Task 4: Active Reservoir Management

(See FEW-0191)

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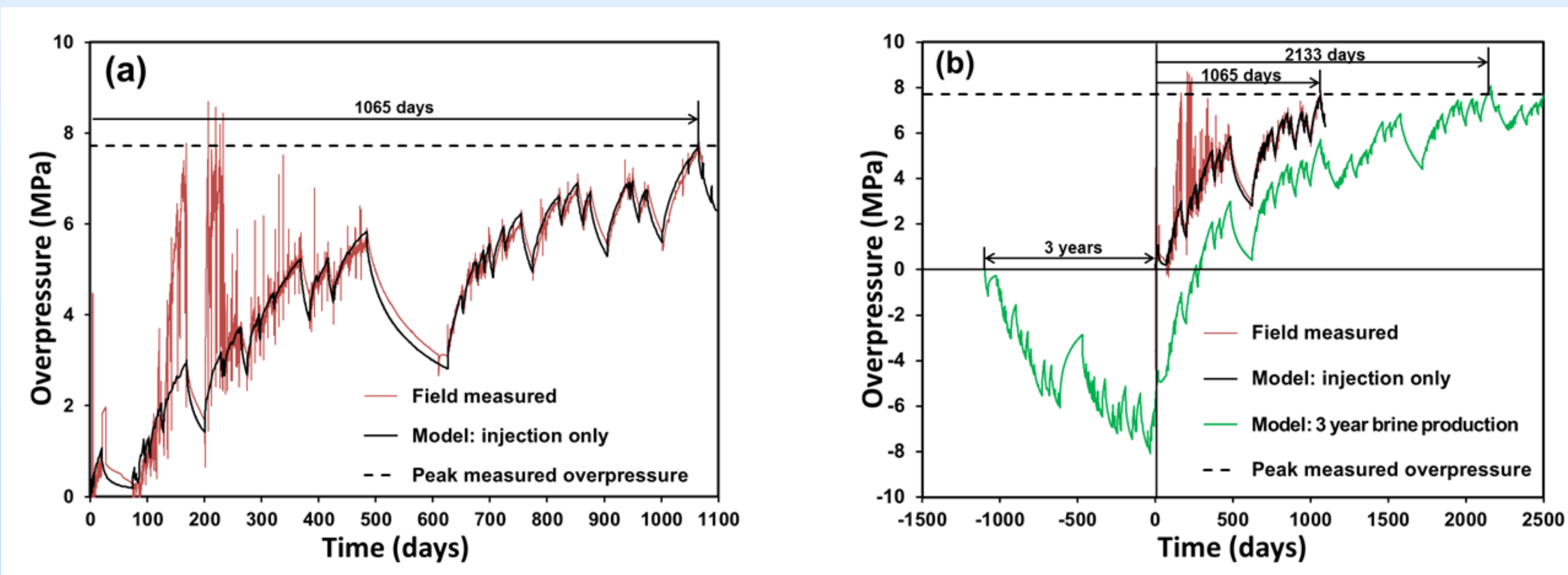
Presentation Outline

- Active Reservoir Management (ARM) of CO_2 capture and storage (CCS) in compartmentalized reservoirs
  – pre-injection brine production analyzed with model constrained with data from the Snøhvit Phase I CO_2 storage test
- ARM of CCS in open reservoirs
  – integration of CCS with saltwater disposal (SWD) operations analyzed with model constrained with data from the Energy & Environmental Research Center (EERC) Brine Extraction Storage Test (TEST) site
- Accomplishments to date
- Lessons learned
- Synergy opportunities
- Project summary

Technical Status: ARM of CCS in compartmentalized reservoirs

Pre-injection brine production analyzed with model constrained with data provided by Statoil of the Snøhvit Phase I CO_2 storage test

- Our model closely predicts overpressure caused by injecting 1.09 MT of CO_2 into the Tubåen Fm.
- Producing a volume of brine equal to the injected CO_2 volume allows injecting an additional 1.03 MT of CO_2, 94.4% efficient on a volume-per-volume basis

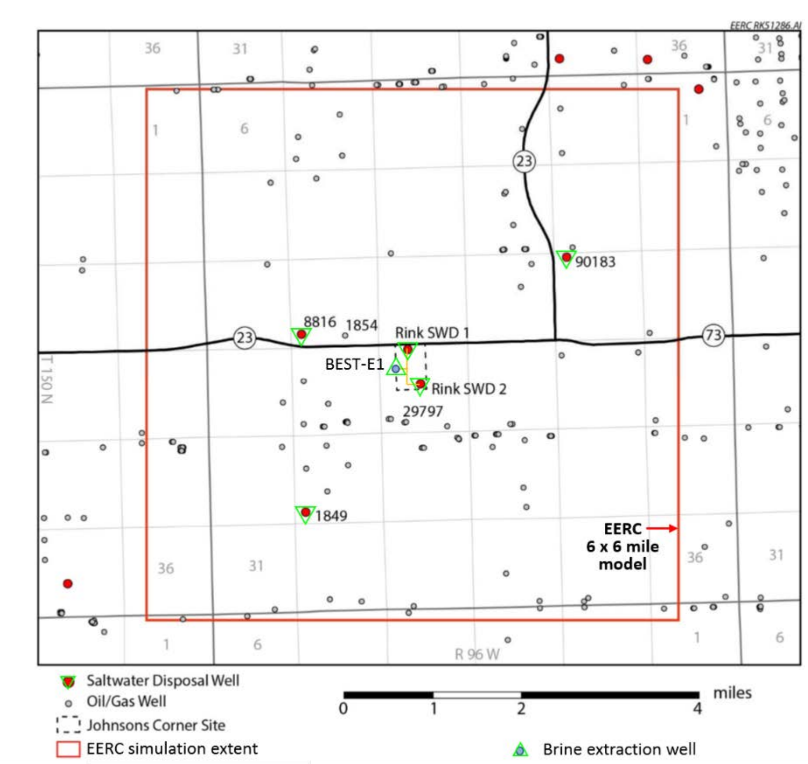


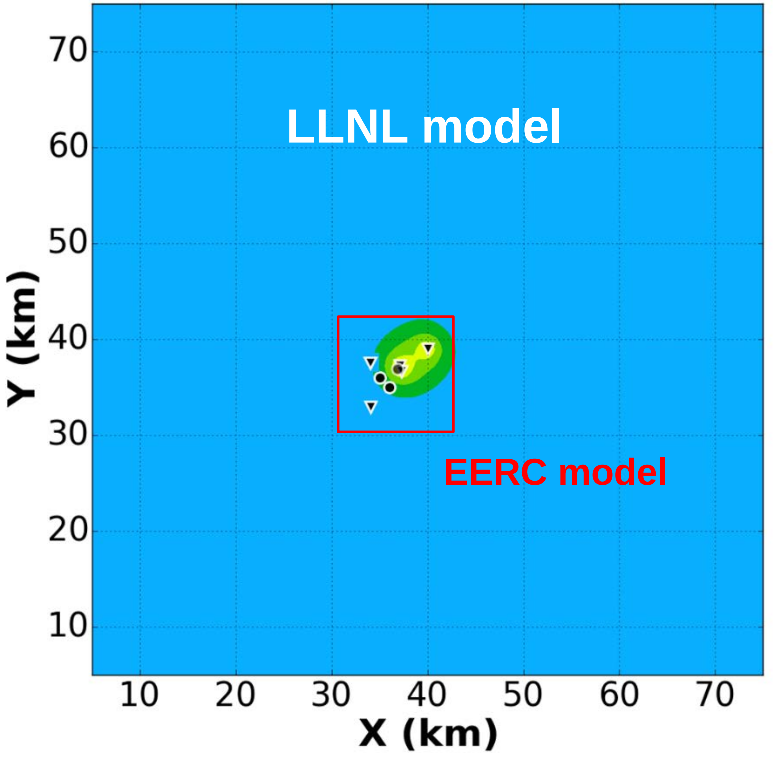
Technical Status: ARM for CCS in open reservoirs

