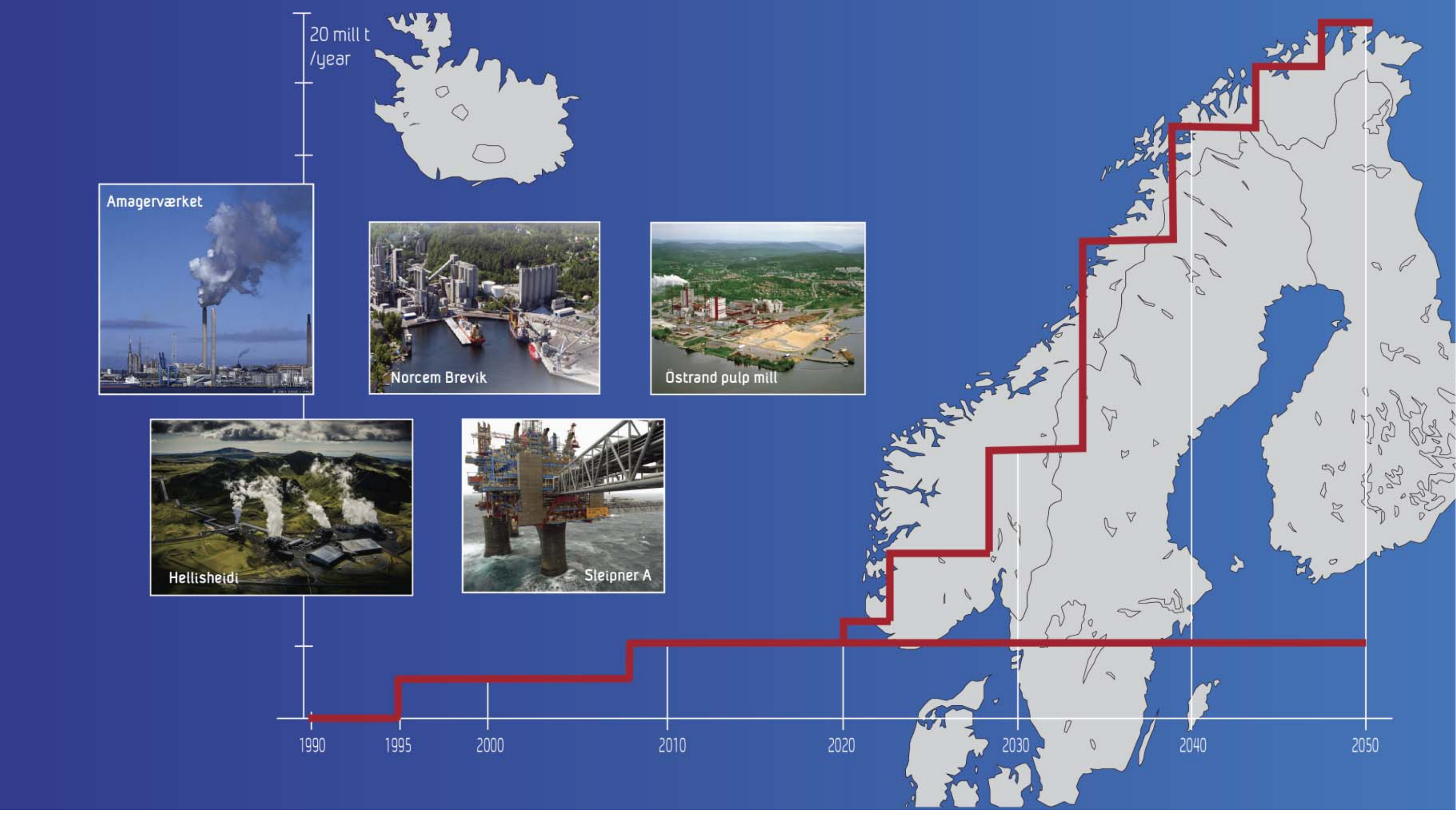

Towards maximum utilization of CO_2 storage resources

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NORDICCS Conference contribution D 6.1.1407 (7)

