Closed-loop management of carbon storage operations

David Cameron & Louis Durlofsky, 2012 GCEP Symposium

Energy Resources Engineering, Stanford University

Introduction

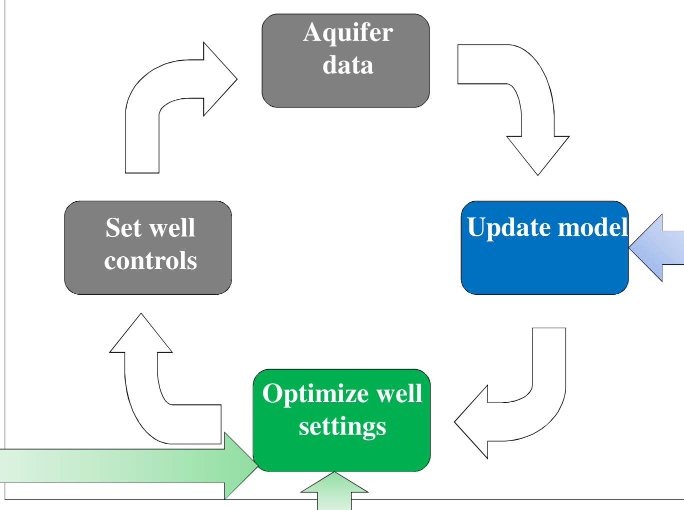
In carbon storage projects, injected CO_2 can:

- **dissolve** in brine,
- be **immobilized** by capillary trapping, or
- settle under the cap rock in a **mobile** phase.

Since, mobile CO_2 may be most susceptible to leakage, we apply optimization and data assimilation techniques, using a synthetic aquifer model to:

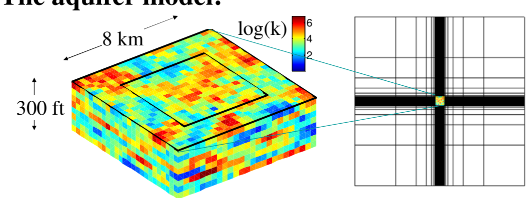
1. Find optimal well placements and settings that **minimize mobile CO_2**
2. Reduce uncertainty in plume characterization

Closed-loop operations



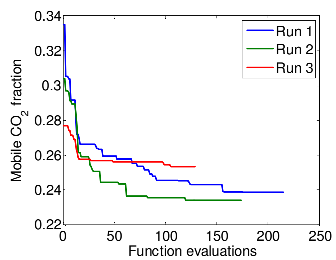
Optimize well positions and settings

The aquifer model:



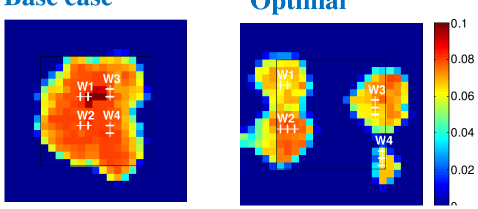
Particle Swarm Optimization (PSO):

- Stochastic
- Parallelizable
- gradient free
- 'Global' optimizer



Mobile CO_2 results:

Base case | Optimal



Optimization with 'brine cycling'

What is brine cycling?

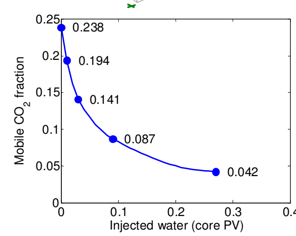
- Inject **CO_2** low, let rise
- Produce **brine** low, re-inject into plume

PRO:

- Reduces mobile CO_2

CON:

- Pumping energy



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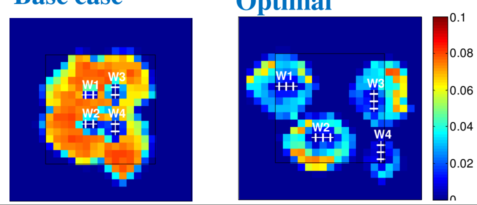


Model updating

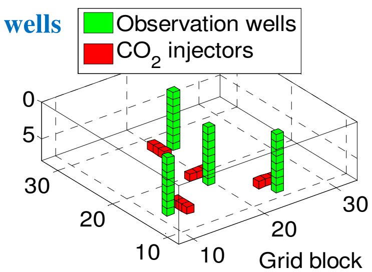
Goal: Determine model parameters (e.g. permeability), such that simulated, $\mathbf{d}_{sim}$ data matches observed data $\mathbf{d}_{obs}$.

Matching data: Injection well pressure (BHP), observation well pressure, CO_2 breakthrough time, etc.

Data assimilation method

- Assign a random 'true' model to find $\mathbf{d}_{obs}$
- Condition geologic realizations to hard-data at CO_2 wells and observation wells

Location of wells



- Reduce unknowns by **Karhunen-Loeve expansion:**

$$\mathbf{m} = \Phi\boldsymbol{\xi} - \bar{\mathbf{m}}$$

- Find $\boldsymbol{\xi}$ to minimize data mismatch:

$$\min_{\xi} \sum_i \left(\frac{d_{obs,i} - d_{sim,i}}{\sigma_i}\right)^2$$

- Calculate model parameters from $\boldsymbol{\xi}$

Saturation match in sample observation well block: