DETECT

INTEGRATED GEOLOGICAL CO_2 LEAKAGE RISK ASSESSMENT

DETECT large-scale modelling

DETECT final dissemination event, 1 December 2020

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Input from WP2, WP3.1-WP3.3 (Heriot Watt and Aachen university)

Accelerating CCS Technologies

The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

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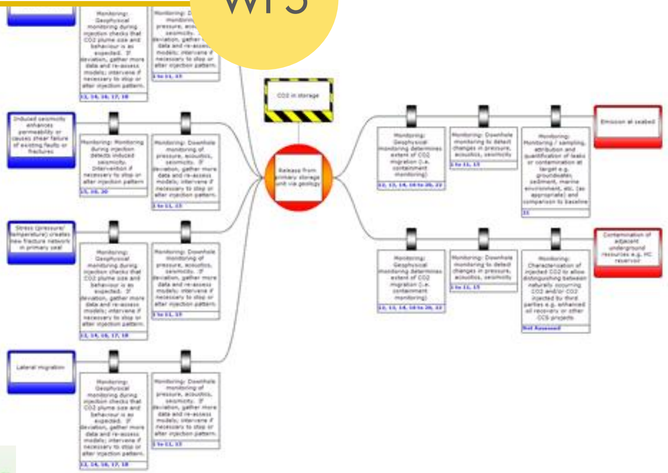
DETECT workflow

The goal of DETECT is to assess geological leakage risks related to fault and fractures in caprocks

WP5

Geological Leakage Risk Assessment

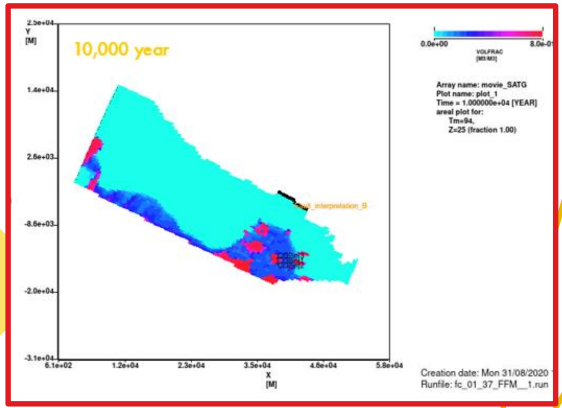
Incorporate all modelling and monitoring barriers in a qualitative bowtie risk assessment framework with associated quantitative scenario modelling tool



WP4

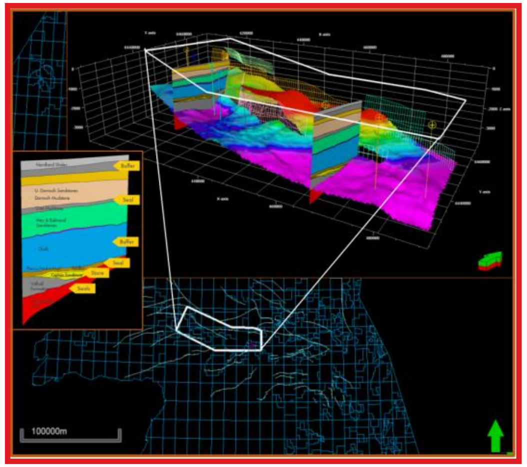
Identify active monitoring barriers relevant for site and expected leakage rates

Modelling results inform effectiveness of passive barriers (in seals and secondary storage units)



Probabilistic dynamic simulation using uncertainty ranges on all (parametrized) controls

Estimation of leakage rate distribution and likelihood at each caprock in CO_2 storage complex



WP3

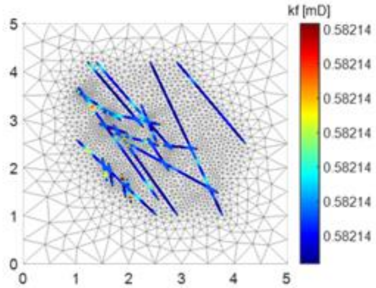
Hydromechanical coupling using lab-derived stress-permeability relations and analytical stress-state model

Effective fracture + matrix vertical permeability, RLP, CPR for each cell in seal derived from numerical up-scaling

Simulate flow in fracture networks in caprocks

Scaling relations based on meso/fine-scale modelling & analogues

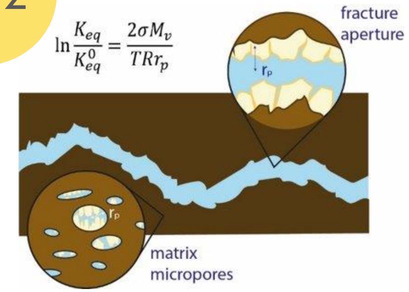
Characterise background stresses and log-derived rock transport and geomechanical properties



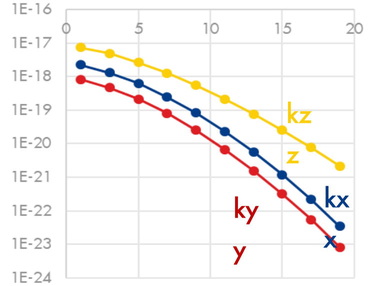
WP2

Experimentation and numerical modeling to characterise single fracture processes

$$\ln \frac{K_{eq}}{K_{eq}^0} = \frac{2\sigma M_v}{TRr_p}$$



Quantifying the impact of small-scale physics on CO_2-brine flow at fine-scale



Characterise fault-fracture networks using analogue derived scaling relations: fault throw-length-frequency

Accelerating CCS Technologies

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Outline

- Input data and workflow
- Insights from semi-analytic results and 2D detailed simulations
- Green River application – history match (workflow validation)
- North Sea application – forecast
- Conclusions

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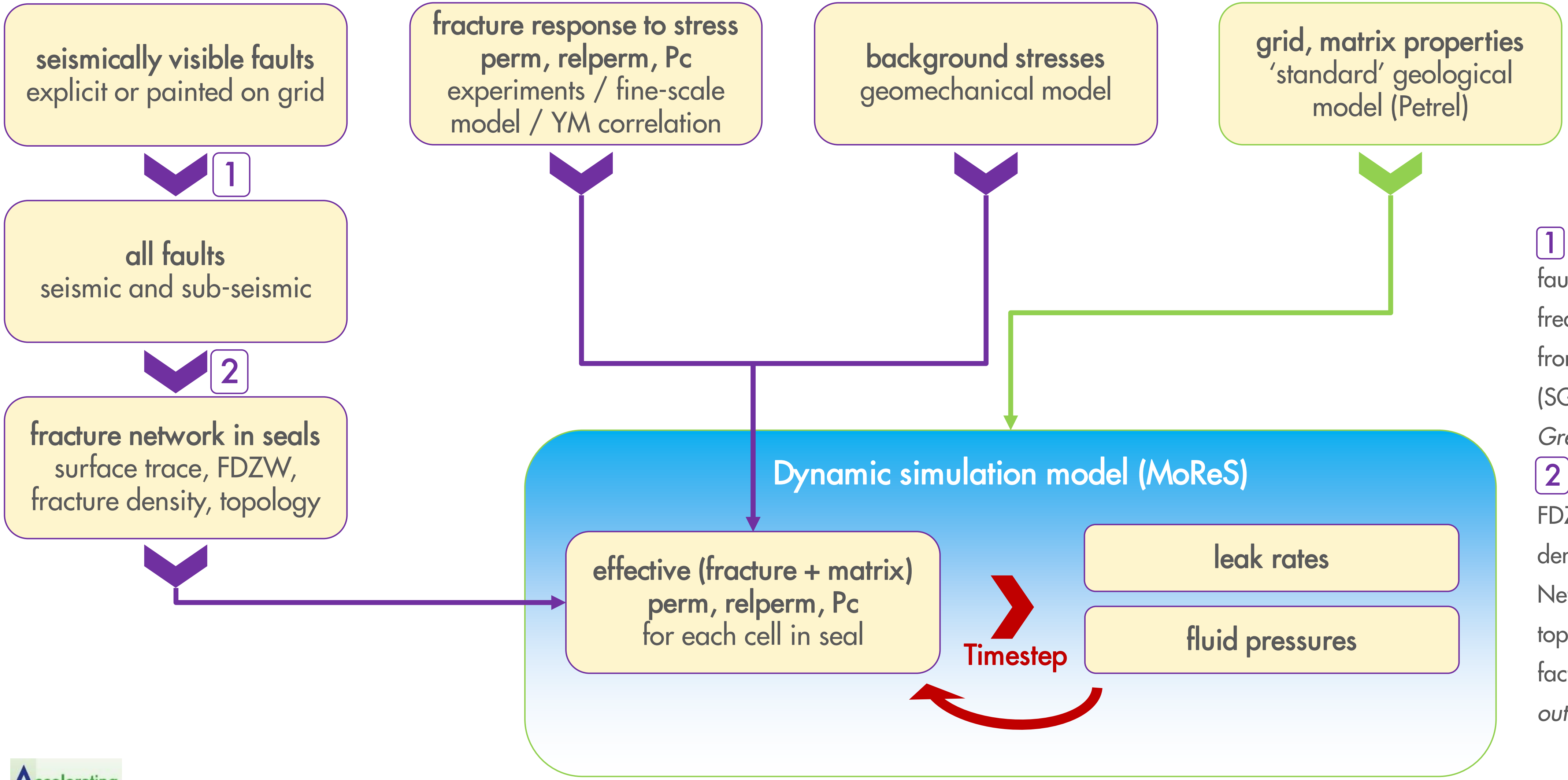
Input data and workflow



1 Scaling relations for fault throw-length-frequency, extracted from seismic faults (SGT). *Skipped for Green River*

2 Scaling relations for FDZW-throw, fracture density-distance. Network connectivity topological reduction factor. *Green River: from outcrop and well data*

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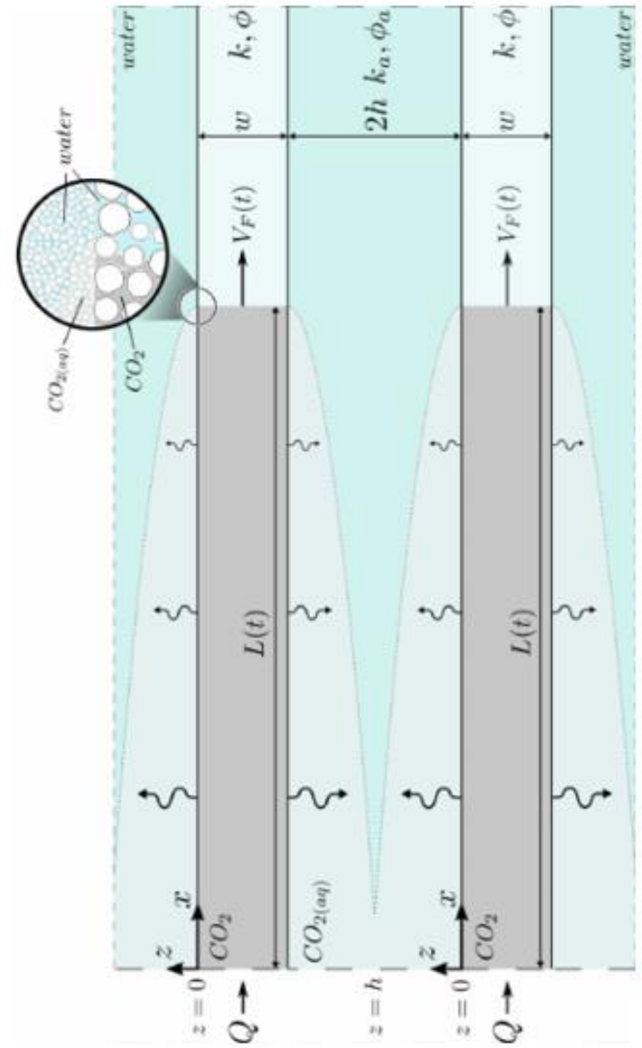
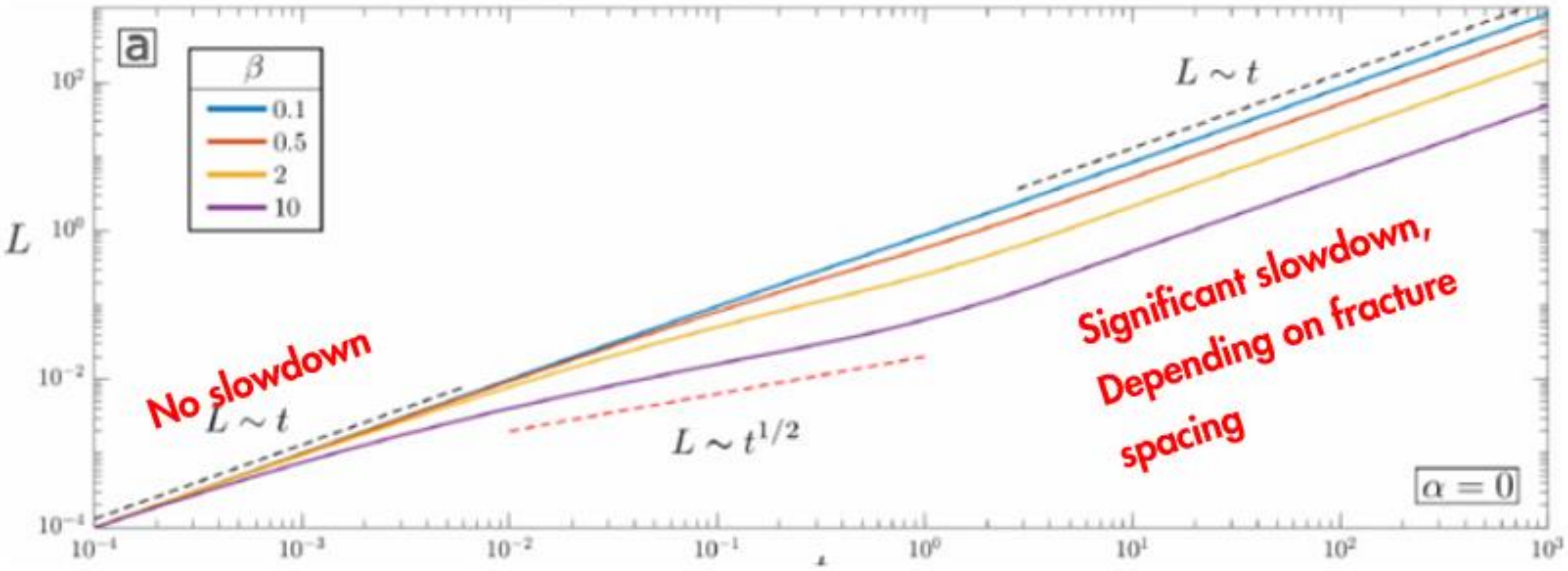
Insight (semi-analytic): Diffusion slows down CO_2 velocity in fractures



- Gilmore et al 2020: semi-analytic treatment of CO_2 in high-perm streaks
  - Rotated 90°, the results are directly applicable to DETECT
- No diffusion → top caprock reached within days, even at low rates
- With diffusion → months (high rate) to >10,000 year (low rate)



Modified from Gilmore, K., J. Neufeld, and M. Bickle, *CO2 Dissolution Trapping Rates in Heterogeneous Porous Media.* Geophysical Research Letters, 2020

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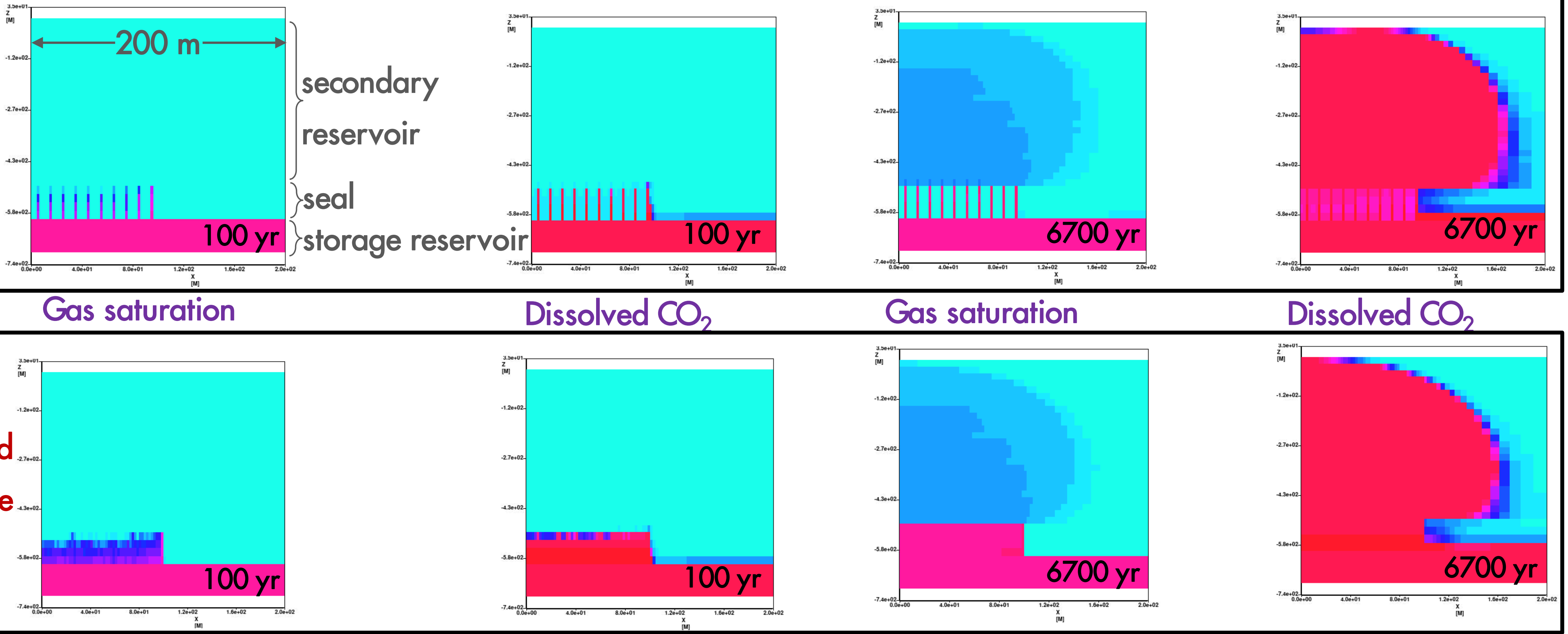
Insight (2D model): Homogeneous treatment of damage zone, with careful property upscaling, reproduces explicit fracture modelling

Individual fractures resolved, diffusion into matrix

Homogenised damage zone



100 year top seal BT, same as analytic (at same parameter settings)

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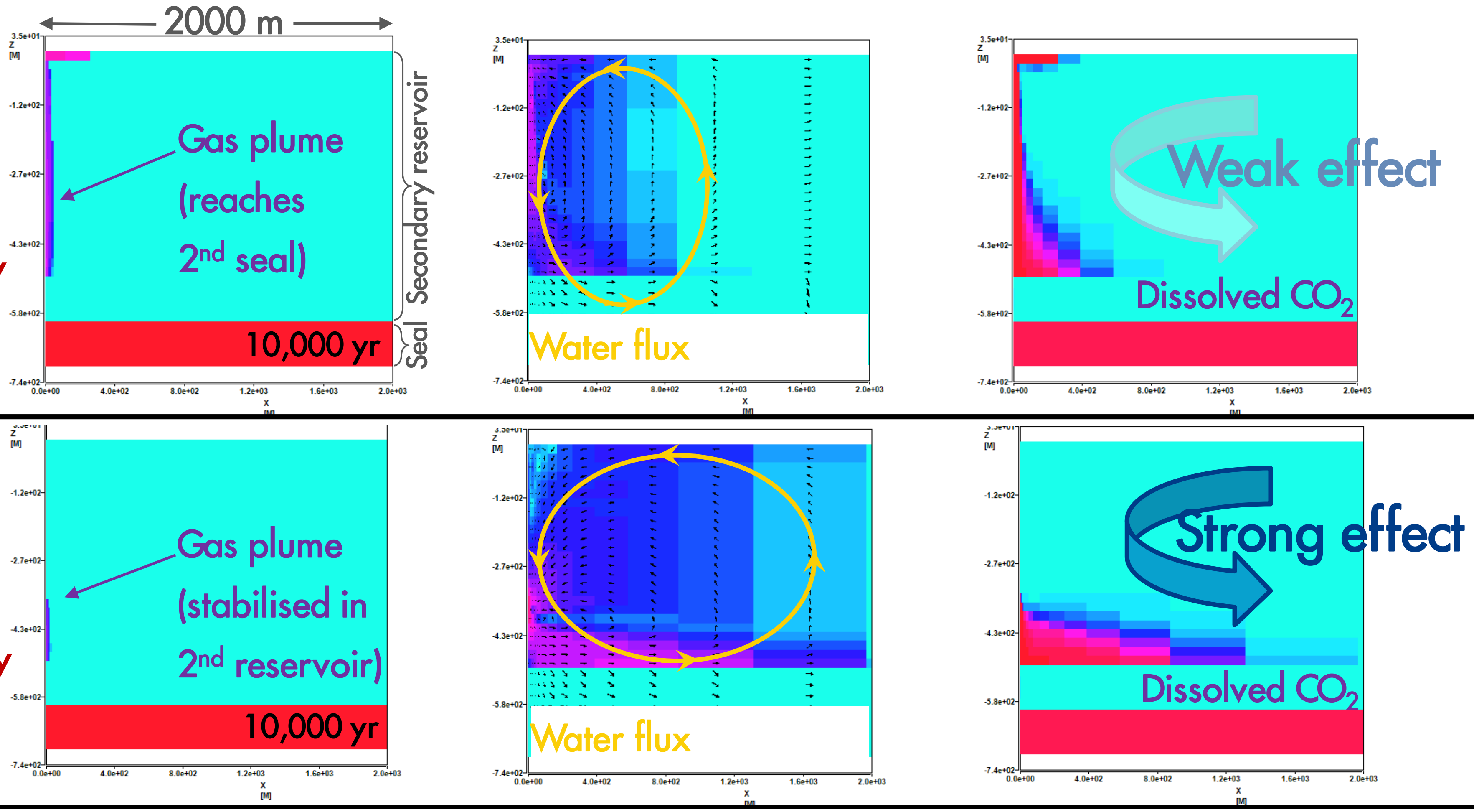
Insight (2D model): Counter-current brine flow dissolves all CO_2 in 2nd reservoir below critical leak rate /above critical permeability

