Influence of CO_2 detectability thresholds and remediation response times on surface leakage rate

Alv-Arne Grimstad, Jean-Francois Vuillaume,

SINTEF Petroleum Research

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Outline

- Geological storage of CO_2
- Safety – monitoring and remediation strategy
- Modelling of leakage scenarios
- Results and discussion

Geological storage of CO_2

- Large-scale option to reduce man-made CO_2 emissions
- Estimates indicate that storage capacity is sufficient if saline aquifers can be used
- Selection of storage sites can be expected to have minimal leakage (=migration out of the storage complex) as one of the main selection criteria
- Due to the complexity of real-world geology (and other factors such), it will probably not be possible to predict with certainty how a given storage site will behave
- The only thing we can be sure of is that there will be surprises

How to build safety for CO_2 storage

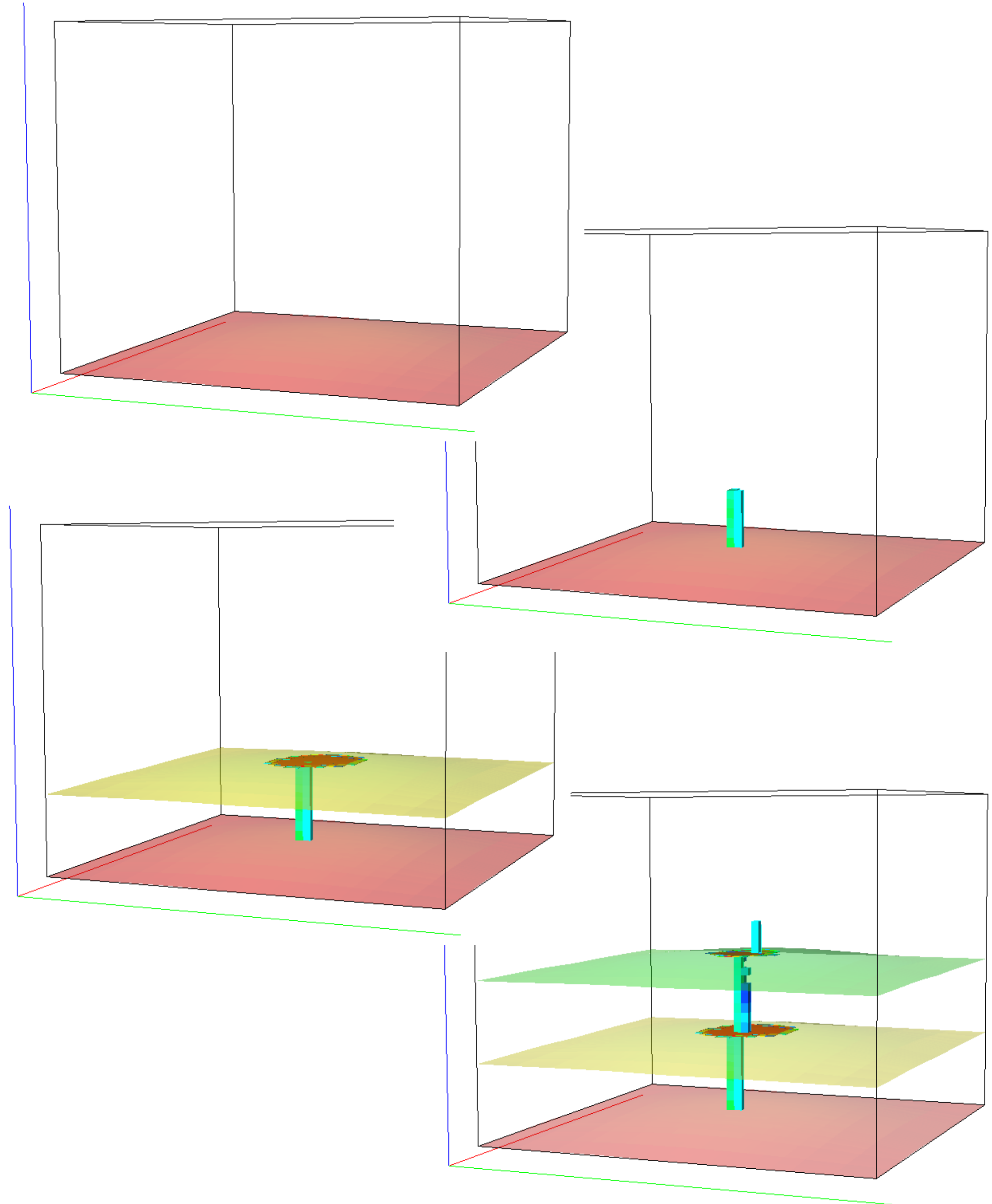
- The monitoring and remediation strategy:
  - Collect optimal amount of information and build models for long-term prediction
  - Collect monitoring data for verification of storage behaviour
  - The monitoring programme needs to be sufficiently accurate to be able to detect unwanted behaviour (penetration through capillary seal)
  - Effective remediation options must exist and it must be possible to employ these early enough to prevent or minimize leakage to surface
- RISCS EU FP7 project: Generate knowledge about impacts on humans and ecosystems of CO_2 leaking from geological storage to the surface
- This work: How will monitoring sensitivity and remediation response time influence leakage?

Scope of study

- Focus on potential CO_2 migration in geological layers above the storage complex (=main storage unit and any shallower units with assumed good seal)
  - Migration in storage complex is not modelled
  - Mechanism for leakage out of storage complex is unspecified
- Assume that regular monitoring surveys are performed and that efficient remediation options exist for the storage site
- Question to be answered: If sufficiently large accumulations of CO_2 above the storage complex can be detected and the source remedied, how large can the near-surface flux of CO_2 be?