- Our initial focus was the use ARM to address the limited storage capacity of closed, compartmentalized 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  - estimated CO_2 storage capacity of 20–80 billion tons (Glazewski et al, 2015) and recent unpublished analysis suggesting 2–5 times that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 CCS with adjoining SWD operations

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

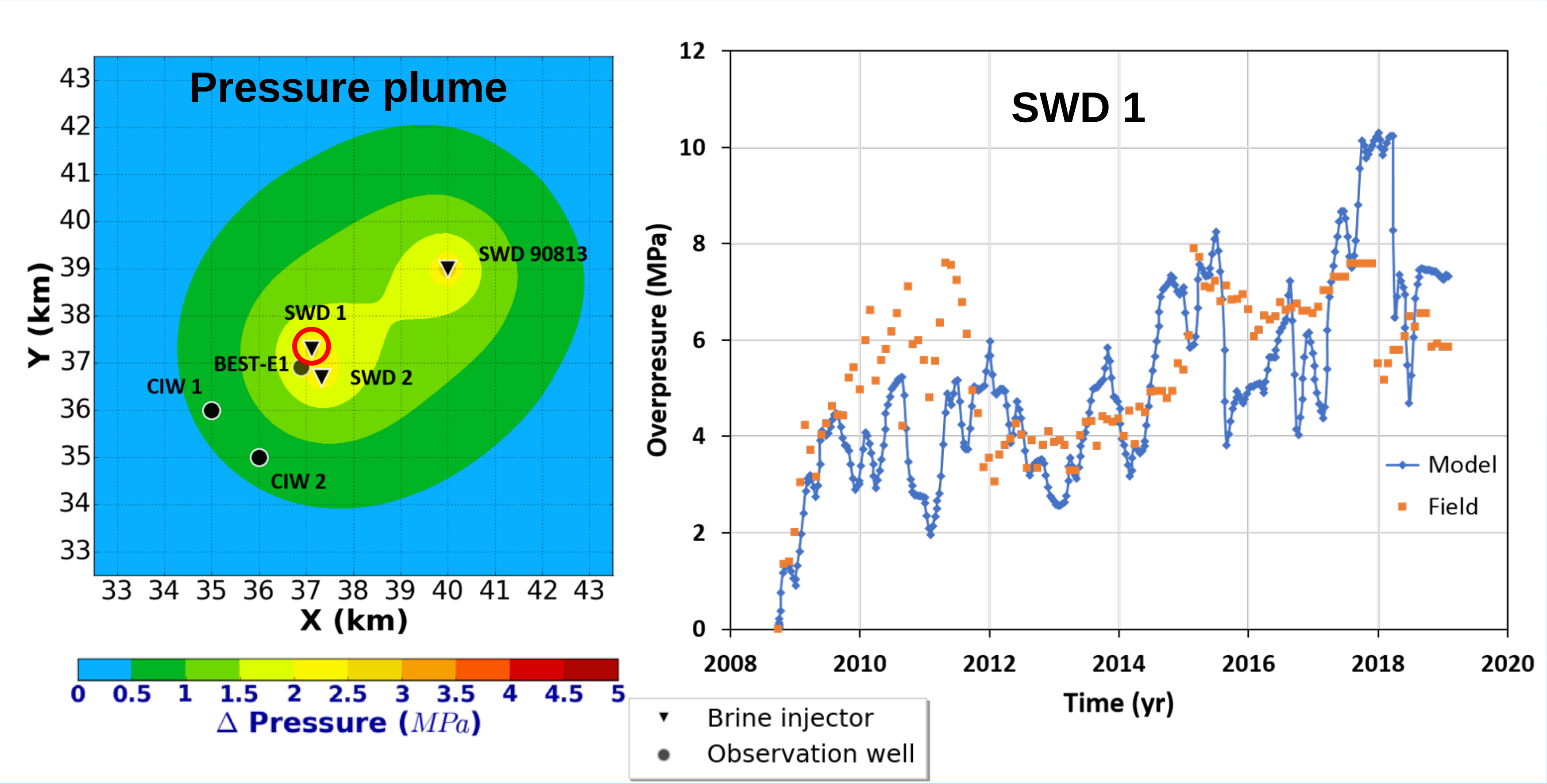
- The EERC BEST site has 5 SWD wells operating since 1961
- The EERC team has used a 6 x 6-mile reservoir model of this site
- Using reservoir models, ranging from 10 x 10-km to 80 x 80-km, we confirmed that the Inyan Kara Fm. is an open reservoir





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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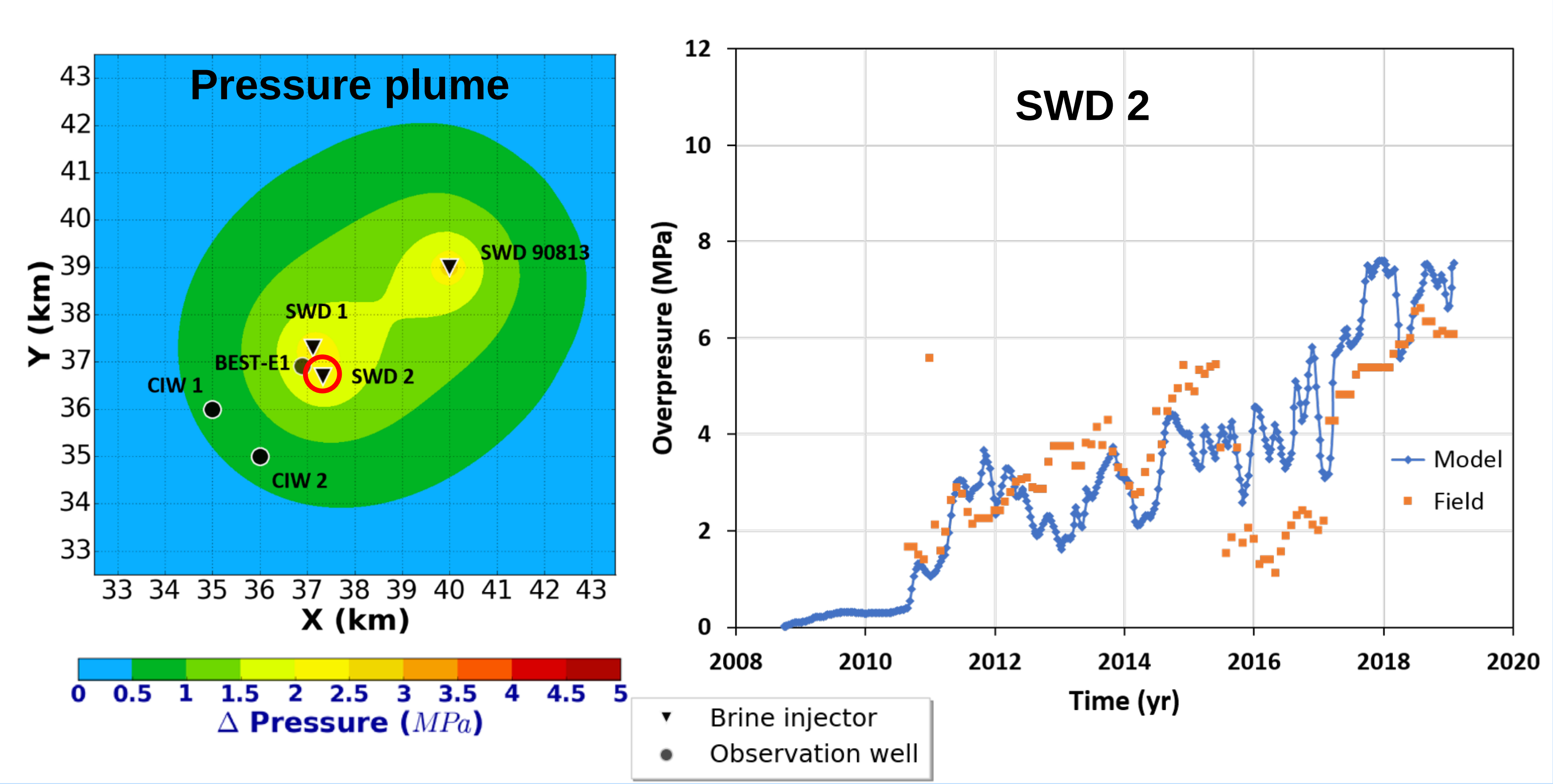

