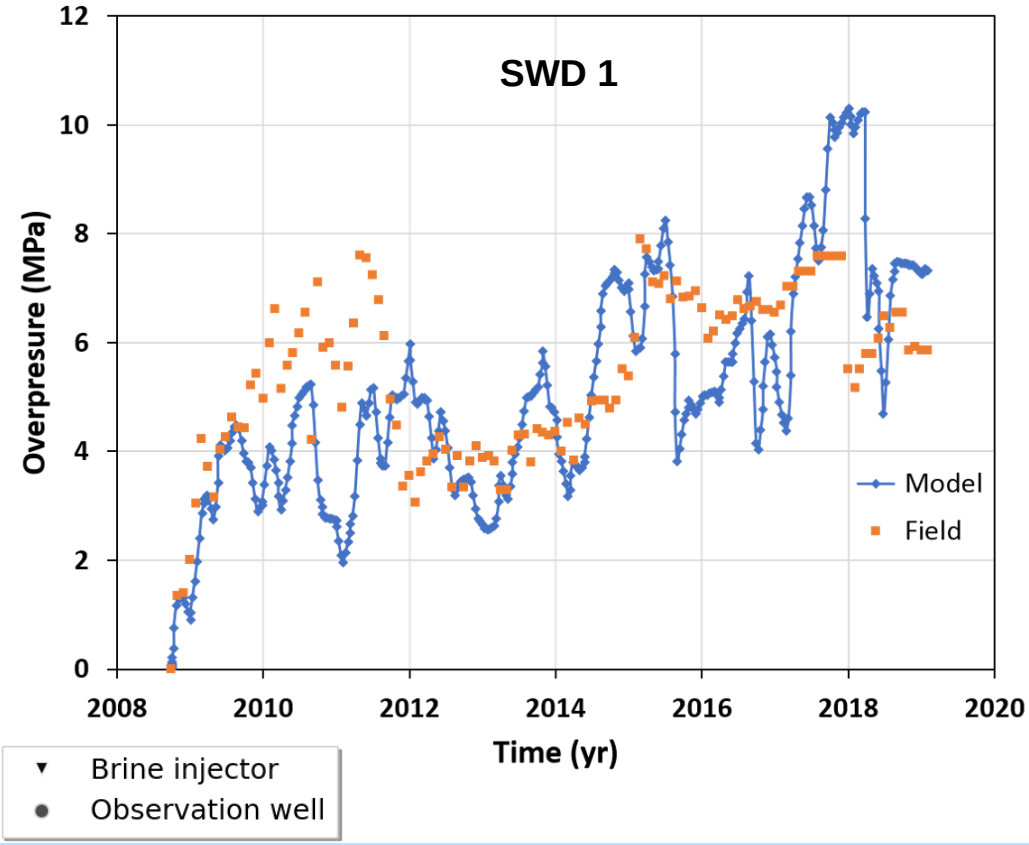




Technical Status: Data-constrained model of the EERC BEST site

- Our model agrees with field values of overpressure at the SWD wells
- Differences between simulated and field result from intermittent injection of co-produced brine, flowback water, and occasional fresh water





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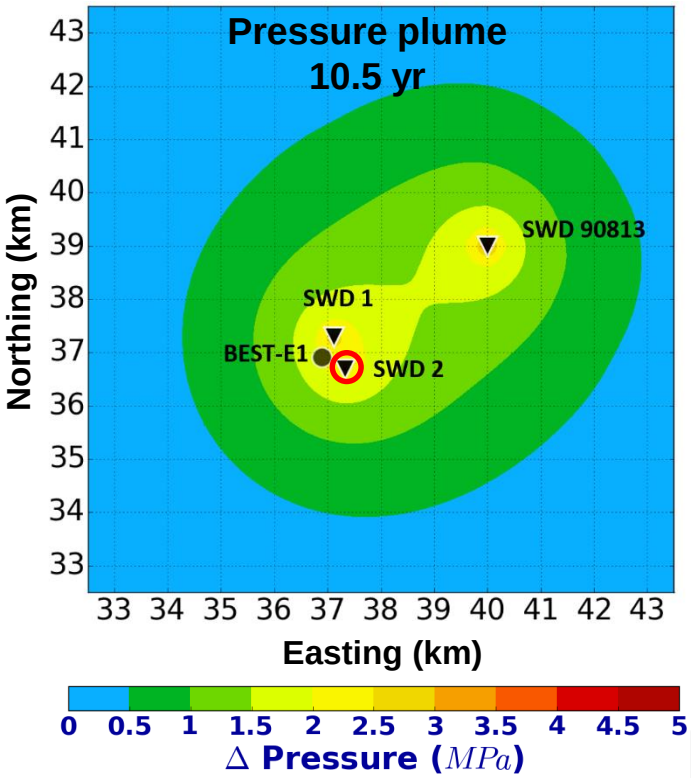

