Using 2D seismic line data to estimate impact of caprock morphology on CO_2 migration in the Gassum Formation

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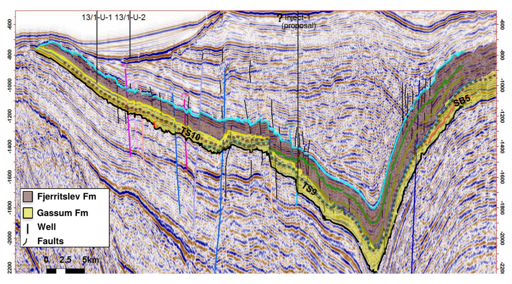
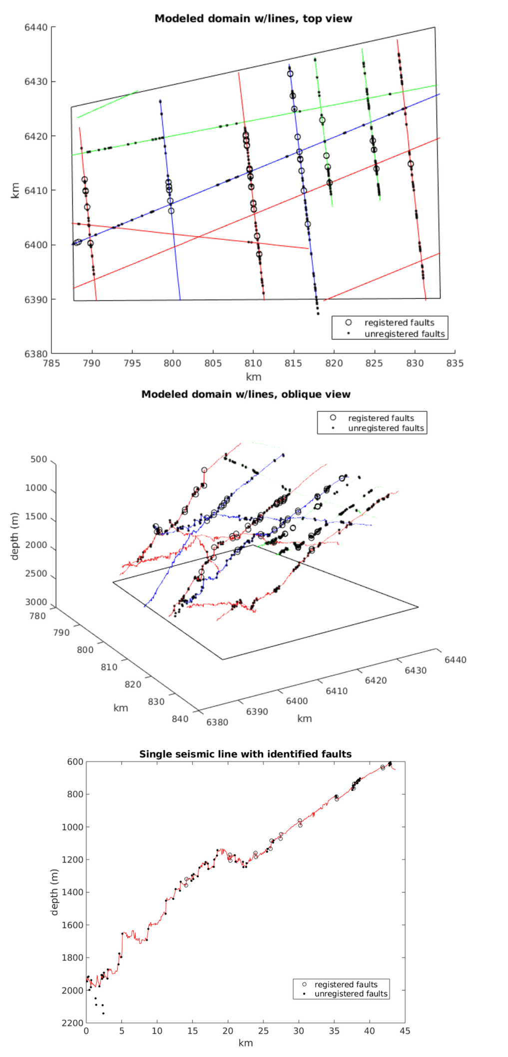
(1) – Introduction and motivation

- The CO2-Upslope project studies how CO_2 migration in sloping open aquifers is limited by factors that may immobilize the plume over the long term (physical and chemical trapping mechanisms) [1, 5].
- A case study is carried out on the Gassum Formation - a sloping open aquifer (Skagerak, south of Norway), for which data from several 2D seismic surveys are available.
- The work presented below aims to assess the potential for structural trapping and plume retardation from caprock topographical features that we try to infer from available data.
- Ultimately, the Gassum aquifer crops out on the sea floor, and sufficient plume retardation is essential to avoid leakage.



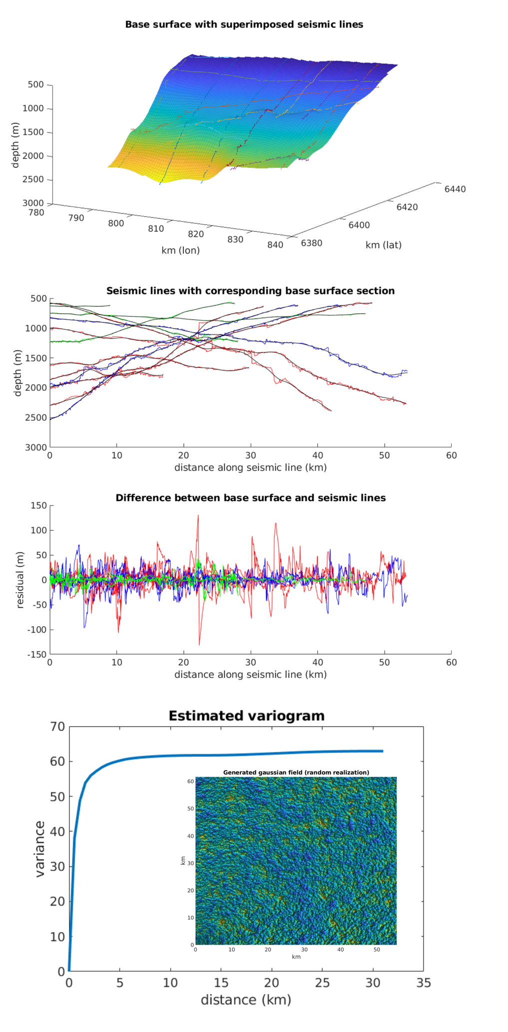
Seismic cross-section of the Gassum Formation (image from GEUS)