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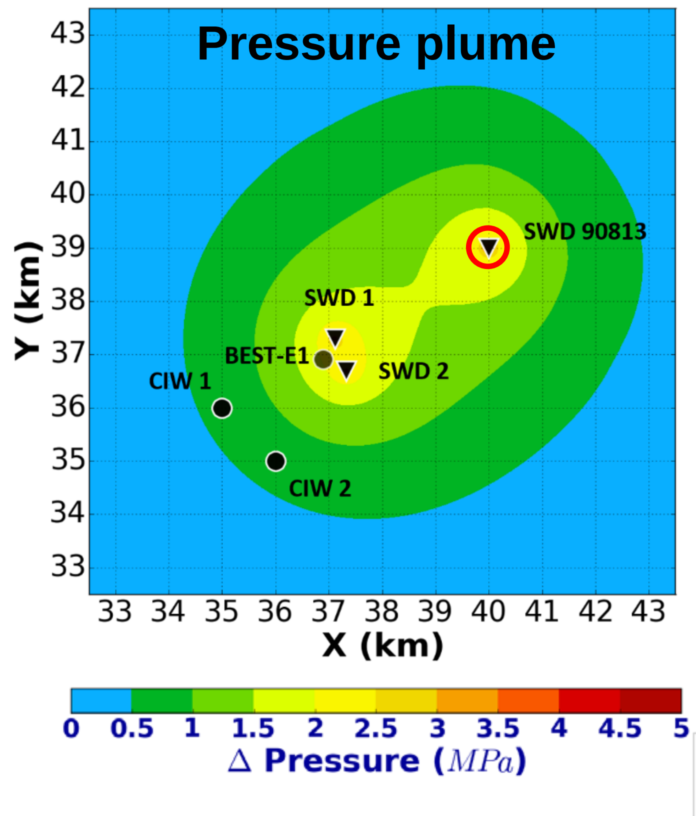
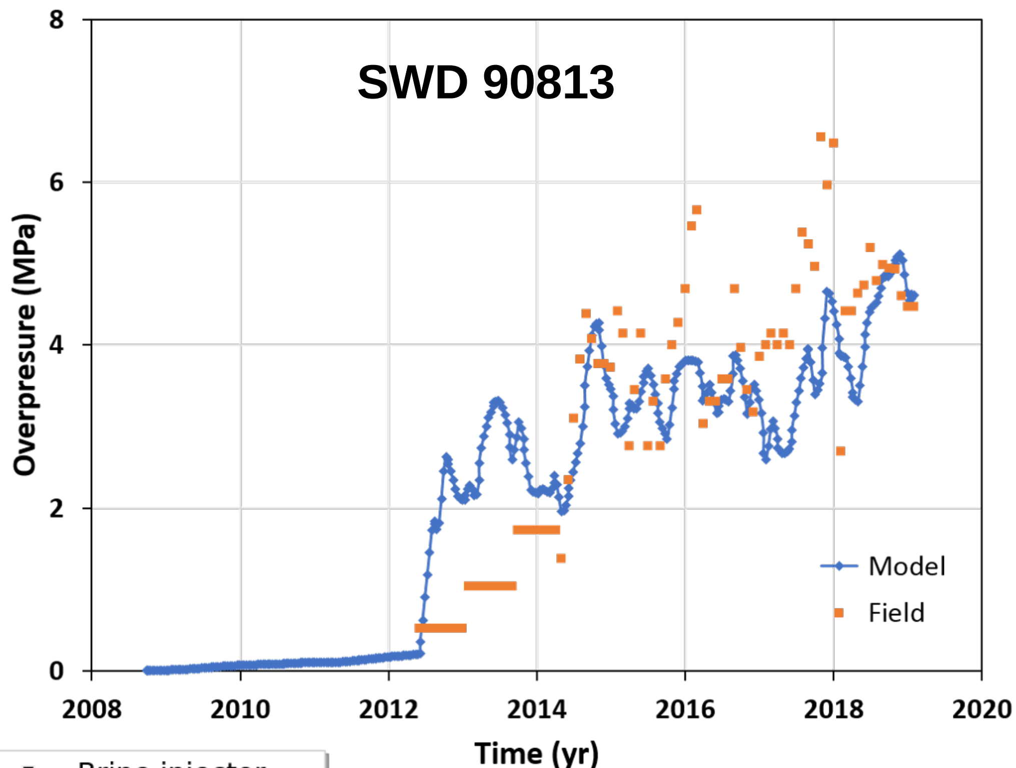
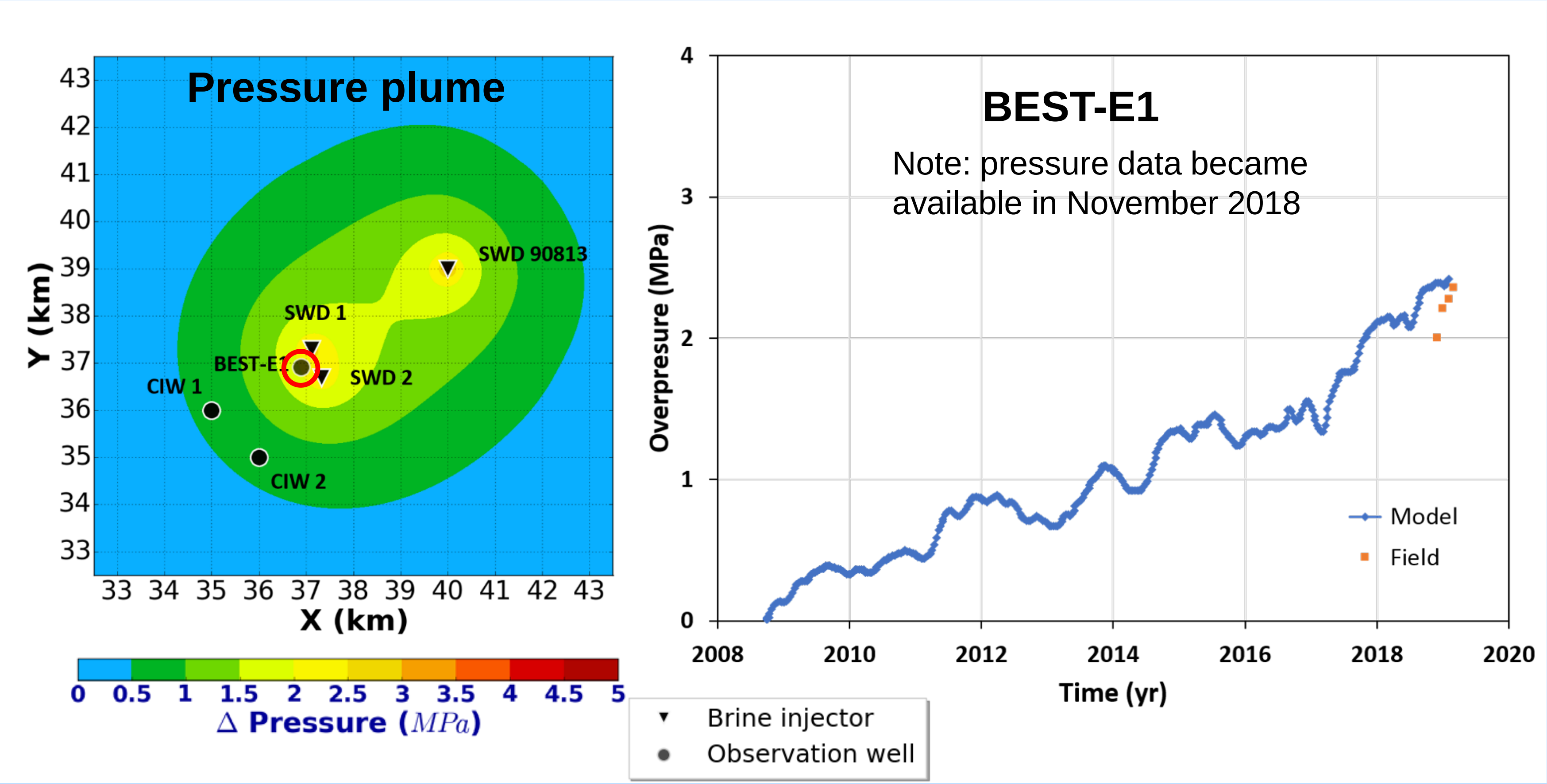




