HIGHLIGHTS PERFORM WP2 MODELLING TOOLS

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HIGHLIGHTS PERFORM WP2 MODELLING TOOLS

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› PERFORM WP2
OBJECTIVES

This work package is designed to apply cutting edge numerical modelling approaches to help developing strategies to improve geothermal performance.

The objective of the modelling work is to:

1. **Develop modelling tools** to understand and predict geothermal performance linked to the reservoir as well as the topside installation.
2. **Provide a knowledge base** on scaling prevention and injectivity.
3. **Constrain uncertainties** related to geological variation and geochemical databases.
4. **Facilitate WP3** the setup and interpretation of the laboratory and field test.
5. **Facilitate WP4** operational advise toolbox by providing model tools and simulation results.
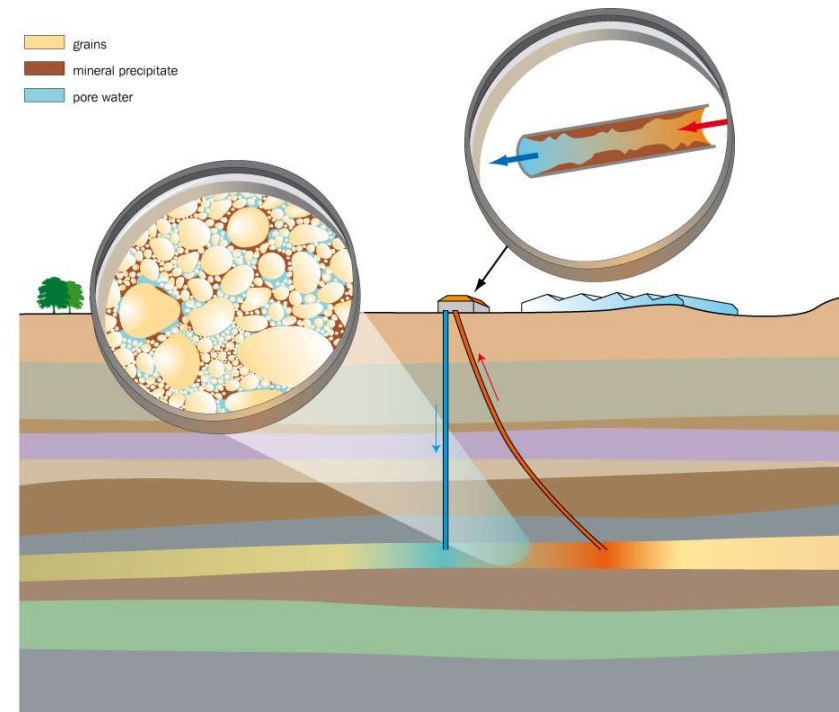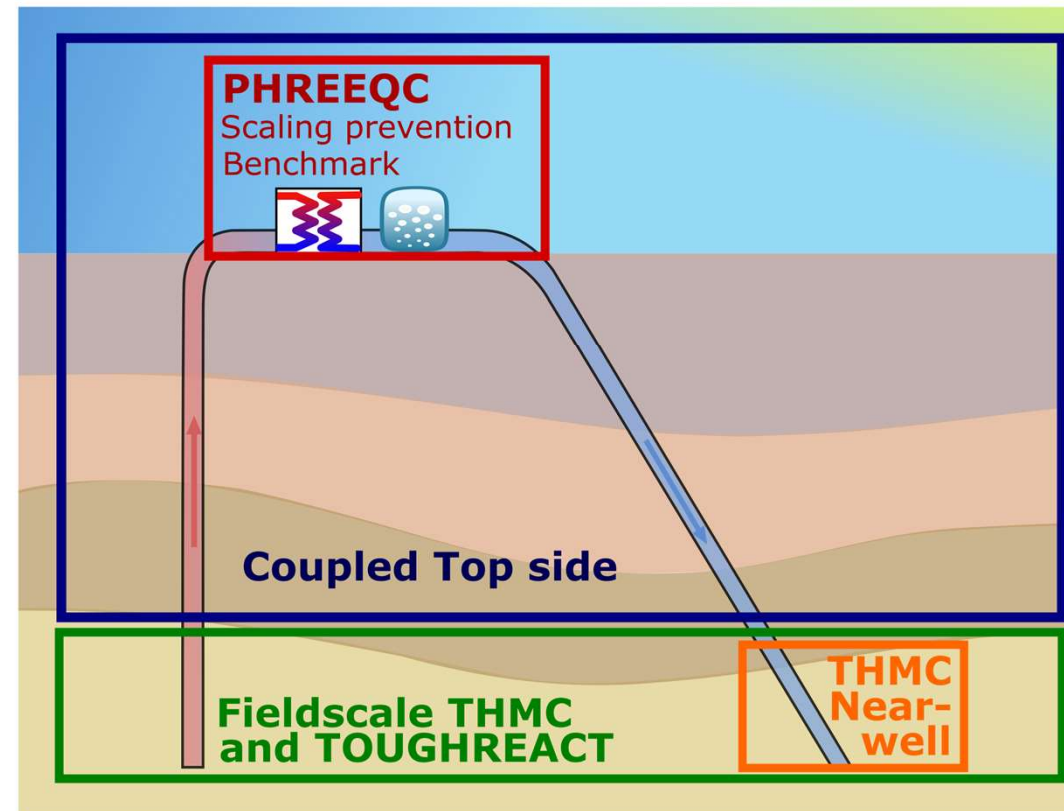
MODELS WP2
WHICH TOOLS DO WE USE?

› Software

  › Geochemical simulators (PHREEQC, TOUGHREACT, TOUGH)

  › Flow simulators (OLGA, LedaFlow)

  › Mechanical simulators (Flac3D)

 › Coupling codes (Matlab based, Flac3DTOUGHREACT)

› Input

  › Databases on fluid and rock properties

  › Thermodynamic databases for solubilities of gas and minerals

  › Data from geothermal doublets

PERFORM WP2 MODELS
WHAT CAN WE DO FOR GEOTHERMAL?

› **Improve modelling tools and reduce uncertainty**
  › Improve and develop model tools
  › Advise on the selection of thermodynamic database

› **Optimize geothermal operations for scaling prevention**
  › Identify the tank pressure required to prevent calcite scaling
  › Asses the applicability of CO_2 re-injection, acid dosing and cation filtering

› **Enhancing reservoir performance**
  › Investigate reservoir pore space reducing and increasing reactions
  › Assess the possibilities for and effects of CO_2 (re/co-)injection
  › Temperature optimization to improve geothermal performance