(2) – Input data



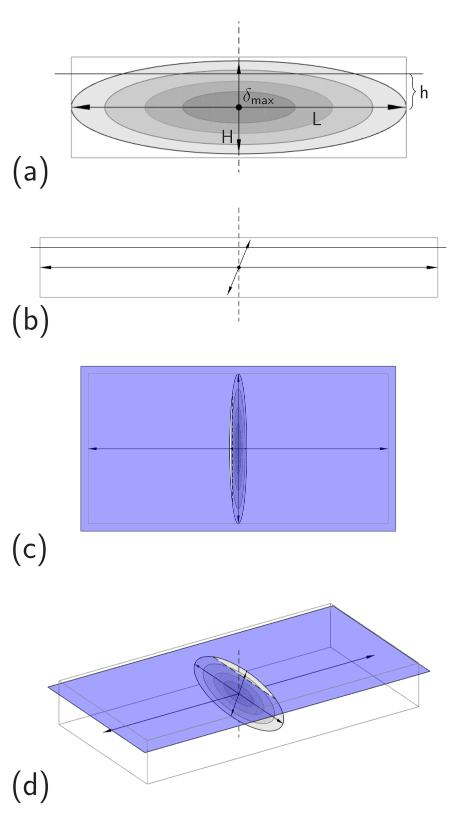
- Domain under study: 1900 km^2
- CO_2 migration is strongly affected by caprock topography. To simulate migration, we must establish top surfaces that are consistent with available data.
- 13 seismic lines from 3 surveys (IKU88, SKAGRE96 and FSB88) cross the domain (red, green and blue on figure)
- Each line intersected by a large number of faults.
- Most identified faults are minor and can only be identified on a single line (unregistered faults)[2].

(3) – Constructing base surface and small-scale detail



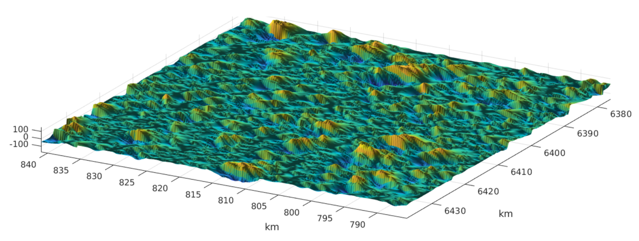
- We use thin-plate splines to construct a base surface representing general caprock shape
- Small-scale variations are important when simulating CO_2 migration, but only available along seismic lines.
- We measure the difference between seismic lines and base surface, and use these residuals to derive variograms.
- We generate corresponding Gaussian fields, which allow us to extend small-scale features from seismic lines to the whole surface in a stochastic manner.