October 2014

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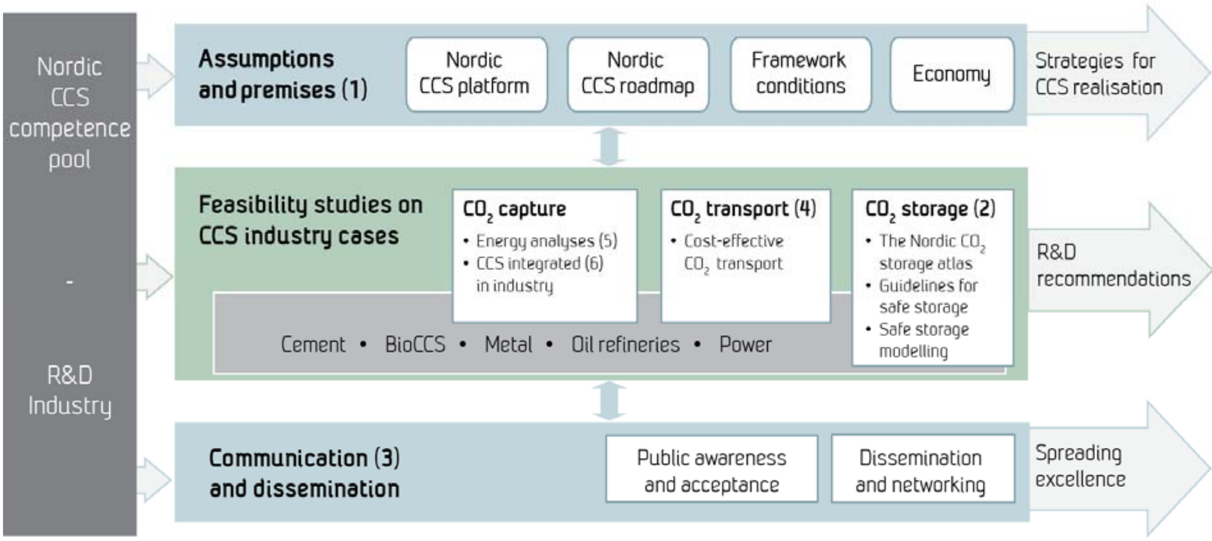

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Summary

If large scale CCS is to be realised the storage resources of saline aquifers should be utilised to their full potential by maximising the storage performance of each aquifer. This cannot be performed without water production to control and relieve the induced pressure increase from CO_2 injection. Large scale CO_2 injection with a large number of injection wells will hence require a large number of water production wells. This study investigates strategies for optimal design of well patterns, inter-well distances, optimal injection rates and average injection period for each well as function of storage characteristics such as areal size, thickness, porosity and safe pressure increase. The main focus is on inverted five spot well patterns in tilted reservoirs and the asymmetry in well positions required due to the tilting.

Keywords CO_2 storage, well patterns, tilted aquifers

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Date October 2014

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About NORDICCS

Nordic CCS Competence Centre, NORDICCS, is a networking platform for increased CCS deployment in the Nordic countries. NORDICCS has 10 research partners and six industry partners, is led by SINTEF Energy Research, and is supported by Nordic Innovation through the Top-level Research Initiative.

Towards maximum utilisation of CO_2 storage resources

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Abstract

To mitigate climate changes large scale CO_2 capture and storage (CCS) could prove to be an important part of the solution. If large scale CCS is to be realised the storage resources of saline aquifers should be utilised to their full potential by maximising the storage performance of each aquifer. This can not be performed without water production to control and relieve the induced pressure increase from CO_2 injection. Large scale CO_2 injection with a large number of injection wells will hence require a large number of water production wells. This study investigates strategies for optimal well timing and well patterns, inter well distances, optimal injection rates and average injection period for each well as function of cost and average storage characteristics such as areal size, thickness, porosity and safe pressure increase (given by an evaluation of the formation fracturation pressure).

To perform a first assessment of optimal storage capacity a generic approach has been developed [1] introducing a proxy function giving the storage rate and capacity of an aquifer. The proxy function is based on a number of traditional quarter five spot flow simulations on generic models by systematically varying up to 10 dimensionless input parameters defined by the reservoir parameters and injection/production scenarios. For a given aquifer the proxy can be used to estimate storage capacity by optimising operational parameters such as well distance, injection rate and well perforation lengths.

The proxy function is based on anisotropic homogenous generic models without tilt and with a regular five spot well pattern. The anisotropy, distance between wells and injection rates will determine CO_2 breakthrough in production wells and the storage efficiency between the wells. Injected CO_2 will segregate to the top of the reservoir and the anisotropy and injection rate will determine how much CO_2 that can be injected before breakthrough. Figure 1 display simulation results for a quarter five spot model (left) and a top down view of a full regular five spot pattern with more than 400 wells. The plots show the distribution of dissolved CO_2 at breakthrough time.

The present study investigates the effect of tilted and heterogeneous aquifers on such high-level parameters as

- the well distance necessary to avoid breakthrough before a given time,
- the maximum allowable injection rate,
- the overall storage efficiency,

This is done by analysing the results of a set of simulations on generic tilted and layered models. For tilted models the regular five-spot pattern will not be optimal. The asymmetry introduced by the tilt may be compensated by a corresponding asymmetry in the well pattern. The change in storage performance and the effect of different well patterns will be studied in order to arrive at recommendations for optimal well placement.

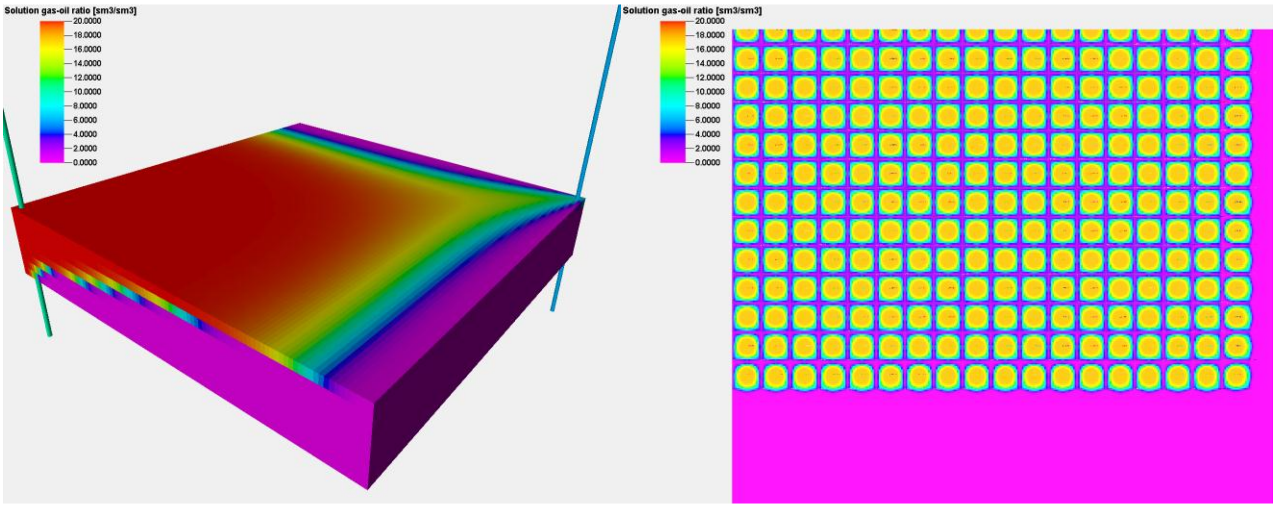

Figure 1 Example of simulation results for a quarter five spot model (left) and a top down view of a full regular five spot pattern with more than 400 wells. The plots show dissolved CO_2 at breakthrough time.

Next, the results from the generic simulations are compared with results from simulations on full field models of tilted saline aquifers in Skagerrak and off shore Mid-Norway. The suggested optimal well patterns from the generic model runs are tested to see if the trends for optimised storage capacity are valid also for more realistic full field models. The work have been funded by the Nordic Top-level Research Initiative and was performed in the Nordic centre of excellence for CCS, named NORDICCS. In line with objectives from NORDICCS a set of guidelines for setting up well patterns for maximum utilisation of an aquifer is given based on typical and average geological formation parameters.

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Active reservoir management

Towards maximum utilization of CO_2 storage resources.

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Introduction

- Large scale CO_2 injection will require water production to control and relieve the induced pressure increase.
- Water production has the potential to increase storage efficiency and reduce the area of impact, thus reducing the need for monitoring and possible future liability issues.
- This study investigates strategies for optimal design of well patterns, inter-well distances, optimal injection rates and average injection periods in tilted reservoirs.
- Modelling has been performed on synthetic tilted models and on representative full field model geometries.