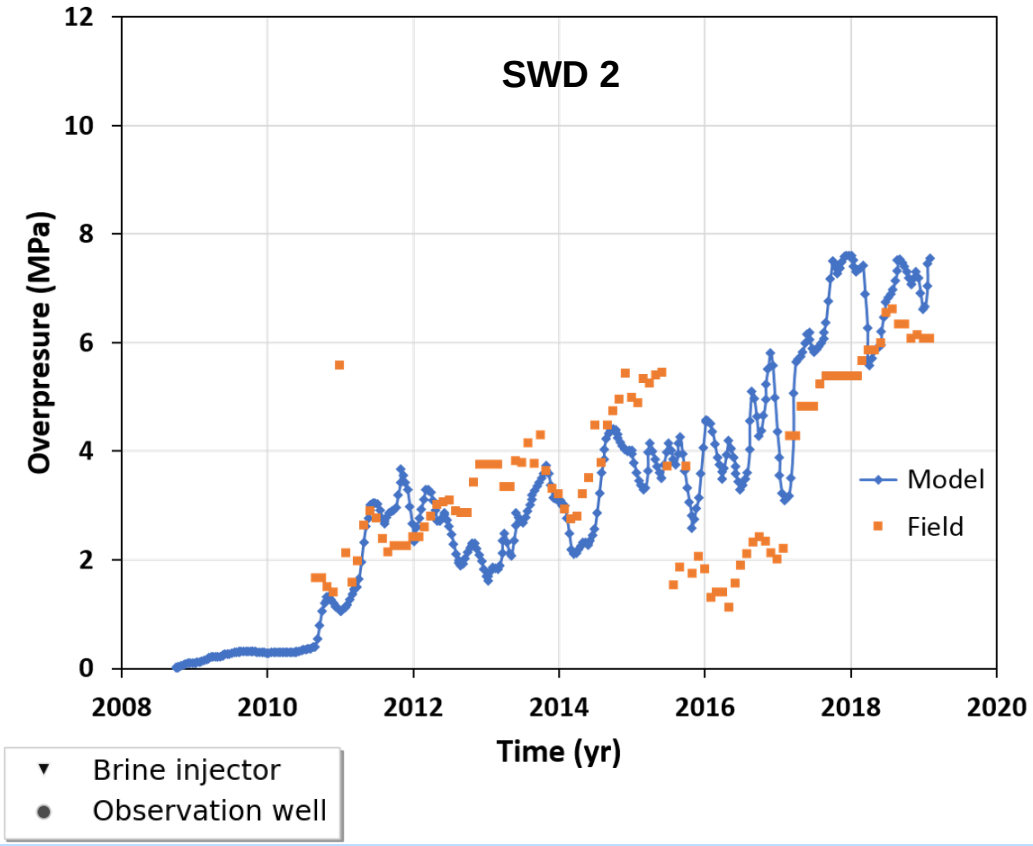

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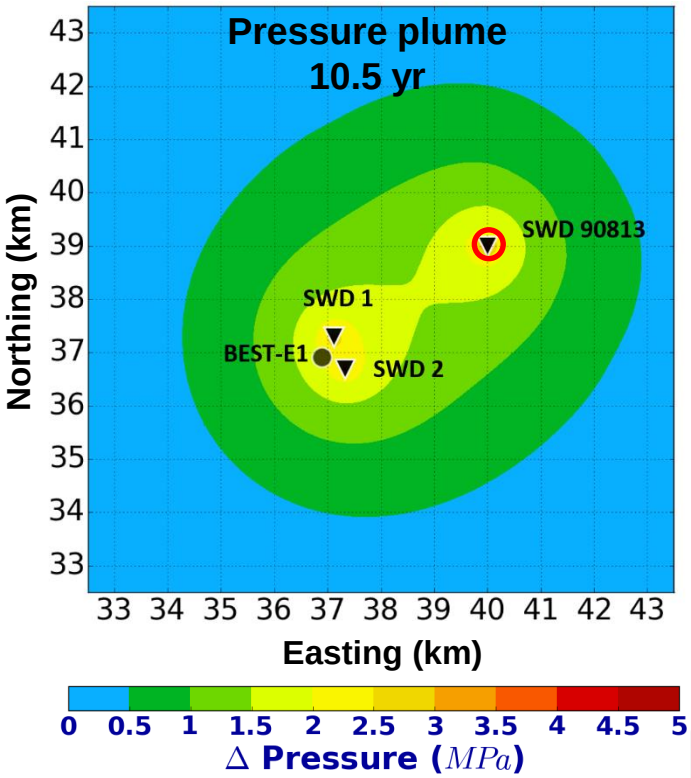
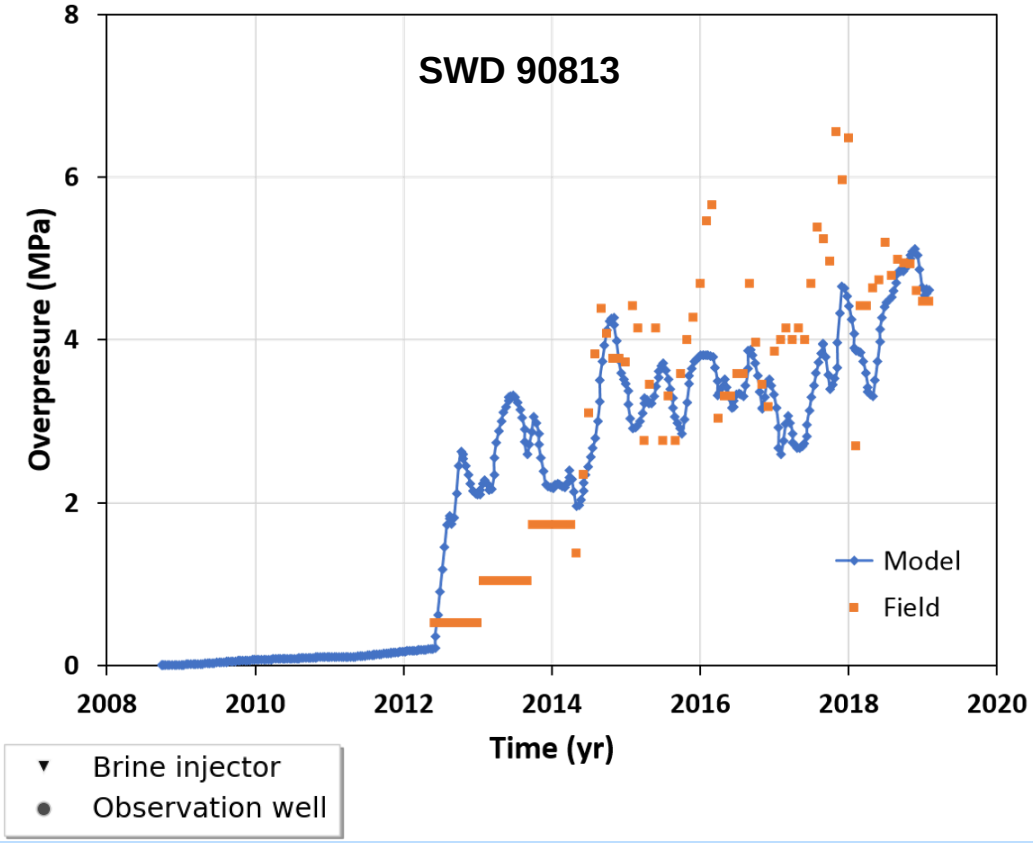
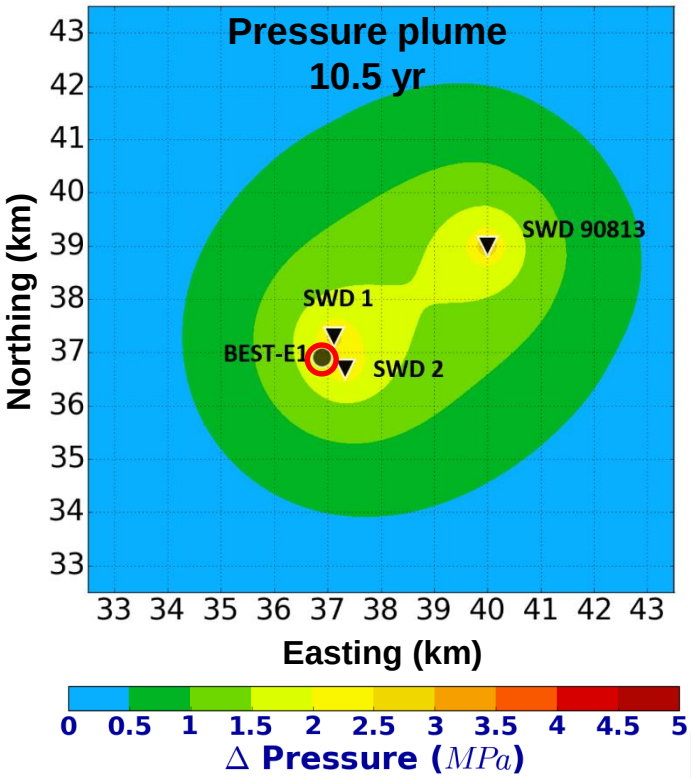
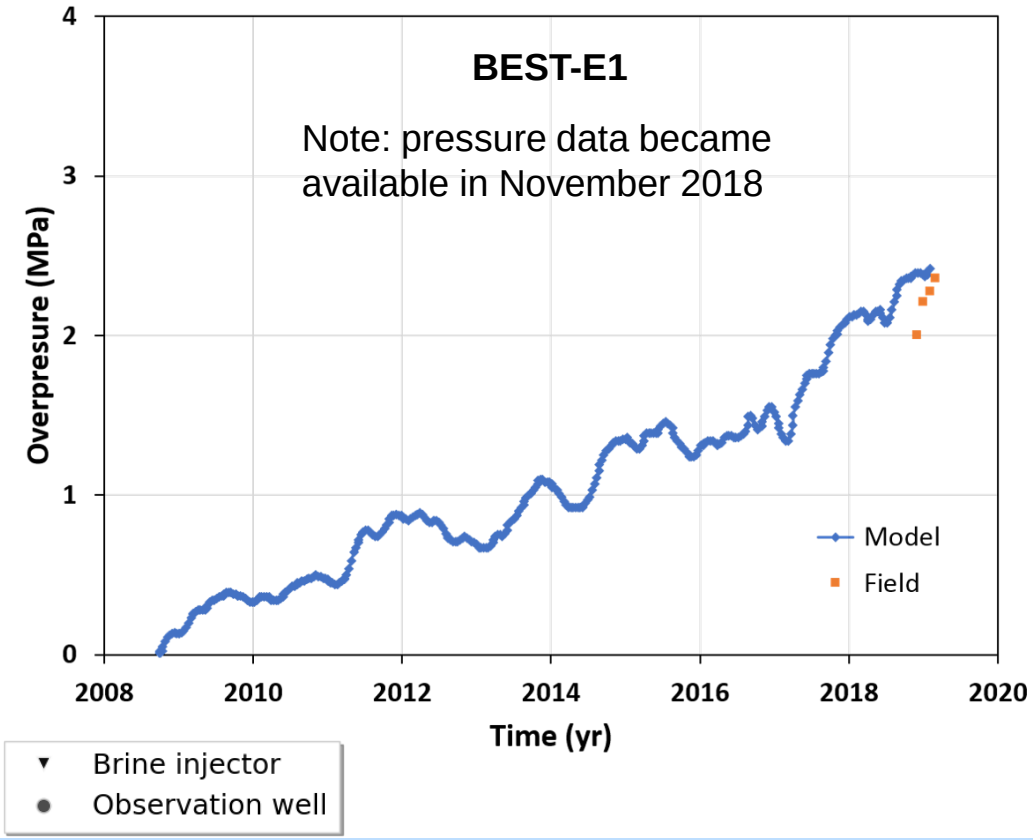




Technical Status: Data-constrained model of the EERC BEST site

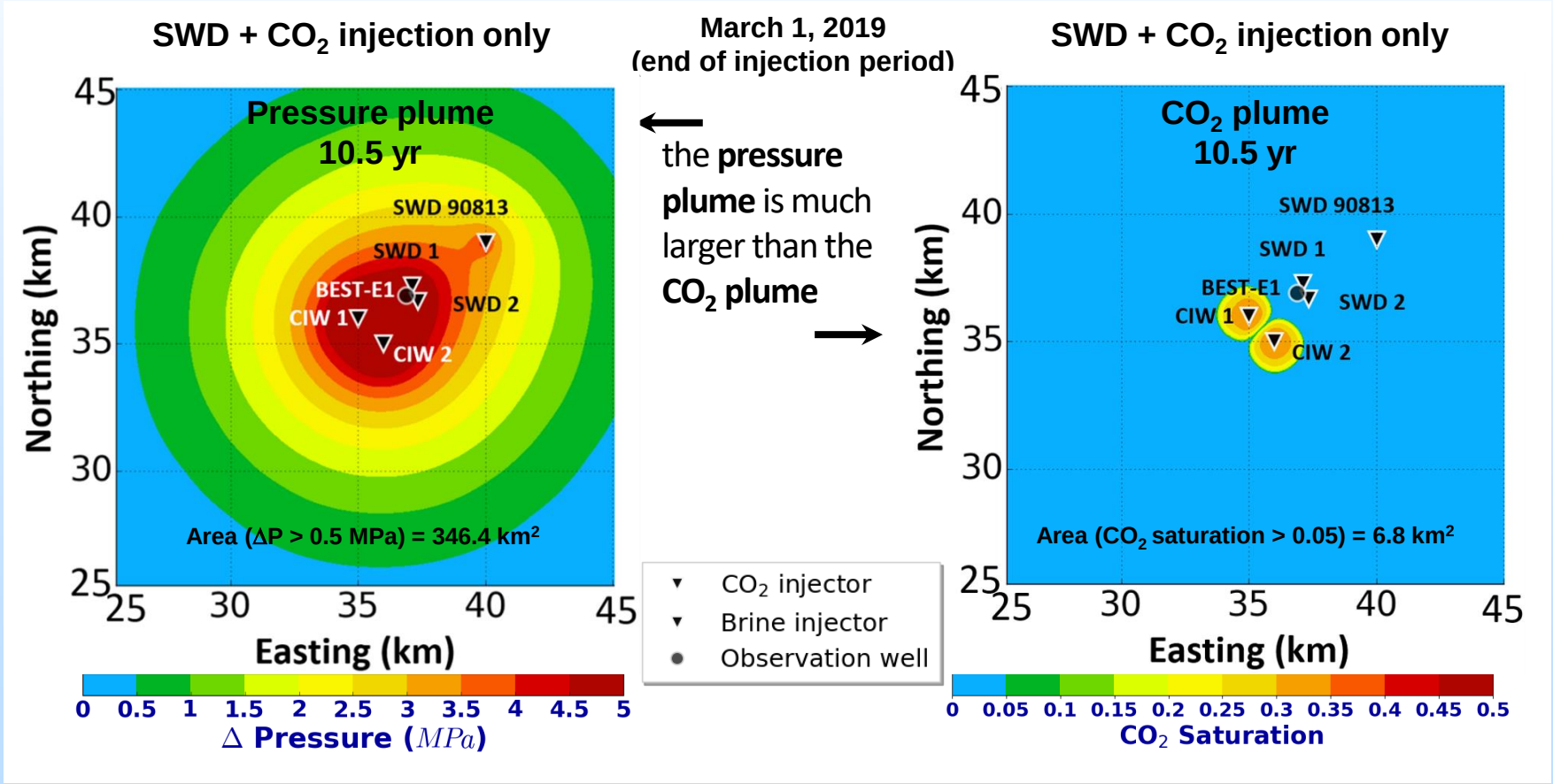
- Our model agrees with field values of overpressure at the BEST-E1 well
- For our study we assume that the BEST-E1 (which is the brine extraction well in the EERC BEST project) is a passive observation well