(4) – Fault modeling



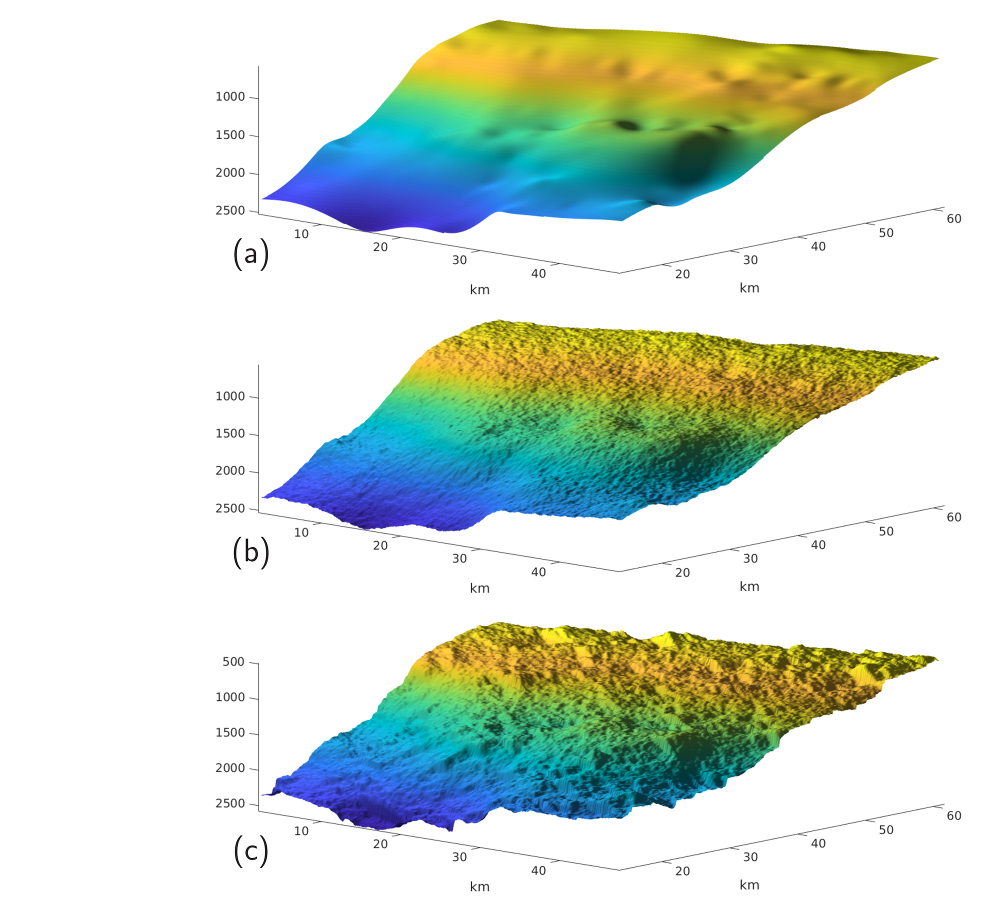
- We use a conceptual fault model from [3].
- Fault surface is modeled as an ellipse, and vertical displacement δ as a function from the center of the ellipse.
- Important ratios are δ to fault length L, fault height H to L, extent of displacement zone D to L, fault orientation θ and throw ψ.

Conceptual fault model. (a) fault surface frontal view; (b) side view; (c) top view; and (c) oblique view. The blue surface (which intersects the fault) represents the horizon of study.



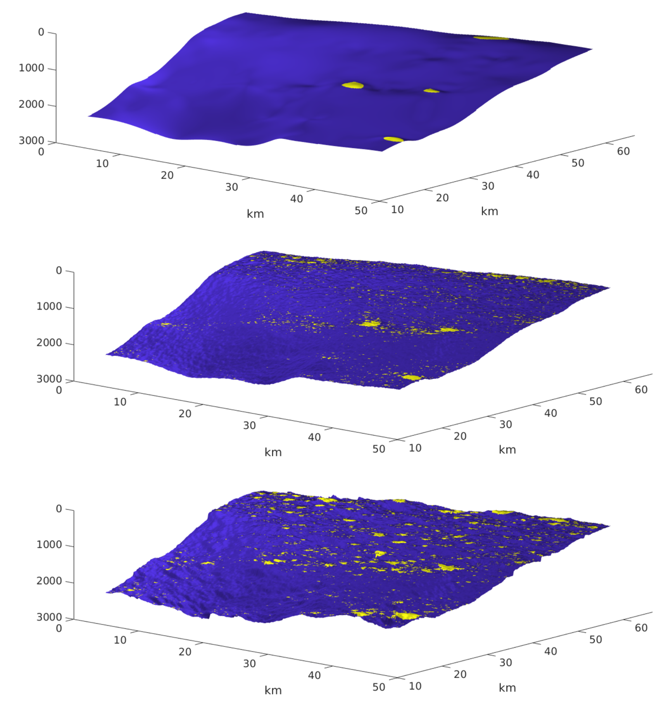
Stochastic generation of 6900 minor faults, with orientation, size distribution and total number estimated from unregistered faults in available line data