› **Asses risks**
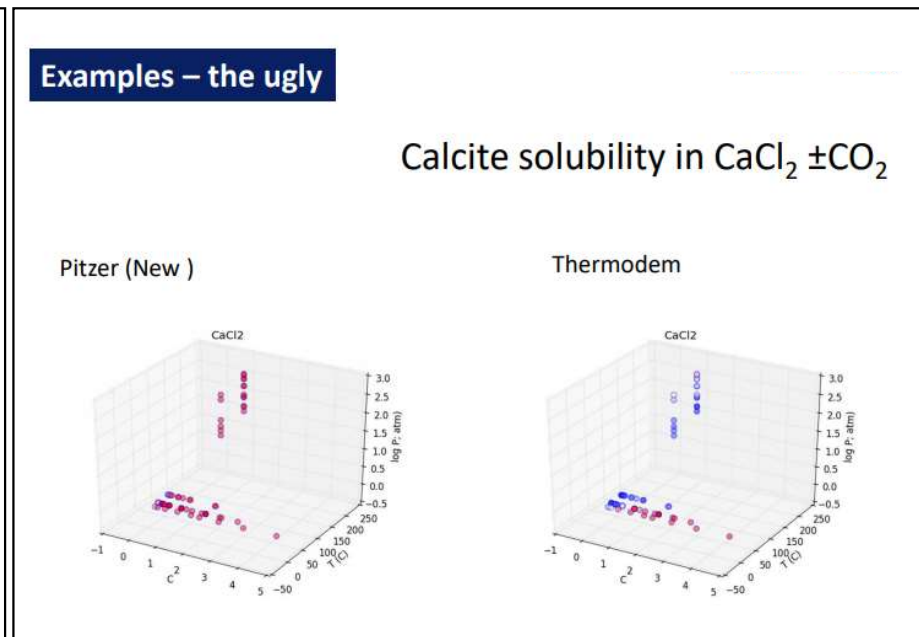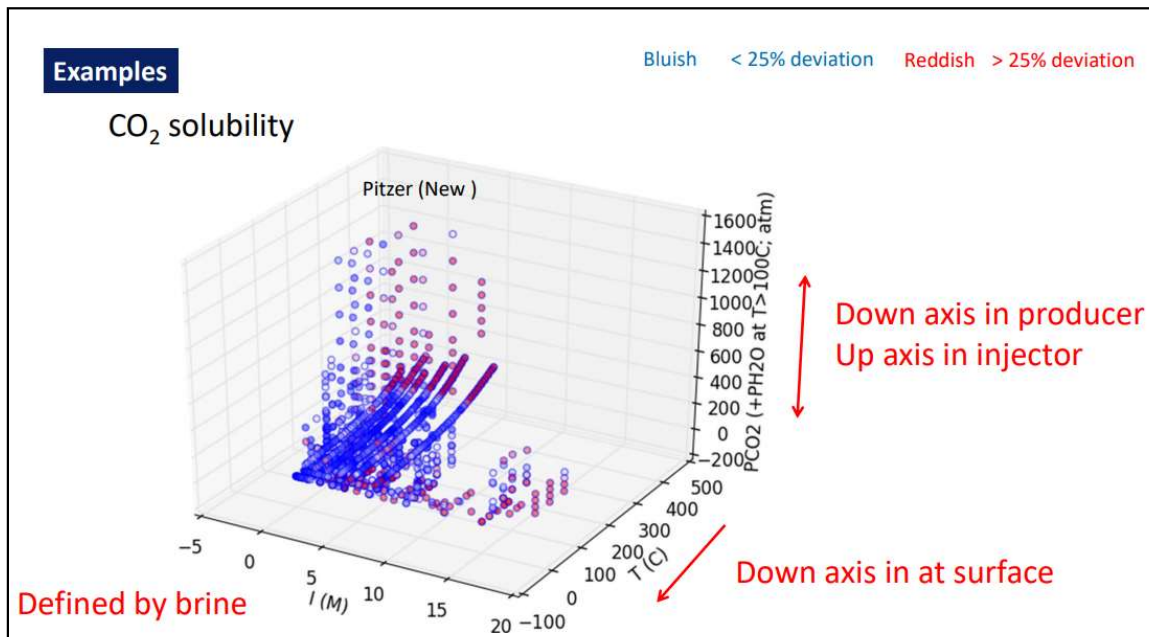 › Investigate near-well chemical-mechanic effects
  › Predict seismic activity
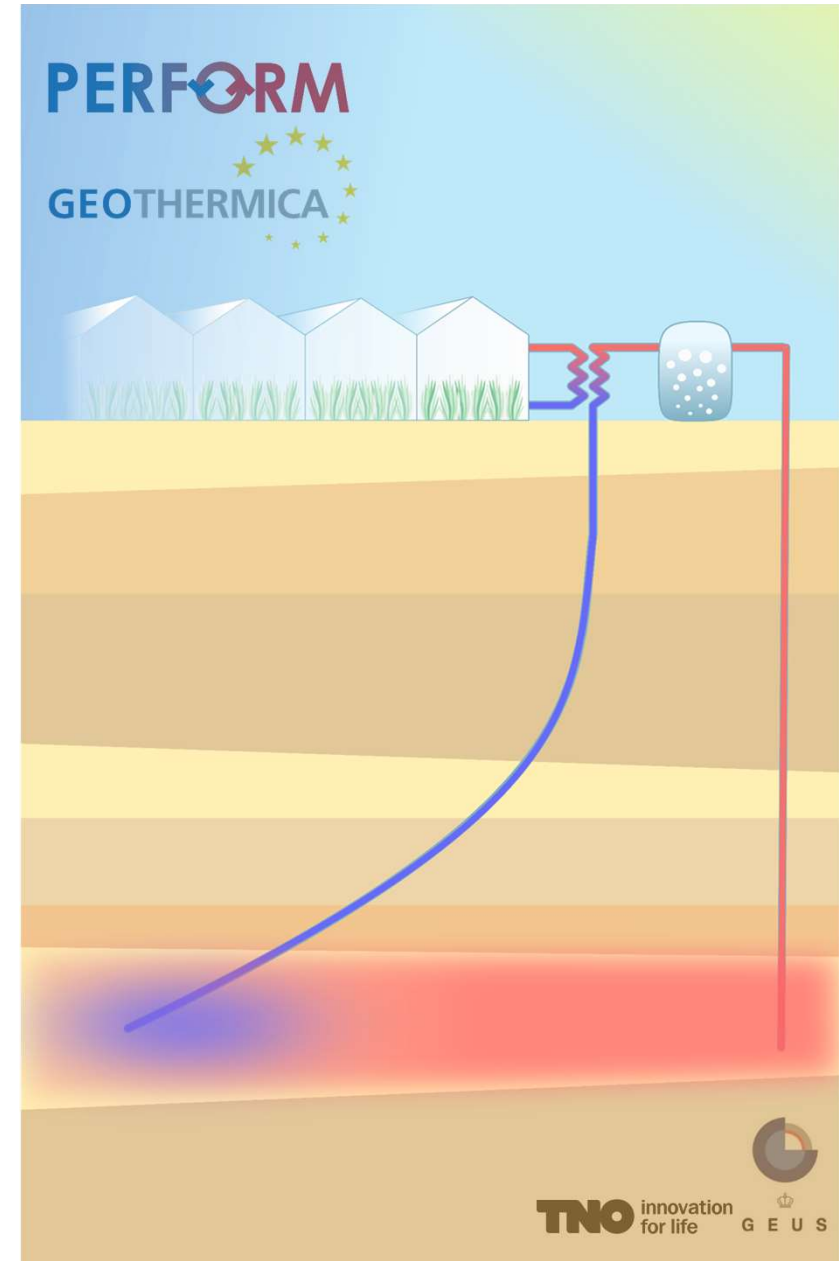
PERFORM WP2 - HIGHLIGHT 1
SELECT THERMODYNAMIC DATABASE
FOR GEOCHEMICAL SIMULATIONS

› Benchmark available thermodynamic databases from various research institutes against experimental solubility data

PERFORM WP2 - HIGHLIGHT 1
SELECT THERMODYNAMIC DATABASE
FOR GEOCHEMICAL SIMULATIONS

Conclusions

For many systems the databases perform surprisingly well

CO_2 equilibrium can be calculated to high T, P, and C

Calculation of calcite equilibrium appear complicate at higher T, P, and C
   But only one data set exist for benchmarking

PERFORM WP2 - HIGHLIGHT 1
## SELECT THERMODYNAMIC DATABASE FOR GEOCHEMICAL SIMULATIONS

› Thermodynamic database use in PHREEQC

  › Differences in predicted calcite and CO_2 solubility and predicted calcite scaling

  › Differences in methane dissolution (importance redox decoupled gasses)