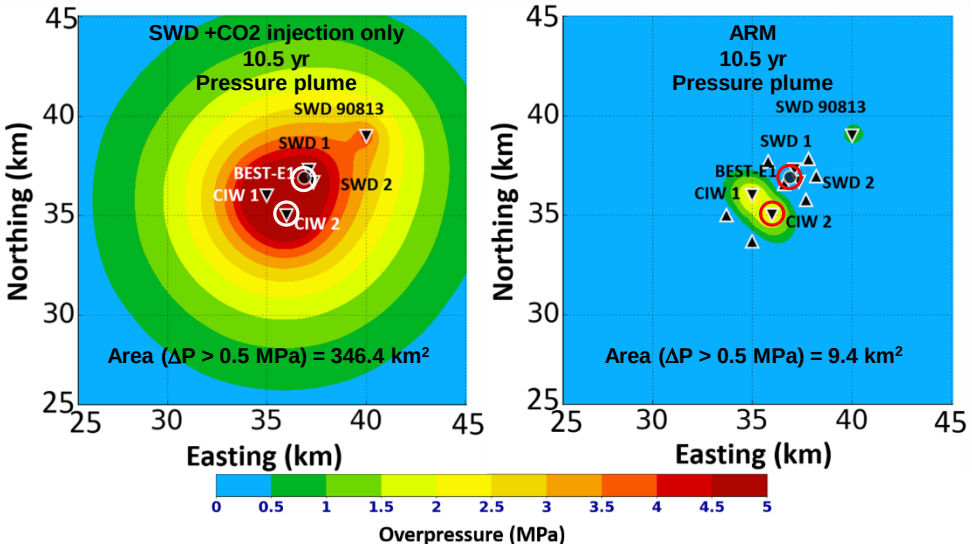
Technical Status: Data-constrained ARM analyses of the EERC BEST site

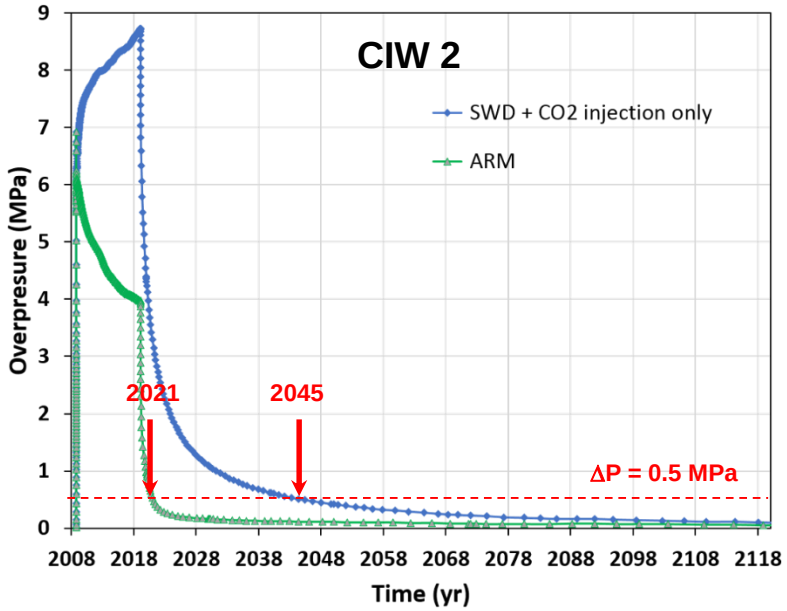
- We conducted a rectrostpective analysis of a 10.5-year GCS operation
  - **injecting 2.0 MT/yr from October 1, 2008 to March 1, 2019**
  - located close enough to the BEST site SWD wells for the pressure plumes to merge

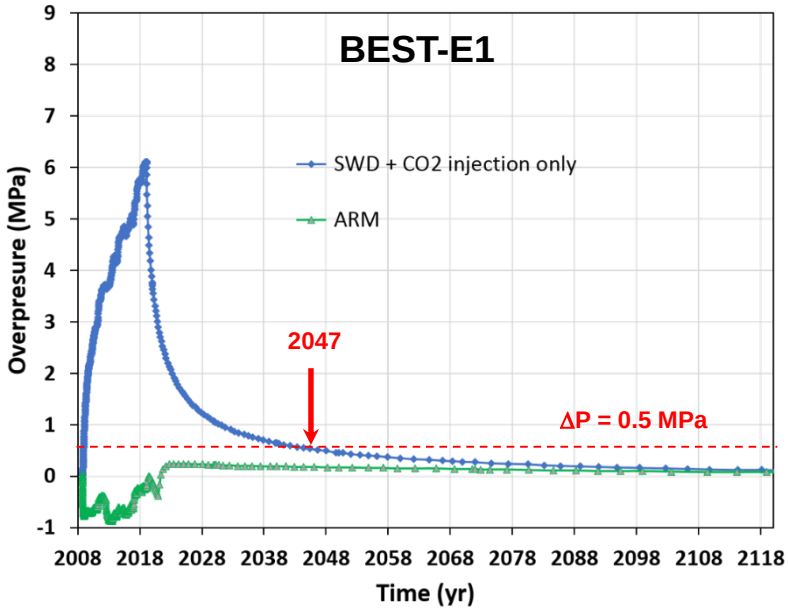


Our analyses indicate ARM can manage overpressure for 10.5 years of GCS and SWD operations separated by 2 km

- 7 brine production wells were used to remove 66,846 BPD, which was moved to 6 re-injection wells 20–30 km from the SWD wellfield
- This corresponds to 6% of the total SWD in the Inyan Kara Fm. in 2018
- Because operations only lasted 10.5 years, the pressure plumes of the SWD wells and brine re-injection wells did not coalesce