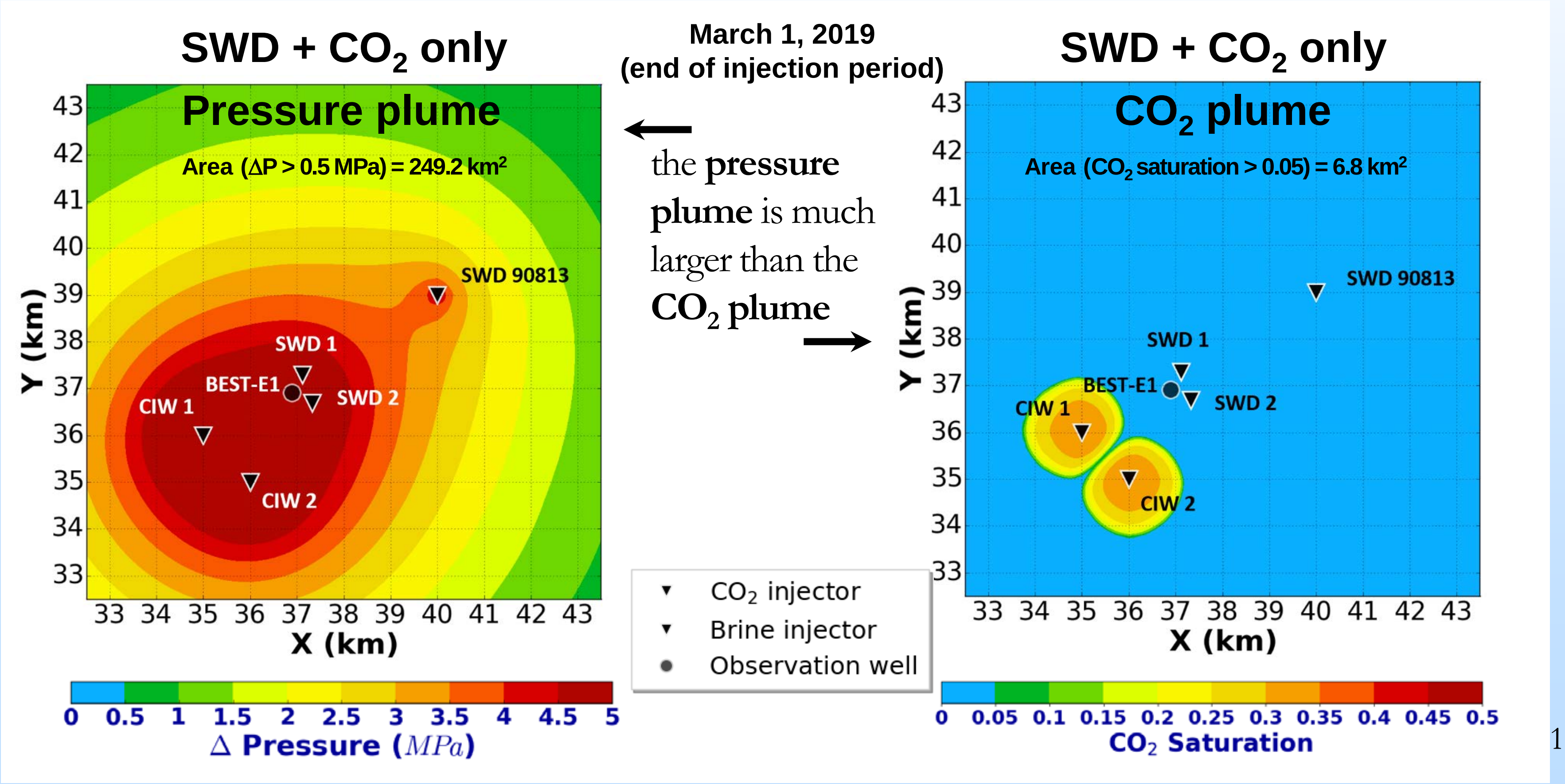
Technical Status: Data-constrained model of the EERC BEST site

- 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 CCS 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



