Project report: 244035 - CO2 Storage in the North Sea: Quantification of Uncertainties and Error Reduction (CONQUER)

Contact person: Per Pettersson (per.pettersson@norceresearch.no)

Background

Large-scale storage of CO2 in subsurface formations is necessary to reduce the effect of global warming within the next few decades. Aquifer storage capacity is dependent on the injectivity of the formation and the long term pressure buildup that evolves during injection. This risk should be mitigated to avoid CO2 leakage through a compromised caprock. There are extensive geological formations in the North Sea that are either currently used for CO2 storage, or candidates for storage, but some of them are subject to significant lack of geological data. The possibility to use the theoretical storage capacity in a safe manner is obstructed by significant geological uncertainties.

Even in the presence of data, feasible mathematical models cannot account for a comprehensive geological description. It is essential to use models that can handle the relevant temporal and length scales of CO2 storage when evaluating aquifer capacity and risk of migration over aquifer boundaries. However, the important trapping and migration processes occur at very small scales, on the order of meters or less, while the aquifers themselves are on the order of 1000 to 100,000 square kilometers in areal extent. It is infeasible to numerically resolve all the relevant physical scales and simplified models is an option to reduce the complexity. This means that numerical simulation within a deterministic framework cannot take all relevant information into account but still produces an output. This may create a false sense of reliability, unless complemented with Uncertainty Quantification.

Objectives

The CONQUER project has delivered improved understanding of the risks of large-scale CO2 storage by the development and application of methods that account for uncertainties in CO2 migration, pressure buildup and damages to the caprock. This was achieved by focusing on the following objectives:

O1 Development of practical methods for stochastic representation of permeability, and the development of efficient pressure solvers.

O2 Development of reduced-physics models for UQ in CO2 migration in large-scale storage operations.

O3 Identify physical processes and parameters that are critical for assessing risk of creating leakage pathways through the caprock overlying the injection formation, and develop suitable numerical methods for uncertainty quantification.

O4 Devise a module based framework where each module consists of a tailored numerical method for one of the subproblems (geomechanics, pressure and transport problem).

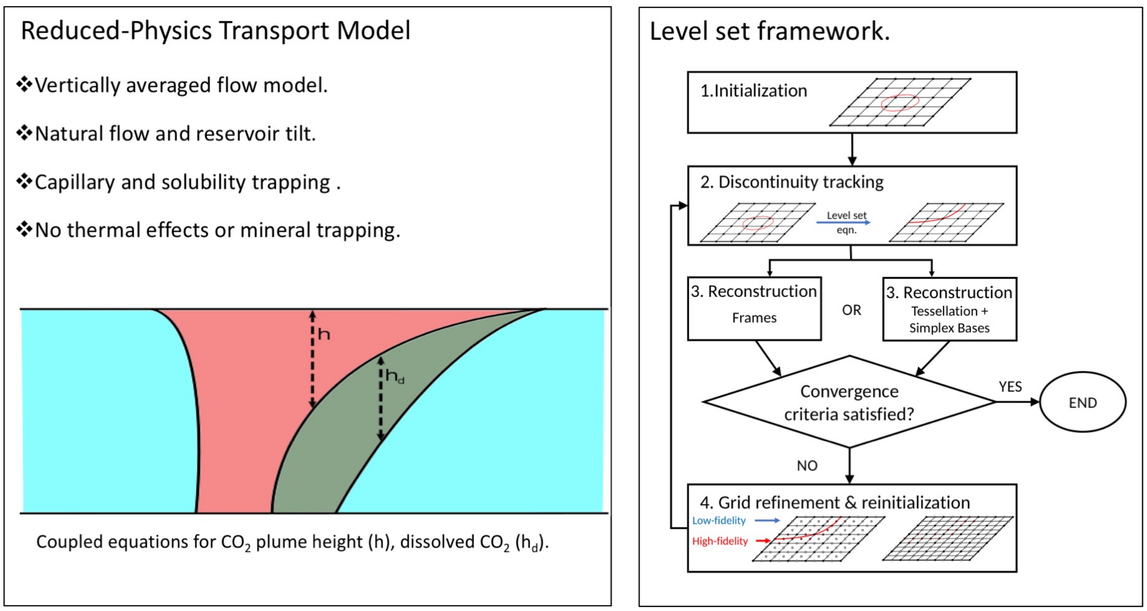

Figure 1: Vertical equilibrium models for accelerated simulation of CO_2 transport in the aquifer (left), and stochastic level set framework for discontinuity tracking (right). The right figure is from Pettersson et al., Level set methods for stochastic discontinuity detection in nonlinear problems, J. Comput. Phys. 2019.