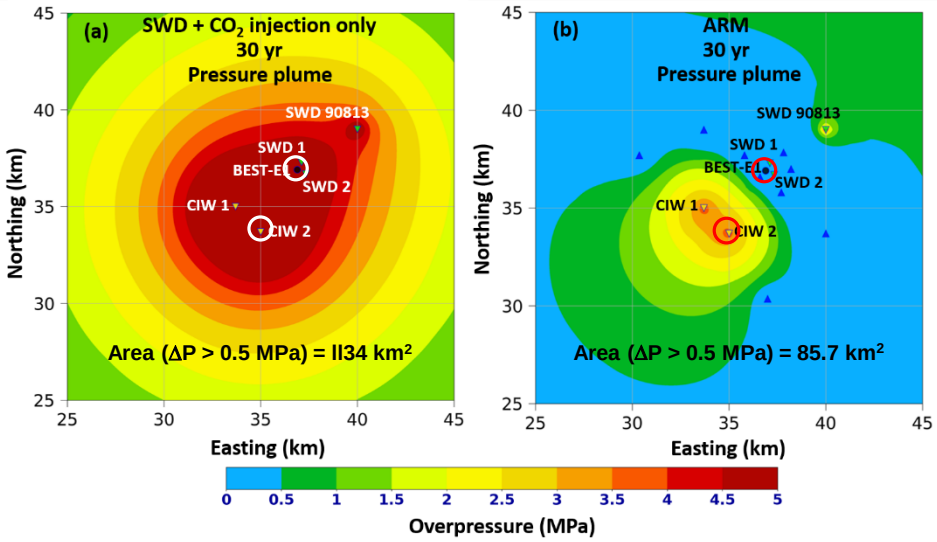


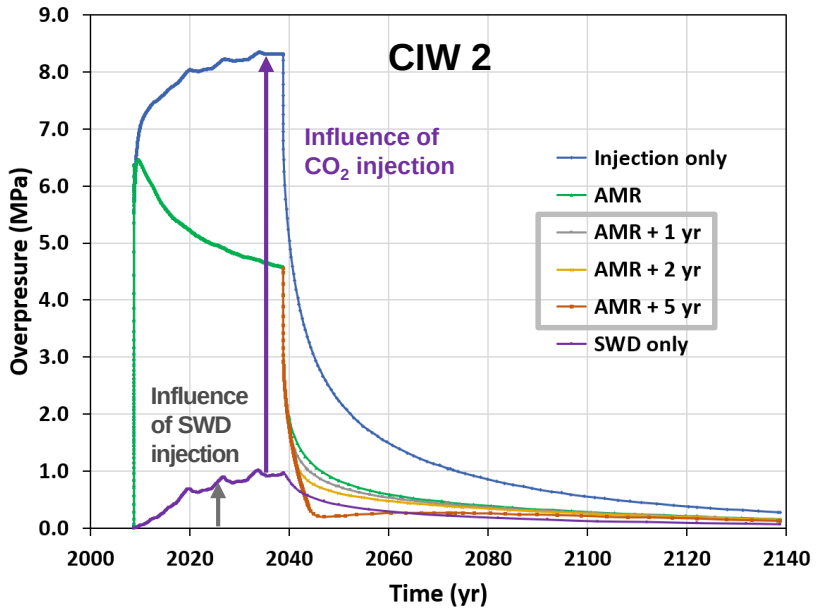


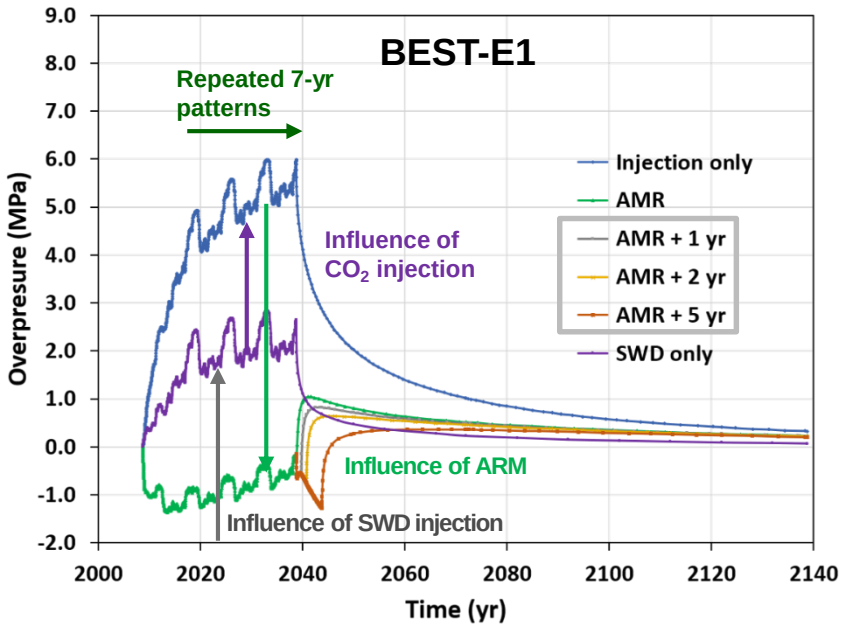


Our analyses indicate ARM can manage overpressure for 30 years of GCS and SWD operations separated by 4 km

- 30 years of injection necessitated moving the CO_2 injectors 2 km further away from the SWD field
- To improve plume control, we added 2 brine producers, for a total of 9 brine producers
- To add 19.5 years of injection data, SWD histories from Oct 1, 2012 through Oct 1, 2019 (when all 3 SWD wells were operating) were repeated 3 times
- Coalescing pressure plumes necessitated extending brine removal 1 to 5 years beyond 30 years

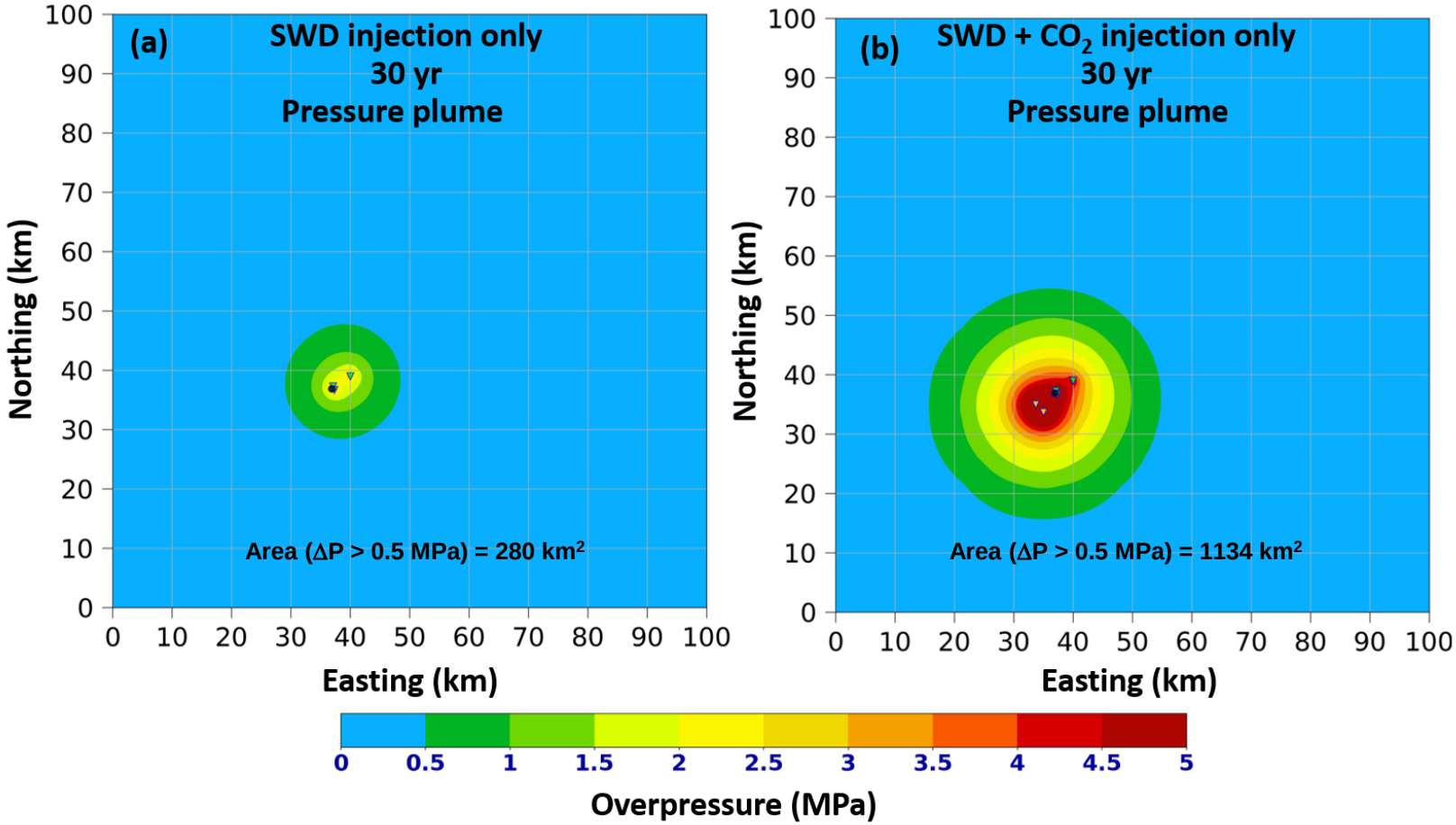






Our analyses indicate ARM can manage overpressure for 30 years of GCS and SWD operations separated by 4 km

- The pressure plumes from the CO_2 injectors and the SWD wellfield merge into one large plume
- After 30 years of SWD injection, the area where $\Delta P > 0.5$ MPa is 280 km^2
- After 30 years of SWD and CO_2 injection, the area where $\Delta P > 0.5$ MPa is 1134 km^2



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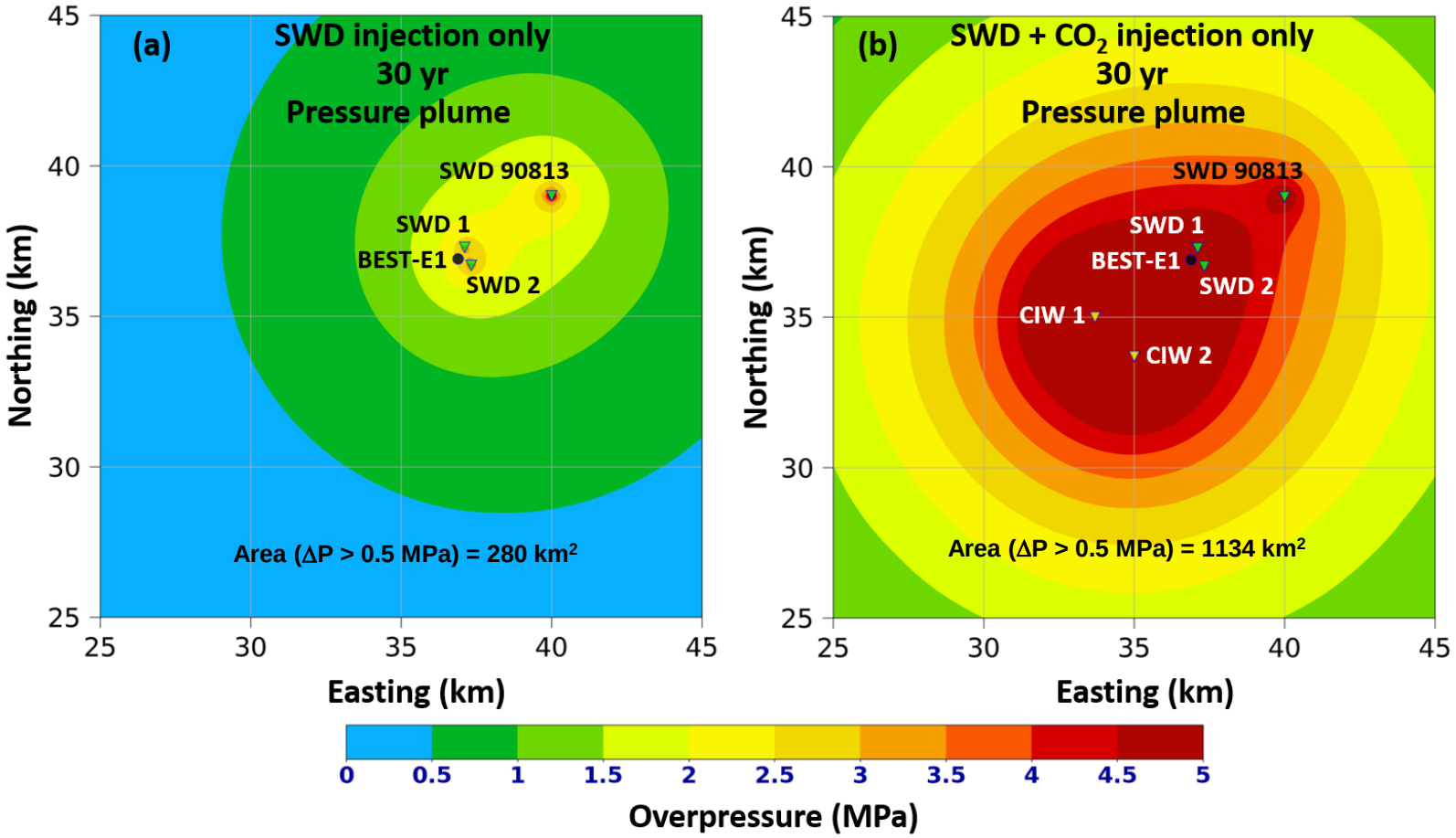