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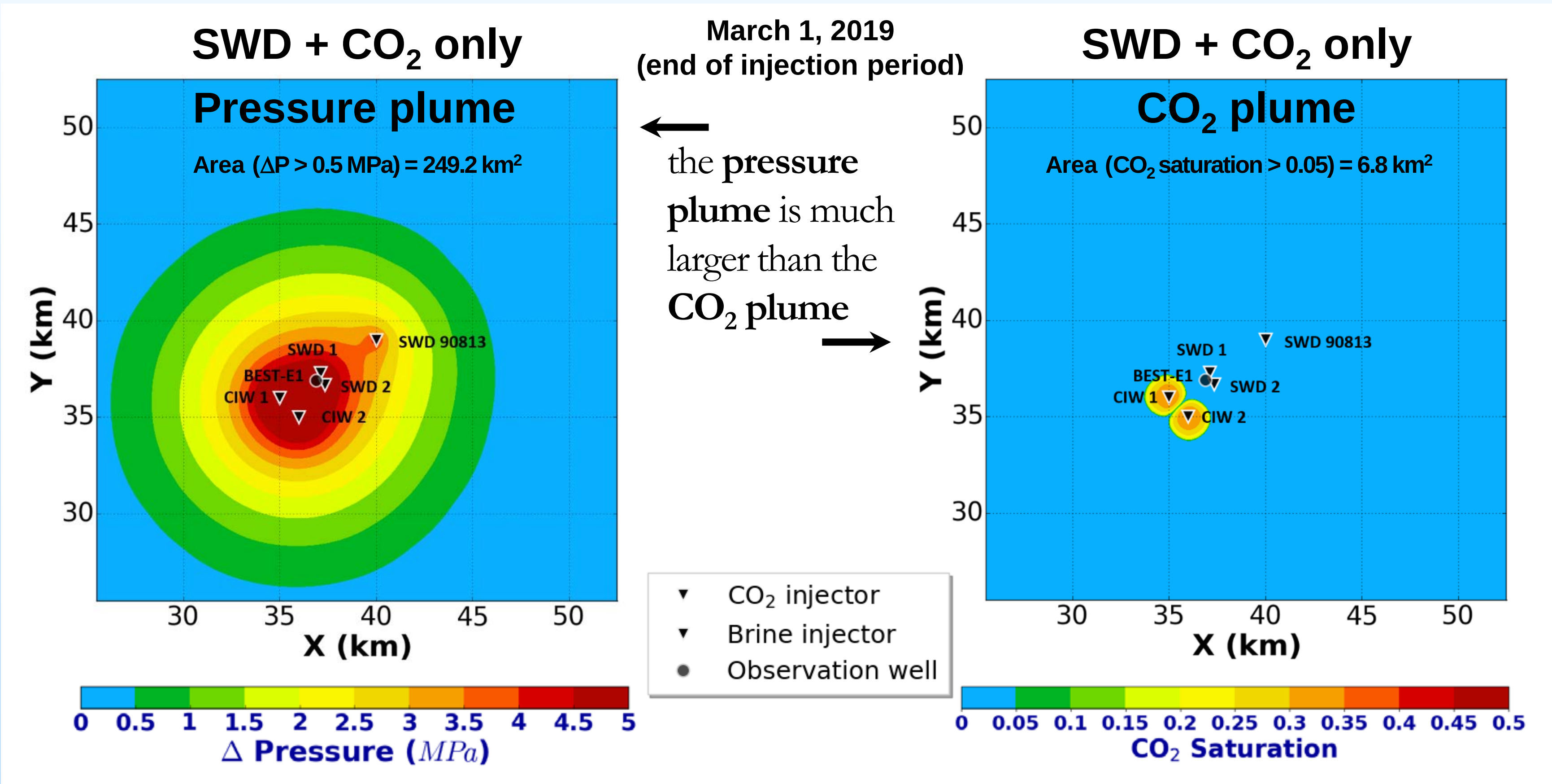
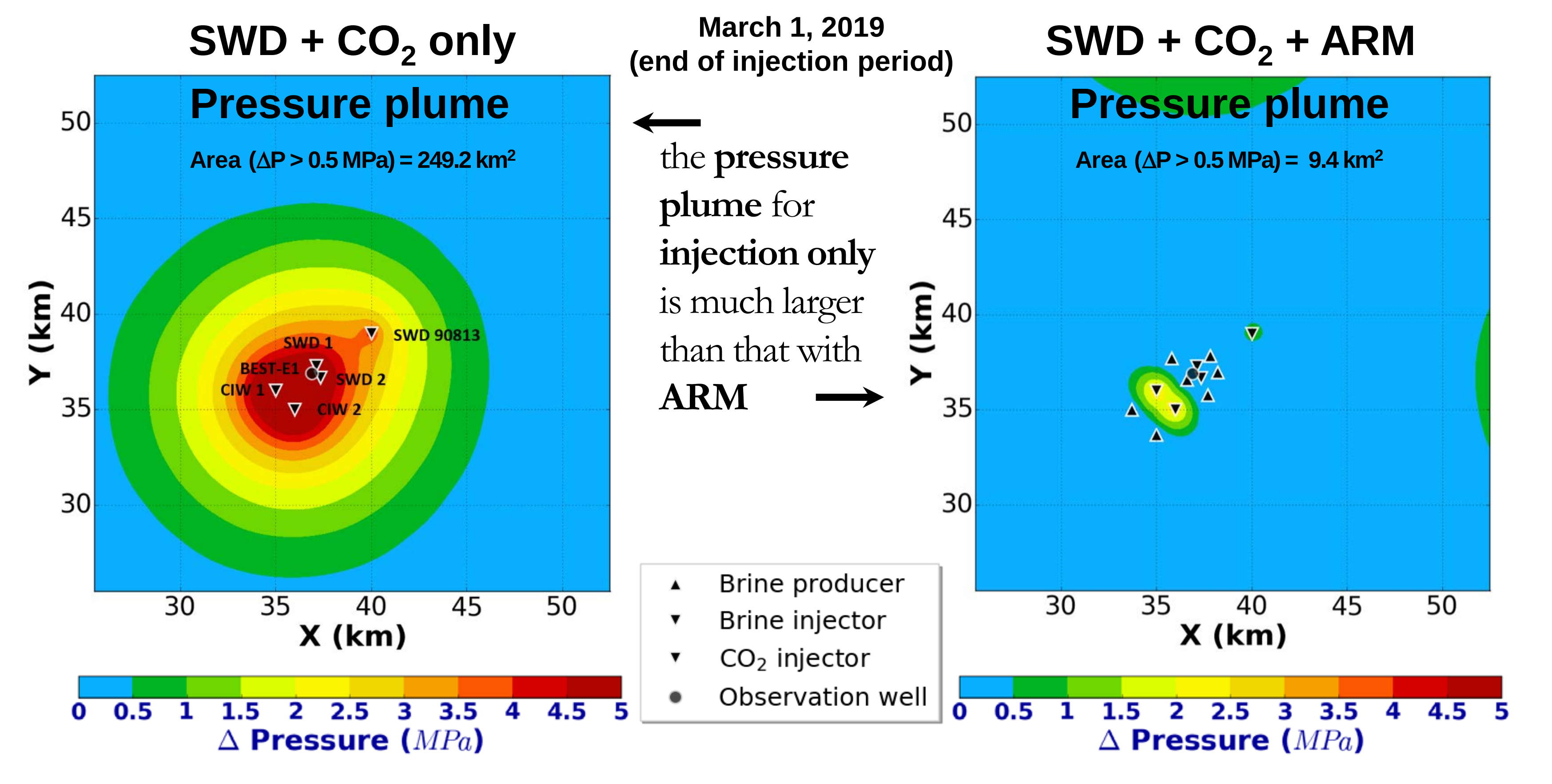


Technical Status: Data-constrained ARM analyses of the EERC BEST site

- A volume of produced brine equal to the total injected volume of CO_2 plus saltwater reduces pressure plume size and Area of Review (AoR)