Above critical leak rate/
Below critical permeability

Below critical leak rate/
Above critical permeability



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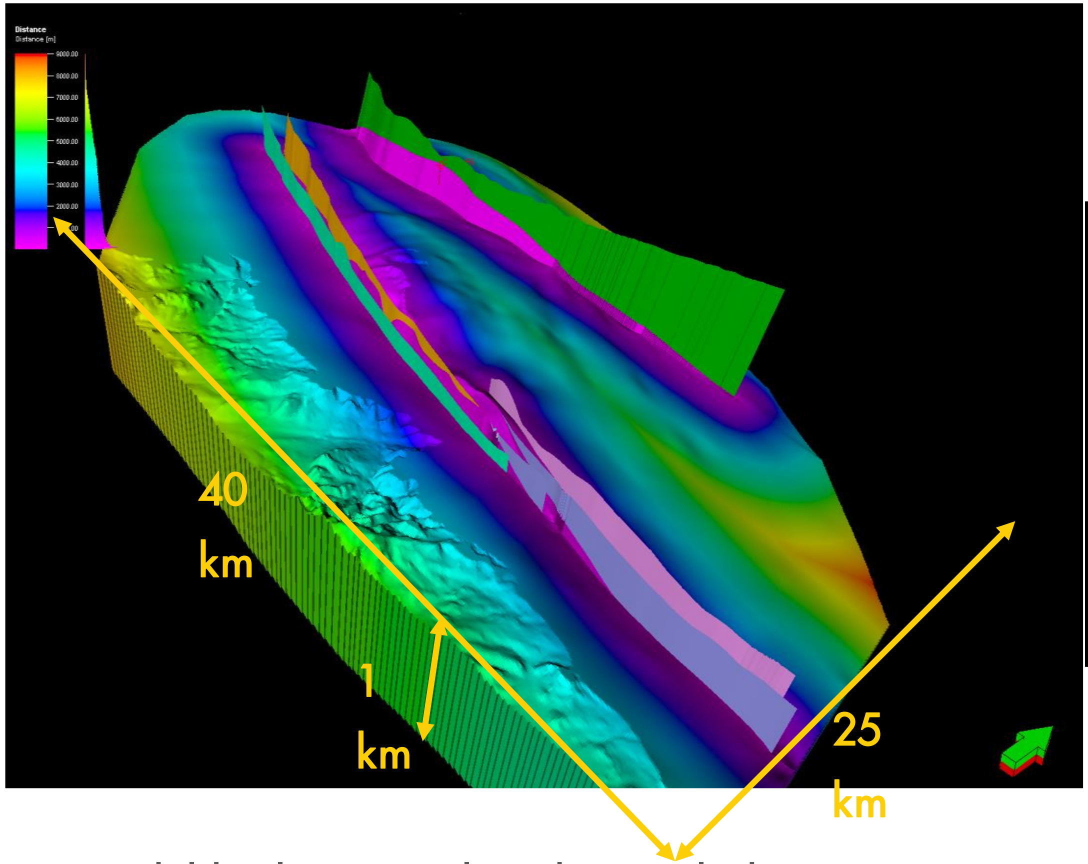
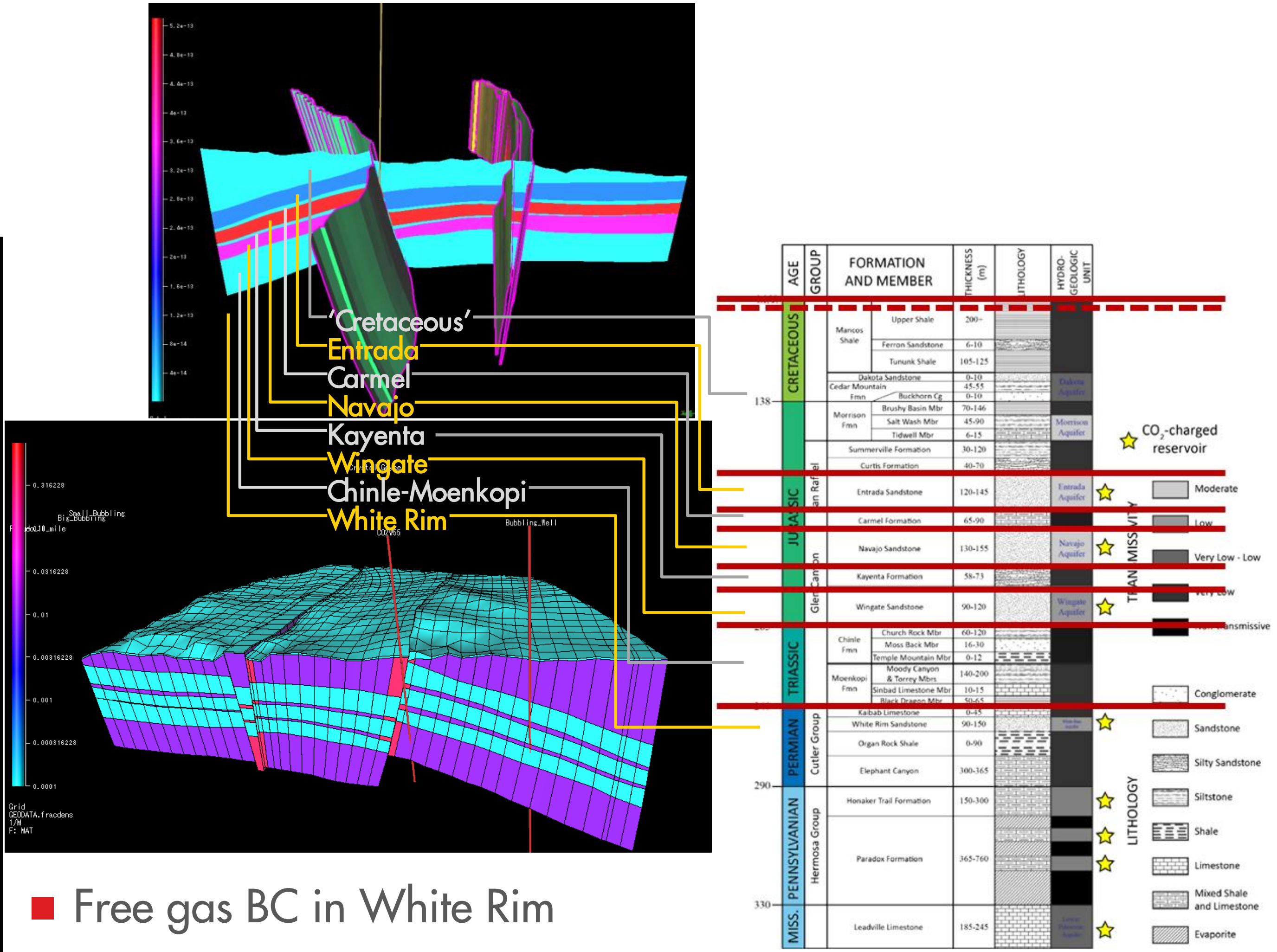
Green River: Model overview





- Model built in Petrel and upscaled to MoReS
- 500m x 500m grid, down to 50m near faults
- Free gas BC in White Rim
  - Has been observed in E&A wells
  - Uncertainty range based on spill point analysis
- Fracture input from experiments, characterisation, fine-scale models