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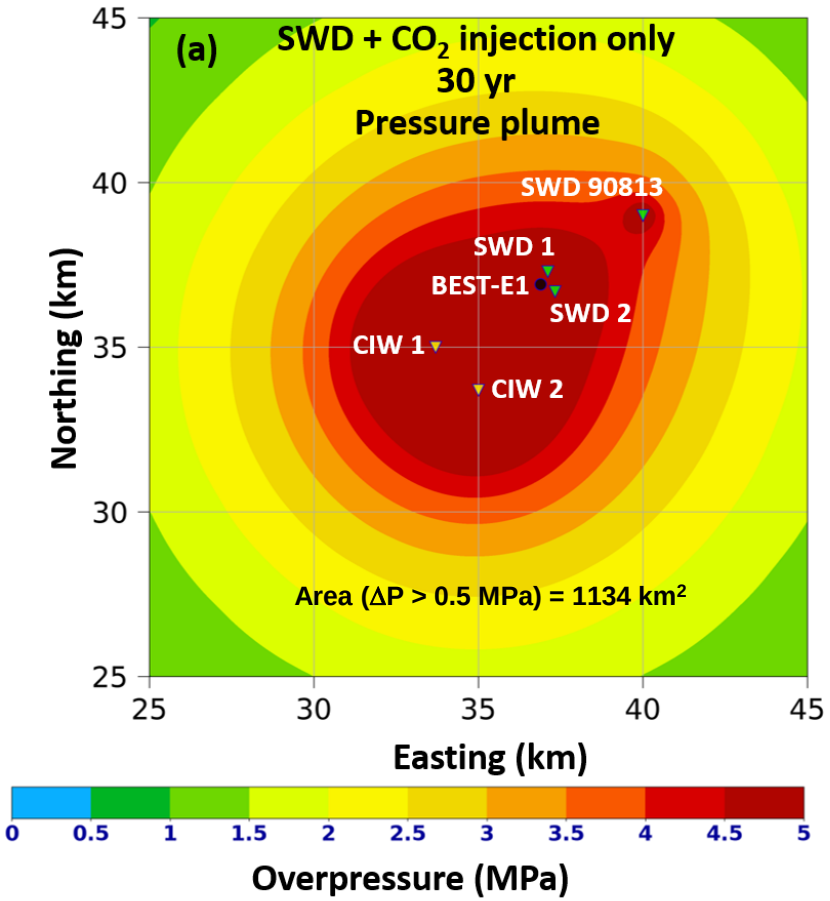
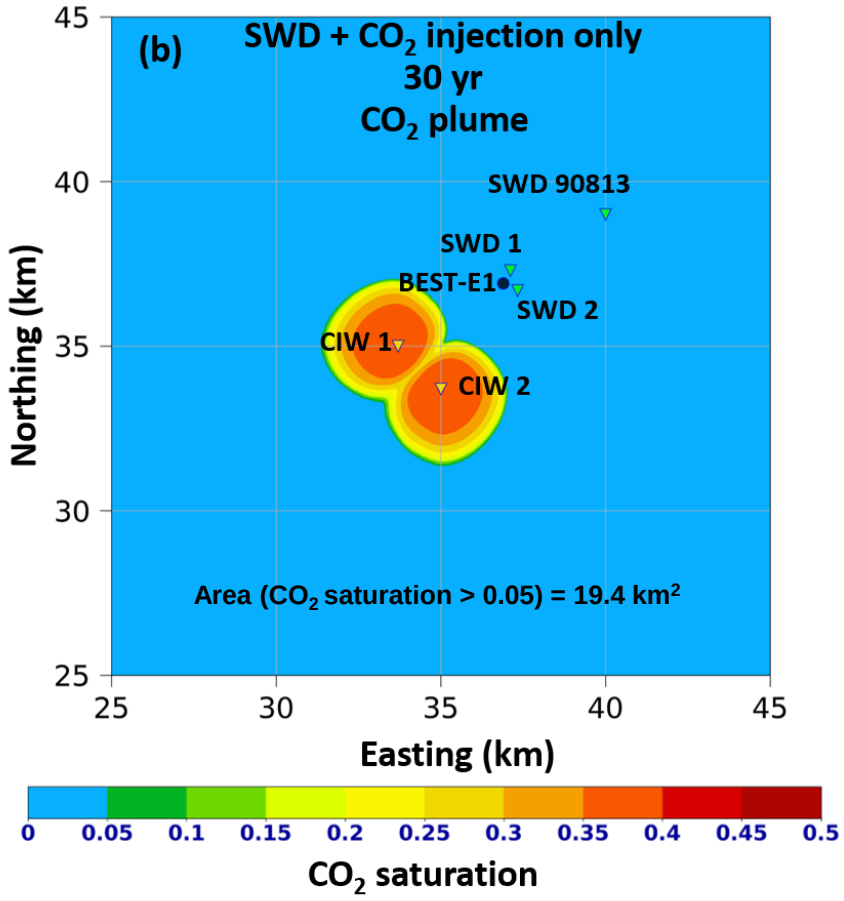
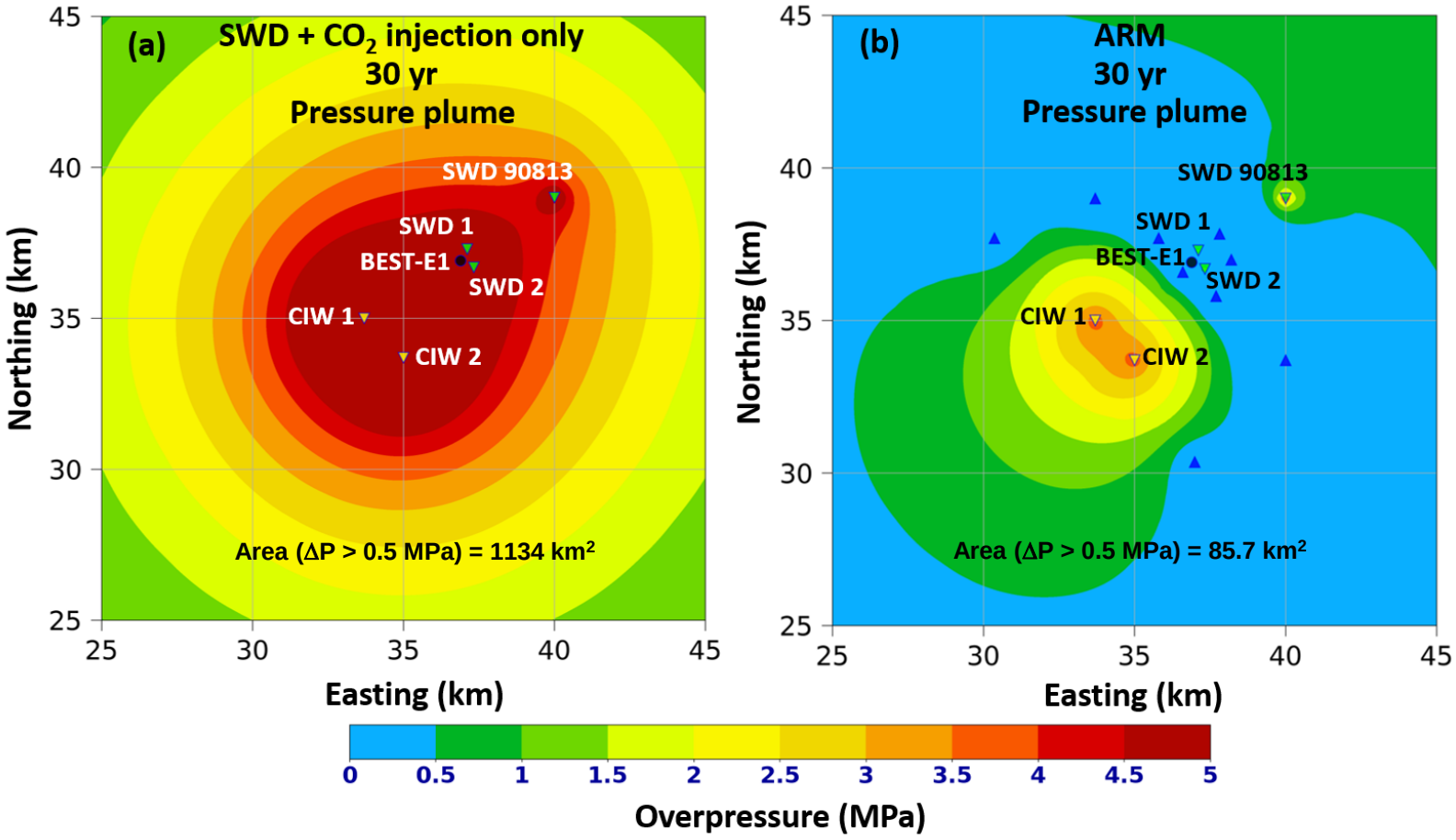
- The pressure plume is much larger than the CO_2 plume
- After 30 years of SWD and CO_2 injection, the area where $\Delta P > 0.5$ MPa is 1134 km^2
- After 30 years of CO_2 injection, the area where CO_2 saturation > 0.05 MPa is 19.4 km^2