Model Setup

- Models representing half the area of an inverted five-spot well pattern are investigated (Figure 1).
- Three synthetic model grids with 2, 5 and 10° dip has been constructed (Figure 2).
- L is 3000 m, average depth is 1600 m.
- Grid resolution is 50 by 50 by 2 meters with refined layer thickness below the top.
- Initial hydrostatic pressure is assumed, salinity and temperature is constant: 8 wt% TDS and 49°C.
- Fluid and flow properties for water and CO_2 are based on [1], [2], [3], [4], [5] and [6].
- Simulation parameter setup is listed in Table 1.

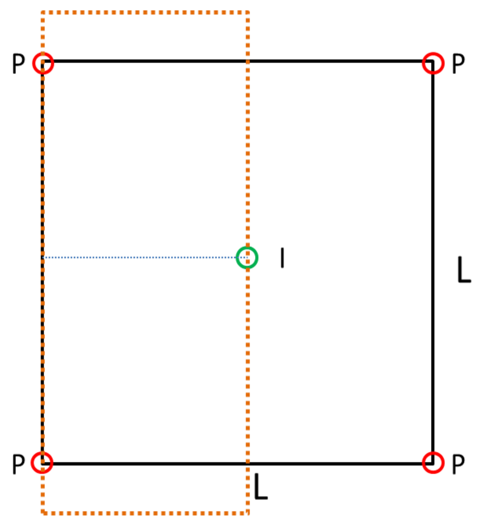

Figure 1: Schematic view of an inverted five-spot well pattern. Synthetic model is inside the dotted line.