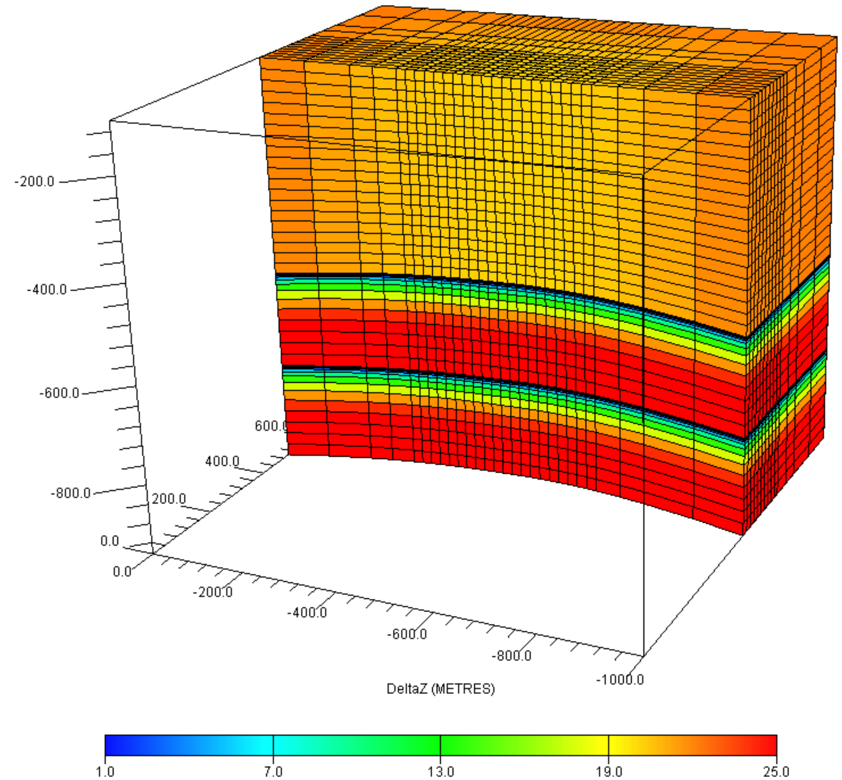
Assumptions

- Storage in aquifer at 1 000 m depth
- A weak point exists in the seal, and injected CO_2 reach the weak point
- Above the seal, the CO_2 migrates upwards through the overlying sediments
- Secondary barriers (semipermeable layers) exist above the storage complex
- CO_2 will form accumulations underneath the secondary barriers
- Accumulations above a given size will be detected by geophysical monitoring methods
- When detected, the leakage from the storage site can be stopped



Simple geomodel

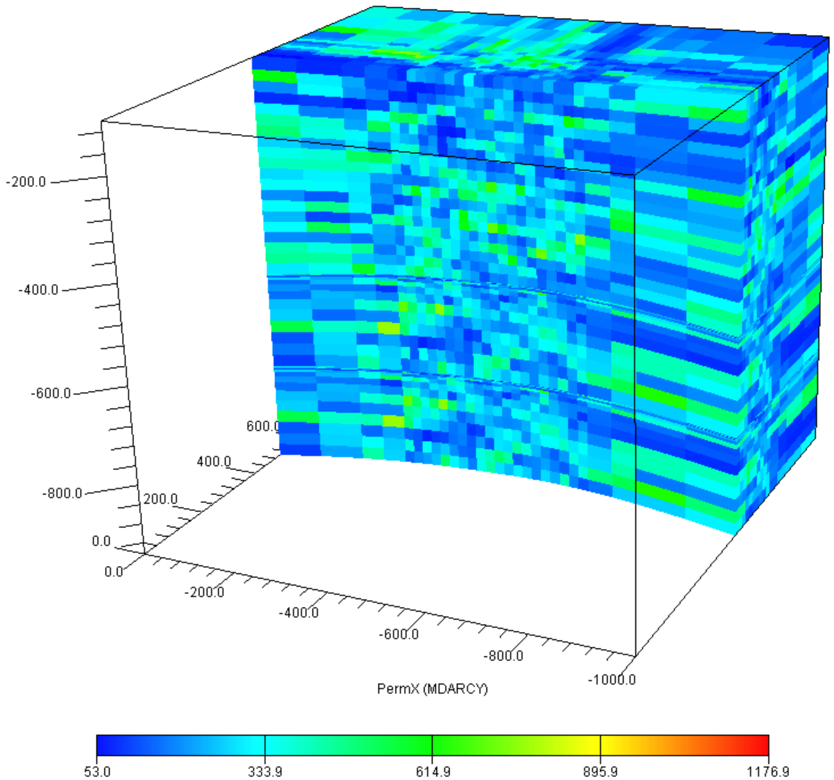
- Lower boundary: Top of cap rock at 950 m depth
- Upper boundary: Unspecified strata at 100 m depth
- Low-permeable layers at 700 m and 500 m depth
- Secondary barriers have low vertical transmissibility except for holes
- Medium to good fluid flow properties between barriers
- Slight anticlinal topography
- Closed top and bottom boundaries
- Constant pressure maintained at lateral boundaries

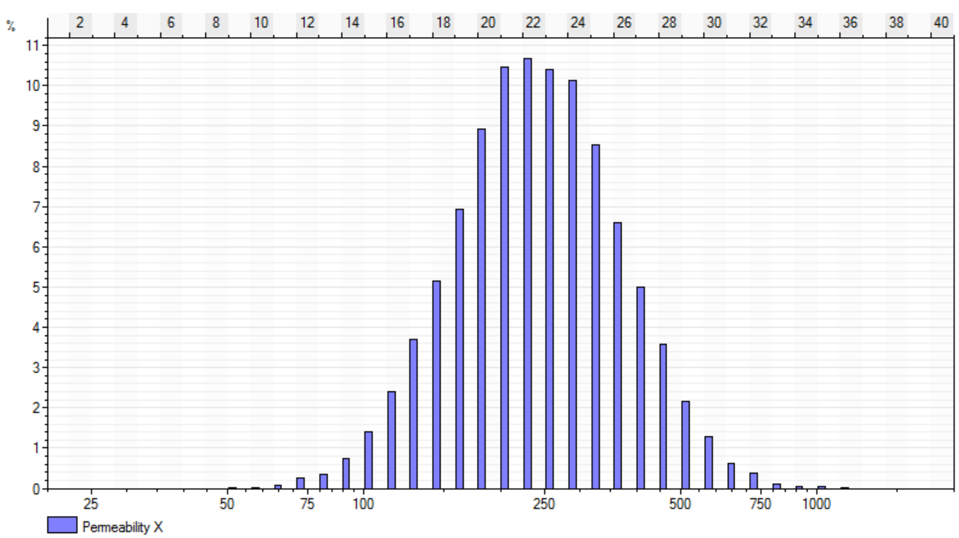


- 28x28x50 cell simulation grid
- Layer thickness from 1 to 25 m
- Lateral size from 20 to 100 m