(5) – Final top surface



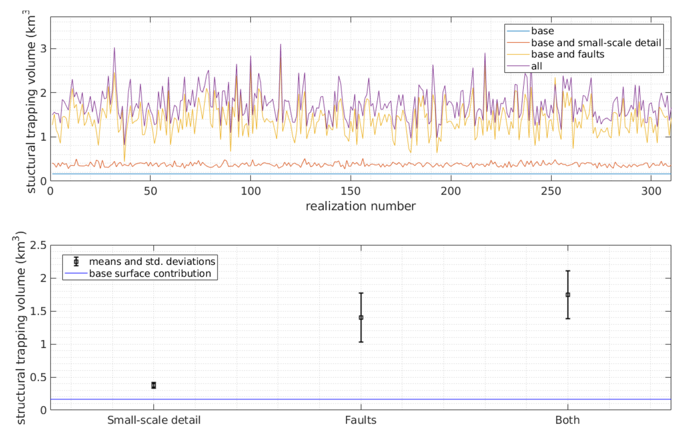
By combining the base surface with randomly generated small-scale detail (cf. box 3) and faults (cf. box 4), we create top surface representations that are statistically compatible with the 2D seismic line and fault data. (a) base surface; (b) base surface and small-scale detail; (c) base surface, small-scale detail and faults.

(6) – Global trapping analysis



Identified structural traps in (a) base surface; (b) base surface with small-scale detail; (c) base surface, small-scale detail and faults

- Structural trapping capacity significantly impacted by small-scale features and faults
- We use `MRST-co2lab` to compute structural traps for base surface and 310 realizations of added detail and faults
- Results suggest a significant additional structural capacity, but also with large variation between realizations.