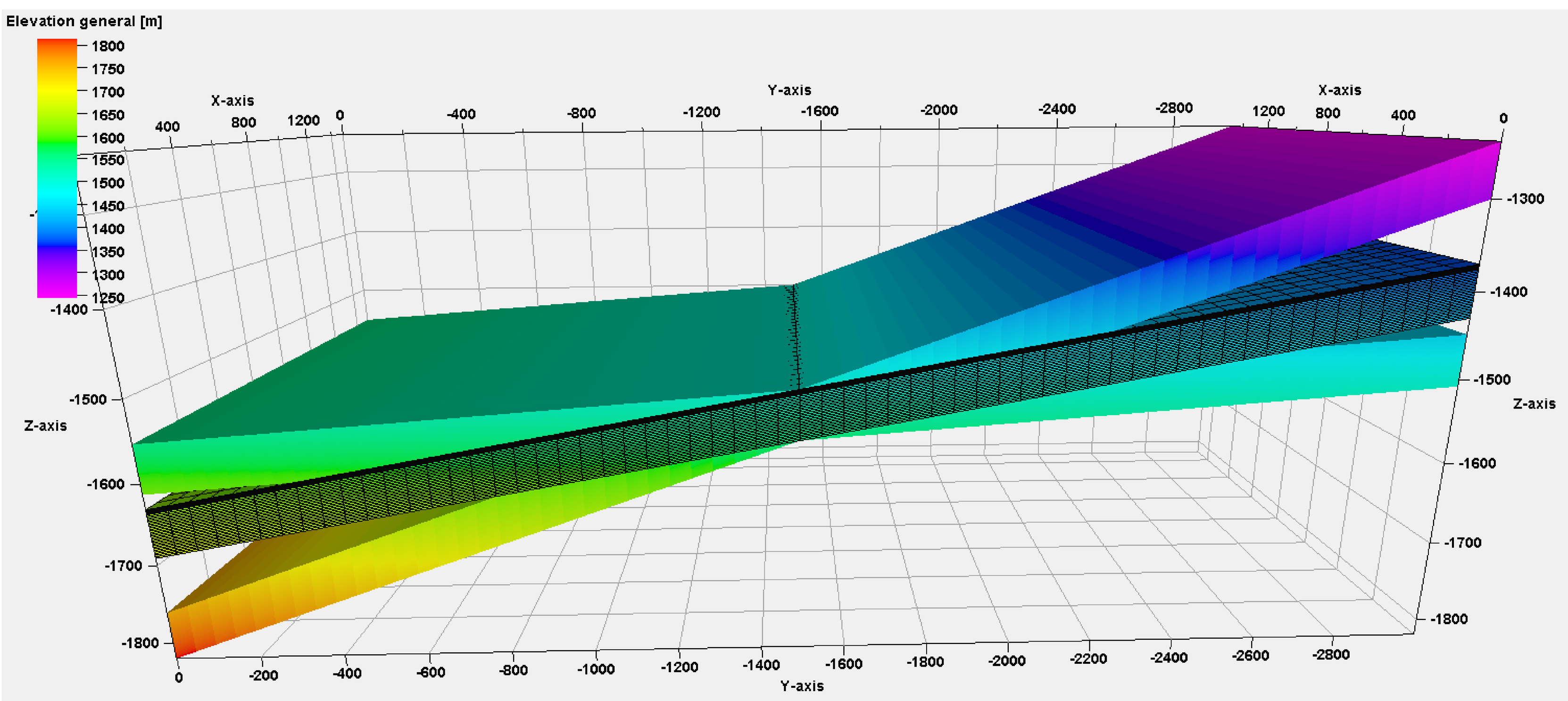

Figure 2: Depth plot of the synthetic tilted reservoir models. The figure shows all three model grids with 2°, 5° and 10° tilt. Gridding is shown in the 5° tilted model.

Table 1: Overview of simulated cases and parameter values for simulations on tilted grids (homogeneous)

Case	Model dip	Kv permeability	BHP injection	Height of model
#	°	mD	Bar	m
Case1	2	100	195.5	20
Case2	5	100	195.5	20
Case3	10	100	195.5	20
Case4	2	100	195.5	60
Case5	5	100	195.5	60
Case6	10	100	195.5	60
Case7	2	5	195.5	60
Case8	5	5	195.5	60
Case9	10	5	195.5	60
Case10	2	500	195.5	60
Case11	5	500	195.5	60
Case12	10	500	195.5	60
Case13	2	100	231	60
Case14	5	100	231	60
Case15	10	100	231	60

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Conclusions

- A shift in position of the injector is required to account for the tilt of the model. (Asymmetric inverted five-spot well pattern)
- The resulting asymmetry in well pattern will depend on the tilt, but also on the anisotropy and injection rate.
- Low vertical permeability (high anisotropy) increases the storage efficiency of the operation and also requires the largest asymmetry in well patterns.
- Storage efficiency on the synthetic models is in the range of 10 to 18 % with the use of inverted five-spot well patterns.
- Simulations on full field models show that a shift in the symmetry for the well pattern based on the synthetic modelling give up to 20 % extra injection volume without optimising well placement with regard to local heterogeneity and topography.