Petrophysical properties

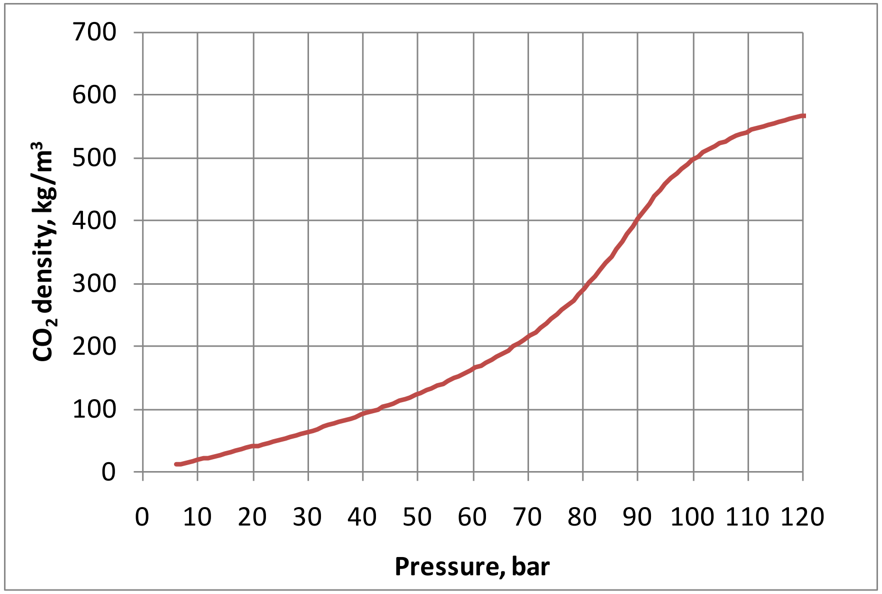
- Random porosity in interval 0.2 – 0.3
- Log-normal permeability with mean k_h~250 mD and correlated to porosity
- k_v/k_h anisotropy 0.6

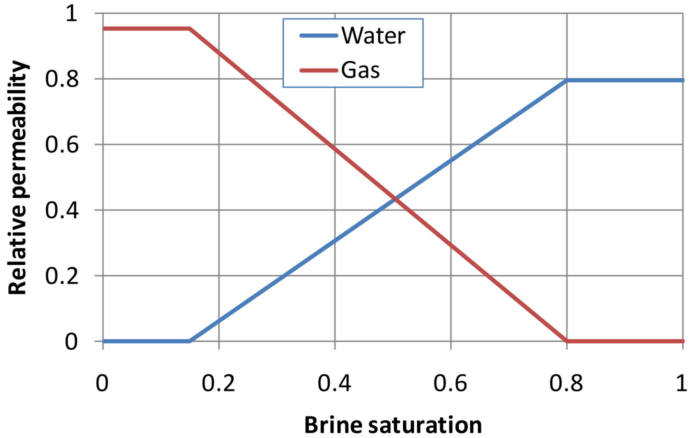


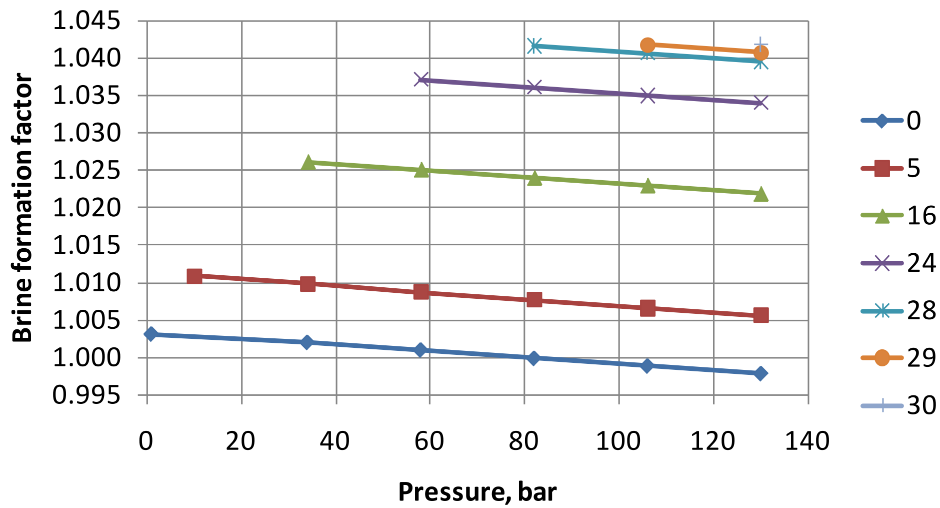


Fluid properties

- Assume migrating CO_2 to be in thermal equilibrium with surrounding rock
  - Use Eclipse black-oil version with custom-made pVT tables for brine and CO_2
- Straight-line relative permeability curves with end-points at 0.15 and 0.8