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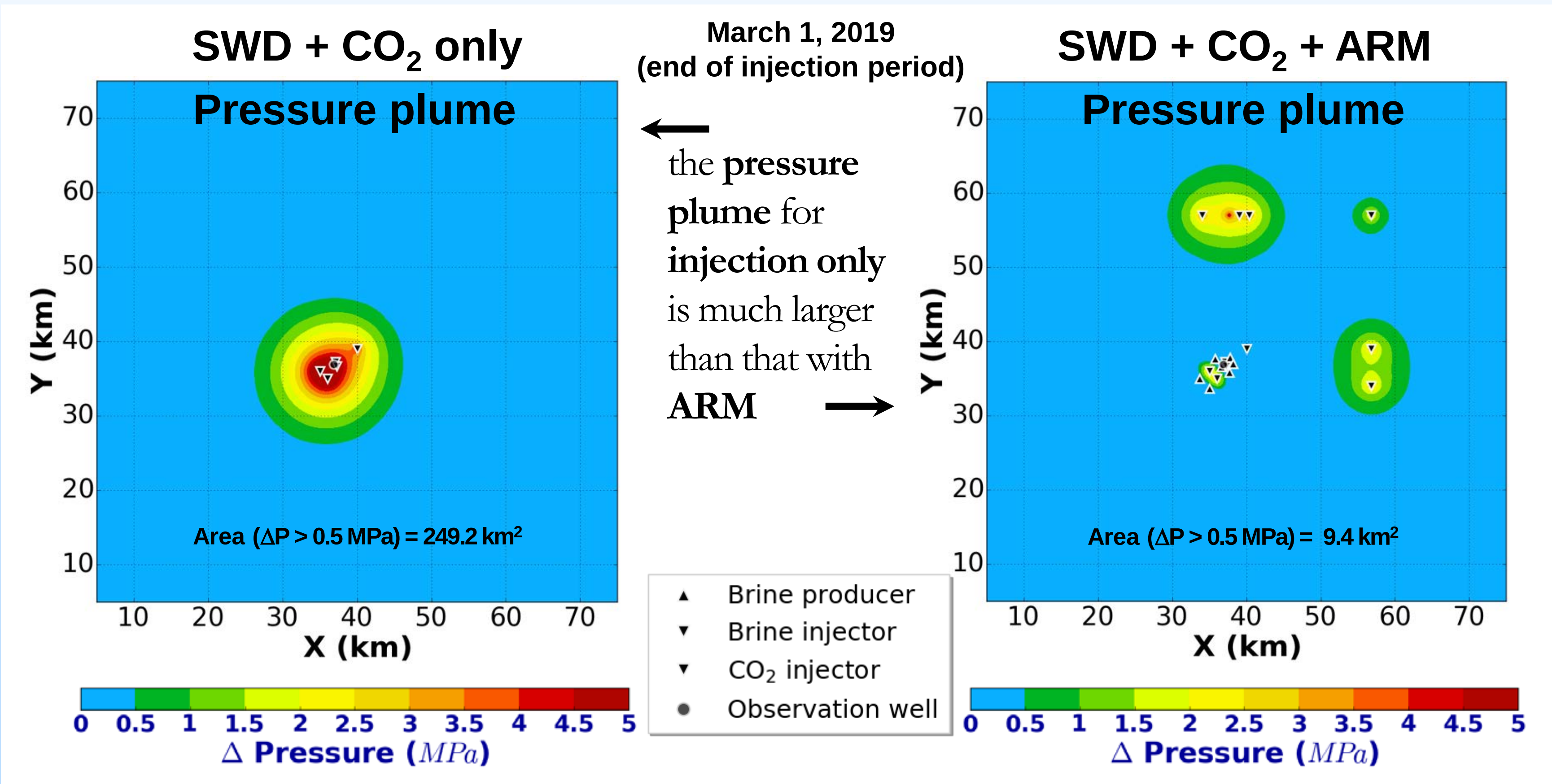
- The reduction of the pressure plume was achieved by moving 66,846 BPD of produced brine to 6 brine injection wells located 20–30 km away
  - this corresponds to 6% of the total rate of SWD in the Inyan Kara Fm. in 2018

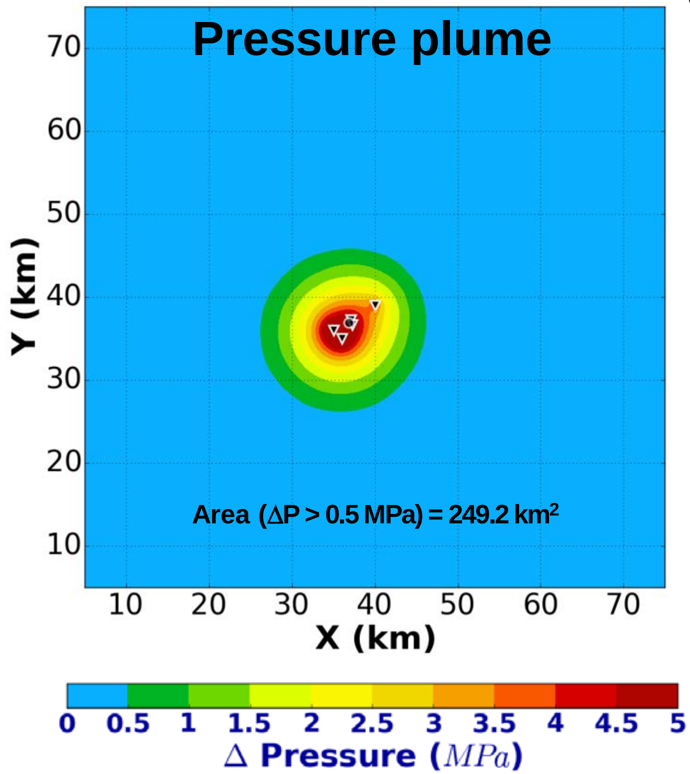


Technical Status: Data-constrained ARM analyses of the EERC BEST site

Affected Area (km²) at end of injection

	Overpressure (MPa)								
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
Injection only	249.2	192.7	130.0	90.6	64.4	46.0	31.9	21.3	14.9
ARM	9.4	5.6	3.0	1.0	0.1	0.0004	0.0	0.0	0.0

SWD + CO_2 only

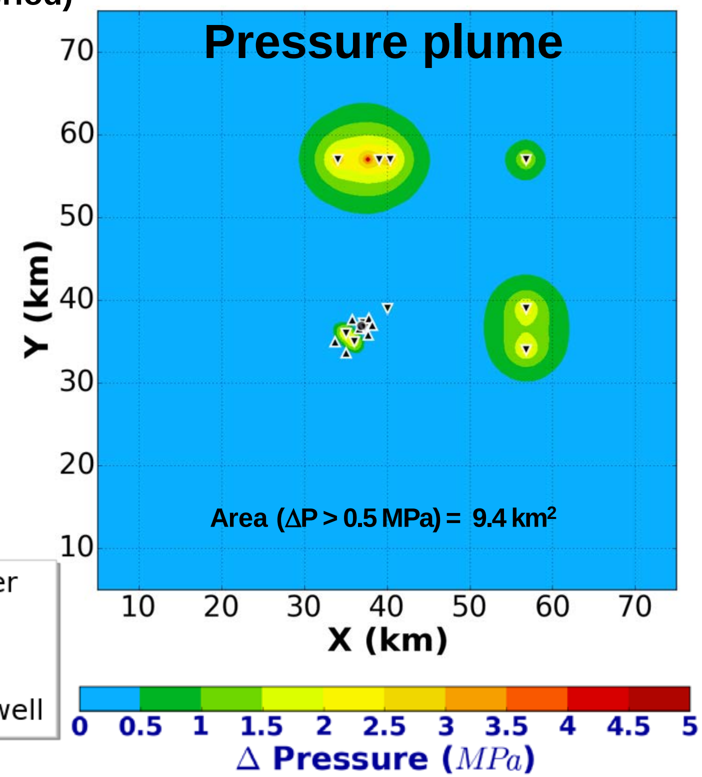


March 1, 2019 (end of injection period)

← the **pressure plume** for **injection only** is much larger than that with **ARM** →