Our analyses indicate ARM can manage overpressure for 30 years of GCS and SWD operations separated by 4 km

- After 30 years of SWD and CO_2 injection
  - ARM reduces the area where $\Delta P > 0.5$ MPa from 1134 km^2 to 85.7 km^2 in the vicinity of the GCS operation
  - the pressure plume from the brine re-injection wells has reached the northeast corner of the SWD wellfield



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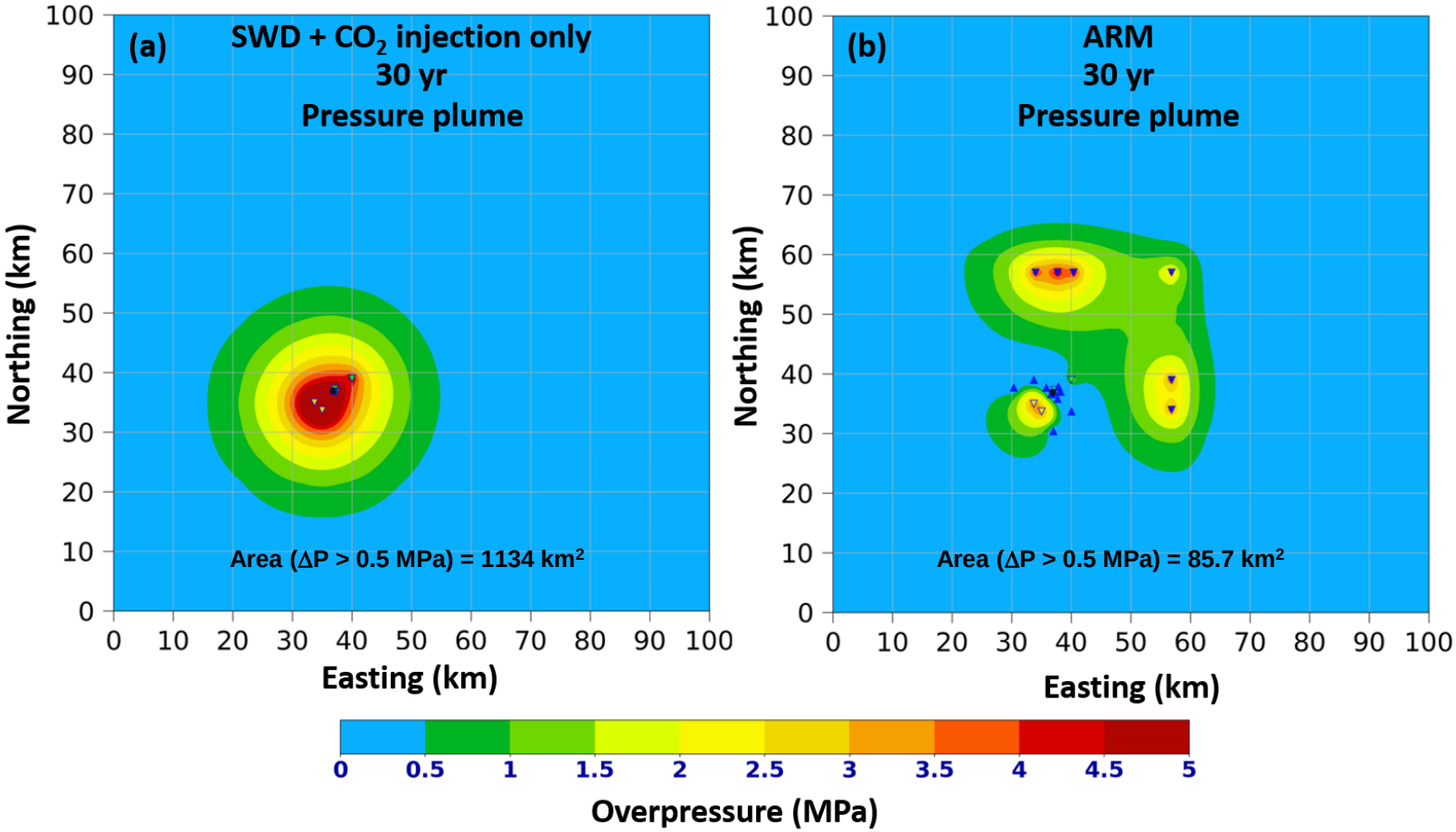
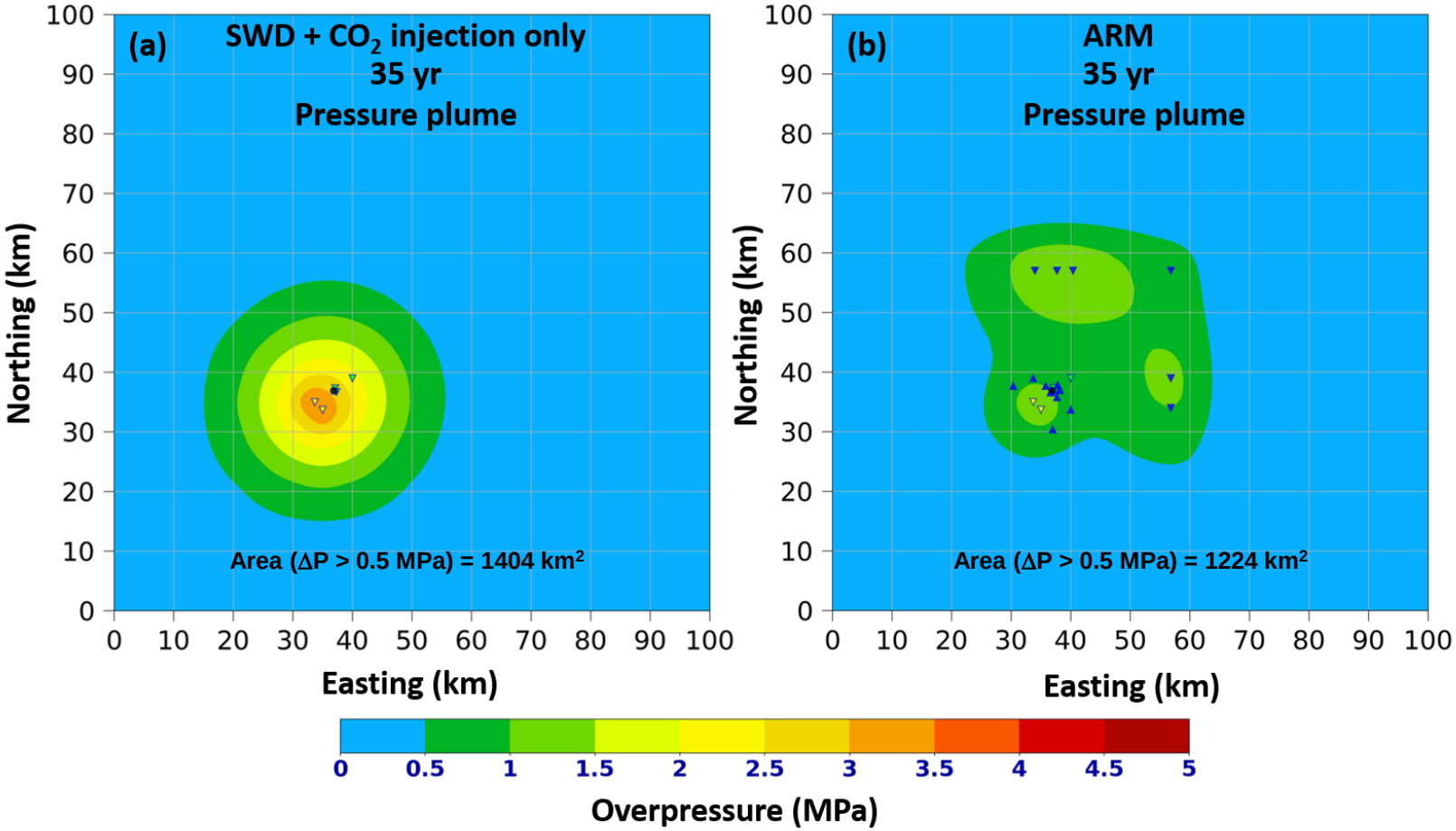


Our analyses indicate ARM can manage overpressure for 30 years of GCS and SWD operations separated by 4 km

- 5 years after the end of SWD and CO_2 injection operations
  - the area where $\Delta P > 0.5$ MPa has increased to 1404 km^2 for SWD and CO_2 injection only
  - the pressure plume from the brine re-injection wellfield has merged with the plume surrounding the GCS and SWD wellfields, with the area where $\Delta P > 0.5$ MPa increasing to 1224 km^2