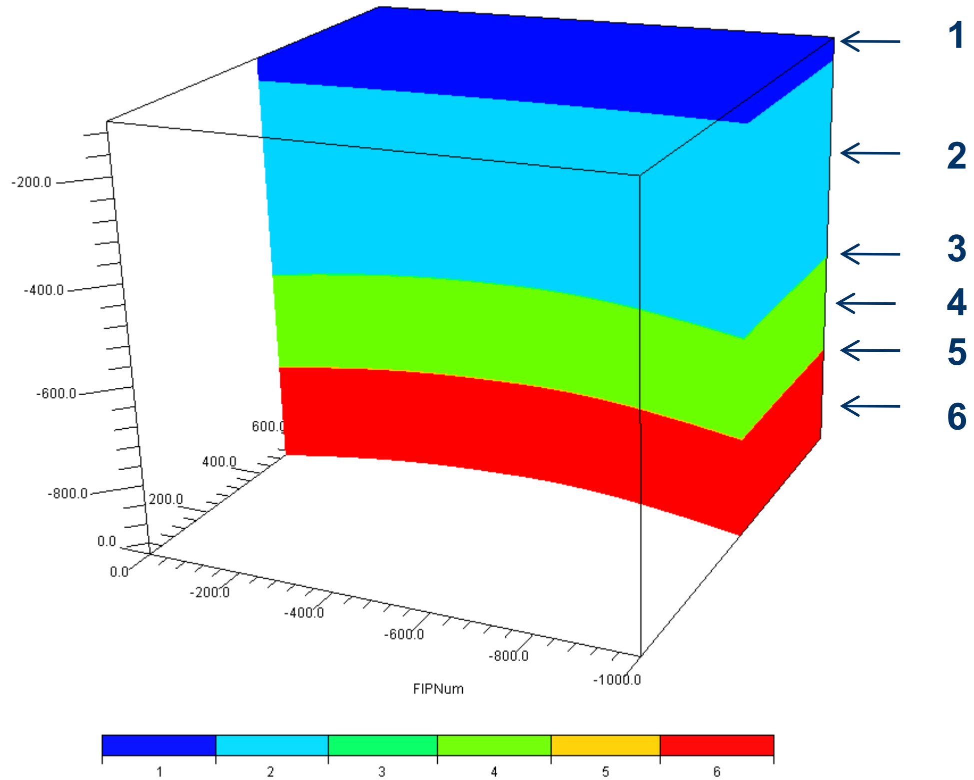






Tracking CO_2 migration

- Divide model grid into Fluid-In-Place regions to track distribution of CO_2



Limits of monitoring

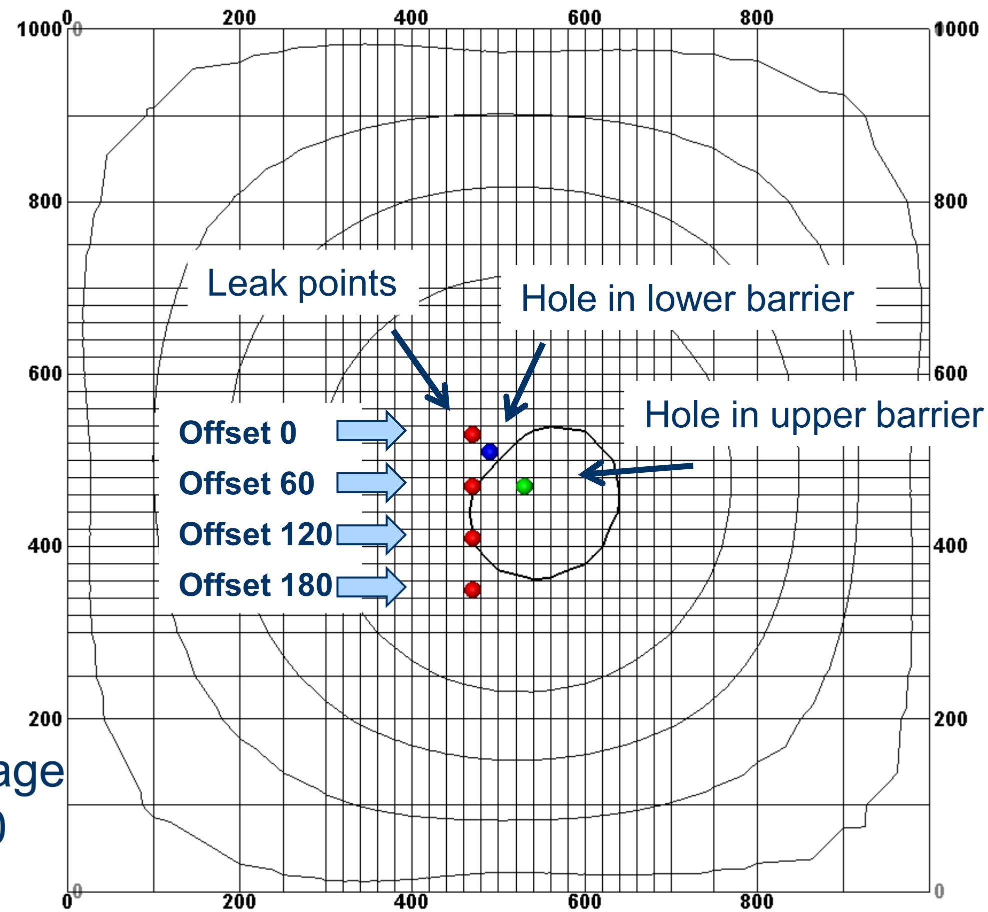
- Need to be able to detect if CO_2 from storage site is present above the seal.
- How small accumulations can be detected?
- Depends on geology and on separation from main storage
- Estimate from Utsira-like geology:
  - An accumulation at a distance above the main storage volume larger than the resolution in the seismic (couple of wave-lengths) should be detectable by seismic monitoring if it is larger than 4 000 Rm^3
  - At larger separation the threshold should be lower.
  - Complicated geology will make unambiguous detection more difficult
  - Will use 4 000 Rm^3 as the base case in this work, and run sensitivity simulations for 2 000 and 8 000 Rm^3

Delay time for successful remediation

- All remediation will have an associated delay made up of
  - Time before any accumulation above storage complex is large enough to be detected
  - Time from threshold is exceeded until next monitoring survey
  - Time for necessary analysis of monitoring data
  - Time to deploy chosen method of remediation, e.g.
    - Stop of injection
    - Diversion of CO_2 away from weak point in seal (clever use of injection/production wells)
    - Extraction of CO_2 from region near leakage point and re-injection into backup storage site
- In this study, assume one year delay between exceeding threshold and successful remediation, and run sensitivity simulations with 0.5 and 2 years delay

Base cases

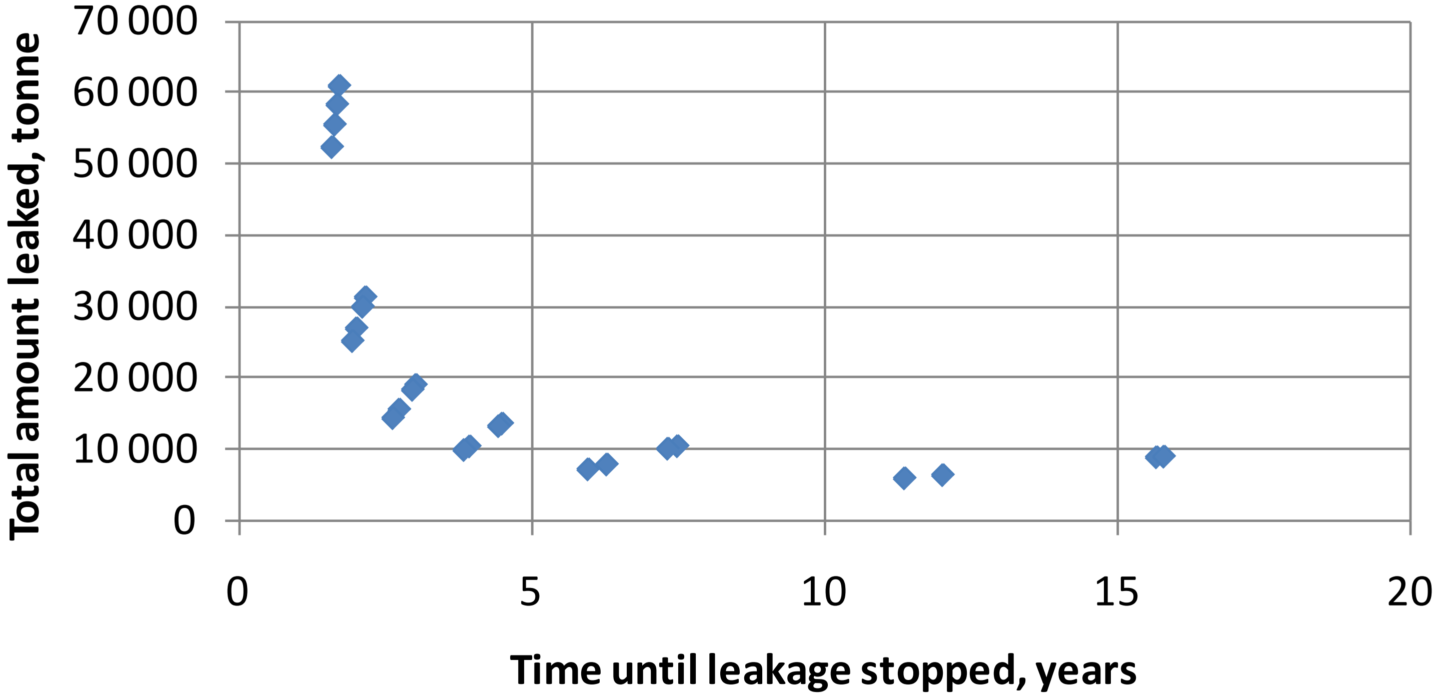
- Detectability threshold 4 000 Rm^3, remediation delay 1 year.
- Vary lateral displacement of weak point in seal relative to "holes" in secondary barriers
- Vary influx of CO_2 at bottom of model
  - 1.87 to 580 tonne CO_2/day maximum rate (680 to 210 000 tonne/year)
  - (Examples of estimated total leakage at natural analogues: 100 to 1 500 tonne/day)
  - Influx increase linearly from zero to maximum over a 5 year period



Top-down view of grid and iso-depth contour lines for one of the secondary barriers

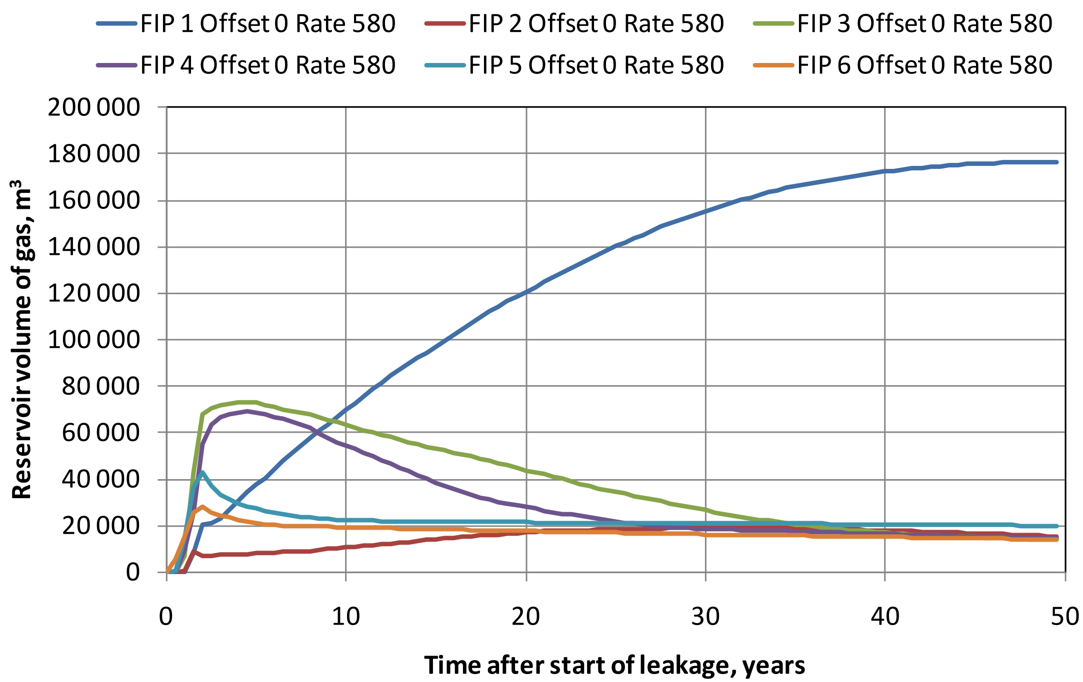
Results from base cases

- Longer time until detection for smaller leakage rates, but total leakage also smaller (less CO_2 "in transit" between leakage point and accumulation)
- Leakage to "surface" (upper part of model, 100 m below surface) only for two largest rates

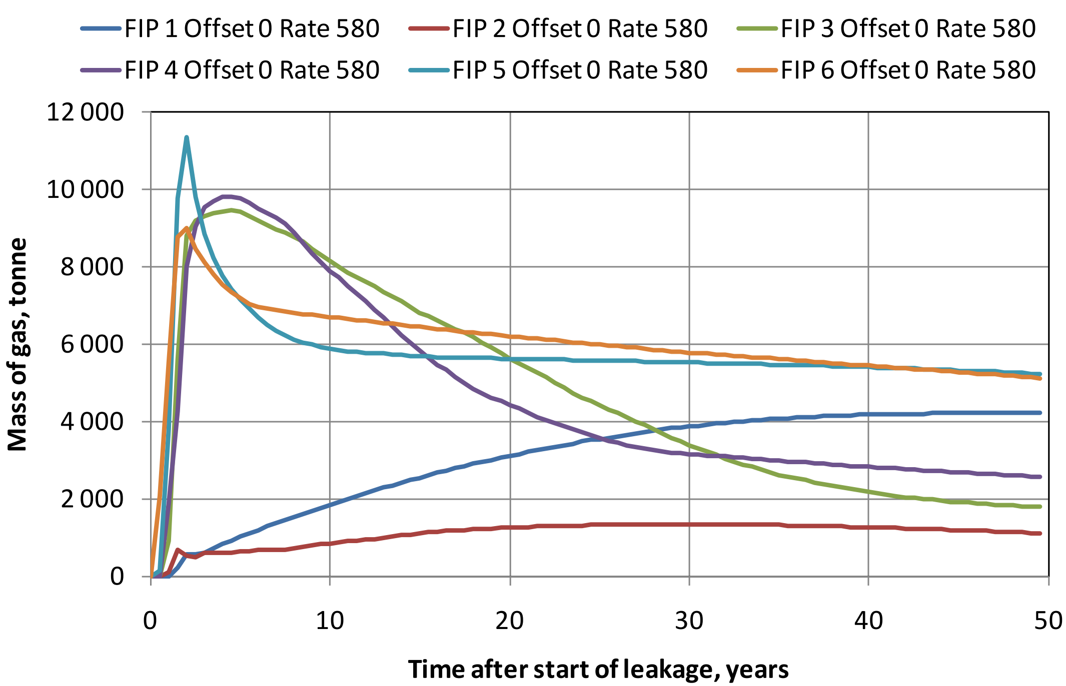


Distribution of leaked CO_2

- Case with largest leak rate
- Exceed threshold after 254 days (0.7 years).
- Stopped after 1.7 years
- Most of the leaked CO_2 stays in the lower parts of the model (FIP3 to FIP6, below 500 m)