  › Pitzer database selected while previously llnl and Thermoddem were used

  › Selection based on database benchmark by GEUS and on match experiences from running doublets
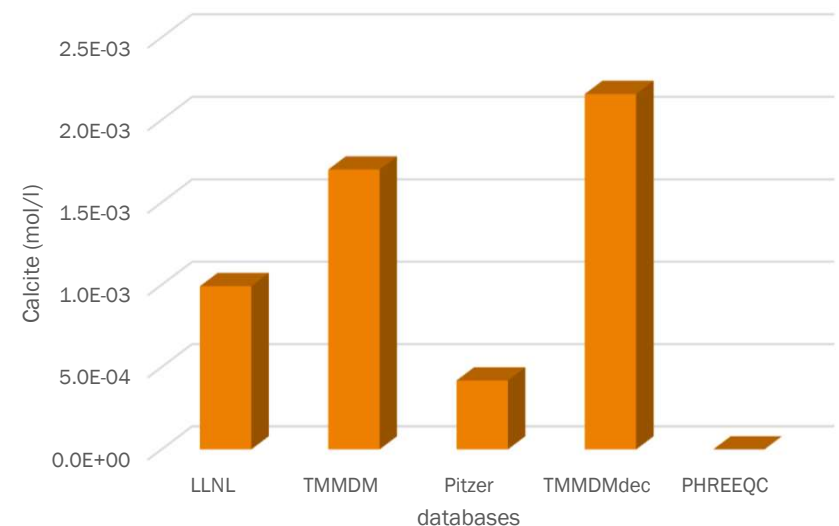
PERFORM WP2 - HIGHLIGHT 2
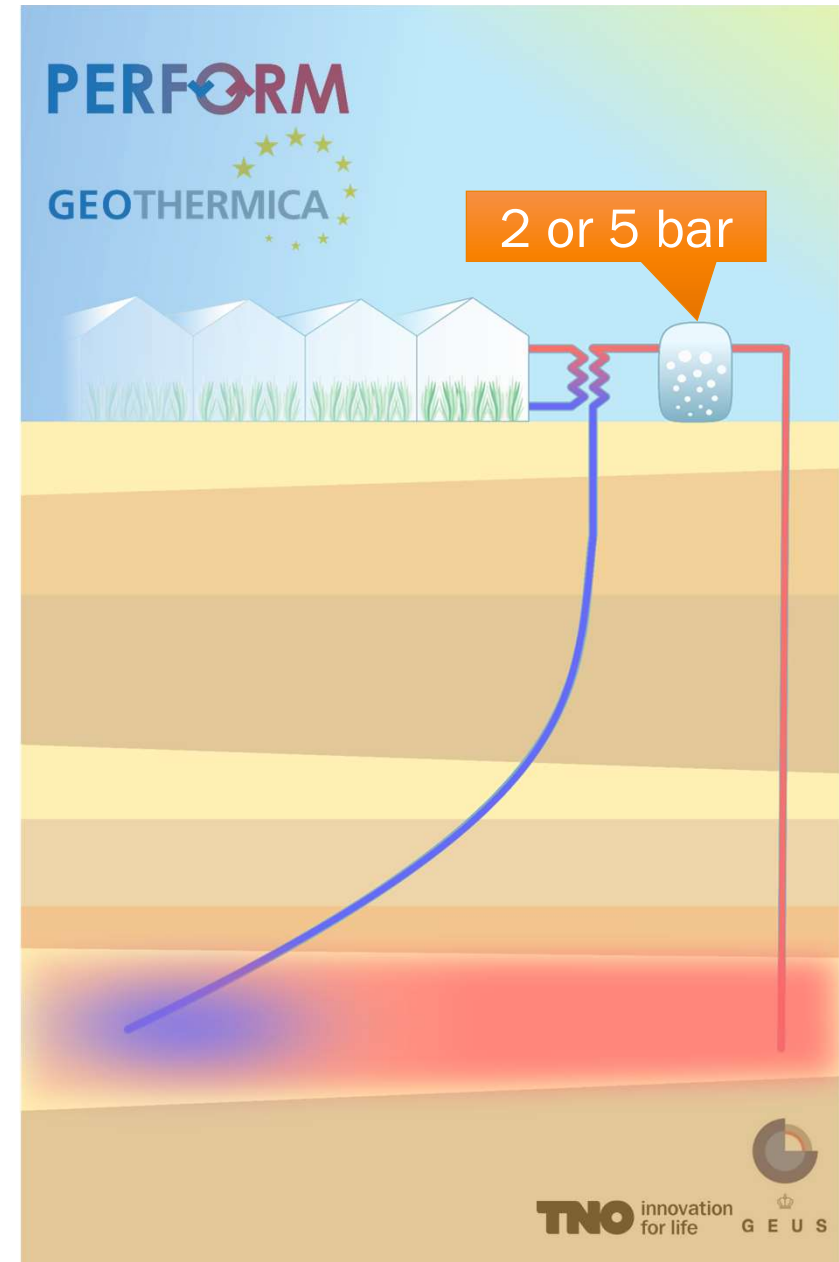## COUPLED CHEMICAL AND FLOW MODELS FOR SCALING MANAGEMENT

› MATLAB based coupling code to integrate the chemistry (PHREEQC) and Flow (LedaFlow)

› This enables us to simulate the scaling potential along the wellbore and for any point in the topside system

› This opens the possibility to test scaling prevention strategies

› Easily adaptable for new doublets
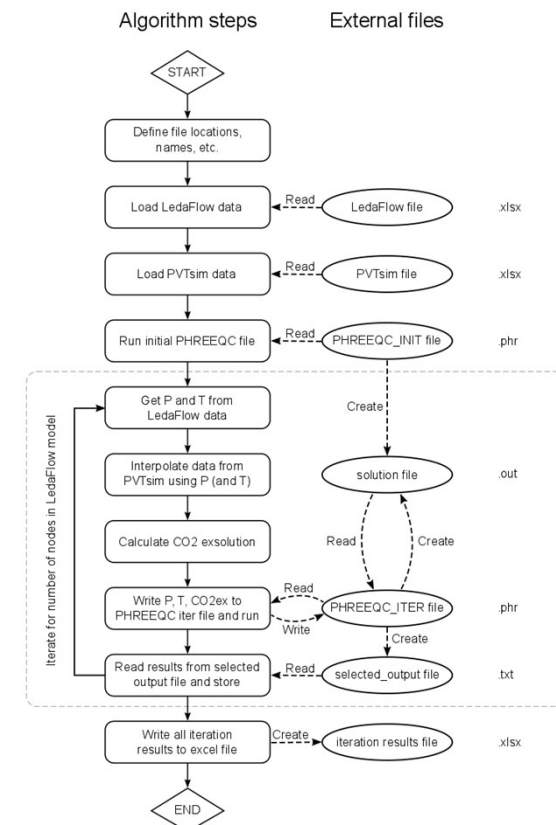
PERFORM WP2 - HIGHLIGHT 2
COUPLED CHEMICAL AND FLOW MODELS FOR SCALING MANAGEMENT

› Testcase for different gas separator tank pressures

› Different pressure results in more or less CO_2 outgassing, which controls whether carbonate scaling occurs

› Field data @ 2 bar tank pressure

› Pressure decrease causes gas separation

› CO_2 release causes a pH increase and calcite scaling

› Field data @ 5 bar tank pressure

› Pressure decrease causes less gas separation

› Limited pH increase and no calcite scaling

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GEOTHERMICA

2 or 5 bar

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PERFORM WP2 - HIGHLIGHT 2
COUPLED CHEMICAL AND FLOW MODELS FOR SCALING MANAGEMENT

› The 2 and 5 bar tank pressures scenarios were simulated using the coupled wellbore and top-side model.

› For 2 and 5 bar cases, the pressure changes especially downstream of the ESP

› The gas release rate is significantly different when changing the tank pressure
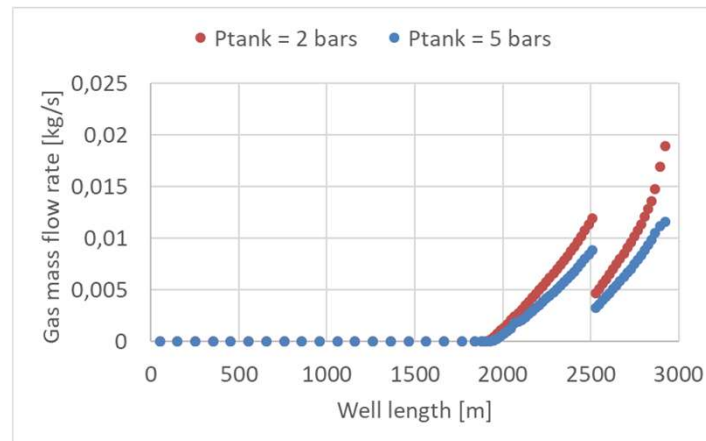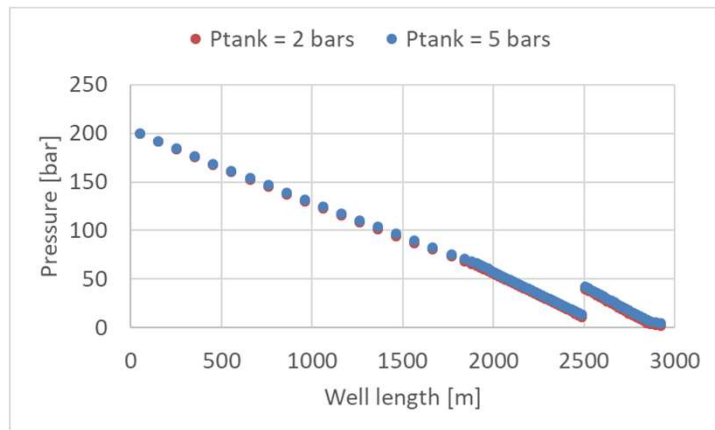
PERFORM WP2 - HIGHLIGHT 2
COUPLED CHEMICAL AND FLOW MODELS FOR SCALING MANAGEMENT

› Although gas exsolves for both cases, the PHREEQC model shows that only in the 2 bar tank case calcite precipitation is to be expected.