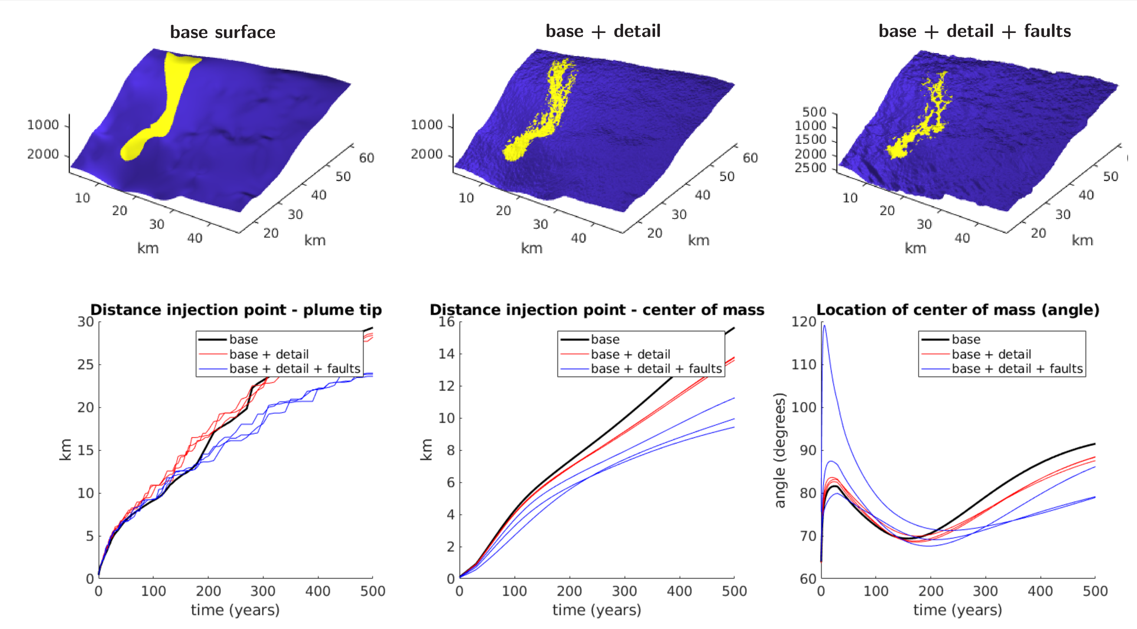


Total trapping capacity for 310 of top surface with stochastic variations, broken down into contribution from base surface, small-scale variation and faults.

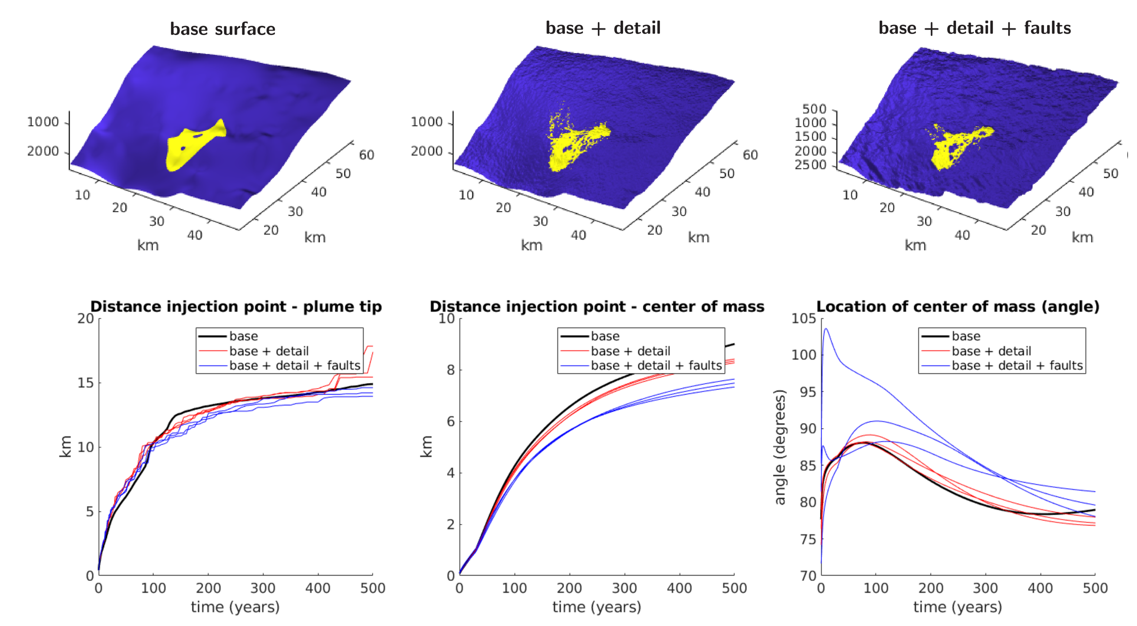
(7) – Simulated injections

- To assess impact of top surface structure on CO_2 migration, we run flow simulations. The vertical-equilibrium simulator in `MRST-co2lab`[4] lets us to run many simulations quickly.
- We consider 3 alternative injectors and 3 megatons of CO_2 per year for 30 years, followed by 470 years of migration.
- We compare *base surface* (left plot), *base with small-scale detail* (middle plot) and *base with small scale detail and faults* (right plot), and three different realizations for each.