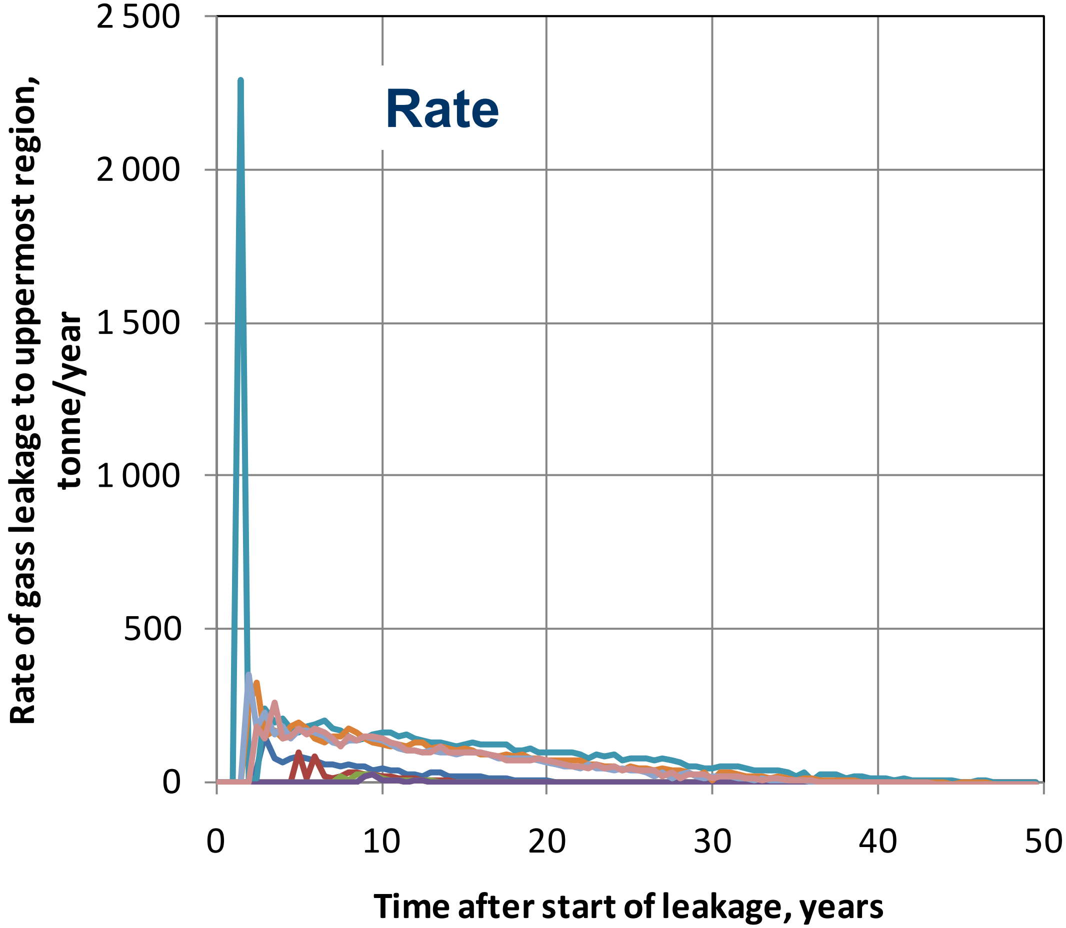
Volume

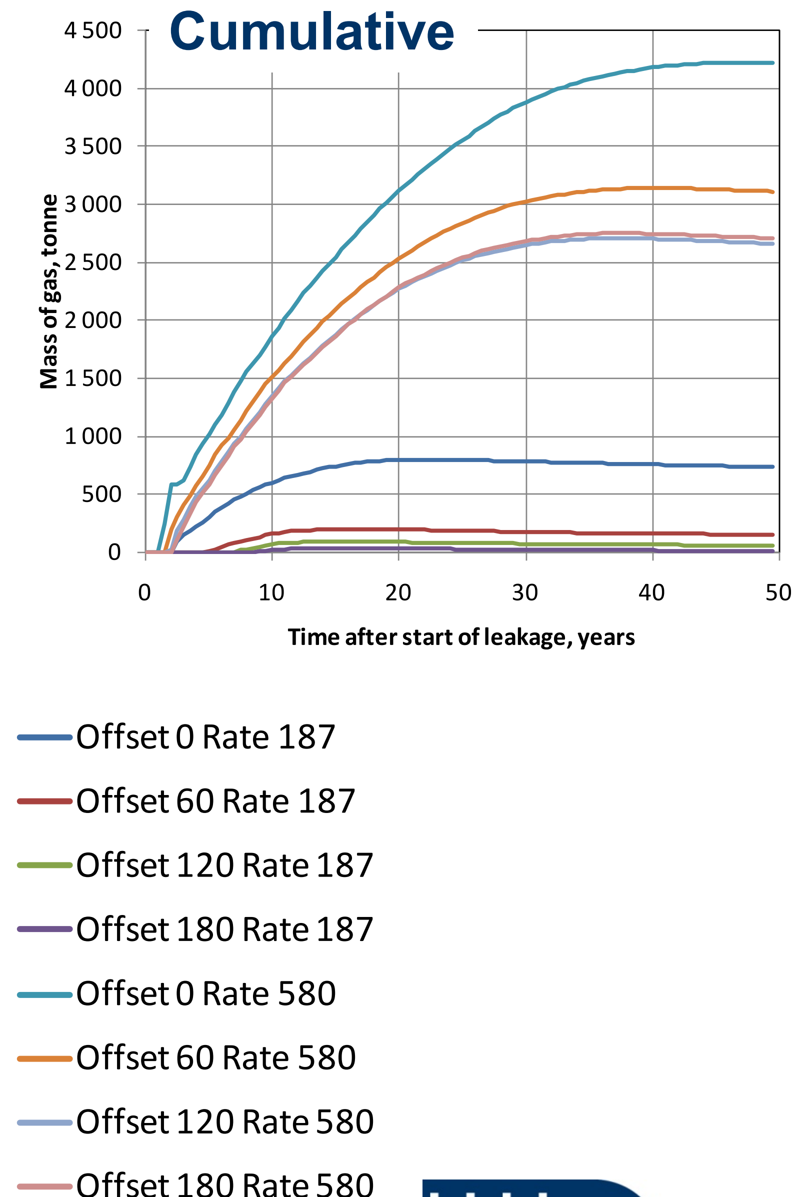


Mass

Amount of CO_2 reaching shallowest part of model

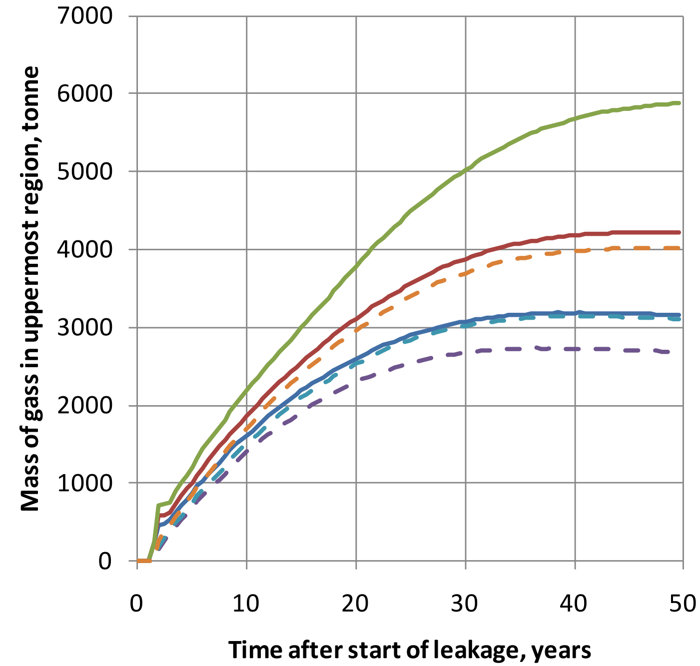
- Mass of CO_2 reaching upper part of model