› The models have been tested on a Dutch doublet and were successful in mimicking the pressure threshold for carbonate scaling with calcite scaling at 2 bar and the prevention of scaling at 5 bar.

› This highlights the importance of an integrated modelling workflow for scaling prediction, management and mitigation.

2 bar

Pipe length [m]	Gas volume fraction	P (bar)	CO_2 as gas (mol)	CO_2 in 1 liter brine (mol)	pH	Calcite (mol/l)
50	0.00	199.7	0		5.70	0
2921	0.35	2.15	1.2E-3	6.50E-4	5.93	1.3E-4

5 bar

Pipe length [m]	Gas volume fraction	P (bar)	CO_2 as gas (mol)	CO_2 in 1 liter brine (mol)	pH	Calcite (mol/l)
50	0	199.8	0	1.85E-3	5.70	0
2921	0.14	5.07	7.4E-4	1.11E-3	5.90	0

TEMPERATURE DEPENDANT PRESSURE THRESHOLD CALCITE SCALING

› Mainly methane and less CO2 degassing

› Calcite scaling pressure threshold is very temperature dependant

› Illustrates the importance of flow and chemical model coupling

Gas release and calcite scaling with pressure decrease
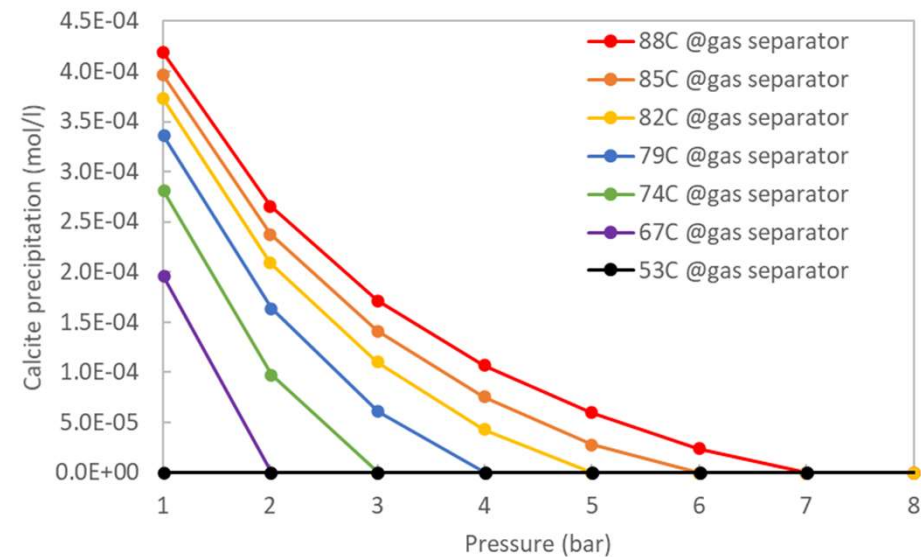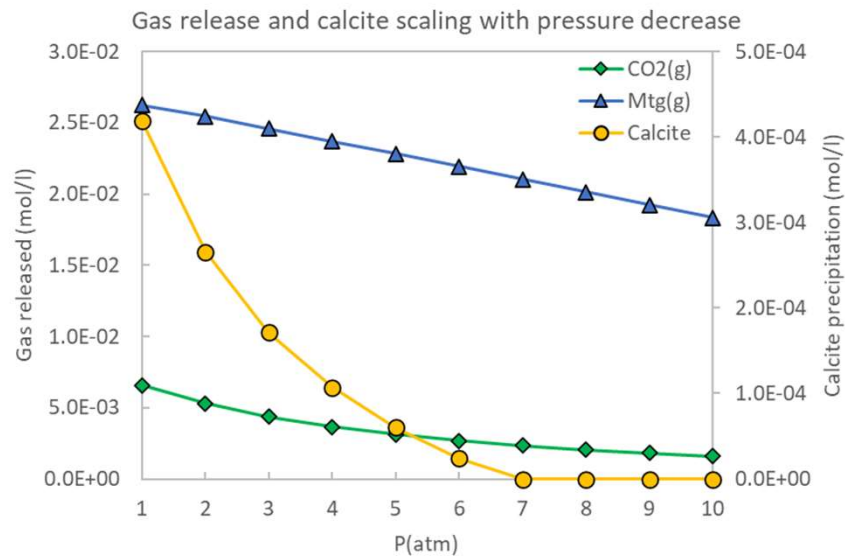
PERFORM WP2 - HIGHLIGHT 4
SIMULATING RESERVOIR PERFORMANCE

➢ A 3D reactive transport model was developed with TOUGHREACT software using the ECO2N fluid property module for H_2O-NaCl-CO_2.

➢ The software Petrasim was used to create a 1.5 by 3 km polygonal mesh of 3509 cells. The cell sizes are smaller near-well.

➢ The geology is simplified to an initially homogeneous rock with a porosity of 18% and a permeability of 7.5E-13 m² (750 mD).

➢ The initial reservoir pressure is 255 bar with a temperature of 88 °C.

➢ For porosity-permeability changes due to chemical reactions the relationship of Verma and Pruess (1988) is used with a critical porosity of 85% of the initial porosity and a power law component of 4.

➢ Initial mineralogy:

| Mineral	quartz	calcite	siderite	pyrite	kaolinite	smectite(MX80)
Volume fraction	0.616	0.101	2.54E-03	4.00E-04	1.85E-02	1.22E-02
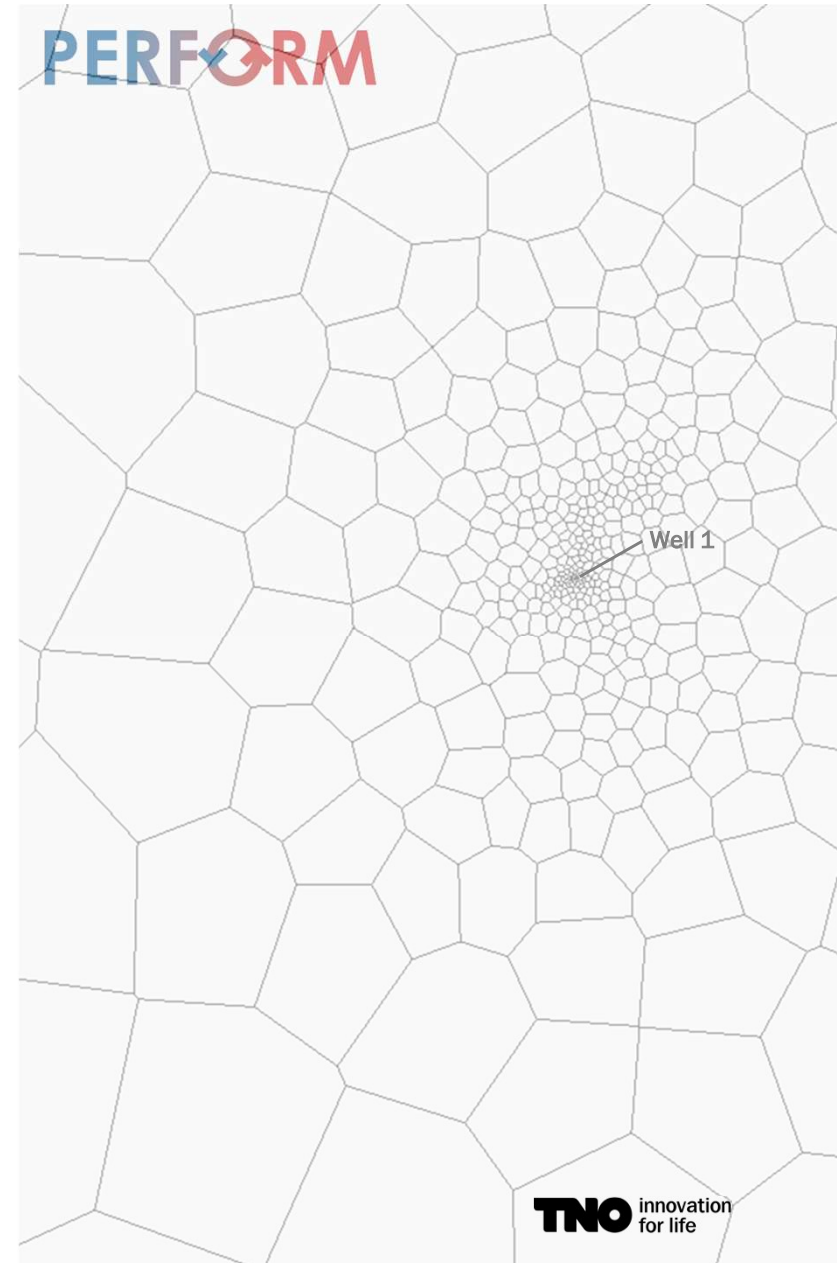
PERFORM WP2 - HIGHLIGHT 4
EFFECT INJECTION TEMPERATURE