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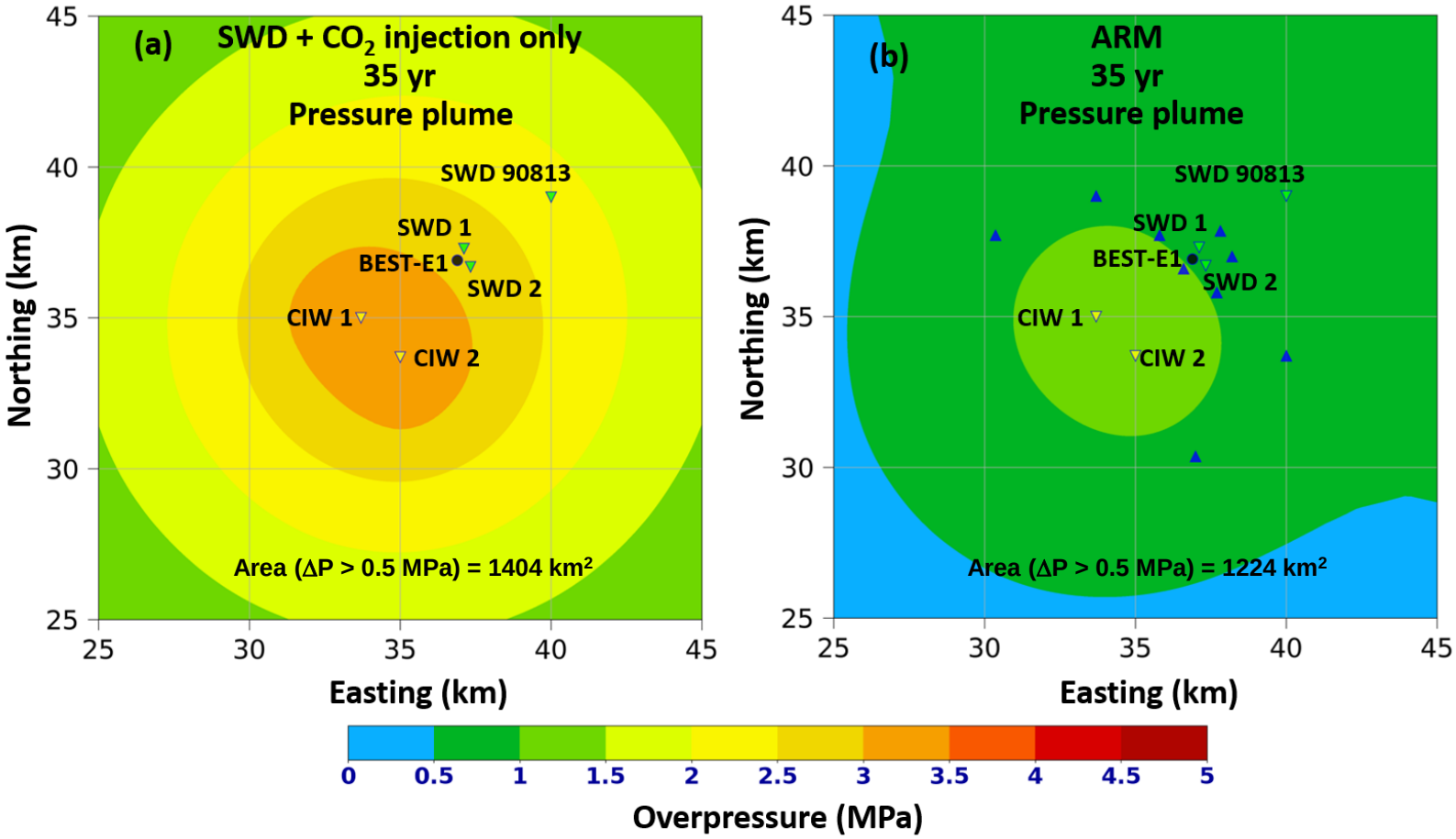

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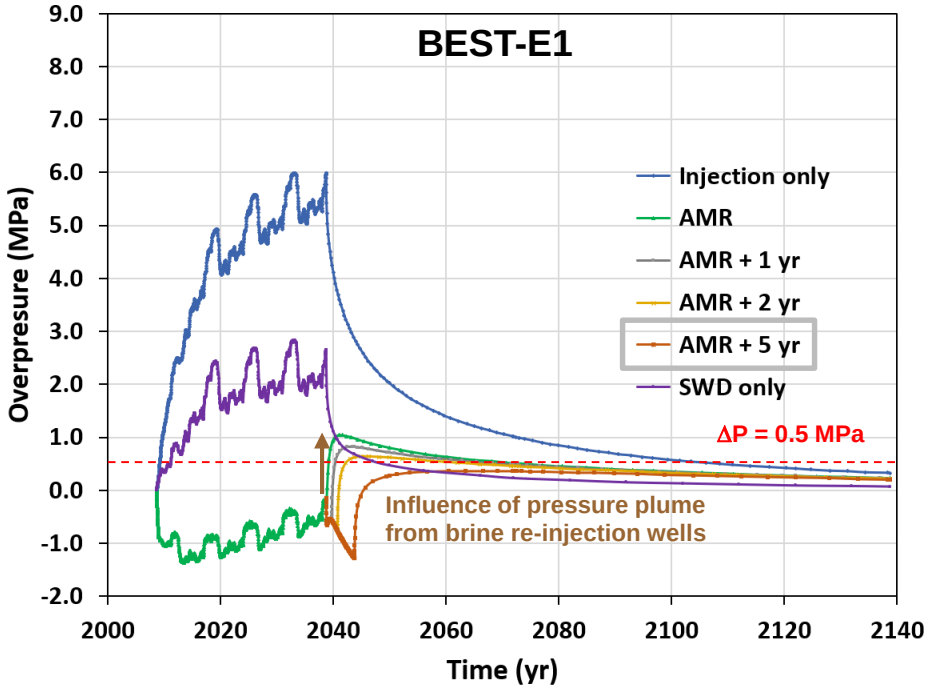
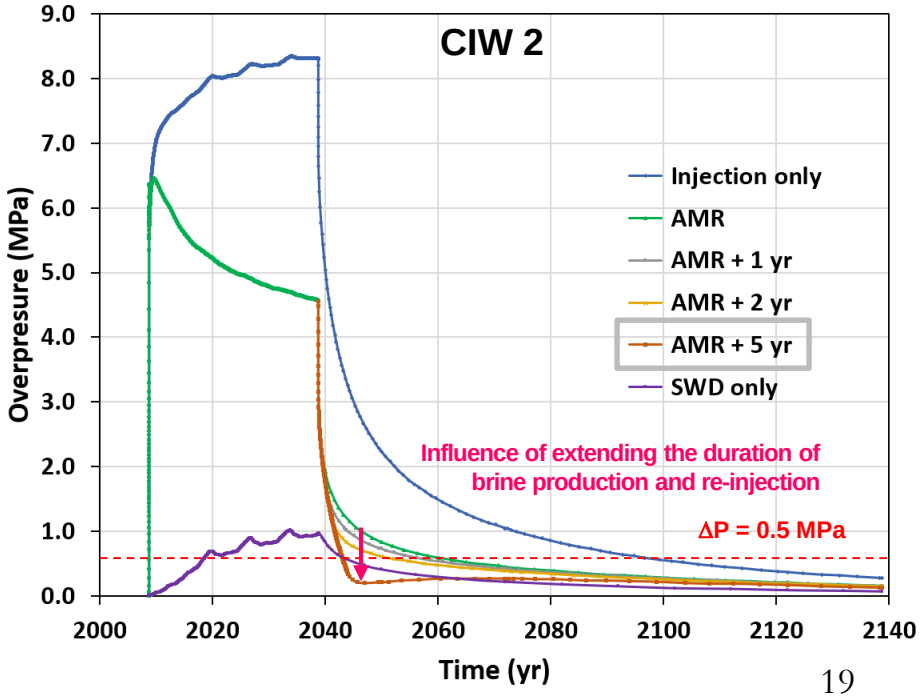
- While brine is actively produced, overpressure is controlled around the CO_2 and SWD injection wells
- After brine production stops, overpressure rebounds in the SWD wellfield as a result of the pressure plume from the brine re-injection wellfield
- Continuing brine production and re-injection for 5 more years prevents the rebound in overpressure from exceeding 0.5 MPa around the CO_2 and SWD injection wells





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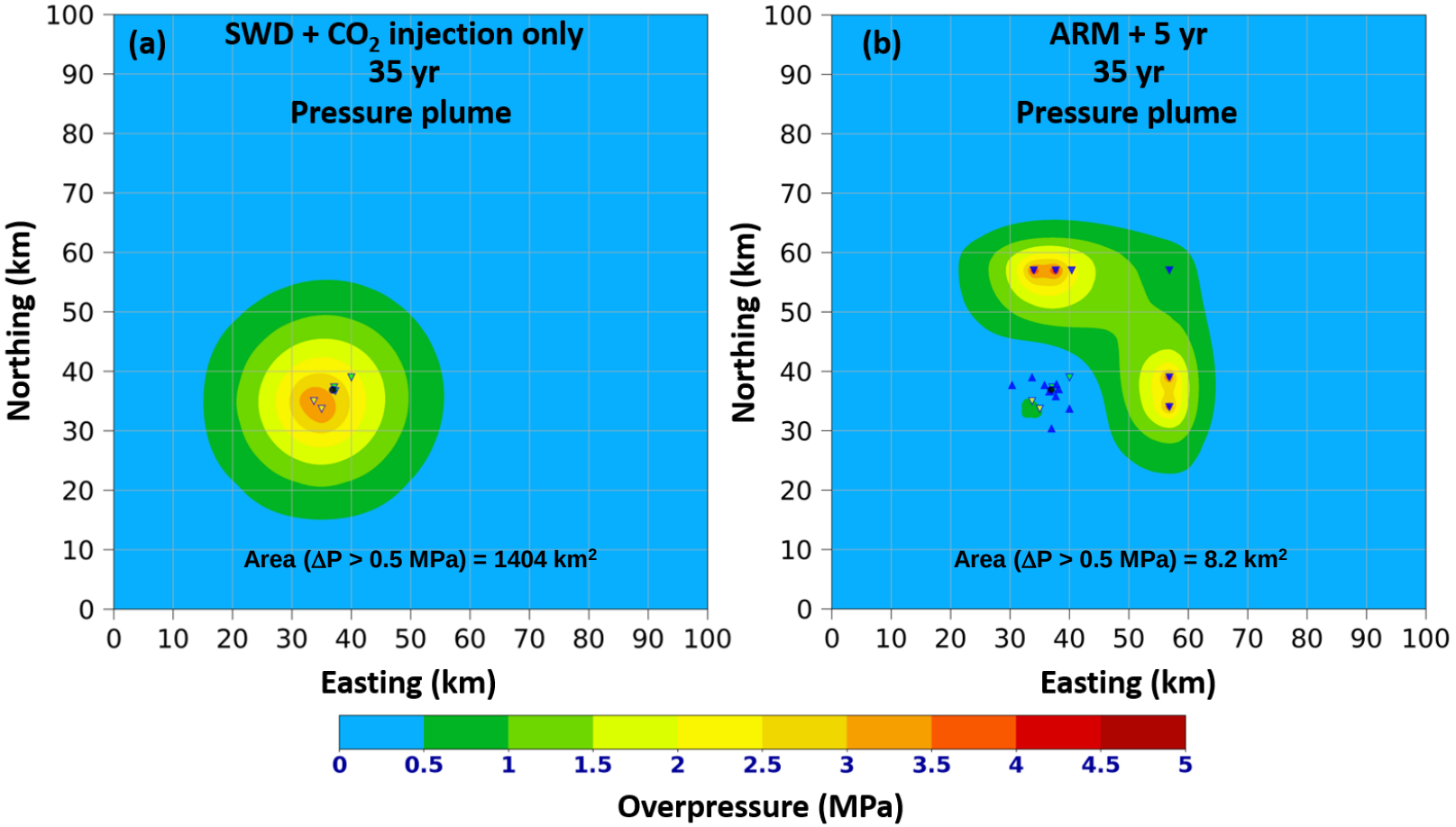
- Continuing brine production and re-injection for 5 more years prevents the rebound in overpressure from exceeding 0.5 MPa in the vicinity of the SWD and CO_2 injection wells
- ARM limits the area where $\Delta P > 0.5$ MPa to 8.2 km^2 in the vicinity of the GCS and SWD operations