Results

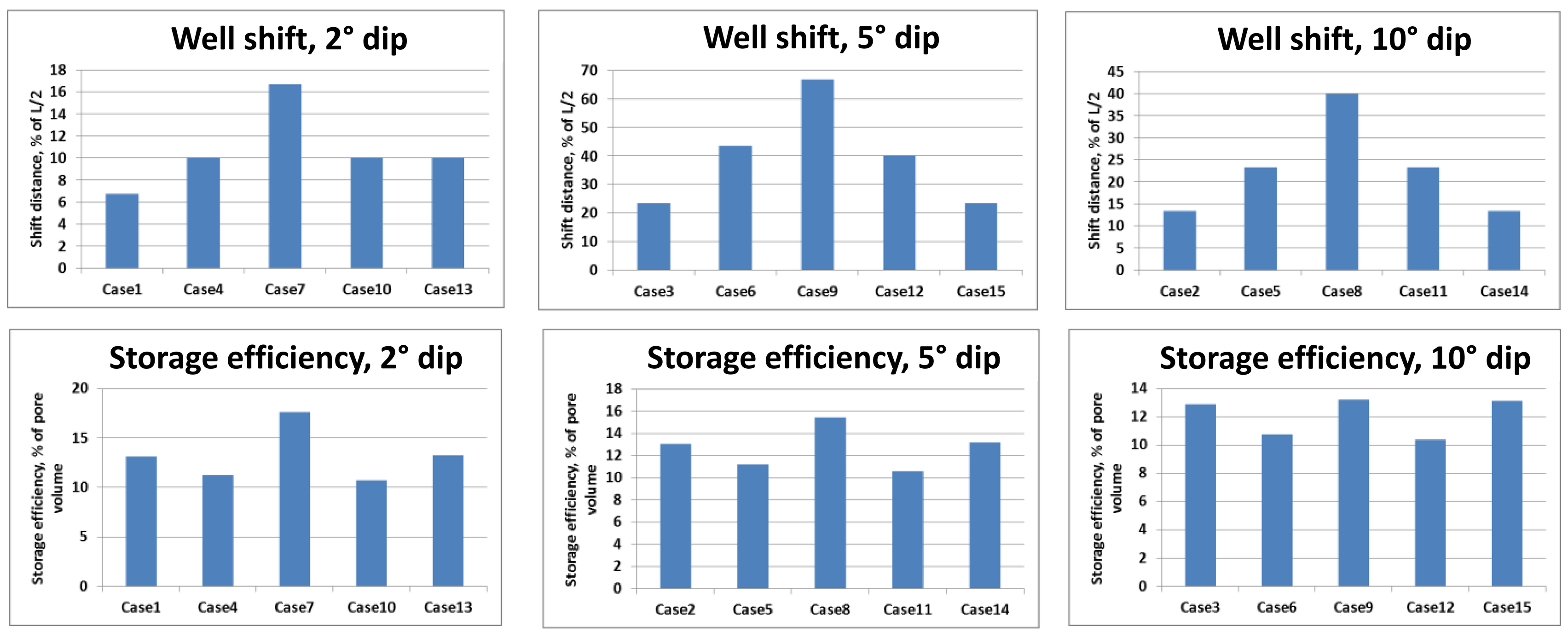

Figure 3: Results from simulation on the synthetic tilted models. Top row shows required shift of the injection well in order to get simultaneous break through. Bottom row shows storage efficiency . Simulations on layered reservoirs show reduced storage efficiency (4-15 %)

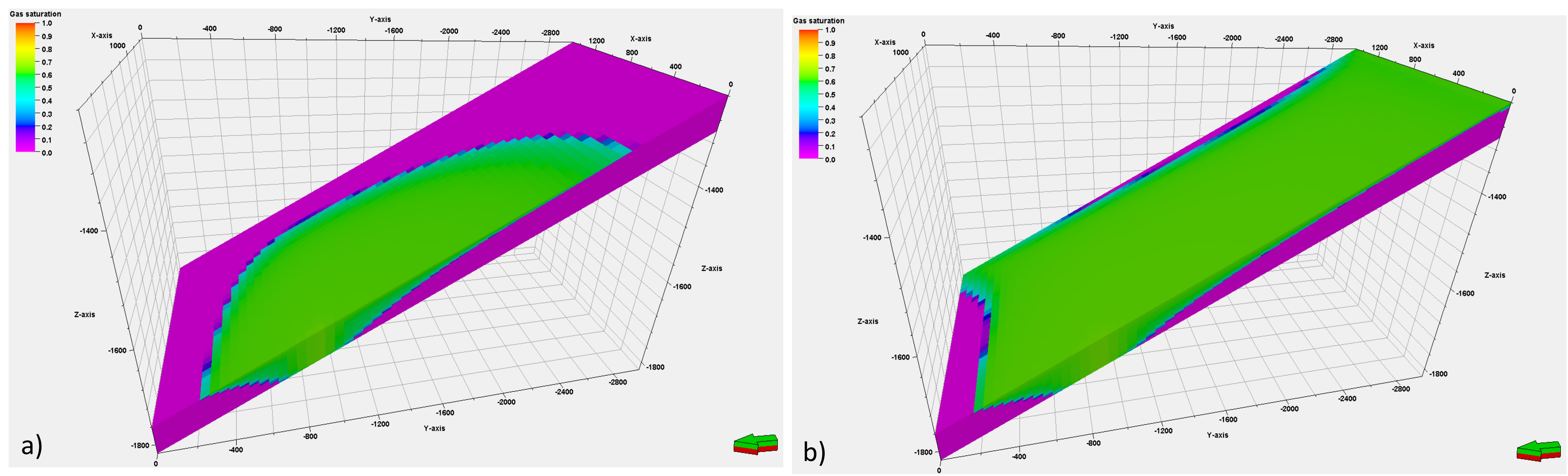

Figure 4: Gas saturation in the 2° tilted model after a) two years injection and b) when the CO_2 breaks through at the production wells (4 years). Injection well is shifted 150 meters down-dip, K_v=100 mD and BHP=195.5 bar.