EFFECT 20, 30 AND 40 °C INJECTION TEMPERATURES

➢ After 7 years of operation, the temperature front reaches about 250 m into the reservoir independent of the injection temperature.

➢ The effect of the different temperatures is seen near-well.

➢ Injection of colder and denser water results in a reservoir wide pressure decrease. The effect is most pronounced for the lowest injection temperatures. Note that open boundary conditions reduce this effect.

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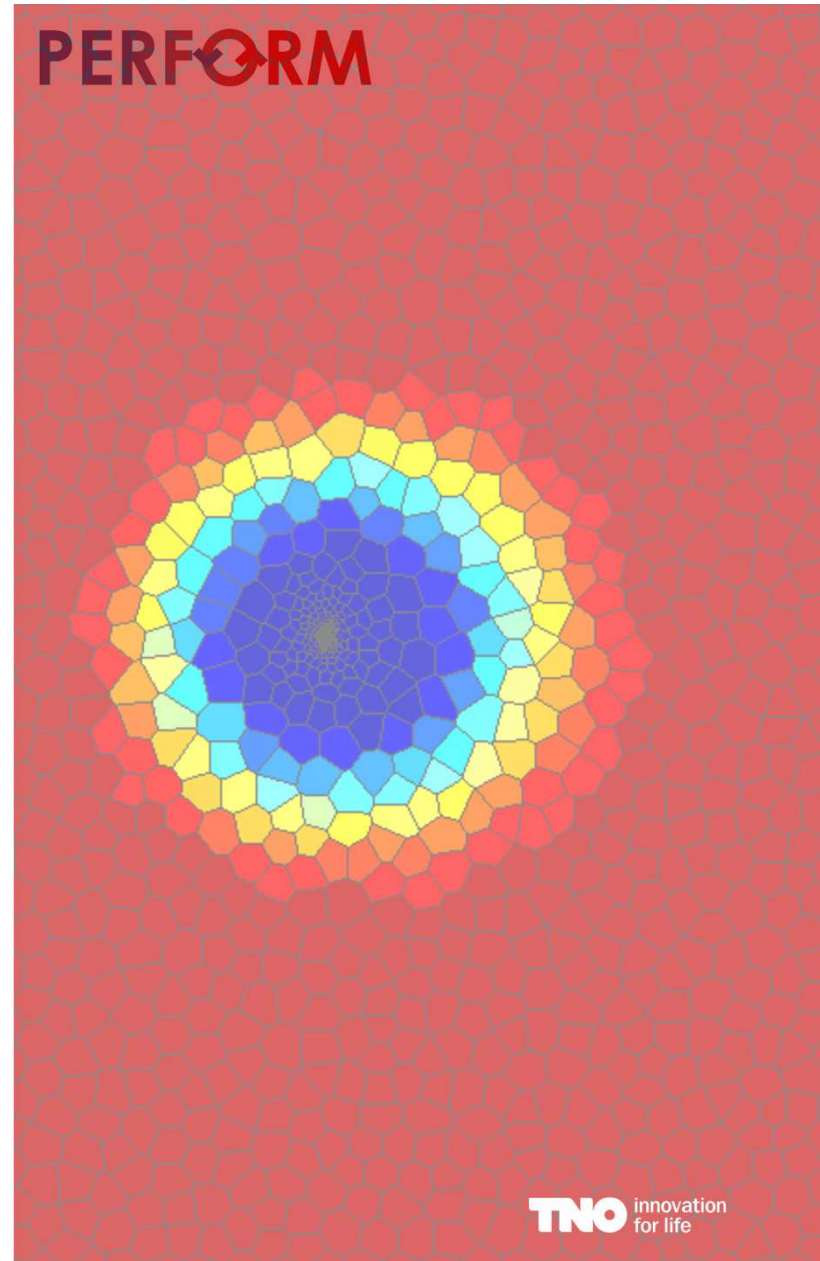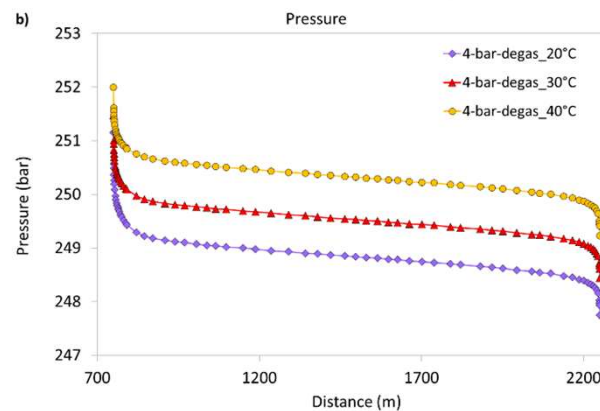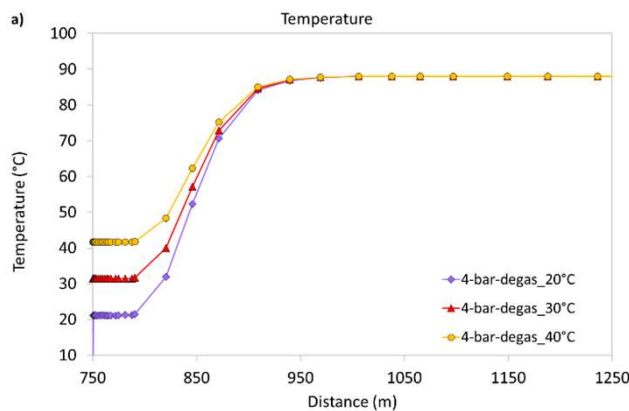
PERFORM WP2 - HIGHLIGHT 4
EFFECT INJECTION TEMPERATURE