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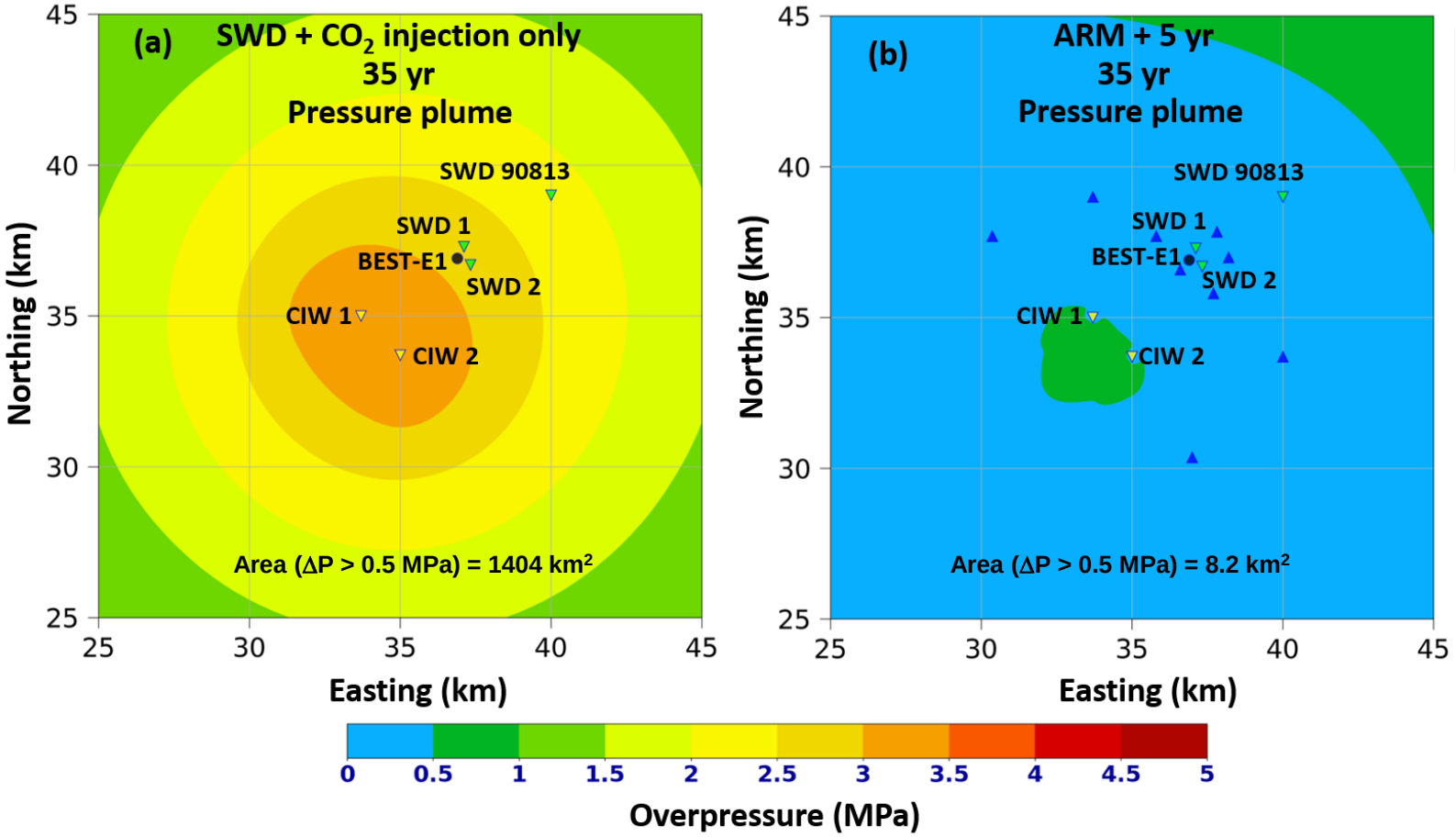

Accomplishments to Date

- Data-constrained reservoir model of the Snøhvit Phase I CO_2 Storage Project used to analyze ARM using pre-injection brine production
- Data-constrained reservoir model of the Snøhvit Phase II CO_2 Storage Project used to analyze ARM with pre-injection gas production for associated storage
- Data-constrained reservoir model analyses of the EERC BEST reservoir system in the Inyan Kara Fm. in the Williston Basin investigating how ARM can be used to minimize pressure interference between adjoining GCS and SWD operations

Lessons Learned

- Active reservoir management (ARM) may be essential for GCS in limited-capacity, compartmentalized reservoirs
- ARM can be useful in leveraging the inherent advantages of large-capacity, open reservoirs
- ARM can enable co-locating GCS with other injection operations with minimal pressure interference between the operations
- ARM may be useful in reducing monitoring costs
- ARM may need to address all sources of reservoir overpressure, including those arising from other subsurface operations, such as saltwater disposal

Synergy Opportunities

- Collaboration with BEST project team
- Conduct economic assessments and cost-benefit analyses that include the costs of ARM and monitoring
- Consider the impact of ARM on permitting and regulatory compliance

Project Summary

- Key findings
  - pressure plumes at GCS sites may be influenced by adjoining injection operations
  - to minimize the Area of Review (AoR), enough brine needs to be removed to account for all sources of overpressure, including adjoining injection operations
  - in large-capacity, open reservoirs, it may not be necessary to export brine out of that reservoir to minimize the AoR
- Next steps
  - seek collaboration opportunities for future, commercial-scale, GCS projects

Appendix

Benefit to the Program

- Project goals that are being addressed include
  - active site characterization using pre-injection brine production
  - assurance of storage permanence
- Benefits to the program include
  - development of geologic CO_2-storage, reservoir-engineering strategies and related best practices that lead to increased assurance of storage permanence, while reducing monitoring costs

Project Overview

Goals and Objectives

- The project goals and objectives include the evaluation of strategies to increase CO_2 storage capacity in limited-capacity, compartmentalized reservoirs
- The project goals and objectives also include the evaluation of strategies to optimize ARM for waste-water and CO_2 injection using data from saltwater disposal operations in North Dakota, in collaboration with the Energy and Environmental Research Center (EERC), including those that
  - minimize the Area of Review
  - prevent recirculation of injected fluids
  - avoid pore-space trespass with neighboring subsurface operations

Organization Chart

- The project team consists of Thomas Buscheck at Lawrence Livermore National Laboratory

Gantt Chart

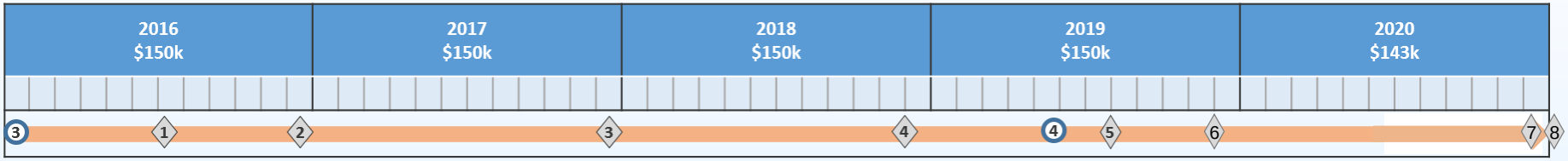

Chart Key

TRL Score

Go / No-Go Timeframe

Project Completion

Milestone

Milestones

1. Publish journal article on pre-injection brine production using data-constrained model of Snøhvit Phase I project.
2. Publish two journal articles on pre-injection brine production.
3. Submit OUO report on pre-injection gas production using data-constrained model of Snøhvit Phase II project.
4. Develop a data constrained reservoir model of the EERC BEST project in the Inyan Kara Fm.
5. Conduct Active Reservoir Management (ARM) analyses to investigate ARM options in the Inyan Kara Fm.
6. Present results of ARM study at 2019 CCUS and Oil & Gas Technologies Integrated Review Meeting.
7. Present results of ARM study at 2020 Carbon Storage Virtual Project Review Meeting.
8. Submit manuscript on Active Reservoir Management in the Inyan Kara Fm. in the Williston Basin, North Dakota.

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