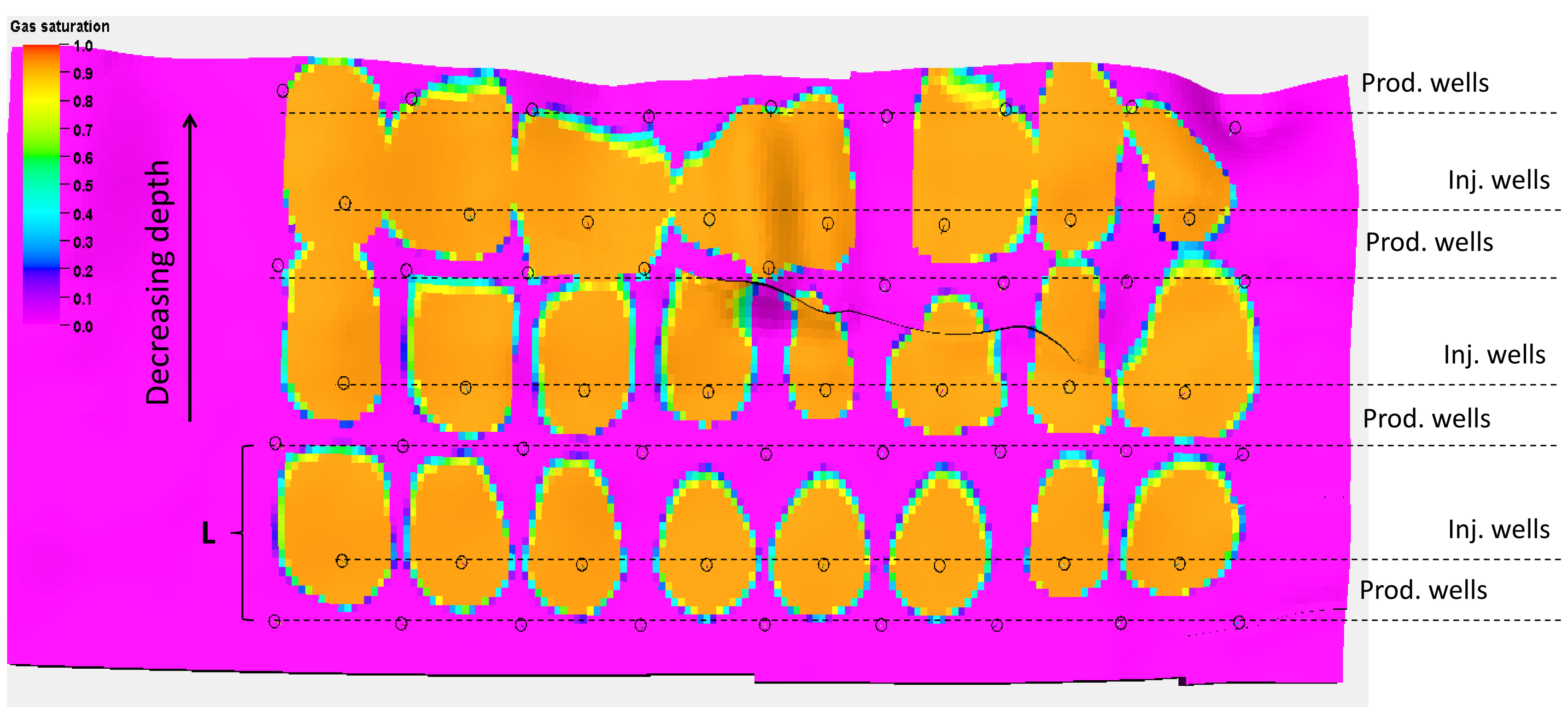

Figure 5: CO_2 saturation after break through in one of the production wells for the field model with average dip 5°. The model is 40 by 15 km (segment from Trøndelag Platform), L=4 km and the injection wells have been shifted 600 m down flank (30 % of L/2).

Acknowledgements:
This publication has been produced with support from the NORDICCS Centre, performed under the Top-level Research Initiative CO_2 Capture and Storage program, and Nordic Innovation. The authors acknowledge the following partners for their contributions: Statoil, Gassco, Norcem, Reykjavik Energy, CO_2 Technology Centre Mongstad, Vattenfall and the Top-level Research Initiative (Project number 11029).