Well position 1 (west)

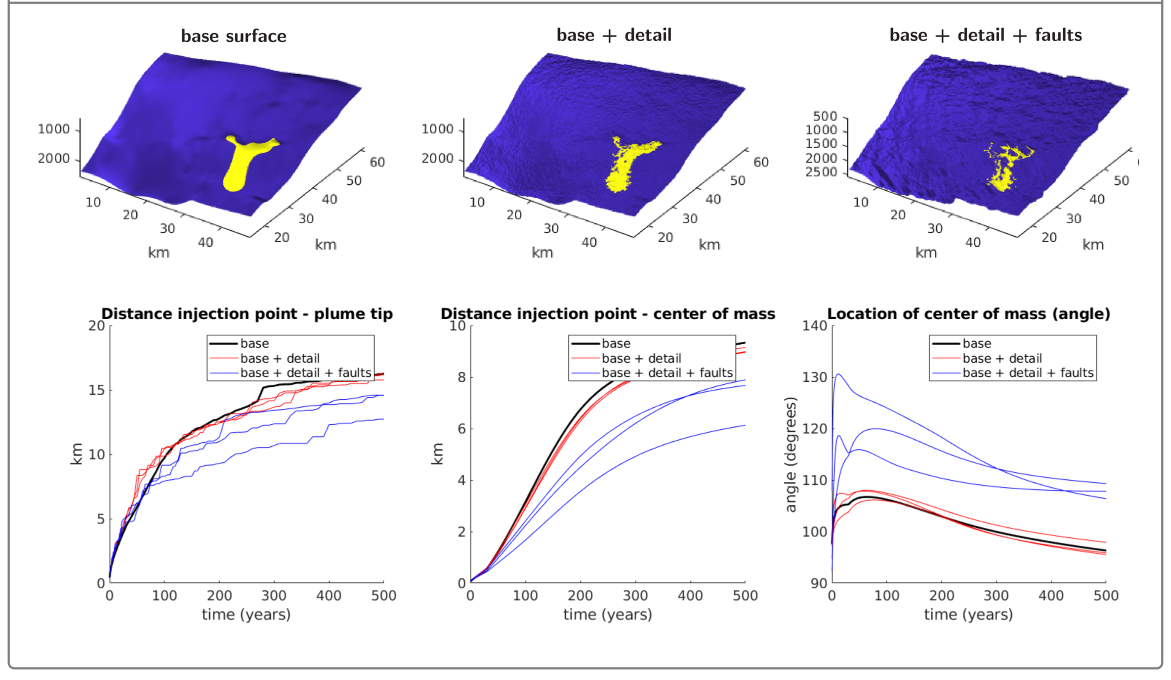


Well position 2 (middle)



(7) – Simulated injections (cont.)

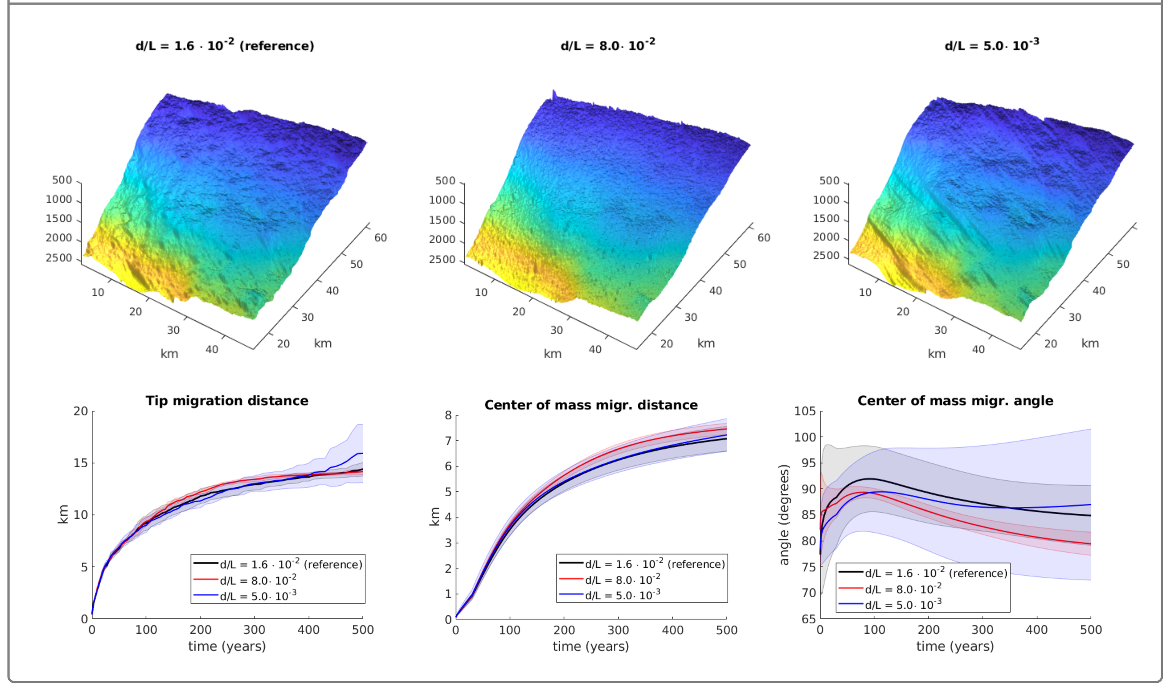
Well position 3 (east)