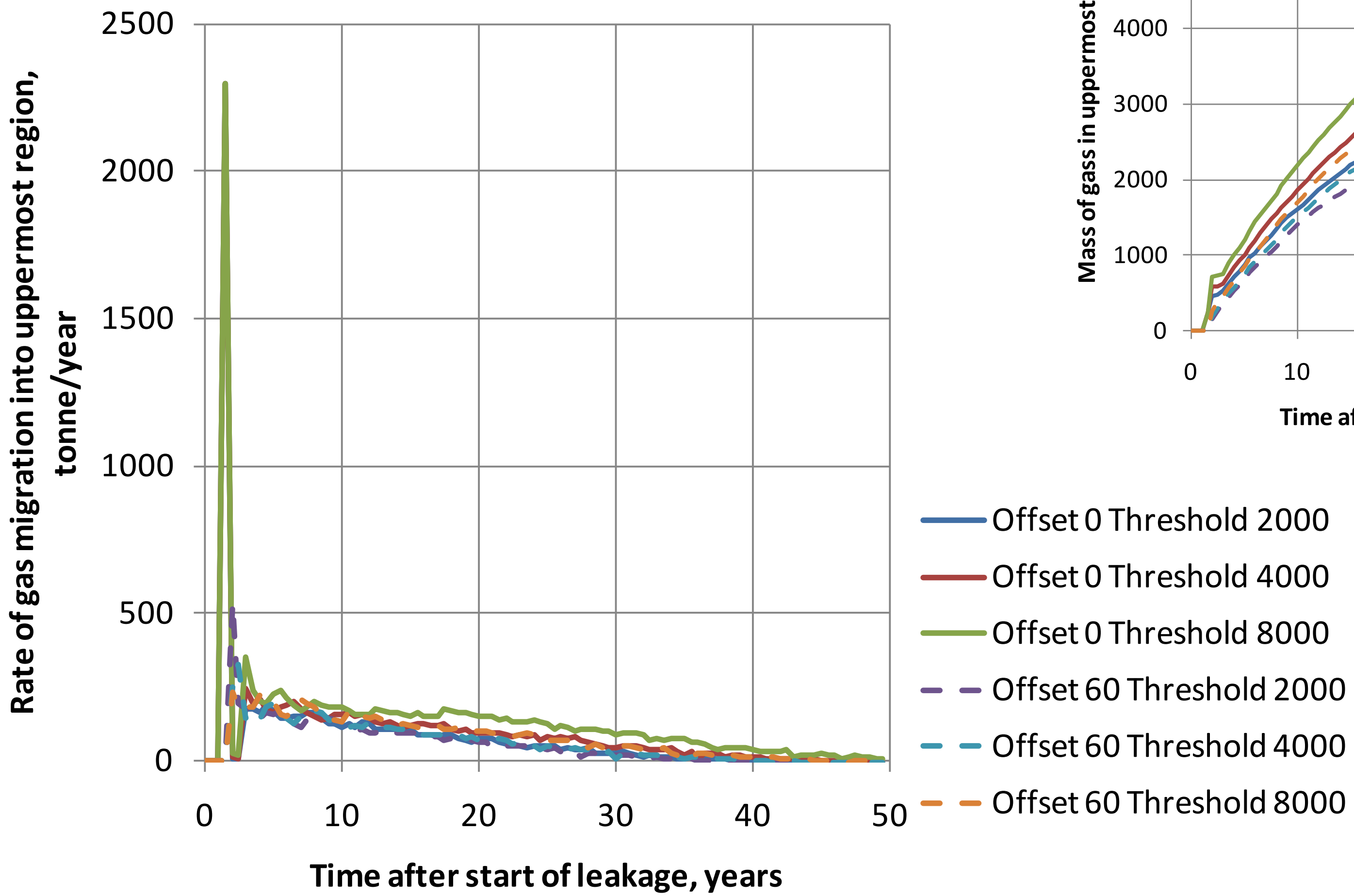




Effect of changing detectability threshold and remediation delay

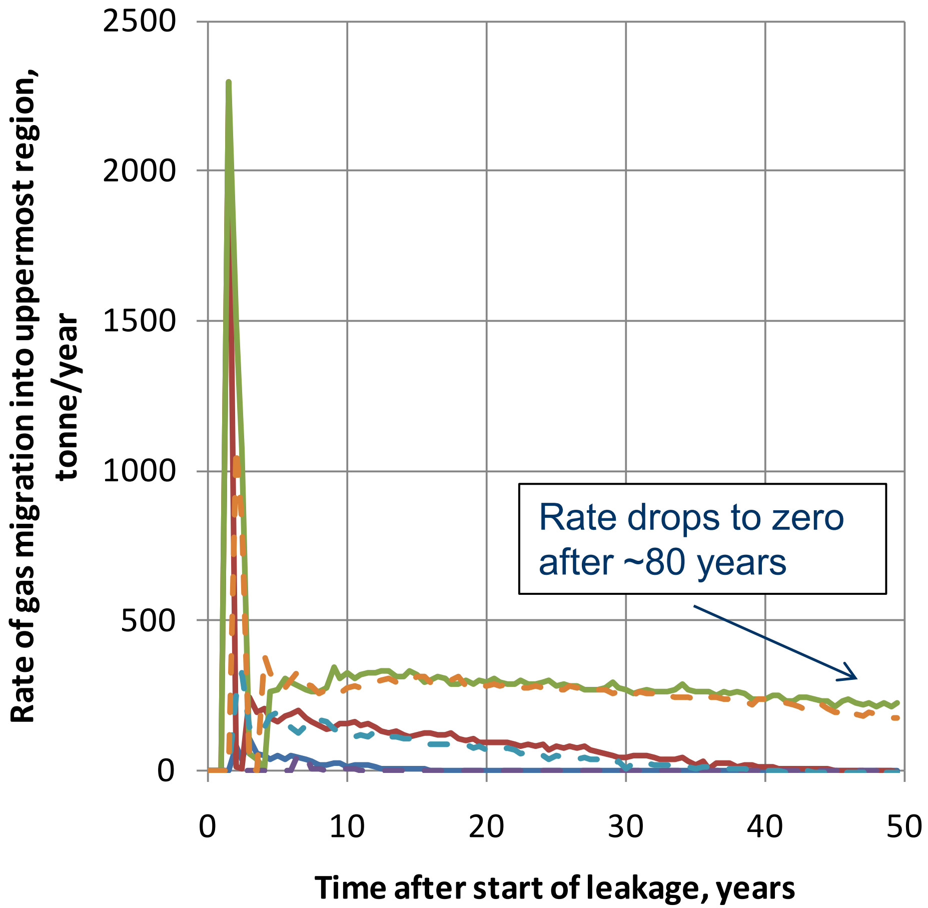
- Threshold: double or half of base value of 4 000 Rm^3
- Moderate changes