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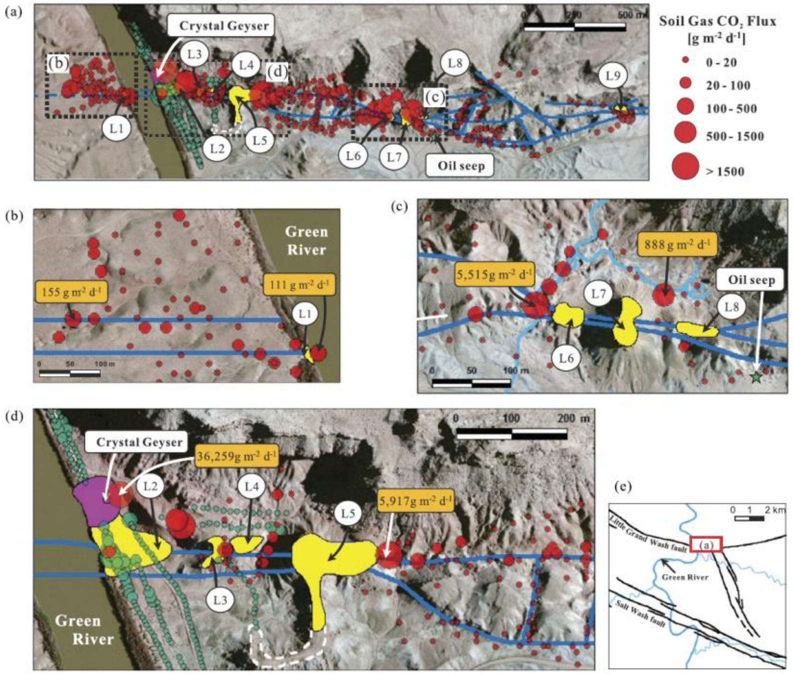
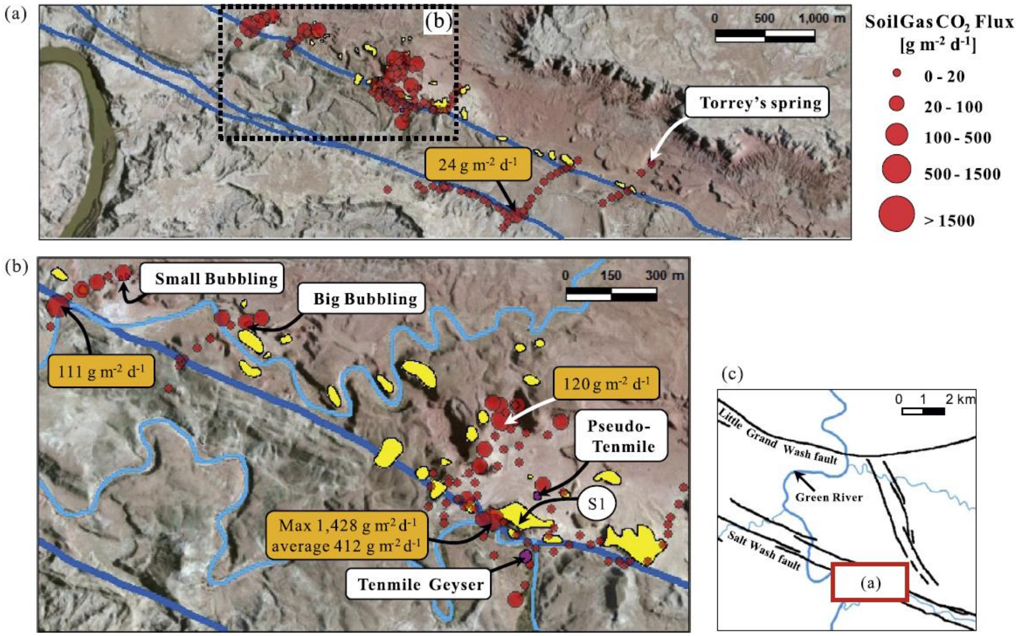
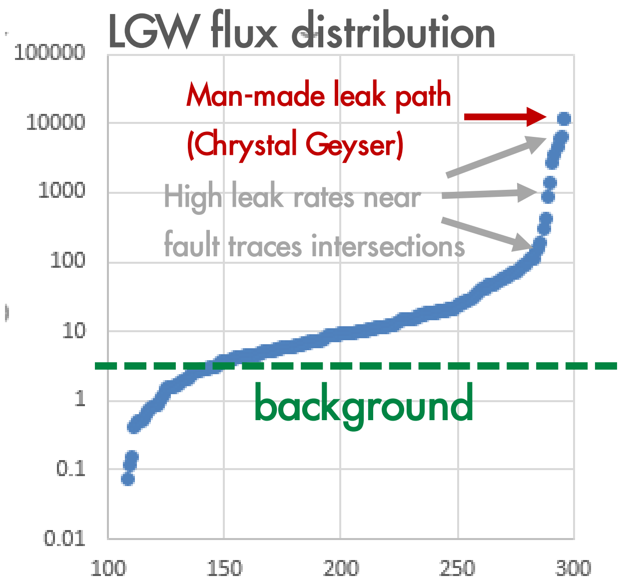
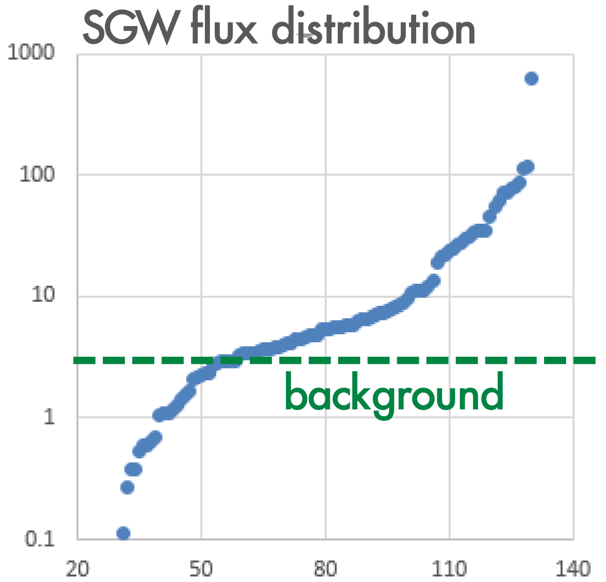
Green River: Observables (history match objectives)









- Data from Jung et al (Earth and Planetary Science Letters, 2014), sampling points distance 9-50 m
- Repeats show temporal variations; areal integration introduces additional uncertainty
  - LGWF total surface leak rate 0.09 – 0.6 – 6 kg/s (DETECT estimate)
  - SWG total surface leak rate 0.03 - 0.12? - 1.5?? kg/s (DETECT estimate)
- CO2W55 log water compositional data (Carmel, Navajo)

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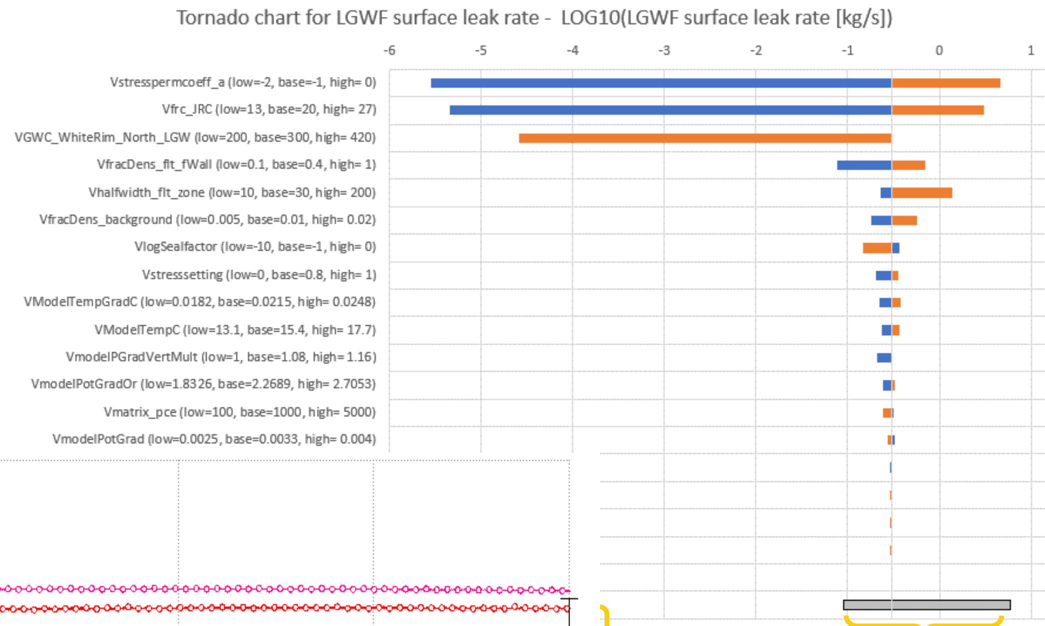
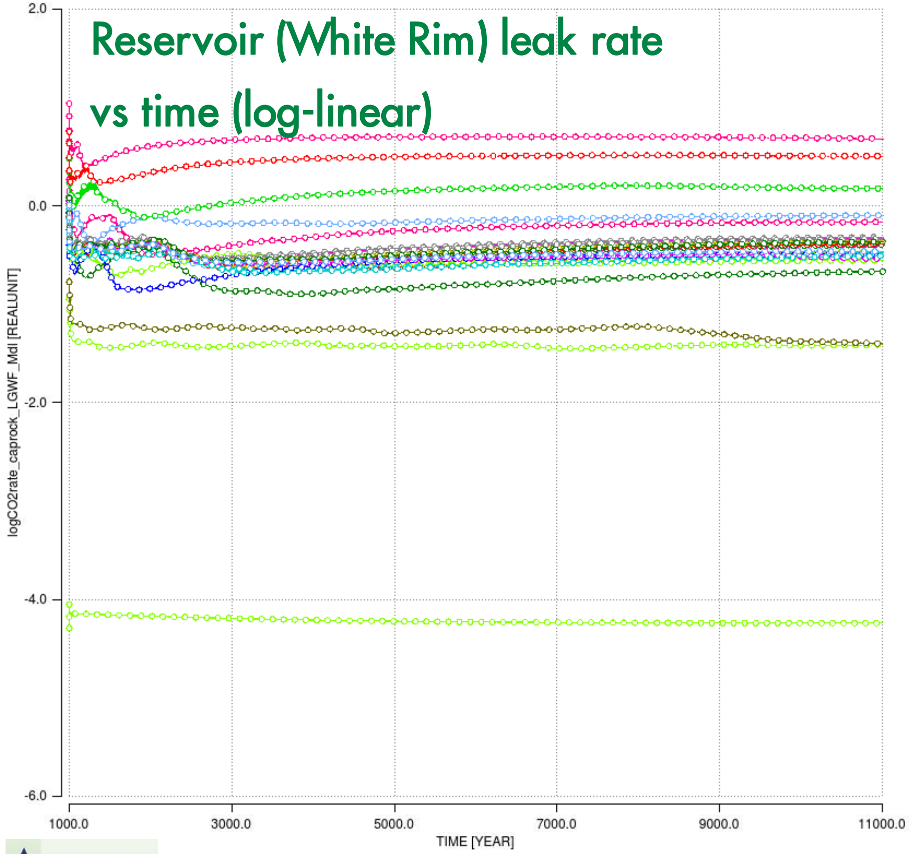
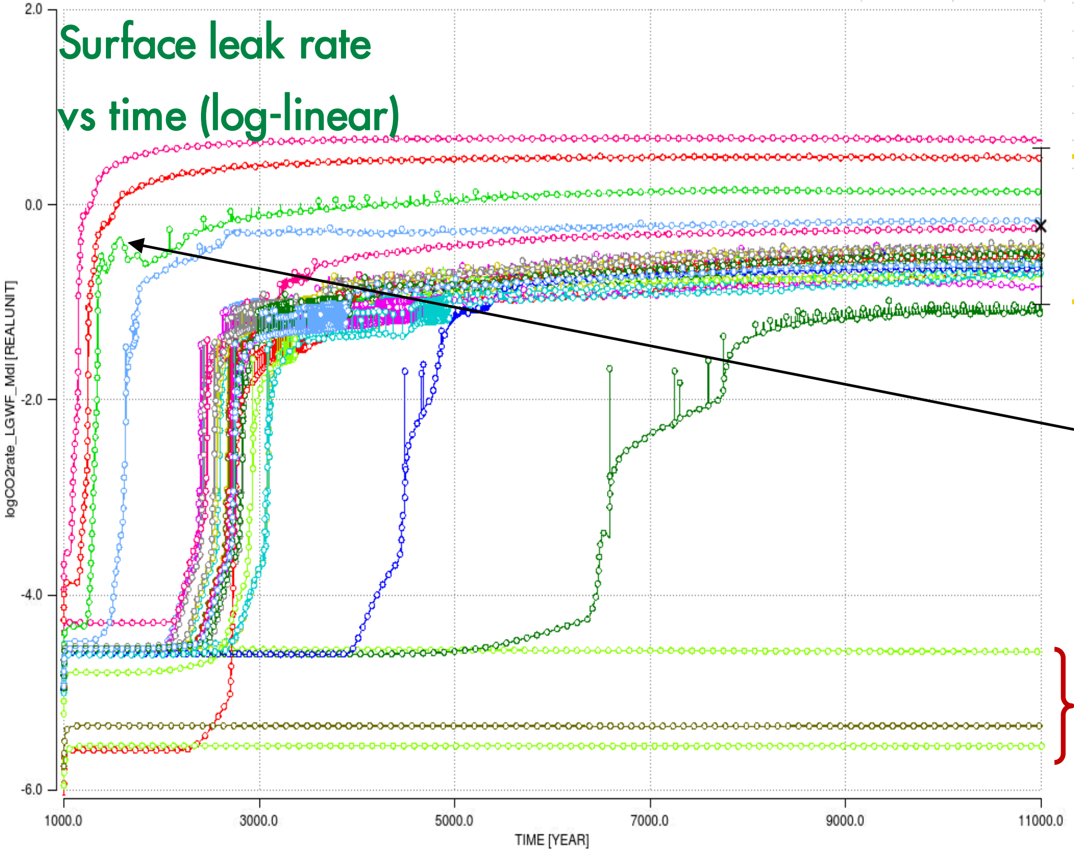
Green River results:
Model reproduces measurements