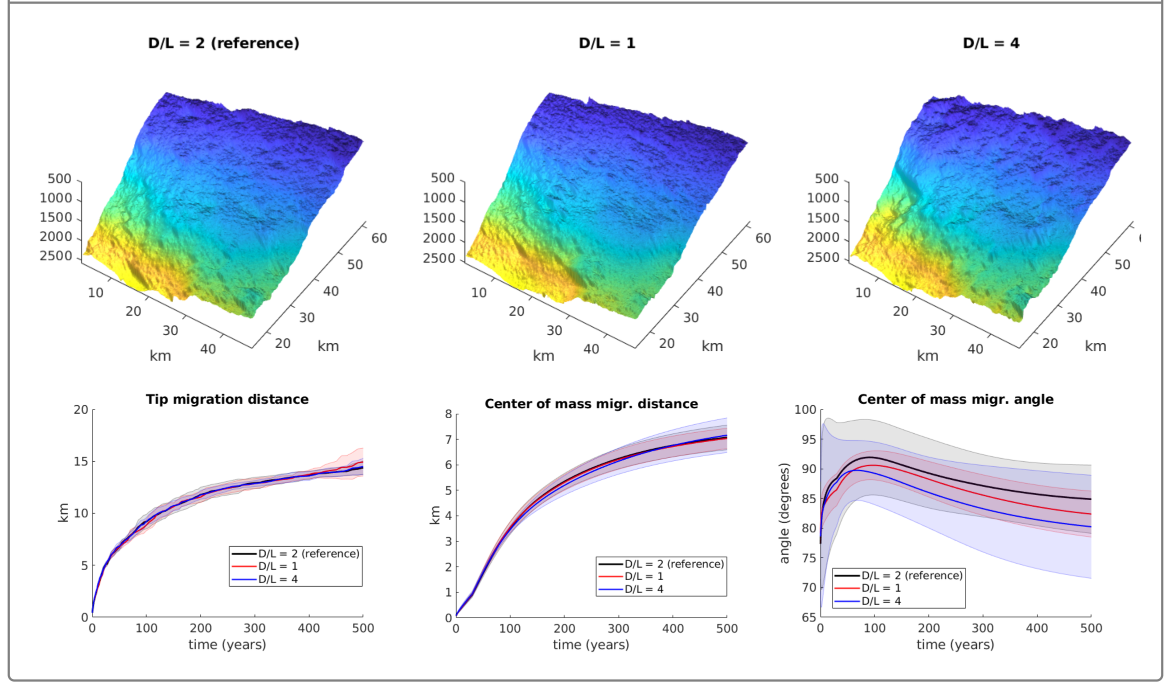
(8) – Fault parameter sensitivity

- Our fault model ratios δ/L, D/L and θ are highly uncertain.
- To assess the sensitivity of migration to these parameters, we vary each of them in turn, and run flow simulations on an ensemble of 10 realizations for each combination.
- We plot the *mean* and *standard deviation* in outcomes for each scenario.