20, 30 AND 40 ˚C INJECTION SCENARIOS
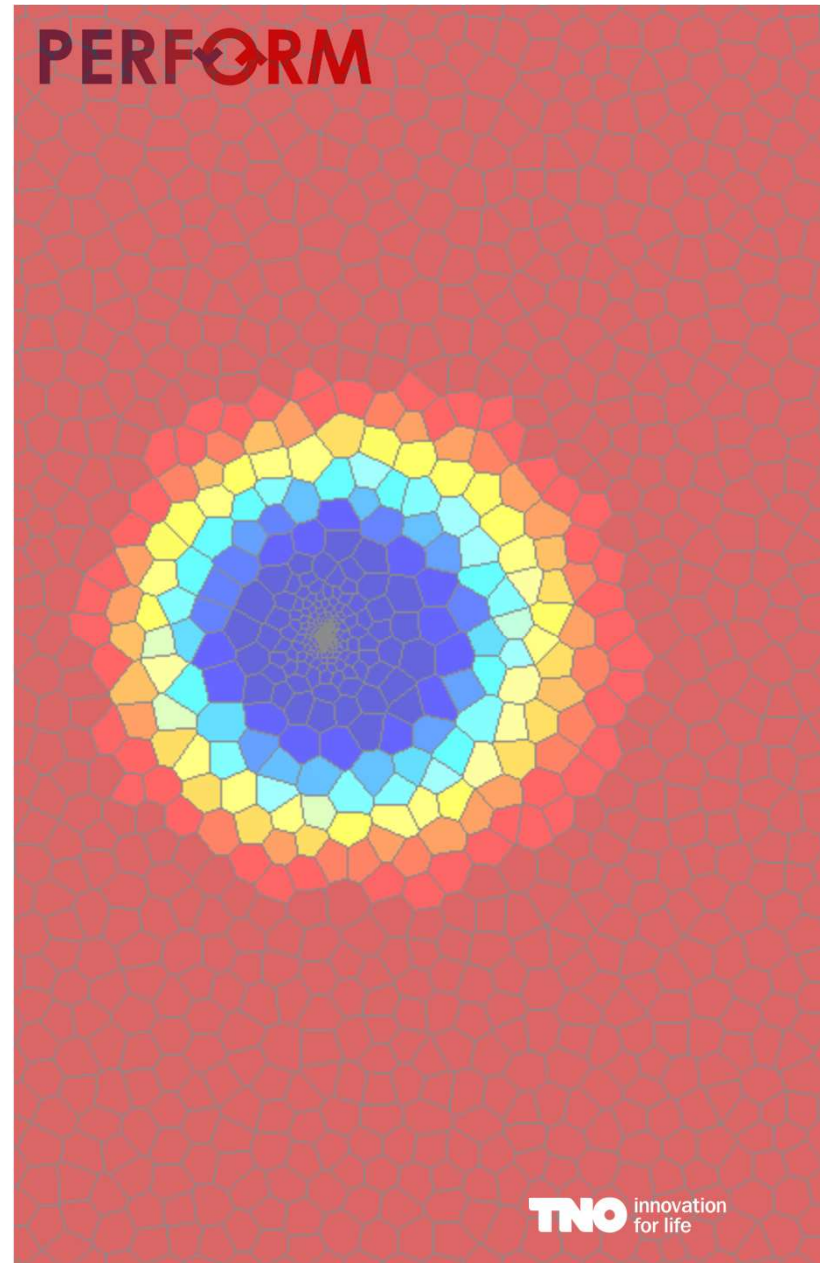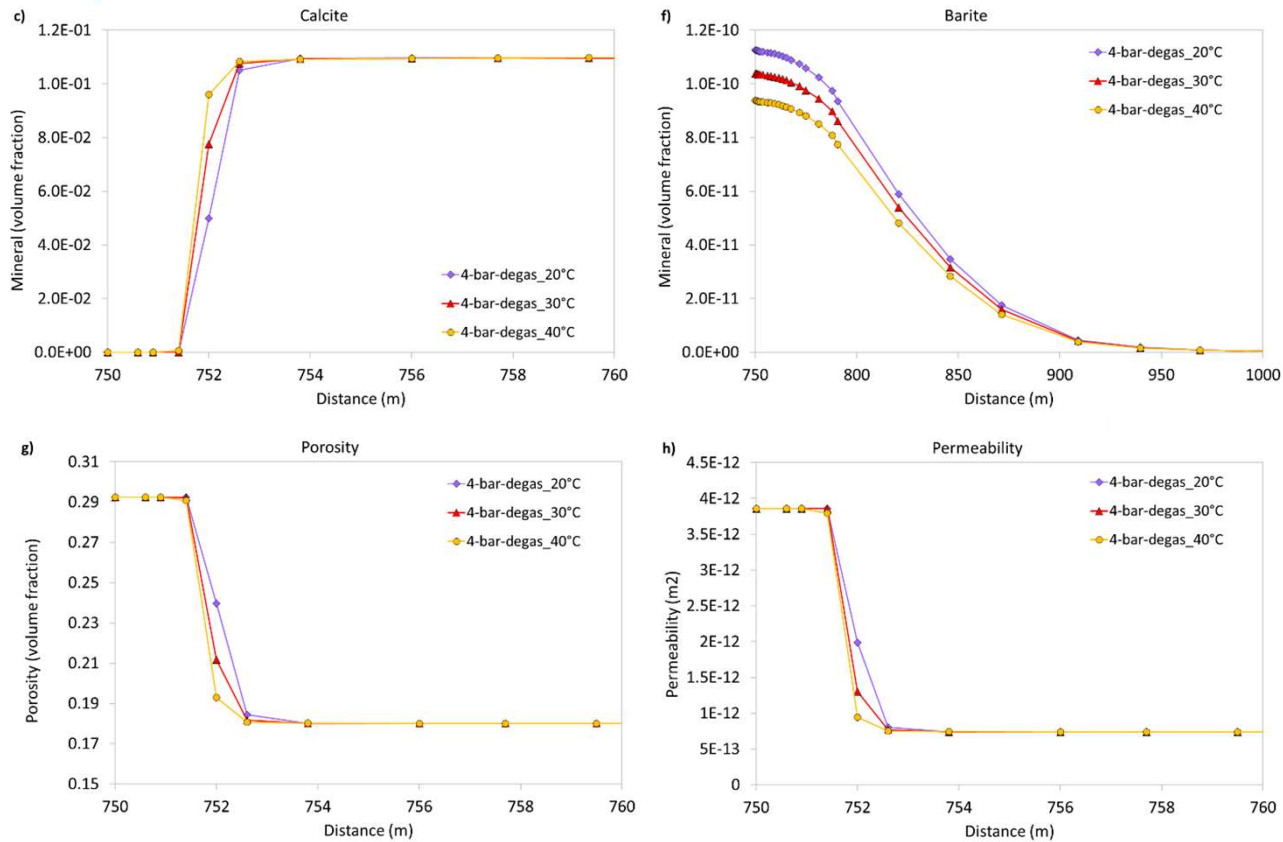
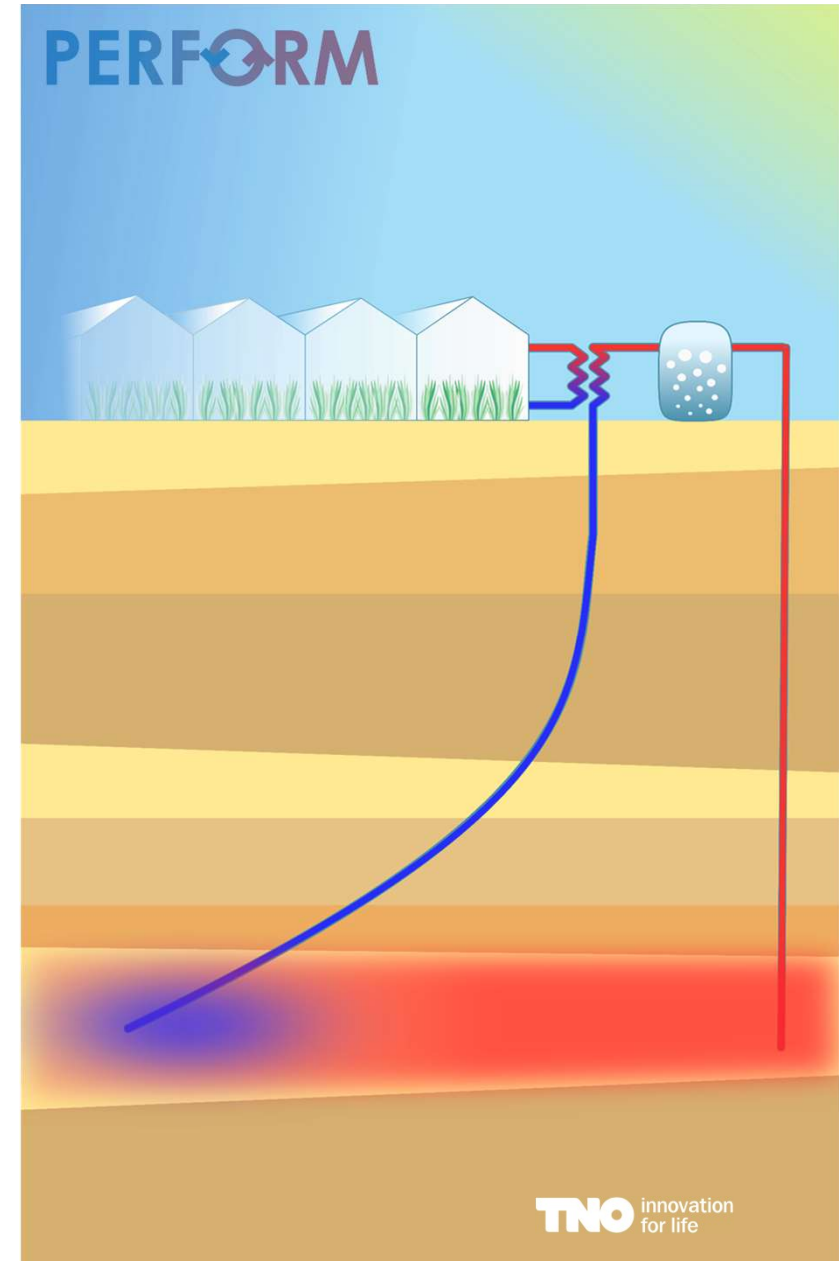# PERFORM WP2 - HIGHLIGHT 4
EFFECT CO_2 CONTENT

CO_2 INJECTION SCENARIOS

The pressure in the degasser defines the amount of gas released and the remaining CO_2 content in the injected water.