Results preliminary, pending minor final model updates







Measurement range

Minor dynamic valving

Realisations with too low leak rate to migrate through the secondary reservoirs

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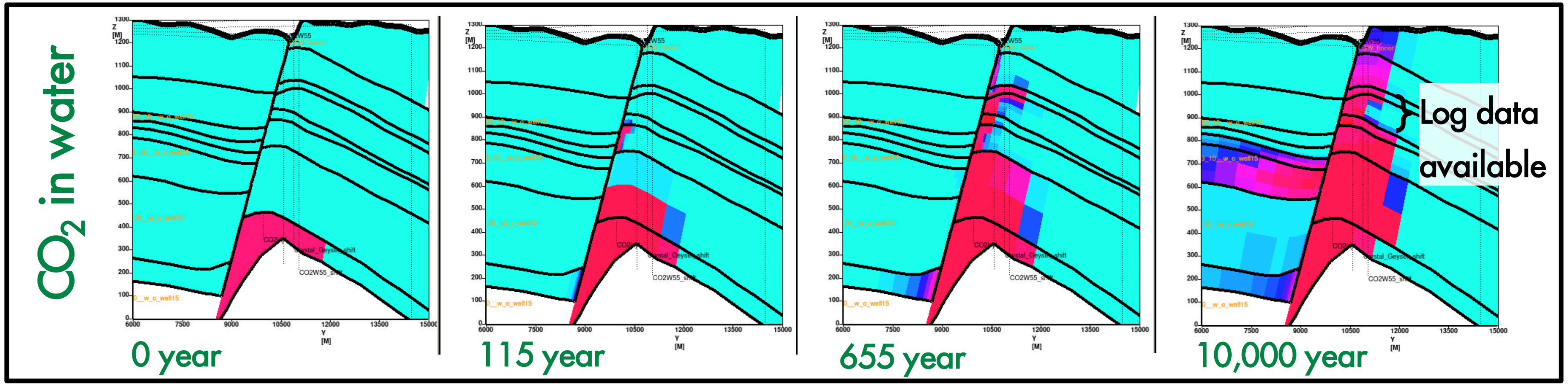
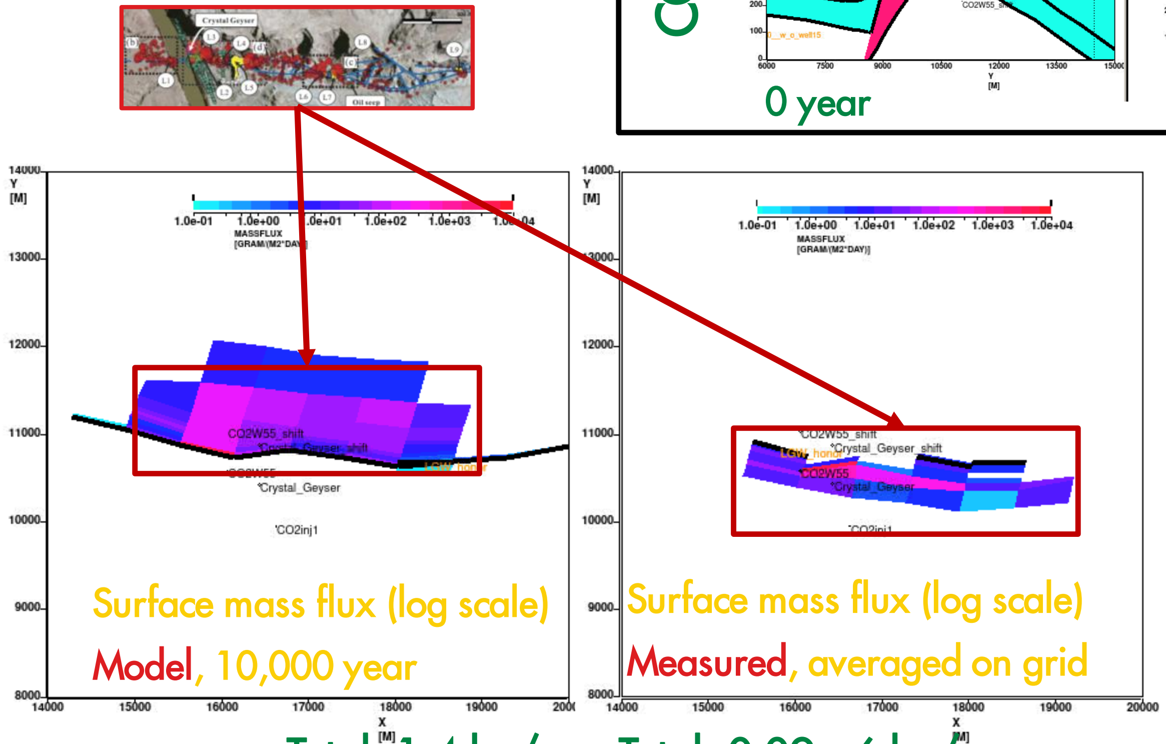
Green River results: LGWF area in one of matching realisations





Total: 1.4 kg/s Total: 0.09 - 6 kg/s

- After 10,000 year, leak rates stabilised
- Some leakoff into the intermediate reservoirs
- Total surface mass rate matches measurements
- Flux pattern matches measurements qualitatively
- Well log qualitatively matched (not presented here)

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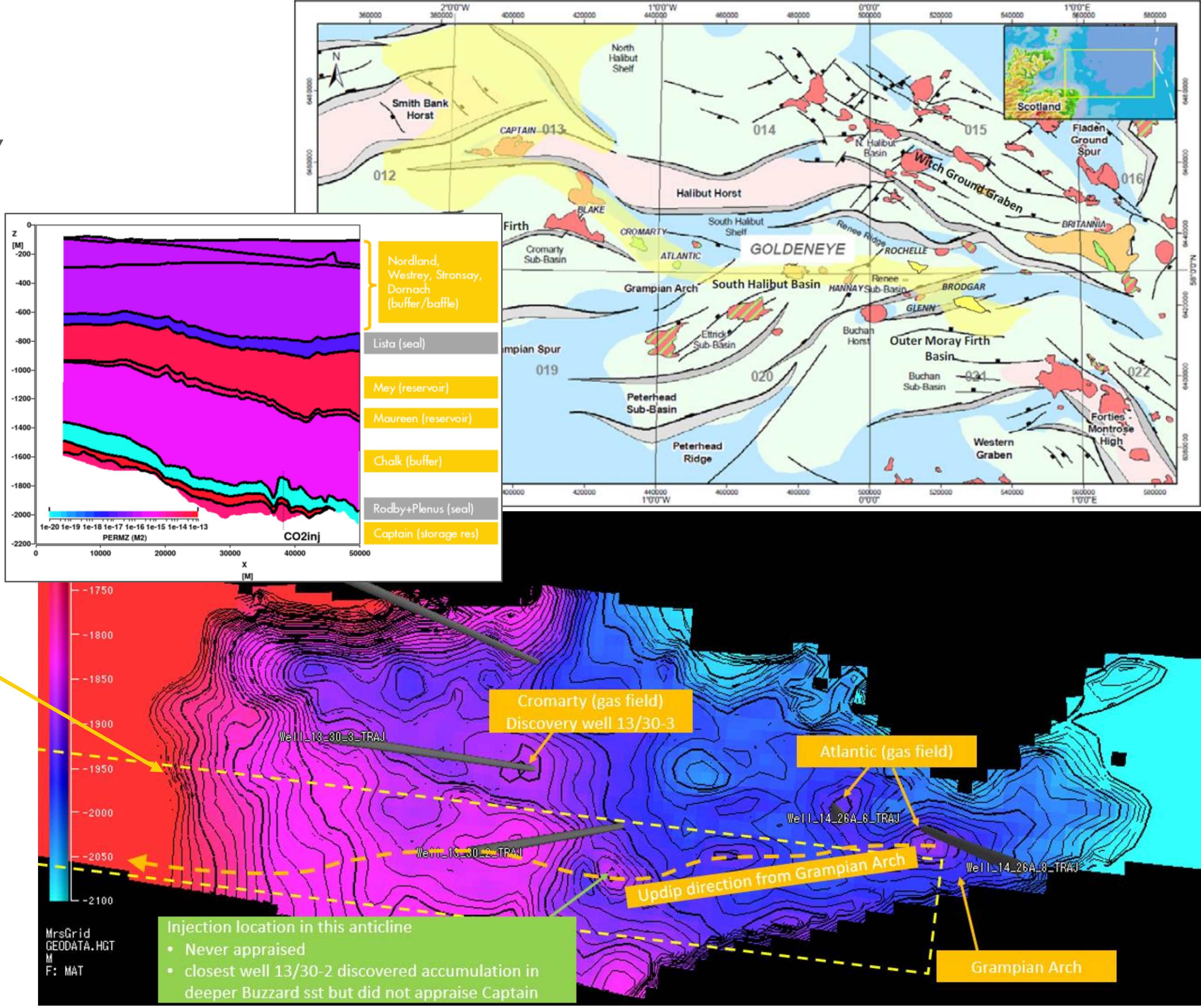
North Sea: Model overview

- Captain Fairway (Outer Moray Firth)
  - Relevance (CO_2 storage capacity)
  - Data availability (Goldeneye; basin models)
- Presence of seismically visible faults
- Dynamic model 50 km x 20 km / 50 km x 4 km (sector)
- Reservoir to seabed
- Primary caprock = Plenus/Rodby
- Secondary caprock = Lista = top of Storage Complex
- 540 MT / 180 MT (sector) CO_2 injection
- Abandoned wells excluded from analysis!



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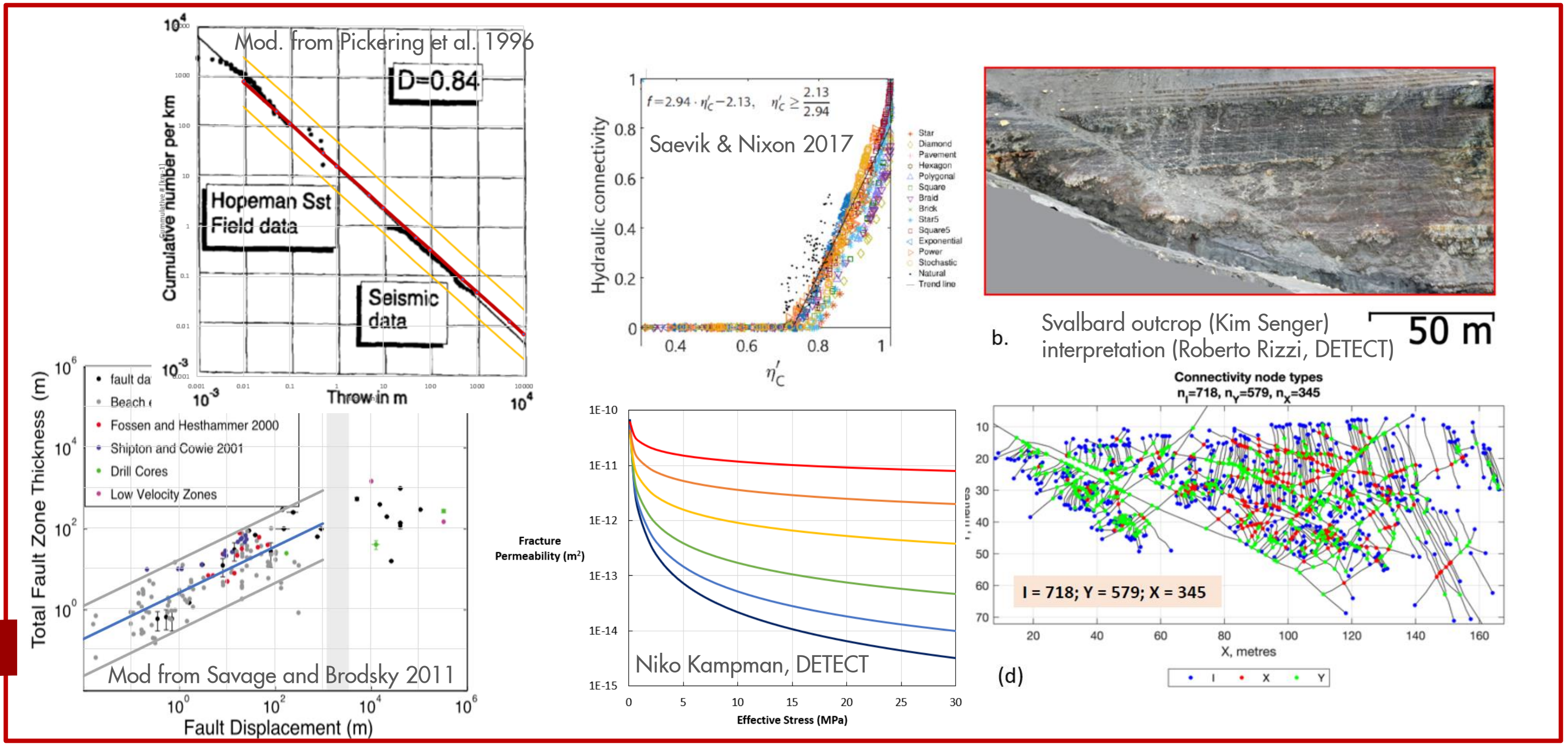
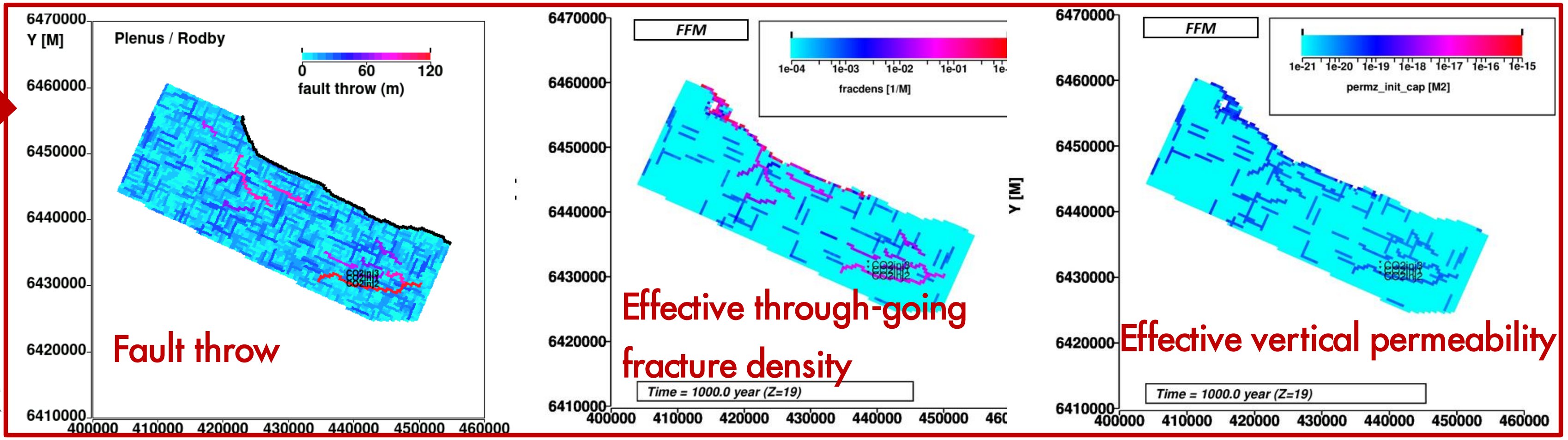
North Sea:
Fault & fracture input

- Seismically visible faults
  - Present at injection location…
- Subseismic faults
- Scaling relations
  - Fault length and density
  - Fracture damage zone width
  - Fracture density
  - Fracture connectivity
- Single-fracture permeability
- Realisations with high-perm fault damage zone extension into Chalk