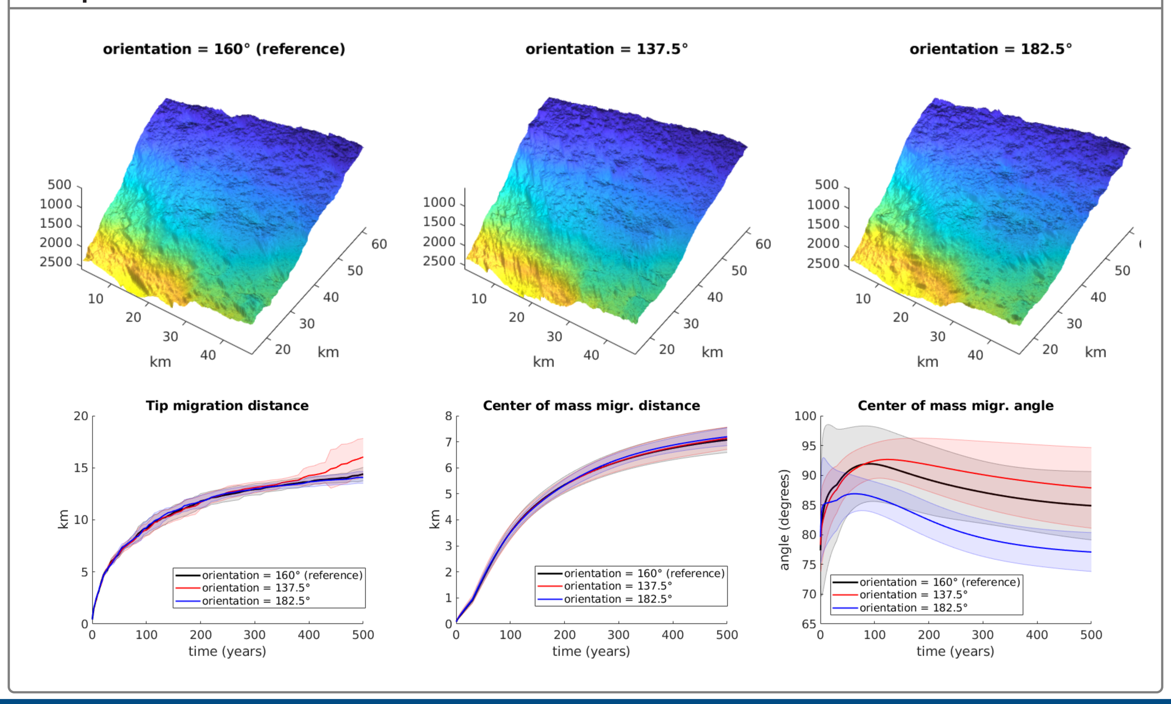
Impact of variations in δ/L ratio



Impact of variations in D/L ratio



Impact of variations in fault orientation



(9) – Conclusion and references

- Small-scale topographical features amount to a significant share of total structural trapping capacity, although variation is high between realizations.
- The presence of faults and small-scale detail appears to slow down overall plume migration with about 10-35 percent.
- Choice of ratios in the fault model seem to have limited impact on plume migration speed
- General orientation of small-scale fault may have non-negligible impact on overall migration direction.

[1] The upslope project: Optimized co$_2$ storage in sloping aquifers (upslope), 2017-2019. URL https://www.mn.uio.no/geo/english/research/projects/upslope/.

[2] G. et al. Seismic interpretation of a potential co$_2$ reservoir; the gassum formation, a sloping aquifer in skagerak between norway and denmark. Oral presentation, Nordic Geological Winter Meeting in Copenhagen, 2018.

[3] Y.-S. Kim and D. J. Sanderson. The relationship between displacement and length of faults: a review. *Earth-Science Reviews*, 68(3):317 – 334, 2005. ISSN 0012-8252.

[4] K.-A. Lie. *An Introduction to Reservoir Simulation Using MATLAB: User guide for the Matlab Reservoir Simulation Toolbox (MRST)*. SINTEF Digital, Department of Applied Mathematics, 2016.

[5] E. P. S. Bachu, W.D. Gunter. Aquifer disposal of co$_2$: hydrodynamic and mineral trapping. *Energy Conversion and Management*, 35(4):269–279, 1994.

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