



*A fast, simple and interpretable alternative to full-physics models.
Open-source implementation written in Julia.*

Batch-filling of traps in individual layers

- Instead of filling cell-by-cell, entire traps are handled simultaneously.
- Use spill-point analysis from `SurfaceWaterIntegratedModeling.jl` (Andersen, 2025) to determine the order of filling.

Model assumptions:

1. Quasi-static equilibrium
2. Buoyant and non-wetting CO₂
3. Only structural and residual trapping
4. Homogeneous properties in each layer

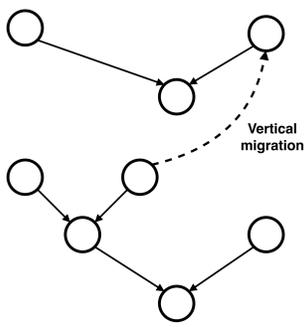


Figure 1: Graph representation

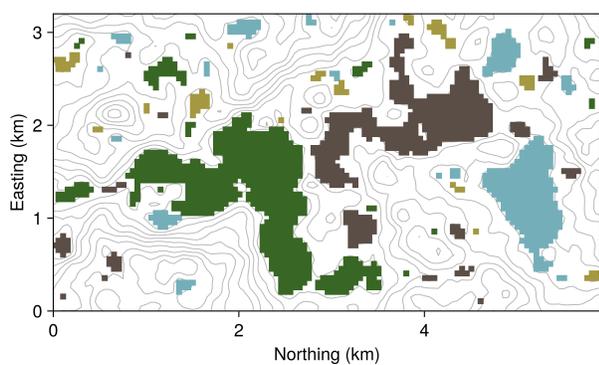


Figure 2: Structural traps in topography

Vertical CO₂ migration using invasion percolation

- Pressure increases with column height and density contrast.
- Leakage when buoyancy pressure exceeds shale capillary threshold pressure.
- Residual trapping in each layer reduces further upward transport.
- Callioli Santi et al. (2025) extend this approach by constructing a Markov chain.

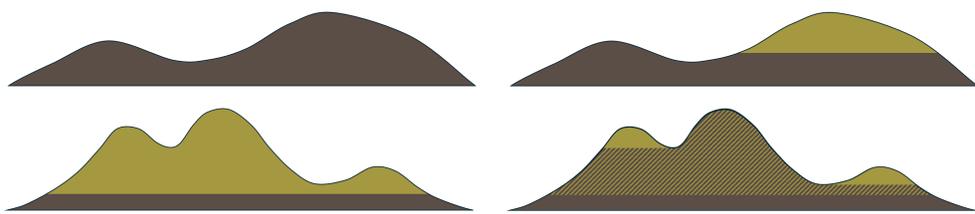


Figure 3: Vertical migration between two layers.

Example 1: Monte Carlo uncertainty quantification

- Monte Carlo uncertainty quantification over 500 simulations, with total runtime of 7 minutes using a single process.
- Injection location and topography from Sleipner 2019 Benchmark 3D model.
- Vary topography, shale capillary pressure threshold, and amount of residual trapping.

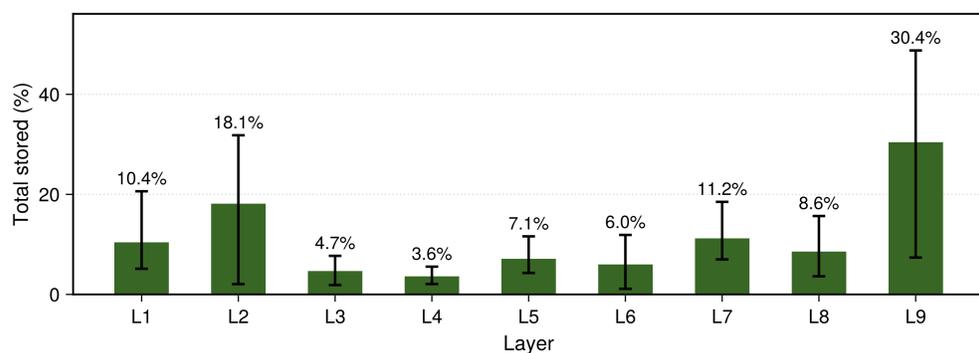


Figure 4: Estimated distribution of stored CO₂ across layers.

Future work

- Currently under active development and experimental validation.
- Integration with Julia ecosystem to support end-to-end CO₂ storage workflows.
- History matching to observed data and comparison with other simulators.

Intended use and limitations

Is designed for:

1. Rapid screening of storage scenarios
2. Uncertainty quantification
3. Optimization of injection strategies

Not included:

1. Detailed plume dynamics
2. Migration after injection stops
3. Mechanical effects like deformation

Example 2: Optimizing injection locations

- Fast evaluation allows for optimization of injection strategies.
- Optimize injection locations to maximize storage.
- Evaluate single-, two- and three-well injection scenarios.
- Assume known physical parameters (no uncertainty).
- Gradient-free optimization using `BlackBoxOptim.jl`.