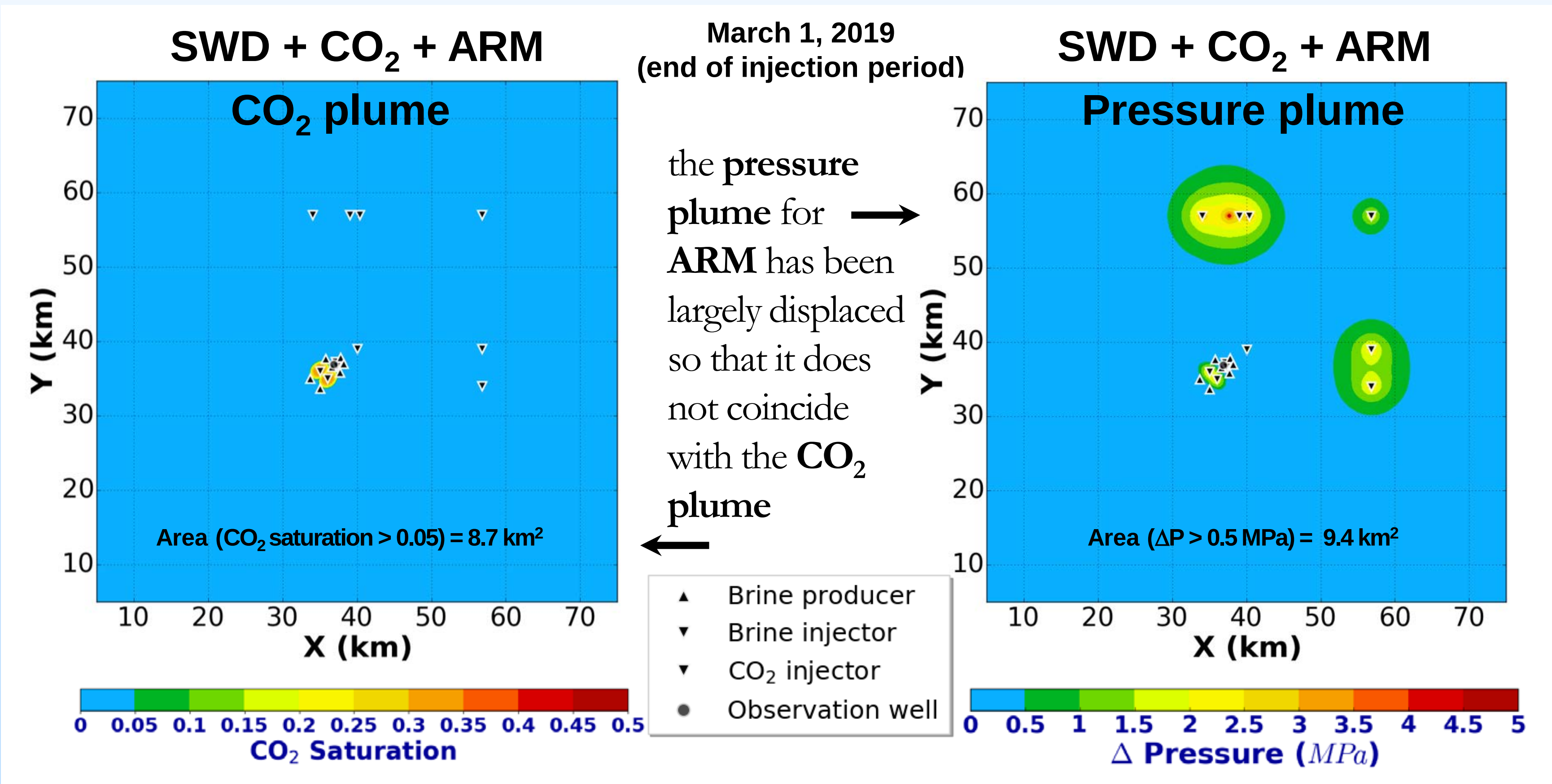
- ▲ Brine producer
- ▼ Brine injector
- ▼ CO_2 injector
- ● Observation well

SWD + CO_2 + ARM



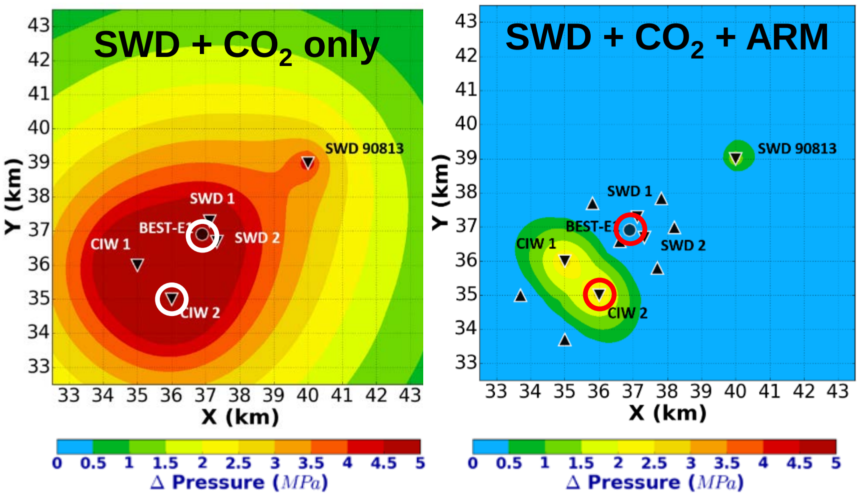
Technical Status: Data-constrained ARM analyses of the EERC BEST site

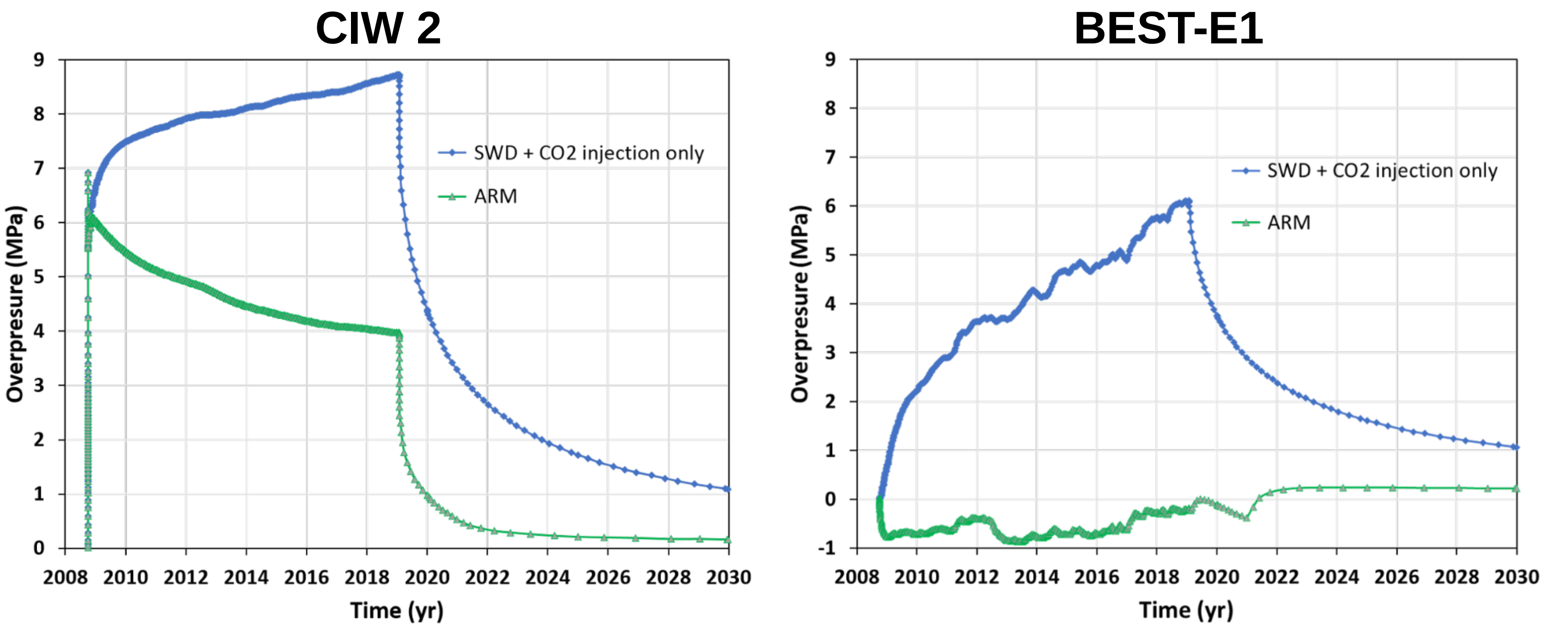
- From a risk management perspective, the key objective is to move as much of the pressure plume as possible away from the CO_2 plume



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

- ARM reduces the magnitude and duration of overpressure, affecting
  - driving force for leakage
  - duration of monitoring for the detection of potential leaks





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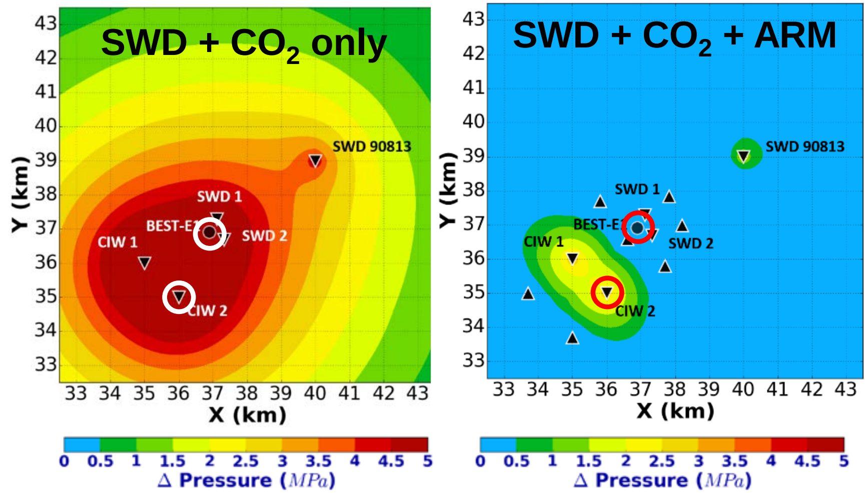
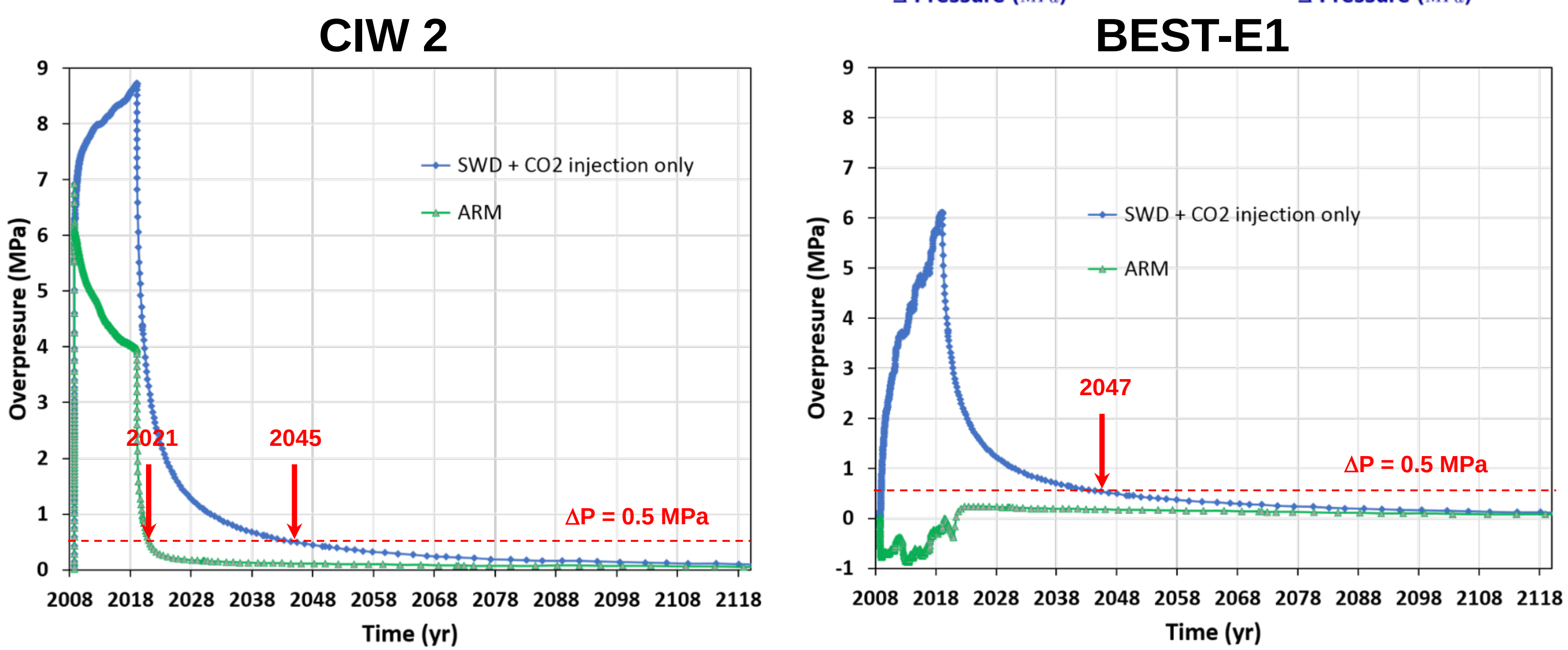




Accomplishments to Date

- 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 efficiently integrate CCS operations with existing SWD operations

Lessons Learned

- Active reservoir management (ARM) may be essential for CCS in limited-capacity, compartmentalized reservoirs
- ARM can be useful in leveraging the inherent advantages of large-capacity, open reservoirs
- 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, as well as from CO_2 injection itself

Synergy Opportunities

- Collaboration with BEST project team
- Collaboration between active reservoir management (ARM) studies and NRAP monitoring studies
- 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 CCS 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, as well as the CCS operation itself
  - in large-capacity, open reservoirs, it may not be necessary to export brine out of that reservoir to minimize the AoR
- Next steps
  - extend ARM analyses to address longer (30+ year) CO_2 injection periods, possibly by converting brine production wells to CO_2 injection well as the CO_2 plume expands

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

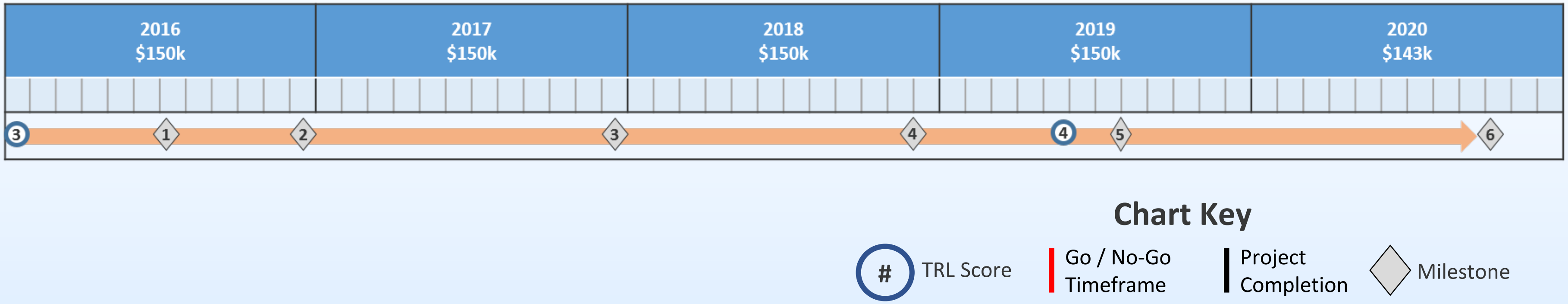
Goals and Objectives

- 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 of this project also include the evaluation of strategies to optimize active reservoir management 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



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. Submit manuscript on Active Reservoir Management in the Inyan Kara Fm. in the Williston Basin, North Dakota.

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