Summary of results in the context of objectives

A data-driven framework for representing and propagating uncertainty in physical parameters for migration of CO_2 has been developed w.r.t O1. The main challenge was efficient stochastic permeability representation, a topic that received more focus and resulted in novel data-driven wavelet representations. Sparse pressure representations were investigated, as those had been found very useful for very smooth test problems, but turned out to not be suitable in the context of CO_2 storage.

In the context of O2, vertical equlibrium models accounting for uncertainty via extended sets of equations were developed in 1D and 2D (vertical direction vanish via integration). A schematic vertical equilibrium model is shown in Figure 1 (left). New features include robust solvers for discontinuous peremabilities (e.g., faults, channels).

An open source toolbox for geomechanics has been developed by the University of Bergen and contributes to fulfilling O3. The software is available in Python and completely free of charge.

In the context of O4, methodology for geomechanics, pressure and the CO_2 problem, was tailored to the needs of each subproblem. Solvers for geomechanics and CO_2 migration received the most attention, as these problems are numerically more challenging than pressure solvers under uncertainty. A stochastic level set framework was devised for migration of CO_2 under uncertain permeability (and thus pressure) that demonstrated an efficiency gain of a factor 1000 compared to standard Monte Carlo sampling. The framework is illustrated in Figure 1 (right). The same stochastic permeability models can easily be modified to be used in geomechanics via ensemble methods, or via extended systems of equations for flow and transport.

Major research tasks

The research tasks performed within the project can be roughly categorized as follows. Active contributors in parentheses.

- Development of software for modeling of geomechanics (University of Bergen).
- Numerical methods for CO_2 transport under uncertainty (Norce).
- Numerical methods for stochastic discontinuity tracking (Norce, University of Colorado, Linköping University).
- Framework for data-driven uncertainty quantification in heterogeneous reservoirs (Norce, University of Bergen, KTH Royal Intsitute of Technology).

Use of resources and implementation

The project relied on computer hardware that was mostly available before the start of the project. Some existing software has been used that also did not add any cost to the project.

The project had two international partners, University of Colorado and ETH Zürich. Both partners were consulted via e-mail and at conferences throughout the project. The collaboration with Colorado resulted in a joint peer-reviewed publication, and an extended exchange visit. Although not a formal project partner, collaboration with Linköping University has also been contributing to the project results.

A PhD student and a master thesis student were connected to the project, working mainly with O2 and O1, respetively. Various measures were taken to improve and tailor the supervision of the PhD student sponsored by the project, including an extended exchange visit at University of Colorado, achievement review meetings, conference and workshop participation, supervisor education for the project leader, and quality control by the presence of an experienced supervisor. Despite this, the results necessary for a PhD degree have not been achieved.

An international three-day workshop with participants from six countries were organized at Finse towards the end of the project. The workshop was successful with very happy participants, new scientific collaborations, and networking leading to at least one SFI application (currently under review).

Anticipated significance and impact

CONQUER has contributed to numerical modeling of subsurface reservoirs under uncertainty, something that is necessary for decision making related to large-scale CCS. The project has resulted in open software available for general use in modeling of geomechanics. Among the results we anticipate to be of most relevance to industry are sampling based methods and software. These methods are not necessarily more efficient than the projection methods we have developed, but they are more amenable to be directly incorporated and combined with commercial software.

Dissemination and utilization

The scientific results have been published in international peer-review journals, and presented at international conferences in computational geosciences, numerical simulation, and uncertainty quantification. CONQUER did not have industrial partners, but via collaboration with other projects hosted by Norwegian Research Centre (e.g., LCSANS and MICAP), the results have been presented or otherwise communicated to their industrial affiliates (e.g. Aker Solutions). Three of the PIs (Gasda, Keilegavlen, Pettersson) are also participants of the KPN project FRISK. The results from CONQUER will be used in FRISK, where they will be complemented with additional research and benefit the associated industrial partner Equinor.

Expected results after the project ends

The outcomes from CONQUER will be utilized and further explored in new and planned research project, e.g., the Quantification of fault-related leakage risk (FRISK) KPN project. We are also anticipating knowledge transfer to fields outside CCS where uncertainty quantification is important. This includes river modeling (work initialized with University of Sheffield on shallow water under uncertainty), spreading of microplastics in the oceans (within the JPI Oceans 2 project FACTS), and rare-event modeling related to permafrost thawing.