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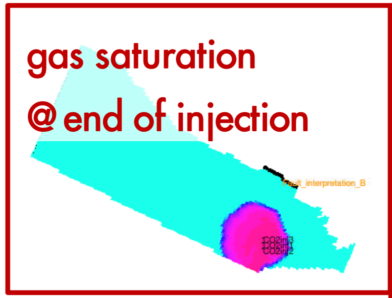
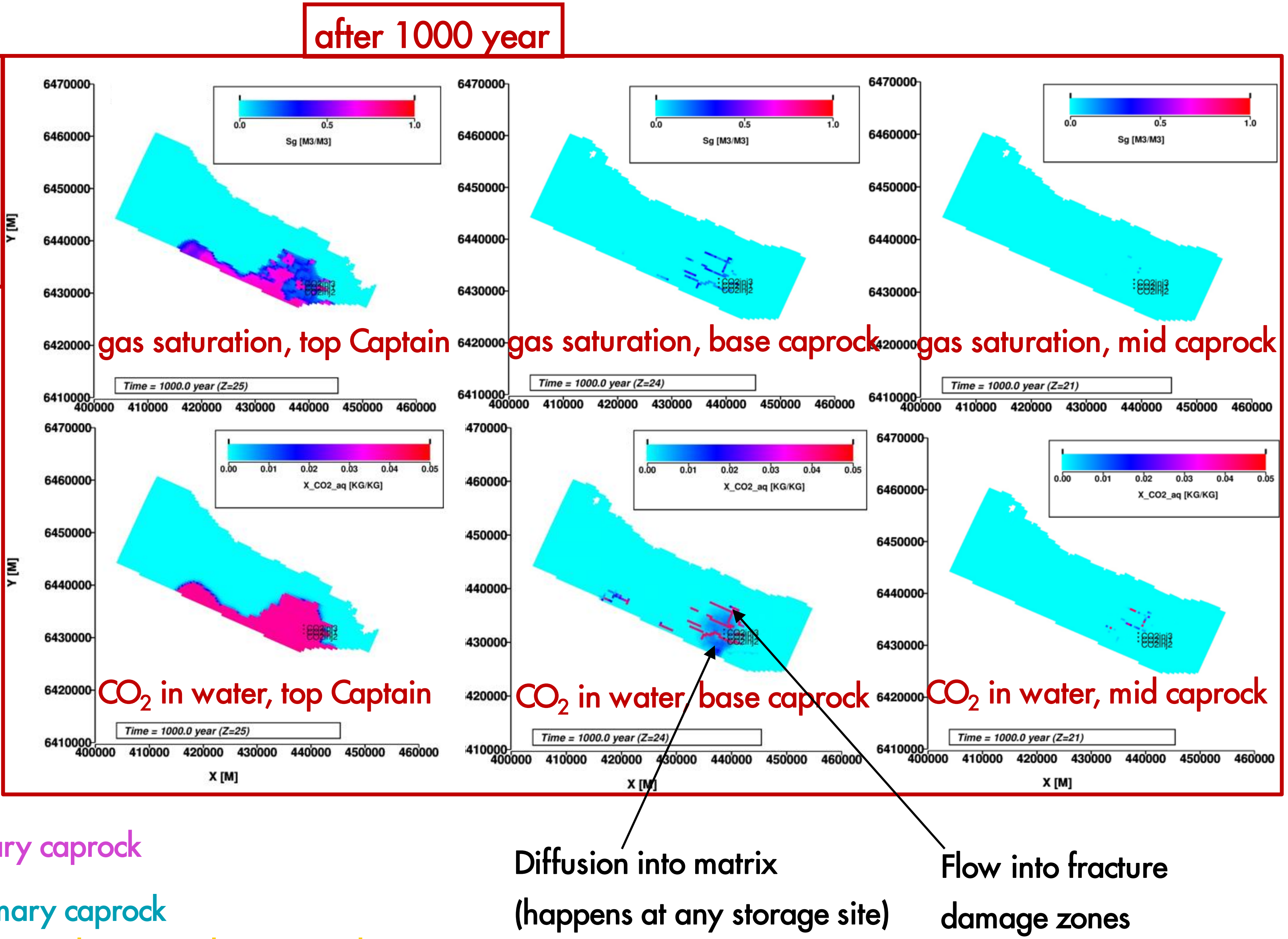
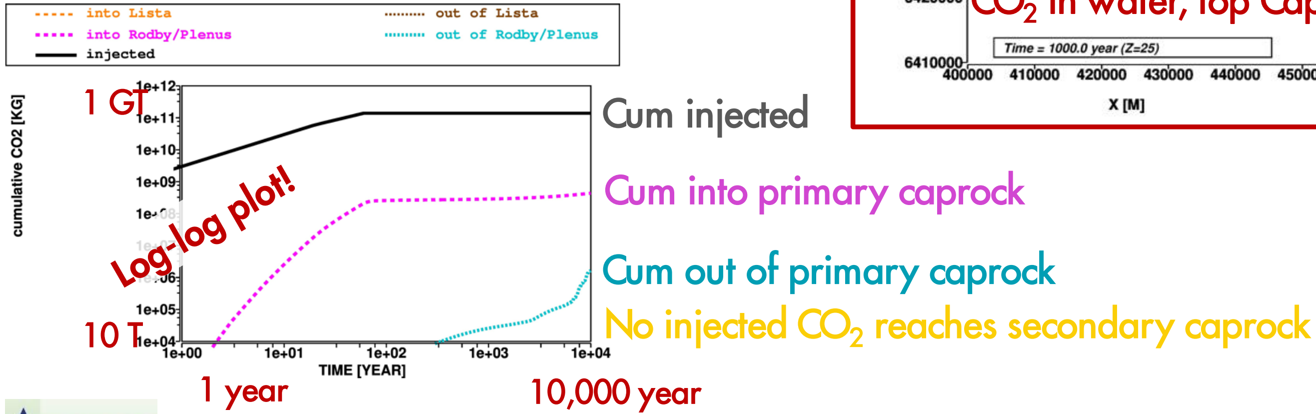
North Sea: Results - base case

- Only 0.001% of injected CO_2 reaches top primary caprock after 10,000 year
- No injected CO_2 reaches secondary caprock (top Storage Complex)







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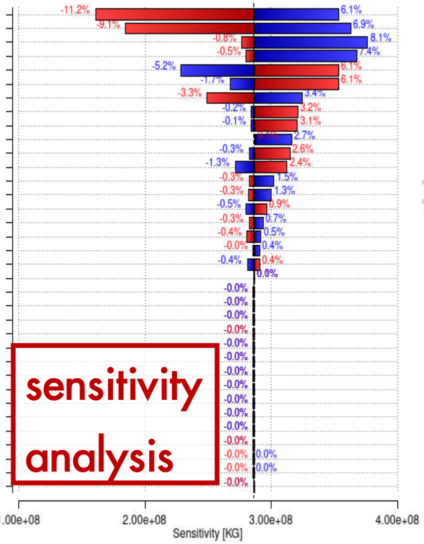
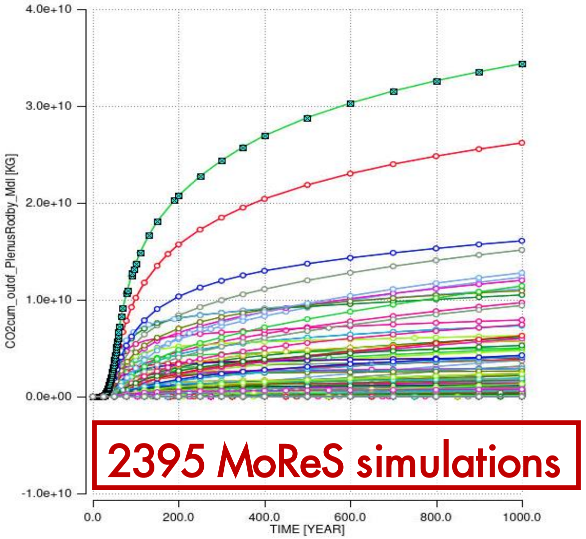
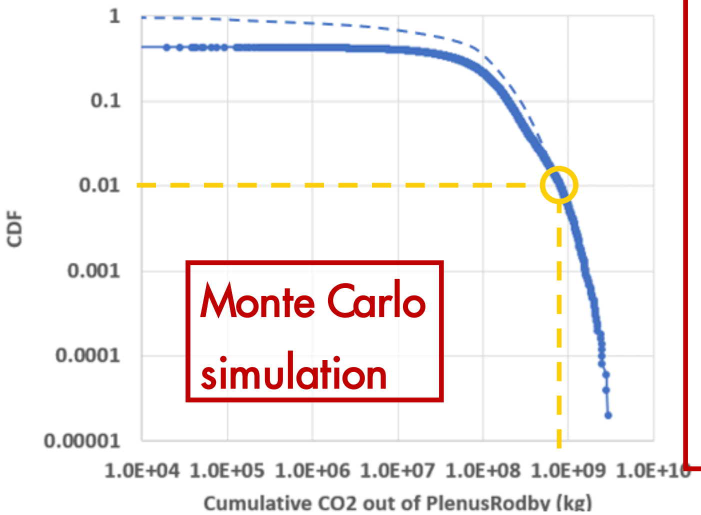
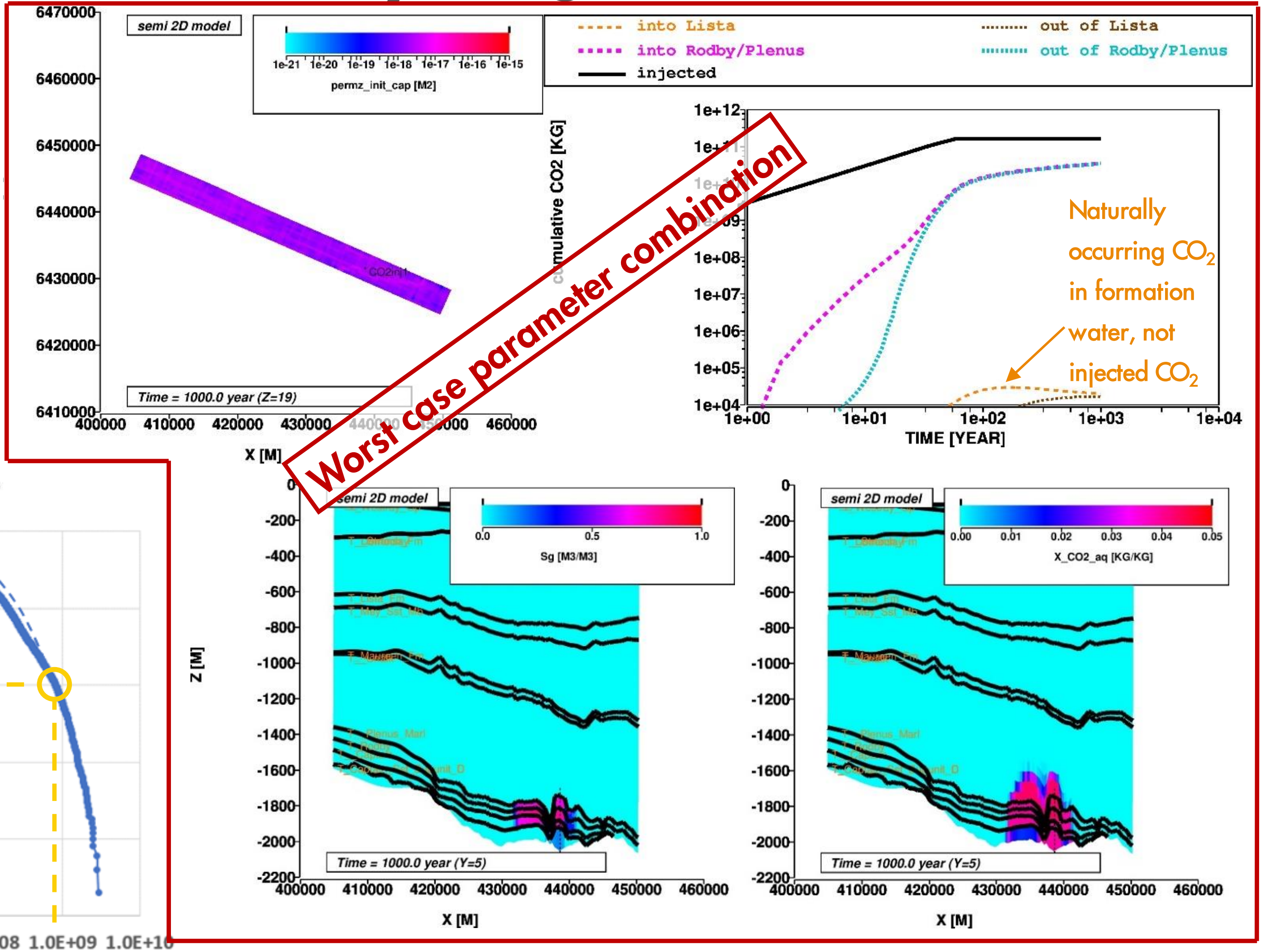
North Sea: Results - worst case & uncertainty range

- Migration across primary caprock unlikely
- No migration to top secondary caprock (Storage Complex boundary) in any realisation









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Conclusions

Green River

- DETECT workflow produces credible matches to measured data

North Sea (Captain Fairway)

- DETECT workflow predicts that fault-fracture systems pose only a low threat to containment
- No migration to top secondary seal (Storage Complex boundary) in any realisation
- Migration across primary caprock unlikely

What are effective geological barriers?