Different scenarios for:

1 CO_2 and CH_4 outgassing @4bar

2 CO_2 and CH_4 outgassing + CO_2 re-addition

3 CO_2 and CH_4 outgassing + CH_4 burning & released CO_2 re-addition

4 CO_2 saturation

Scenario	CO_2 injection rate (kg/s)	Dissolved CO_2, HCO_3^- (mol/l)
1. Base case (CO_2 degassing @ 4 bar)	0.036	1.86E-02
2. CO_2 re-injection	0.042	2.48E-02
3. CH_4-used CO_2 injection	0.098	5.36E-02
4. Maximized CO_2 co-injection	1.834	5.57E-01

PERFORM WP2 - HIGHLIGHT 4
EFFECT CO$_2$ CONTENT

CO$_2$ INJECTION SCENARIOS
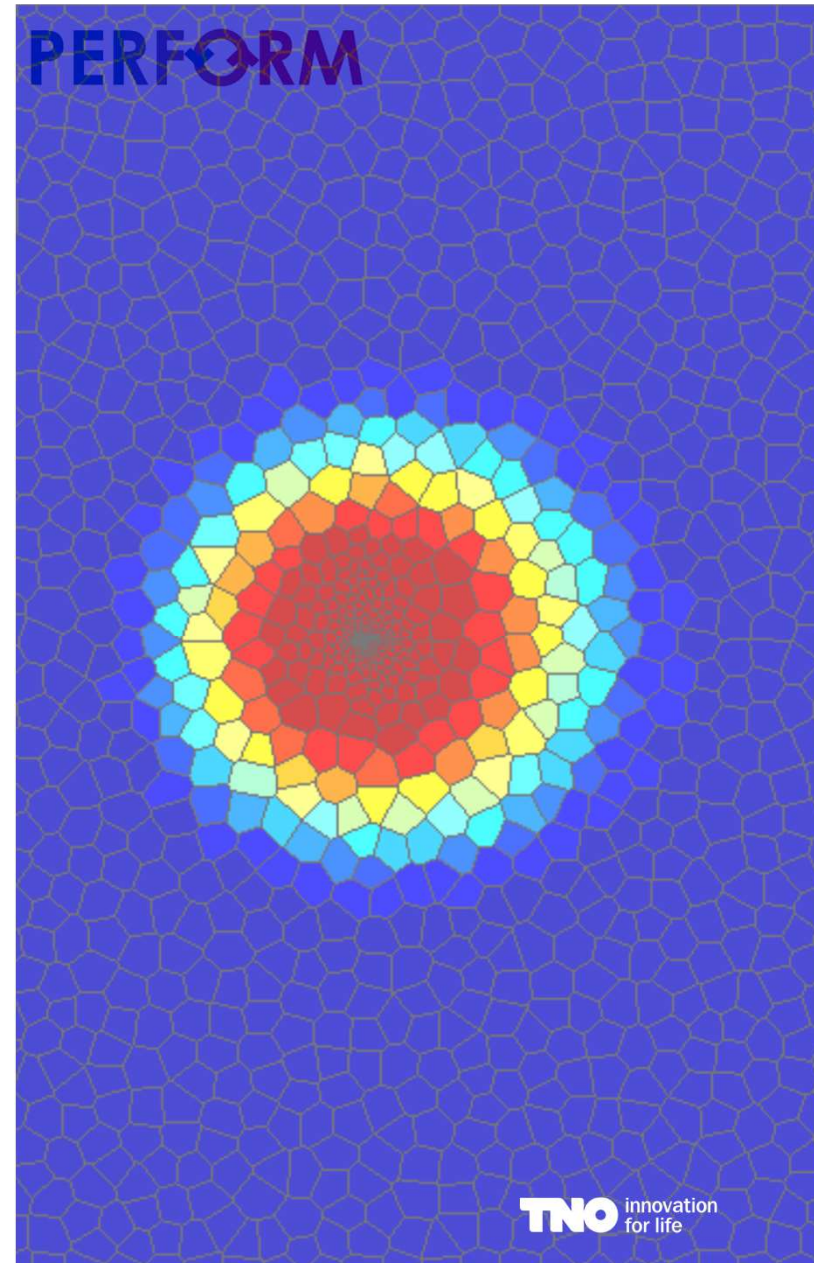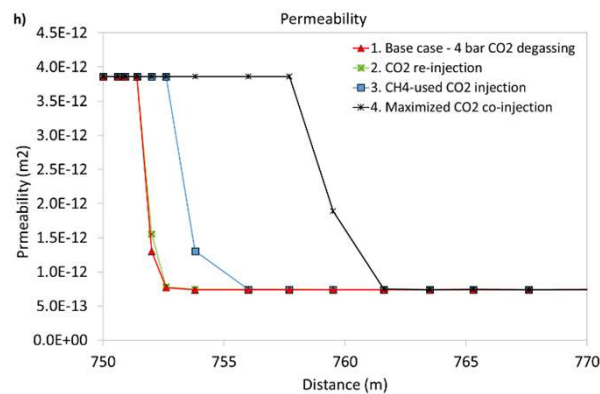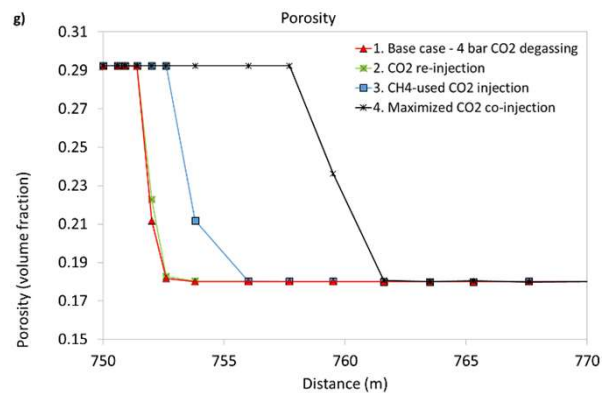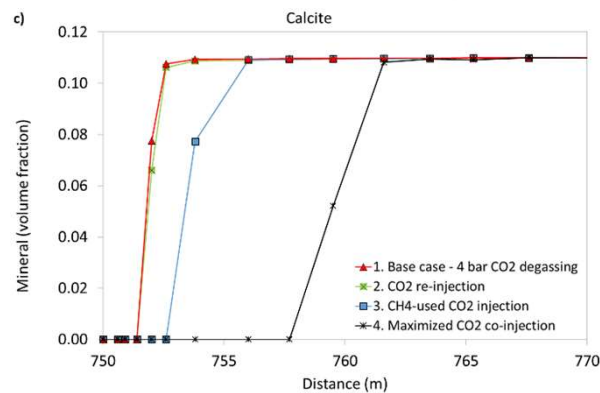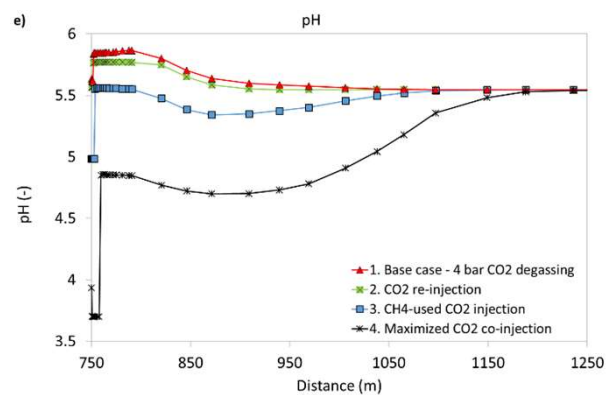
PERFORM WP2 - HIGHLIGHT 4
CONCLUSIONS

TOUGHREACT simulations indicate that soft stimulation of the reservoir by enhanced calcite dissolution may yield a porosity increase from 18 to 29 %.