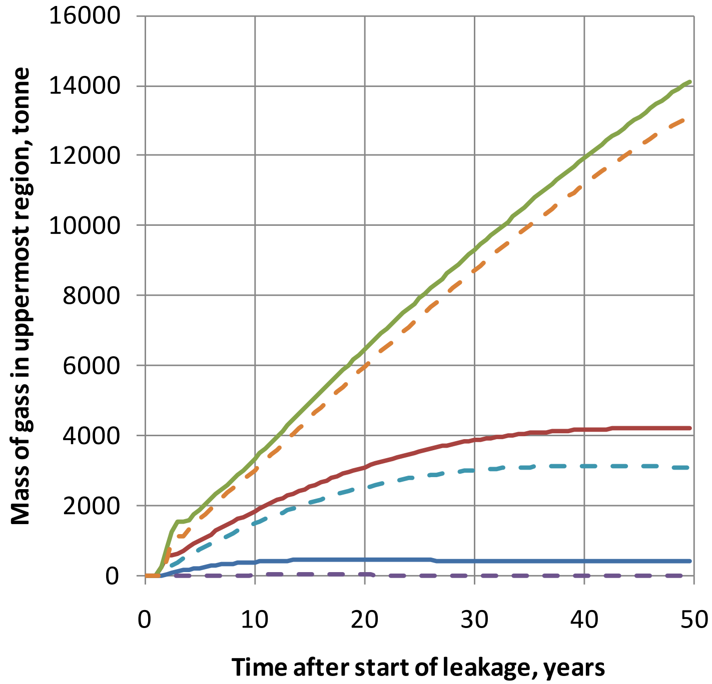




Changing threshold and delay, cont.

- Delay: double or half of base value of 1 year
- Doubling delay has larger effect than doubling threshold





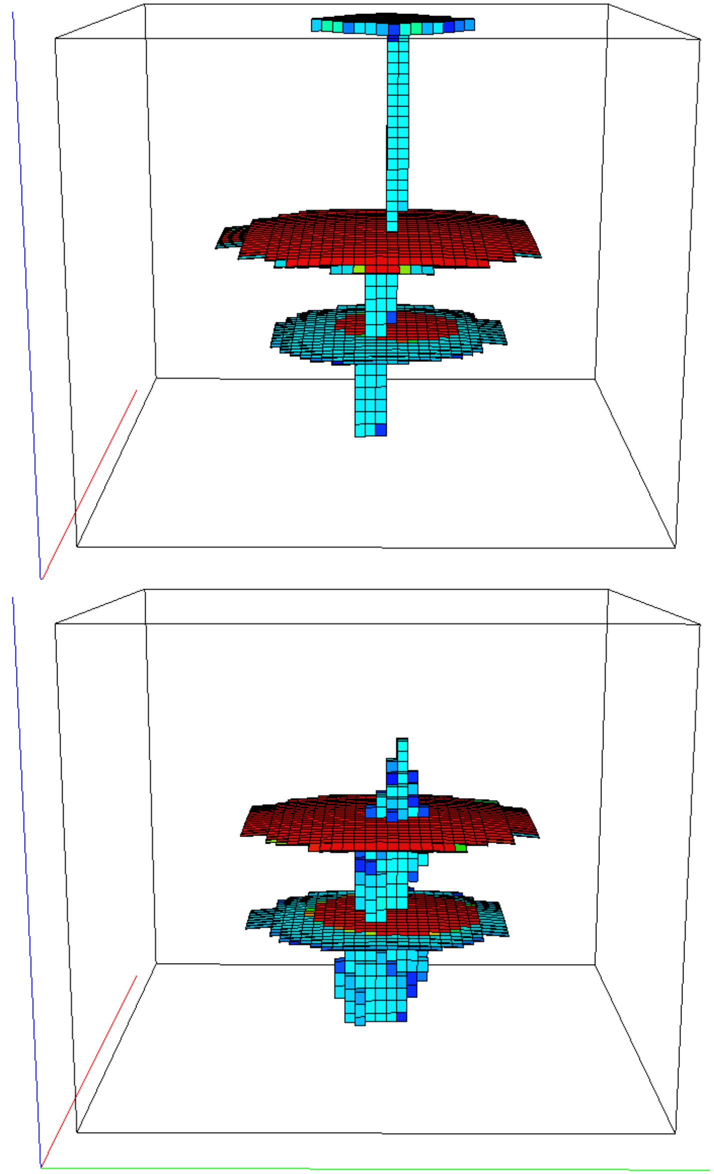
How does these results compare to natural analogues?

- Horseshoe lake tree kill area (approx. 200 m by 400 m):
  - Estimated release 95 tonne CO_2/day
  - Fluxes commonly above 500 g/m^2/day
  - Background flux in region 25 g/m^2/day

- Our results distributed over same area:
  - 5 tonne CO_2/day in first burst
  - 0.5–0.8 tonne CO_2/day sustained over some decades
  - >50 g/m^2/day areal average in burst, 5 g/m^2/day sustained

How about geological heterogeneity?

- Add random low vertical transmissibility (factor 0.01)
- Will cause more lateral spread of CO_2
- CO_2 contacts more brine
- Less CO_2 enters shallowest part of model, even if leak takes longer to be detected and remedied



Summary

- Present methodology for investigation of interplay between monitoring, leakage and remediation
- Attempt to calculate realistic flux of CO_2 at surface resulting from potential leakage from storage sites
- Assume storage site is well managed:
  - Secondary barriers exist
  - Site is regularly monitored
  - Remediation options exist

  (Site is regularly monitored; Remediation options exist) } No "inject and forget"
- Resulting maximum CO_2 flux on the order of natural background soil gas flux, but this depends on mechanisms for transport in the shallowest part of the subsurface (not specified in this study)

Acknowledgements

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