- Ductile caprock (low Young's modulus) → even if fracture networks present, they have low permeability
- Good quality secondary reservoir → even if primary caprock leaks, CO_2 dissolves near base 2^{nd} reservoir
- Good connection of storage reservoir to wider aquifer → main leakage driving force quickly dissipates

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Q&A

Jeroen Snippe, DETECT WP3 lead
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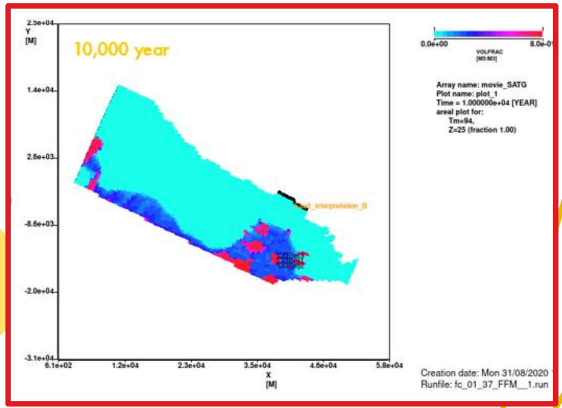
WP4



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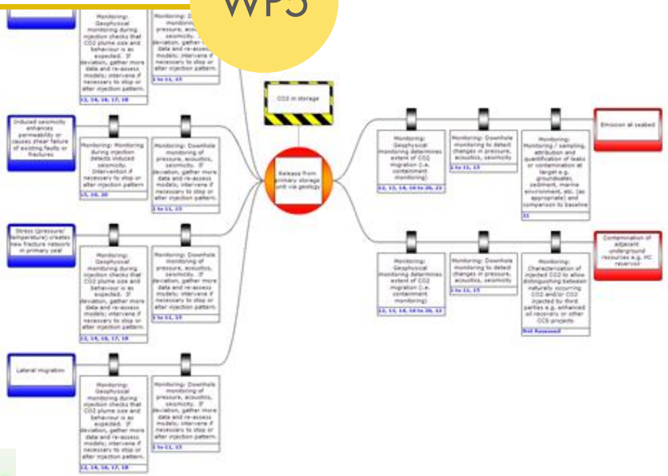

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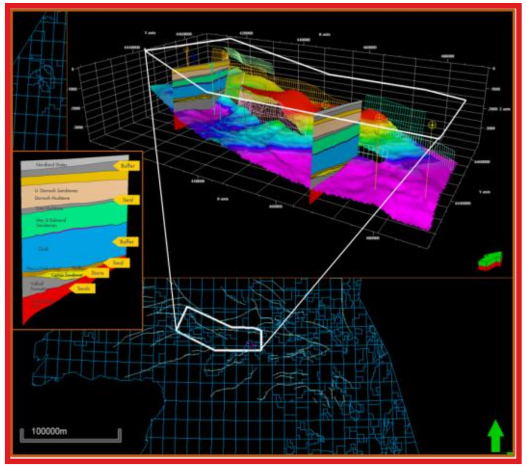

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Hydromechanical coupling using lab-derived stress-permeability relations and analytical stress-state model

Effective fracture + matrix vertical permeability, RLP, CPR for each cell in seal derived from numerical up-scaling

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Scaling relations based on meso/fine-scale modelling & analogues

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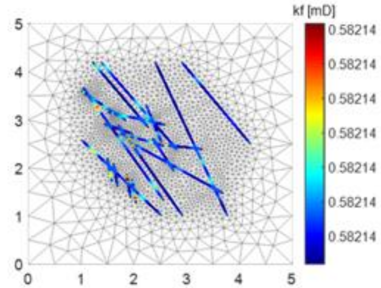
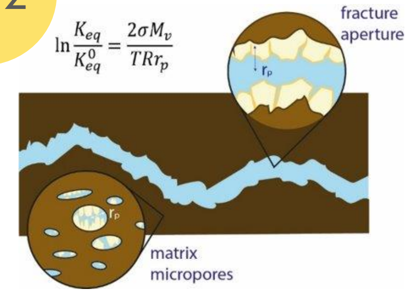
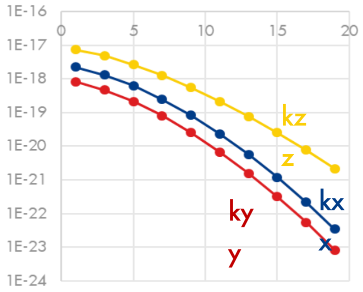


WP2

Experimentation and numerical modeling to characterise single fracture processes



Quantifying the impact of small-scale physics on CO_2-brine flow at fine-scale



Characterise fault-fracture networks using analogue derived scaling relations: fault throw-length-frequency

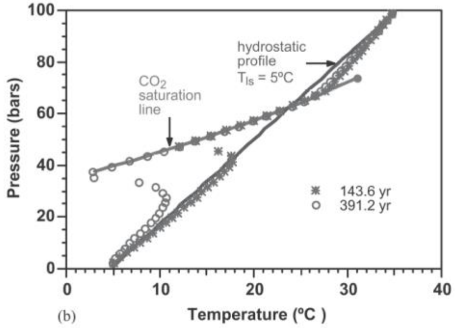
Accelerating CCS Technologies
The project has been subsidized through the ERANET Cofund ACT (Project no. 271497), the European Commission, the Research Council of Norway, the Rijksdienst voor Ondernemend Nederland, the Bundesministerium für Wirtschaft und Energie, and the Department for Business, Energy & Industrial Strategy, UK.

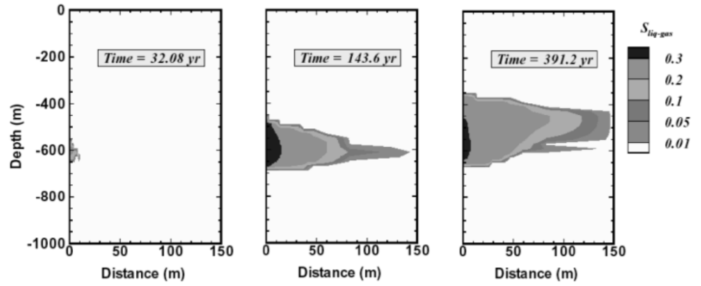
BACKUP

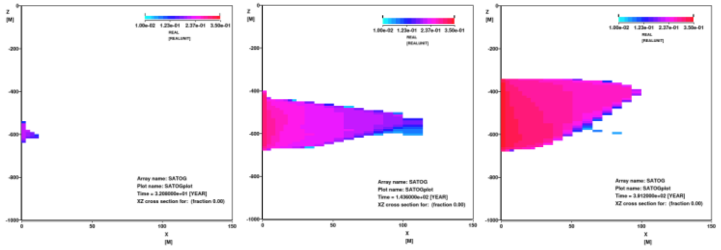
Insights: Isothermal is sufficient

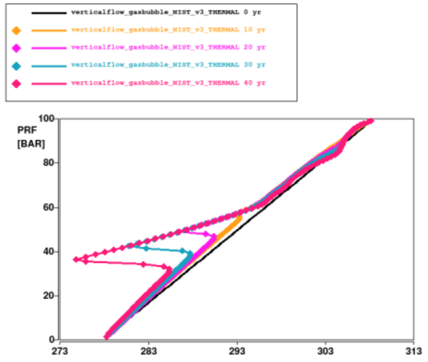
- Pruess 2004&2005 TOUGH2: severe cooling
- Results reproduced in MoReS
- Assumed frac perms/leak rates are extremely high
- Leak rates obtained from DETECT are much smaller
- Application to Green River frac perms/leak rates → <1°C after 10,000 yr
  - Confirmed by semi-analytic approach

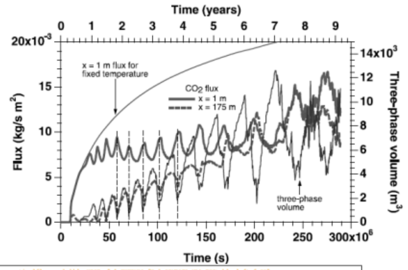
→ for realistic leak rates, isothermal is sufficient
  - As long as initial T-z profile is incorporated
  - Preferable because thermal mode adds complexity

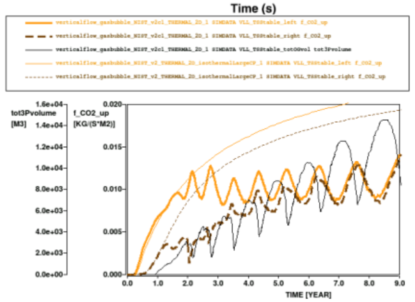


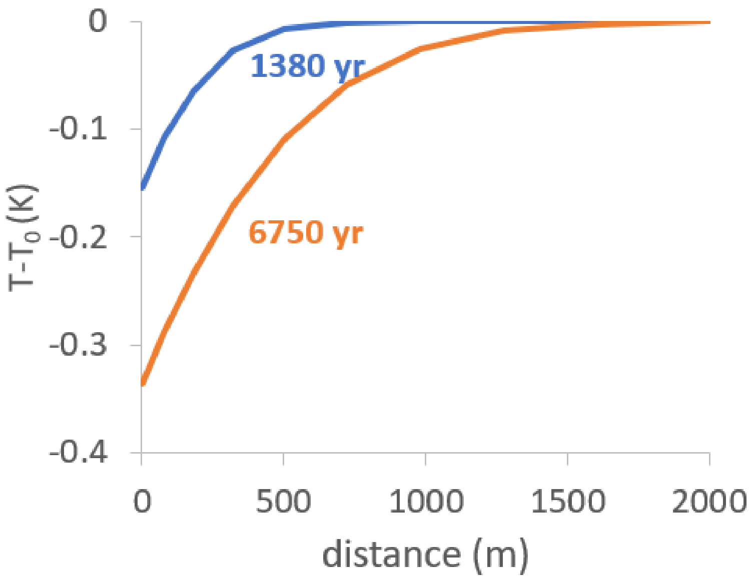












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DETECT application to projects

Process

- Qualitative bowtie. If credible risk → modelling, linking to available monitoring data where available

Minimum input data requirements for quantitative model

- 3D model of primary reservoir, seal, secondary reservoir; or for quick analysis (2D box model) a type log
- Seismic fault set (can be fault traces derived from attributes)
- Scaling relations for fault and fracture distributions
  - Those in the North Sea application are widely applicable, but constrain with local data if available
- Young's modulus of caprock
- P, T, stresses as function of depth
- CO_2 injection rates and locations
- Monitoring data if available

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