Consequently, a considerable permeability improvement around the injection well could be possible of 750 mD to 3.75 D.

This indicates a potential for CO_2 and temperature optimization to improve injectivity by carbonate dissolution. Effect counteracting precipitation such as barite still uncertain.

Increased cooling gives a higher potential for calcite dissolution but the effect is small for the 20°C to 40 °C range compared to the base-case.

The different CO_2 re-injection scenarios indicate that CO_2 addition enhances calcite dissolution, increasing the potential for soft-stimulation of the reservoir. The technology has the additional benefit of reducing CO_2 emissions into the atmosphere.

Field tests of temperature and pressure/CO_2 variations are performed this very week.
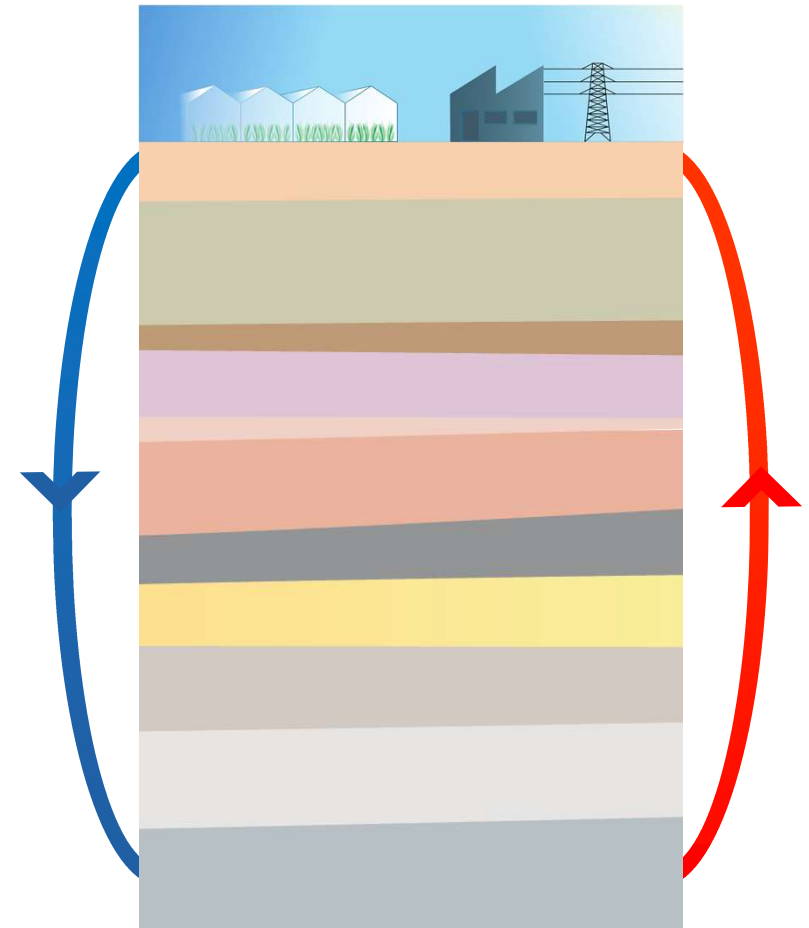
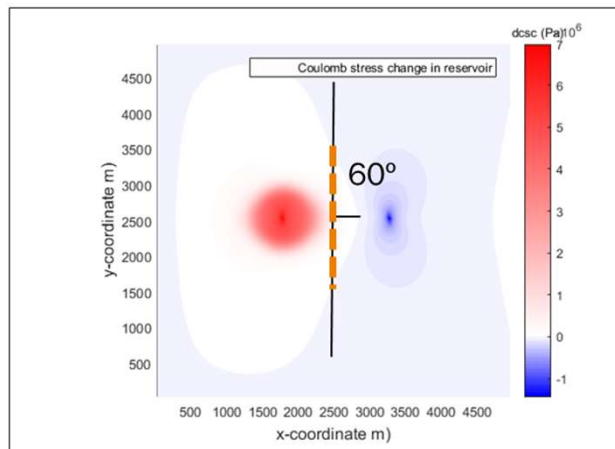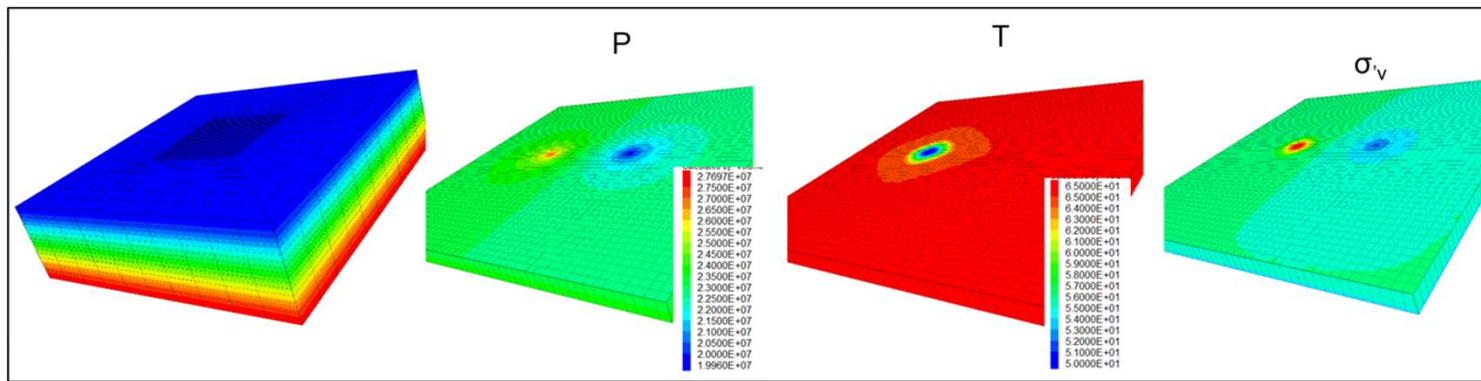# THMC COUPLED MODELS FOR MECHANICAL-CHEMICAL EFFECTS AND SEISMICITY

Thermo-Hydro-Mechanical-Chemical (THMC) coupled modelling

Developments coupling code

I. **Near-well modelling**

Focus on THMC effects on injectivity

Results this summer

II. **Field scale modelling**
Focus on field scale geothermal doublet modelling (porous & fractured reservoirs) and induced seismicity

PERFORM WP2 - HIGHLIGHT 5
PUBLICATIONS

> The use of supercritical CO_2 in deep geothermal reservoirs as a working fluid: insights from coupled THMC modeling

> Quan Gan[1,2], Thibault Candela[3], Brecht Wassing[3], Laura Wasch[3], Derek Elsworth[4]

> Utilizing supercritical CO_2 ($scCO_2$) as a working fluid in deep geothermal reservoirs has a potential double benefit to concurrently increase rates of heat recovery and to concurrently sequester CO_2. A coupled THMC (thermal-hydrological-mechanical-chemical) model is developed and applied to explore the potential feasibility of using $scCO_2$ as a working fluid in geothermal reservoirs.

> Time-dependent seismic footprint of thermal loading for geothermal activities in fractured carbonate reservoirs

> Wassing, B.B.T.[1], Candela, T.[1], Osinga, S[1]., Peters, L.[1], Buijze, L.[1], Fokker P.A.[1], van Wees, J.D.[1]

> This paper describes a workflow to assess the evolution of seismicity associated to injection of cold fluids in a single injector close to a fault. We employ the coupled numerical thermo-hydro-mechanical simulator of FLAC3D-TOUGHREACT to simulate the spatial and temporal evolution of pore pressures and temperatures and associated Coulomb stress changes on the fault. Adopting rate-and-state seismicity theory we assess induced seismicity rates from Coulomb stressing rates at the fault. Seismicity rates are then used to derive the evolution of seismicity in terms of the time-dependent frequency-magnitude distribution of seismic events.

> Submitted to frontiers in earth science

THANK YOU FOR
YOUR TIME

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