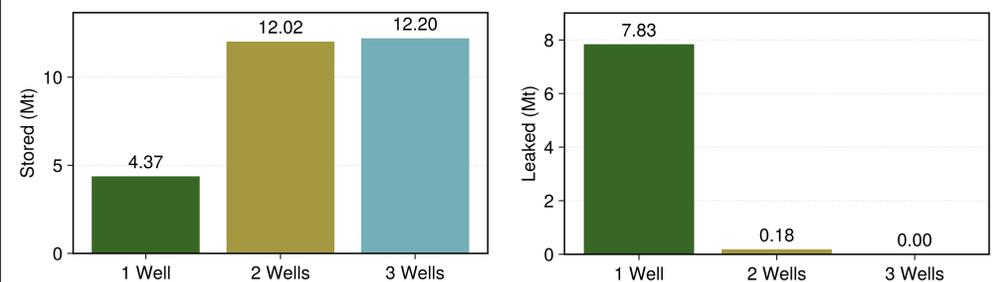


Figure 5: Amount of stored and leaked CO₂ after 15 years of injection.

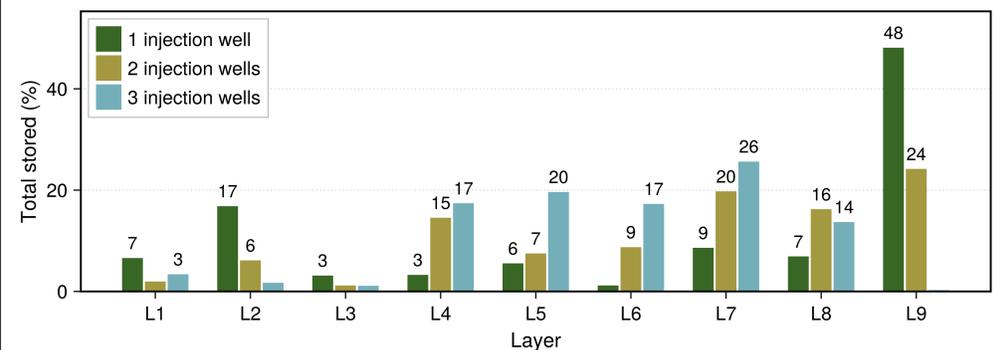


Figure 6: Distribution of stored CO₂ for different well configurations.

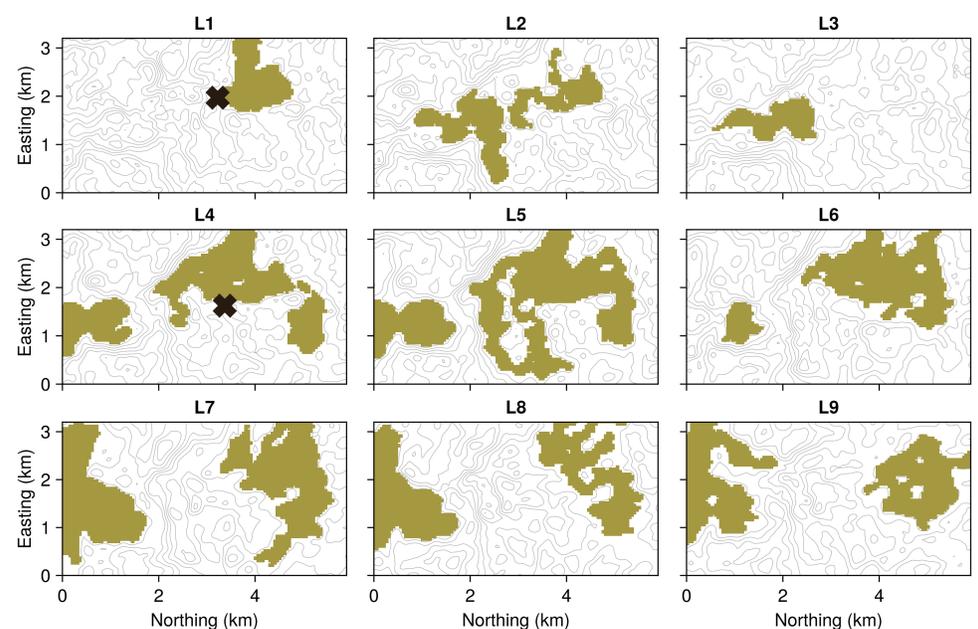


Figure 7: Optimized two-well injection strategy using Sleipner topography.

Bibliography

- Andersen, O.A., 2025. Topography-based surface water modeling in Julia, with support for infiltration and temporal developments. *Journal of Open Source Software* 10, 7785.. <https://doi.org/10.21105/joss.07785>
- Callioli Santi, A., Ringrose, P., Eidsvik, J., Haugdahl, T.A., 2025. Invasion percolation Markov Chains – A probabilistic framework for assessing vertical CO₂ migration. *International Journal of Greenhouse Gas Control* 142, 104338.. <https://doi.org/10.1016/j.ijggc.2025.104338>