Closed-loop management of carbon storage operations
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Introduction
In carbon storage projects, injected CO₂ can:
• **dissolve** in brine,
• be **immobilized** by capillary trapping, or
• settle under the cap rock in a mobile phase.
Since, mobile CO₂ may be most susceptible to leakage, we apply optimization and data assimilation techniques, using a synthetic aquifer model to:
1. Find optimal well placements and settings that **minimize mobile CO₂**
2. Reduce uncertainty in plume characterization

Optimize well positions and settings
The aquifer model:

 Particle Swarm Optimization (PSO):
• Stochastic
• Parallelizable
• gradient free
• ‘Global’ optimizer

Mobile CO₂ results:

Optimize with ‘brine cycling’
What is brine cycling?
• Inject CO₂ low, let rise
• Produce brine low, re-inject into plume

PRO:
• Reduces mobile CO₂

CON:
• Pumping energy

Mobile CO₂ results:

Closed-loop operations
Aquifer data
Set well controls
Update model
Optimize well settings

Goal:

**Define model parameters** (e.g. permeability), such that simulated, \( \textbf{d}_{\text{sim}} \) data matches observed data \( \textbf{d}_{\text{obs}} \).

**Matching data:** Injection well pressure (BHP), observation well pressure, CO₂ breakthrough time, etc.

**Data assimilation method:**
• Assign a random ‘true’ model to find \( \textbf{d}_{\text{obs}} \)
• Condition geologic realizations to hard-data at CO₂ wells and observation wells

**Location of wells**

• Reduce unknowns by **Karhunen-Loeve expansion:**
\[
\mathbf{m} = \Phi \xi = \mathbf{m}
\]
• Find \( \xi \) to minimize data mismatch:
\[
\min_{\xi} \sum_{i} \left( \frac{d_{\text{obs},i} - d_{\text{sim},i}}{\sigma_i} \right)^2
\]
• Calculate model parameters from \( \xi \)

Saturation match in sample observation well block: