Utilizing compressive sensing techniques to reduce geophysical monitoring costs at CO_2 injection sites

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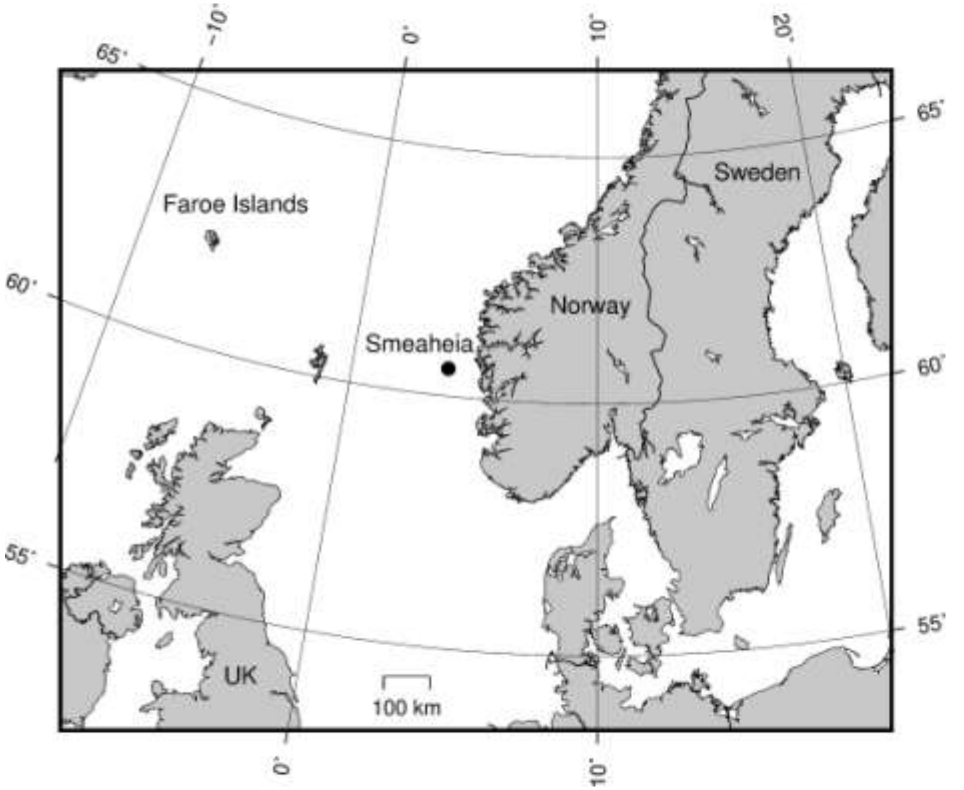
Aims

- Investigate sparse geophysical monitoring techniques that allow assessments of site conformance to be undertaken
- Make use of compressive sensing algorithms to enhance sparse seismic data
- Use analytical solutions to determine likely range of CO_2 migration and set bounds for monitoring
- Assess how plume modelling can guide the use of compressive sensing in data acquisition and interpretation
- Use models of the Smeaheia storage site to test these approaches

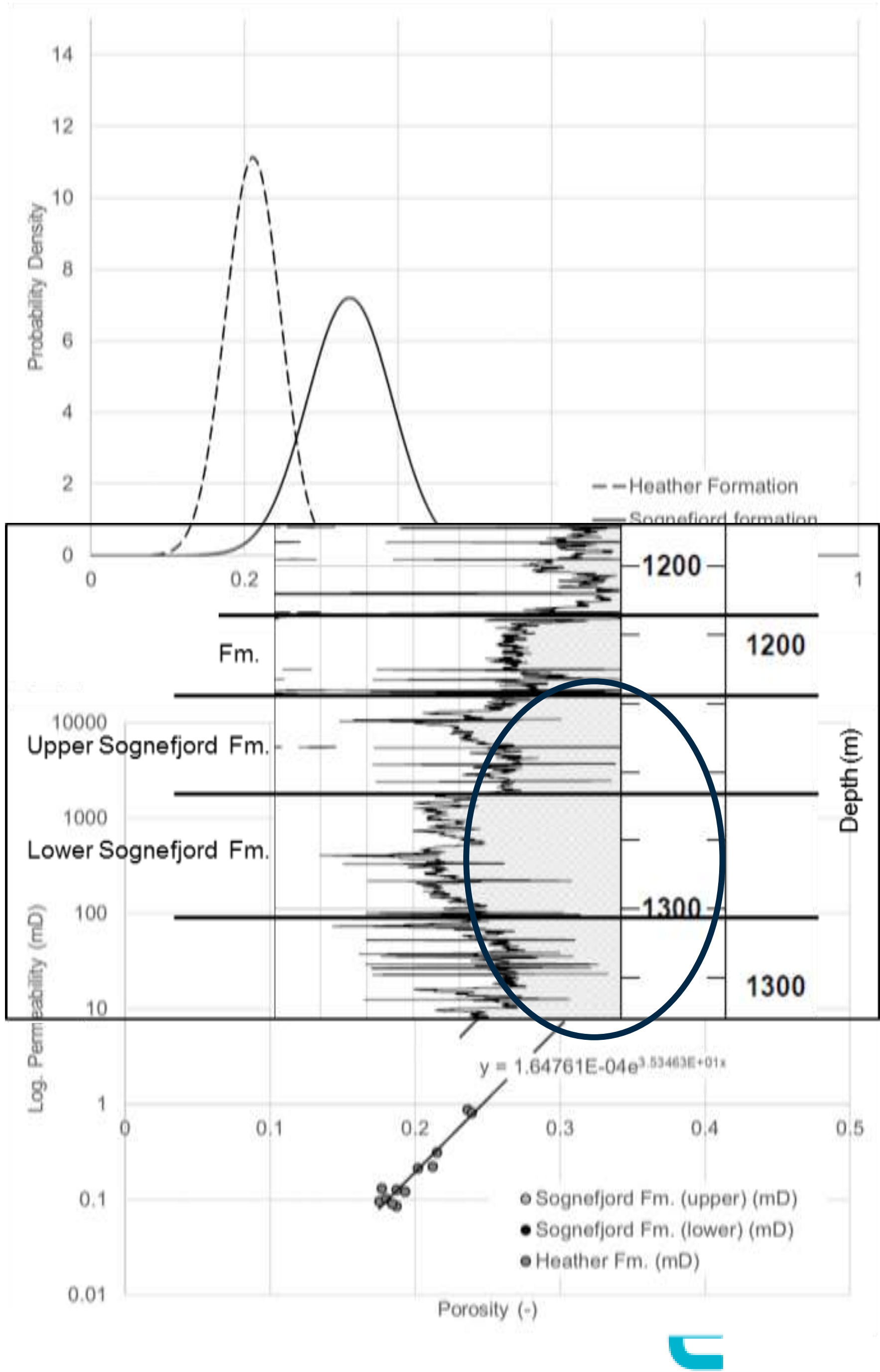
Why Smeaheia?

- Potential storage site for Northern Lights full-chain CCS project
- Expected capacity of > 100 million tonnes
- Excellent scale-up potential
- Offshore Norway, adjacent to Troll Field, so local knowledge and infastructure
- Significant data availability and international interest in site



Smeaheia

- Potential storage in Jurassic Sognefjord Formation
- 1200m – 1500 m depth with high porosity and permeability
- Gamma ray log from Norwegian well 32/4-1 showing the Sognefjord and overlying Heather Formations
- Porosity distributions and permeability relationship from core plug measurements



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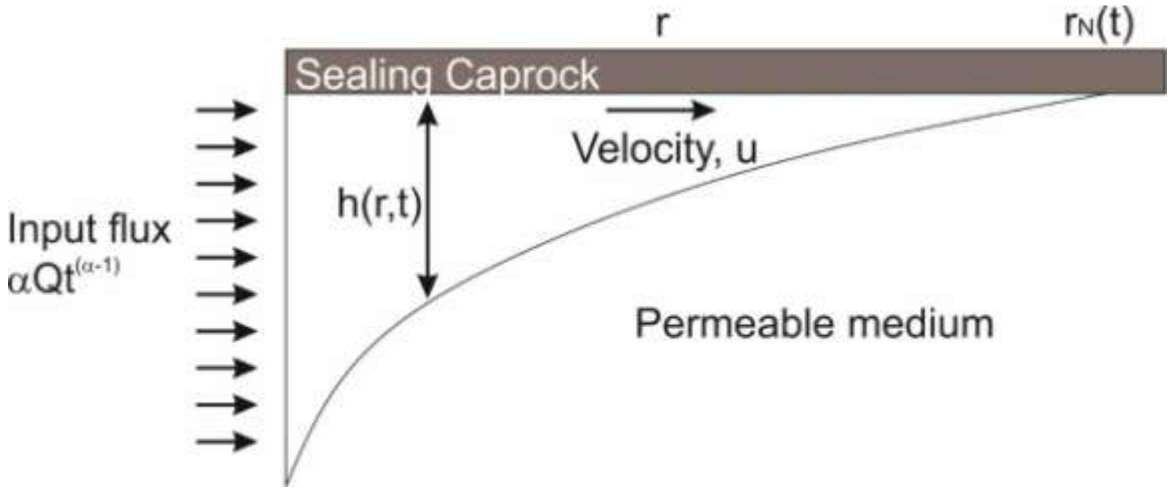
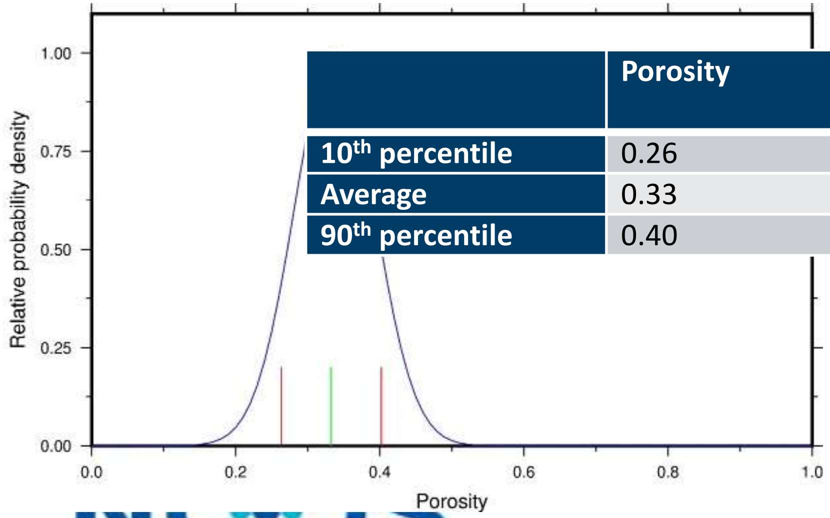
Analytical solutions

- Represent a buoyant fluid spreading radially beneath a sealing caprock
- The solutions require several assumptions
  - no capillary pressure, no relative permeability effects, no viscosity differences
- Compute the radius, r(t), and height, h(r,t), of a spreading CO2 layer as a function of time, t
- A release with a constant flux, Q

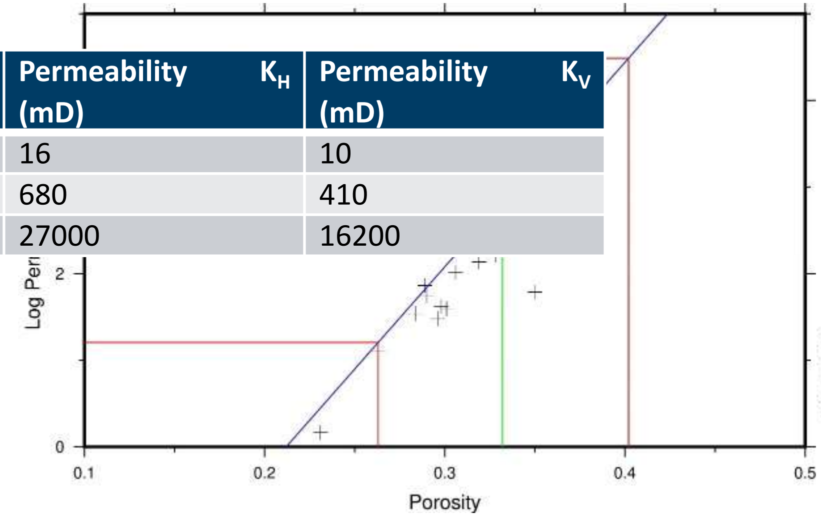


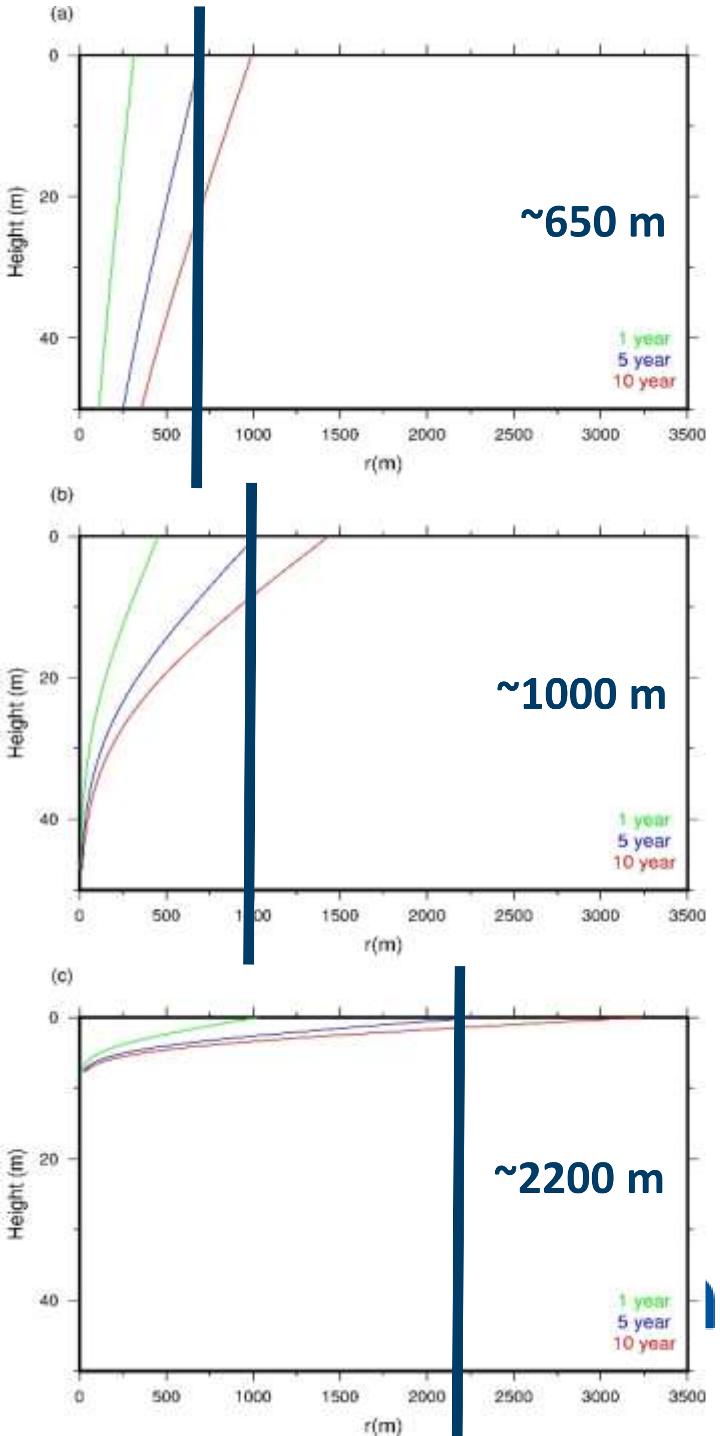
Assessing end members

- Analytical solutions and data from well/core plug analysis are used to define the extent of the monitoring program

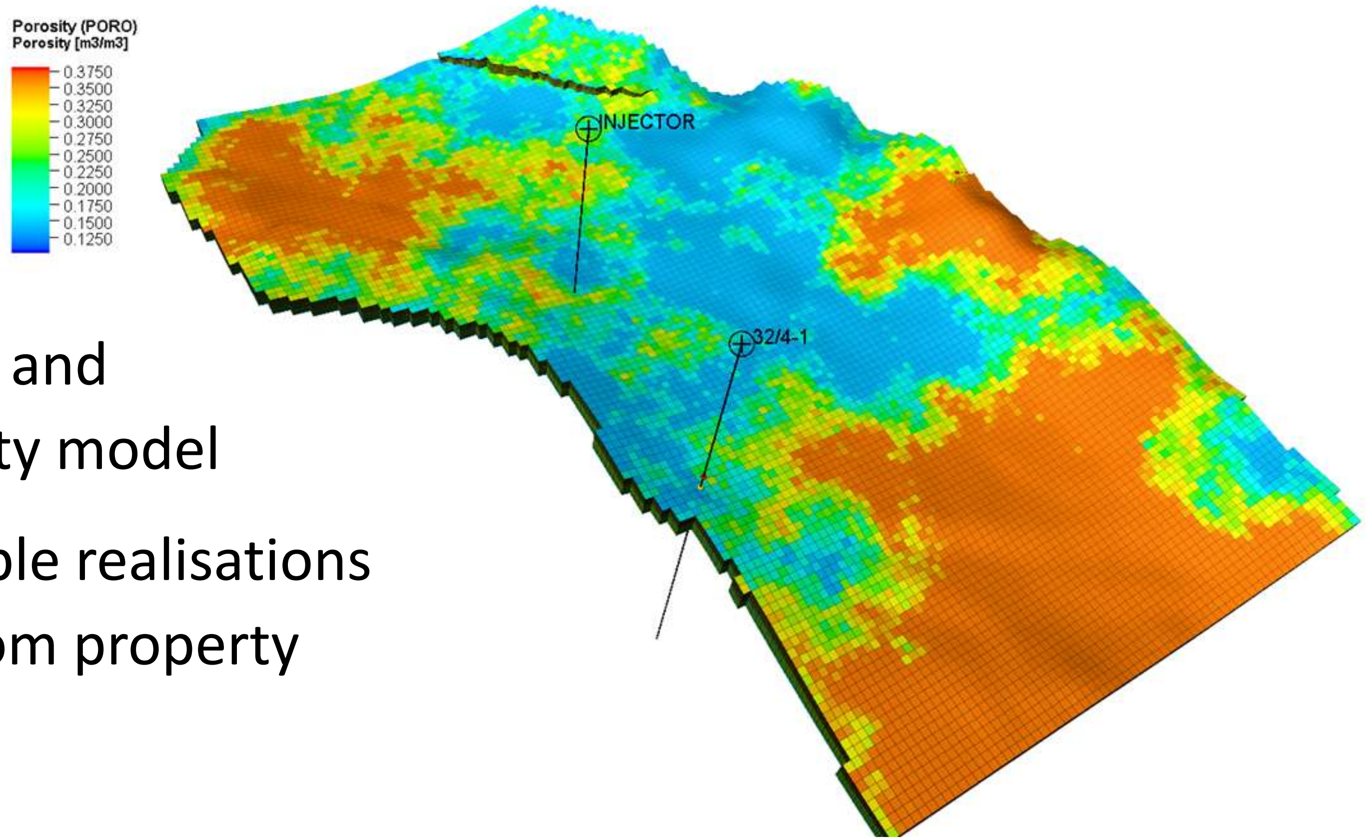


	Porosity	Permeability K_H (mD)	Permeability K_V (mD)
10th percentile	0.26	16	10
Average	0.33	680	410
90th percentile	0.40	27000	16200



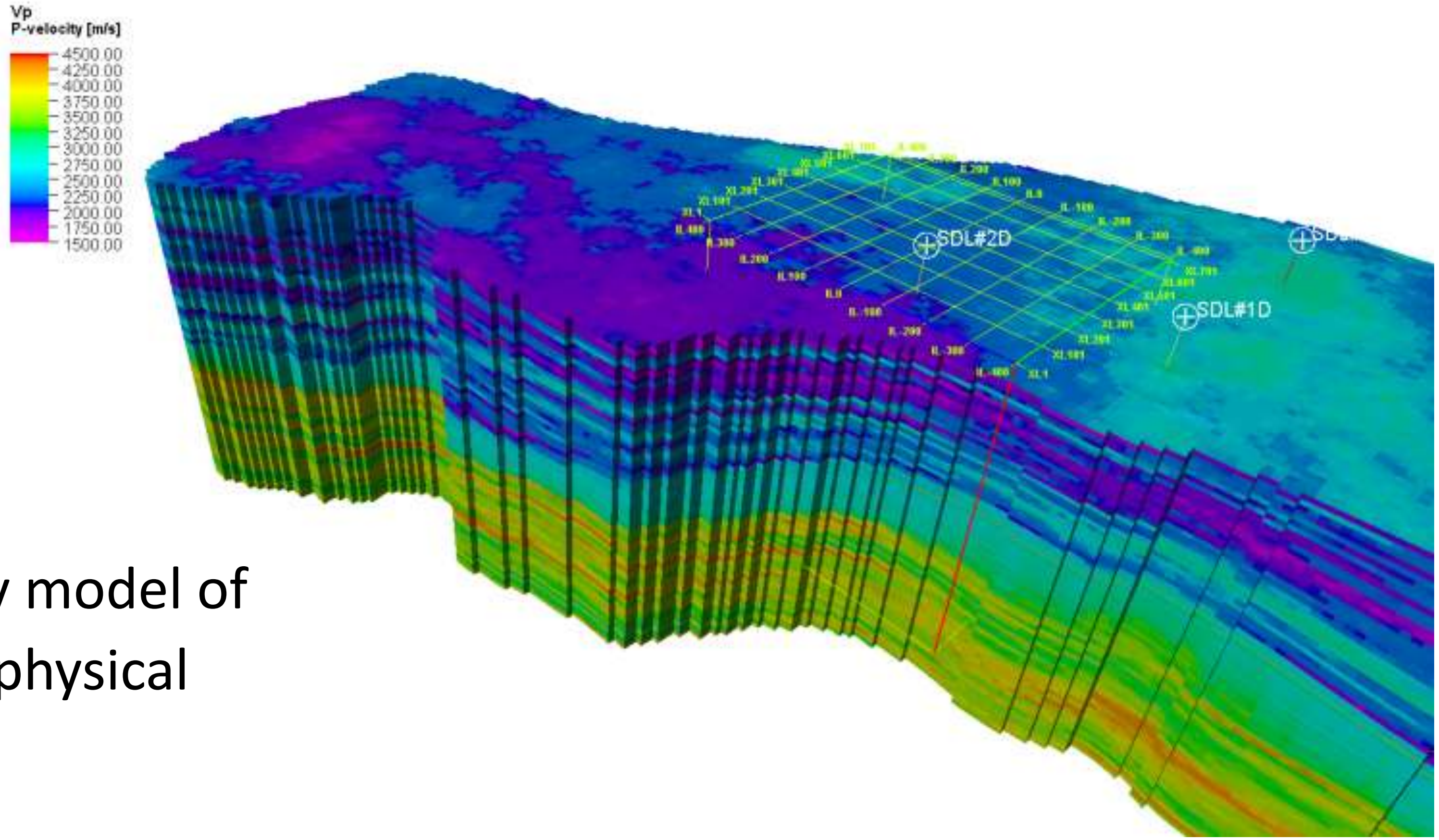


Smeaheia reservoir model



- Initially, map porosity and permeability to density model
- Then, generate multiple realisations of reservoir model from property distributions

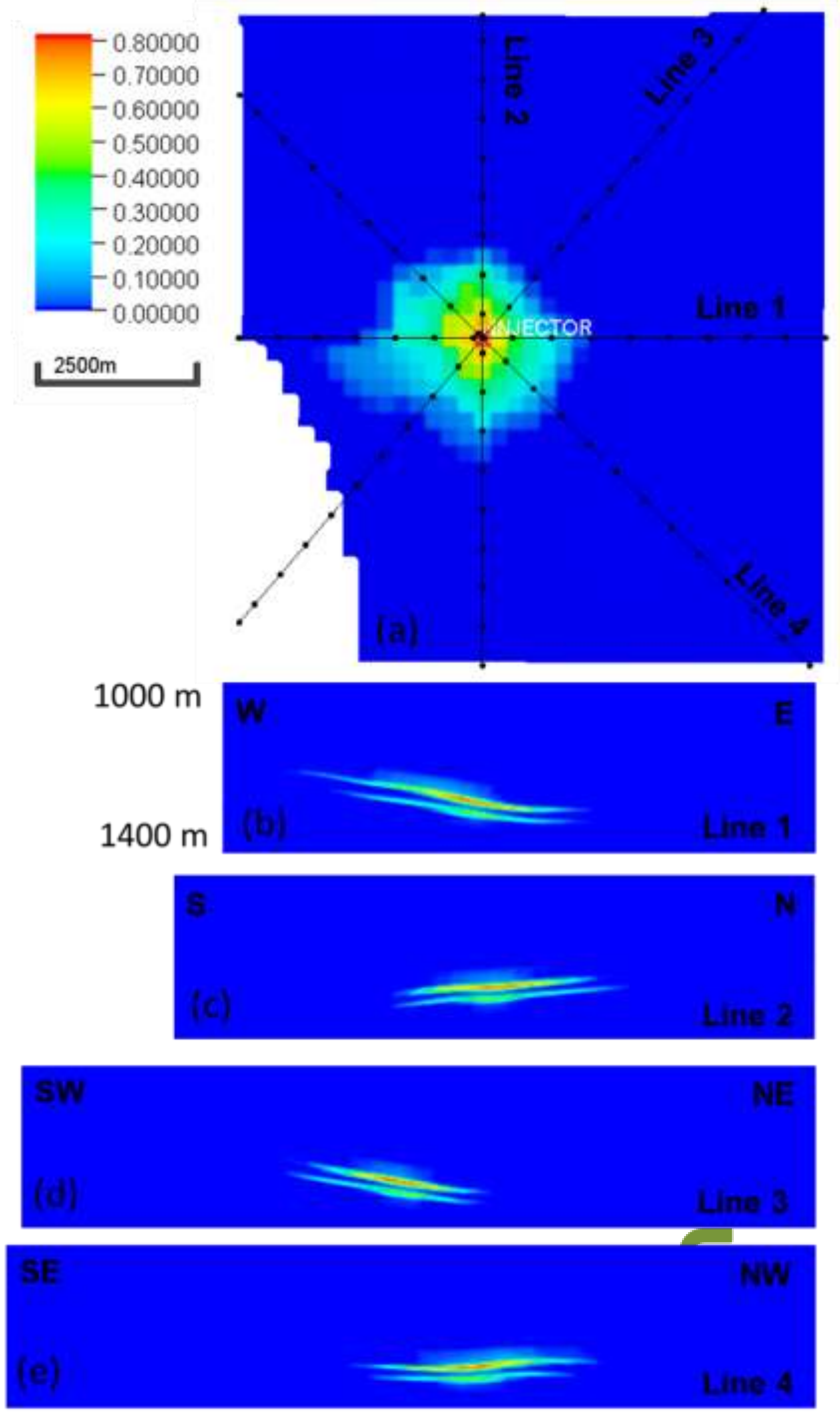
Smeaheia model construction



- Density and velocity model of overburden for geophysical modelling

Smeaheia modelling

- CO_2 trapped under topography of seal
- Multiple realisations of forward flow
- Here, distribution is fairly radial
- Two distinct CO_2 layers form consequence of lower permeability zone between Upper and Lower Sogefjord Formation
- Seismic monitoring array centred on injection point



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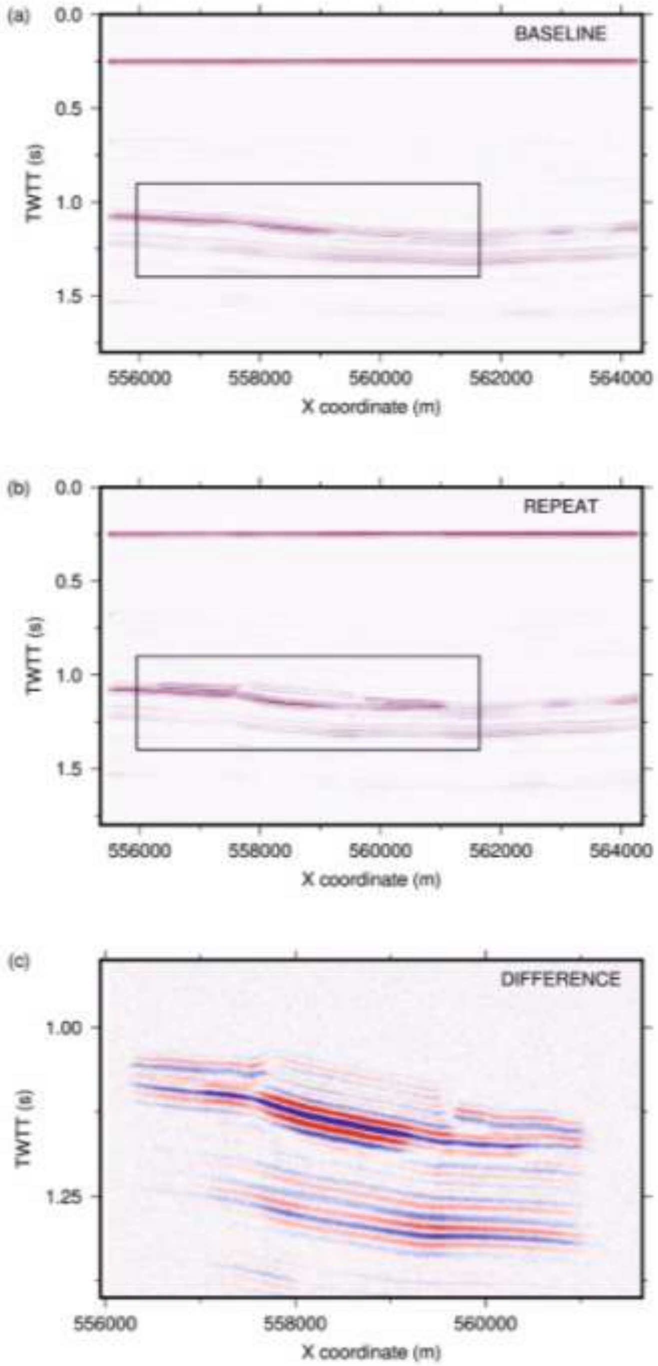
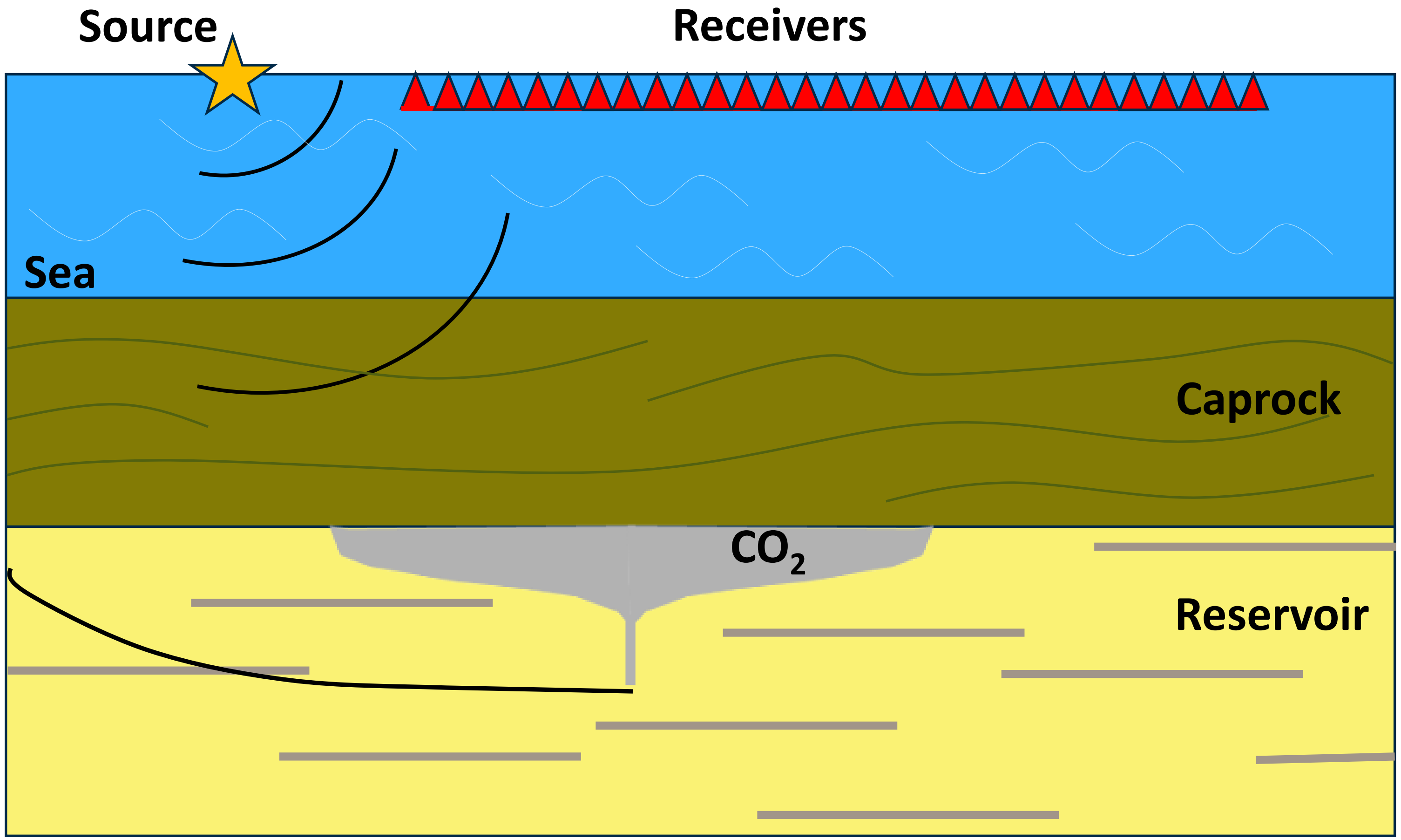
Seismic modelling

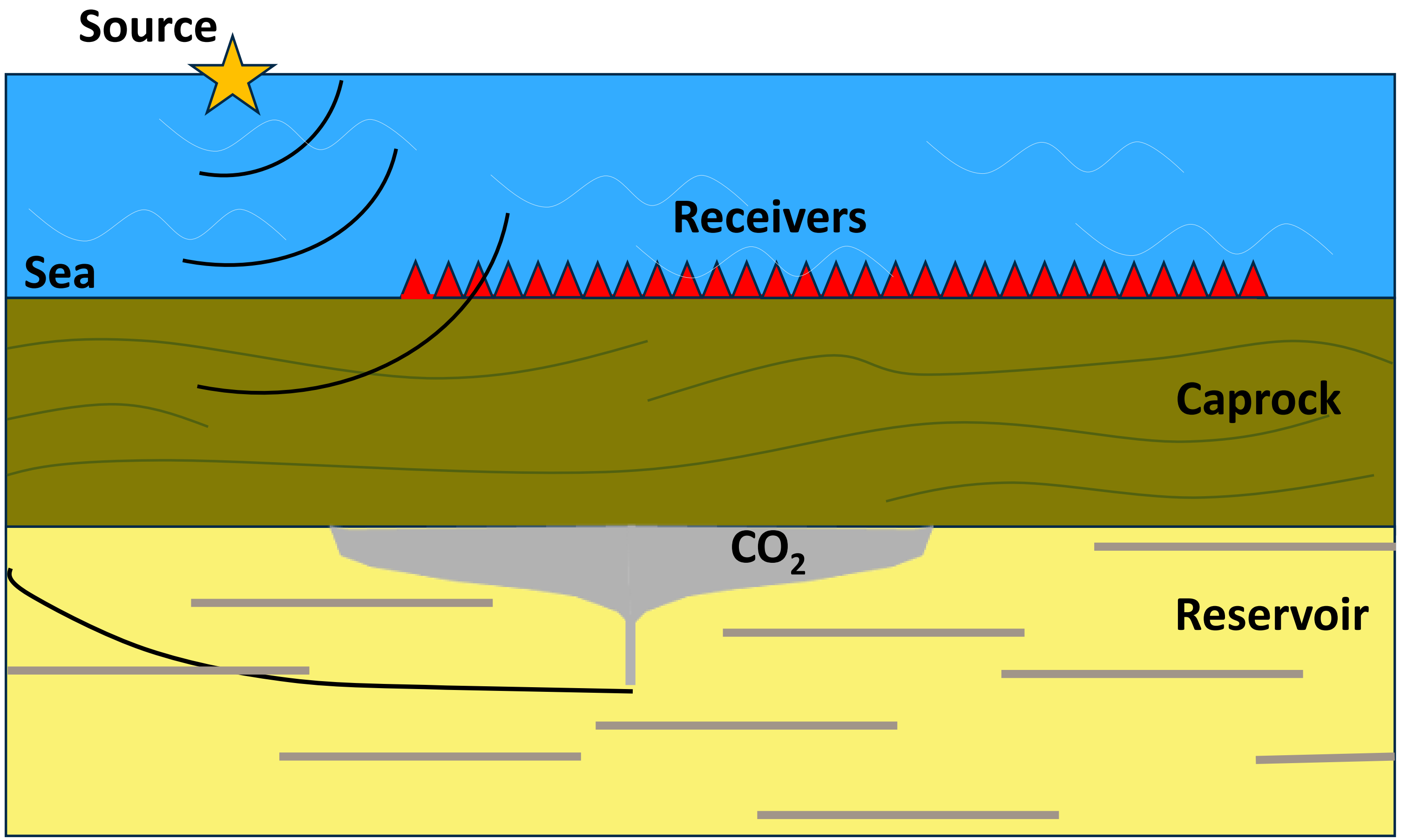
- Baseline and repeat data generated.
- Difference data allows extent of plume to be mapped
- Attribute analysis possible on synthetic data
- Site conformance can be assessed along series of 2D profiles



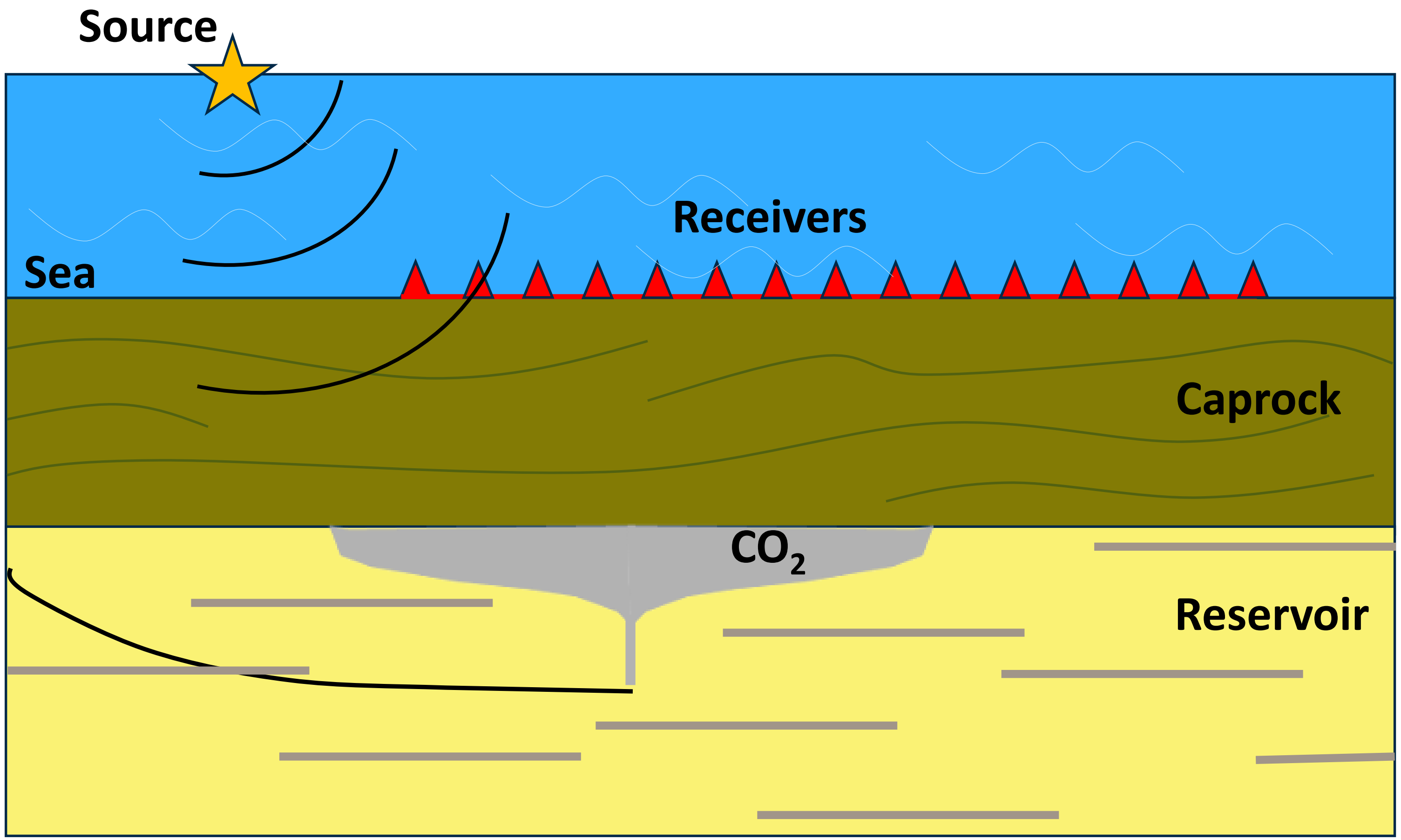
Sparse monitoring - seismic



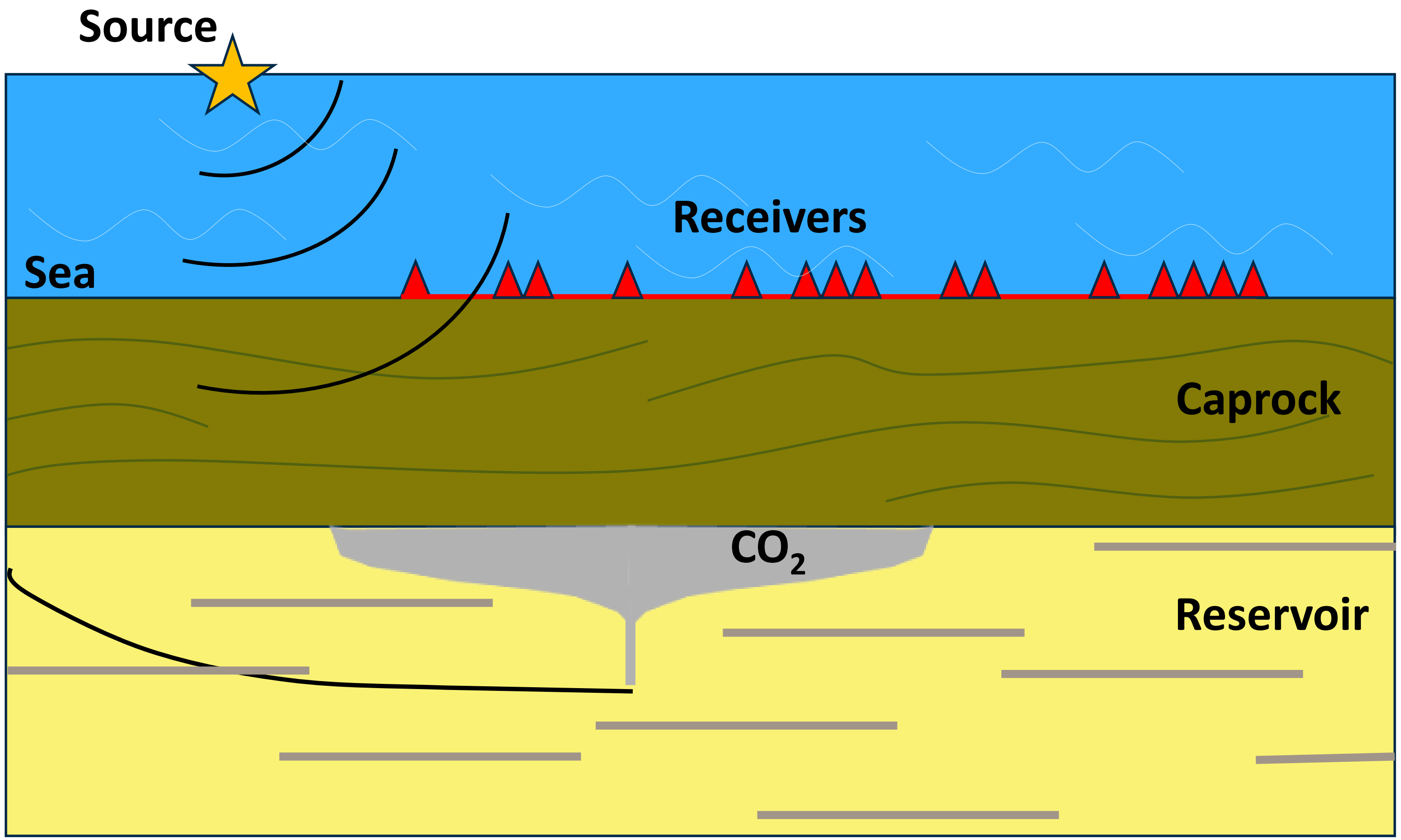
Sparse monitoring – OBS system



Sparse monitoring – reduce receivers



Sparse monitoring – random distributions

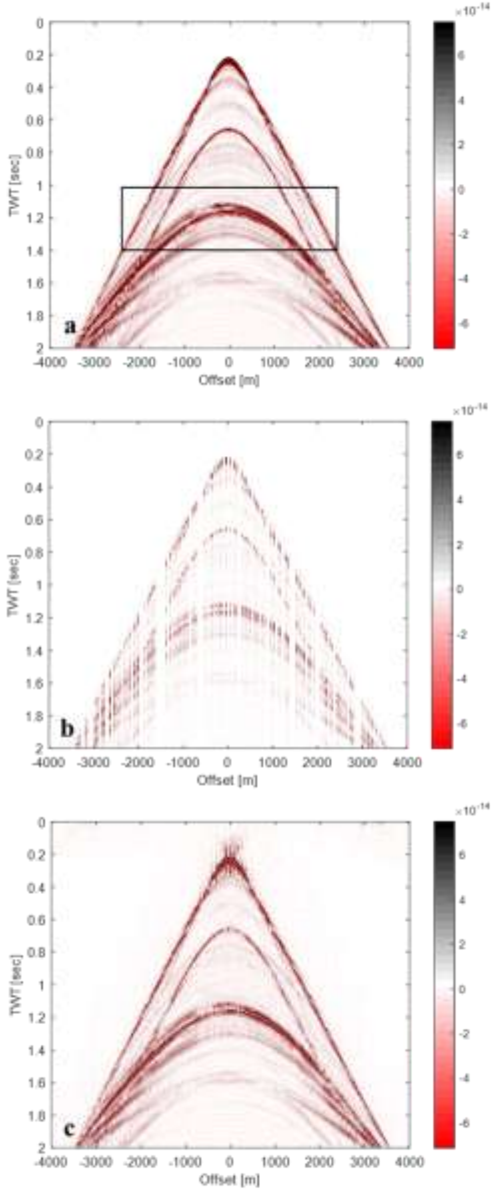


Compressive sensing

- Compressive Sensing (CS) is a signal processing technique that exploits sparsity inherent within a signal to fully recover that signal, using fewer measurements than are required by the Nyquist-Shannon sampling theorem
- We investigate the potential of CS to reduce the cost of monitoring a CCS site using a fixed Ocean Bottom Seismometer (OBS) array
- There are three basic requirements for compressive sensing to be successful (Herrmann et al., 2011): a random sampling scheme, an appropriate transform domain in which the complete signal has a sparse representation and a sparsity-promoting recovery algorithm

Compressive sensing

- Signal is removed through limited receiver stations – pre-stack interpolation
- OBS system used:
  - Improved repeatability.
  - Shear wave information, useful for lithology and fracture characterisation. Shear wave data also has the potential to discriminate fluid and pressure effects.
  - Wide azimuths and longer offsets. Long offsets are desirable for seismic inversion studies.
  - Improved multiple attenuation.



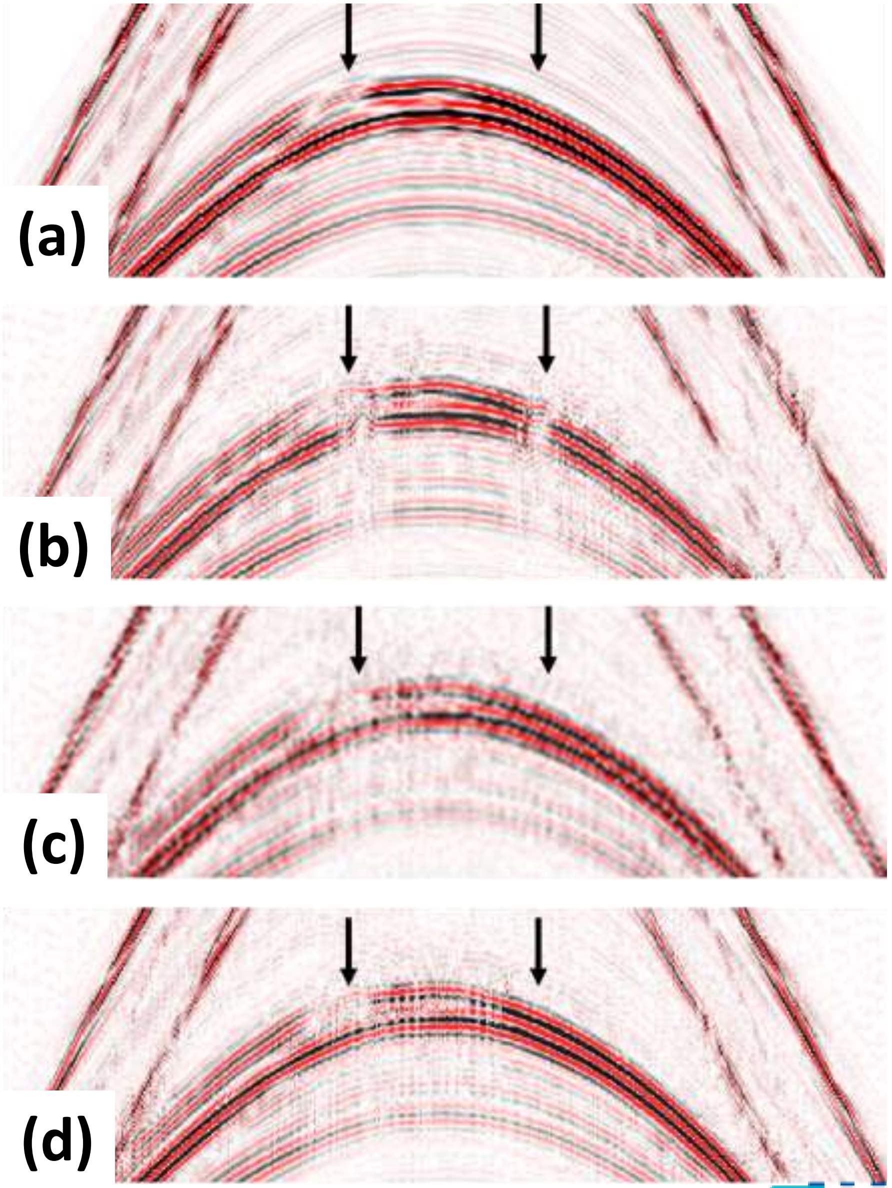
Original

Reduced

Recreated

Compressive sensing

- Assess different sampling schemes:
  - *(a) original data;*
  - *(b) data reconstructed from uniformly random sample;*
  - *(c) data reconstructed from jittered under sampling;*
  - *(d) data reconstructed from random piecewise random sampling*
- Demonstrates the effect of gaps (indicated by arrows) in a random sampling scheme



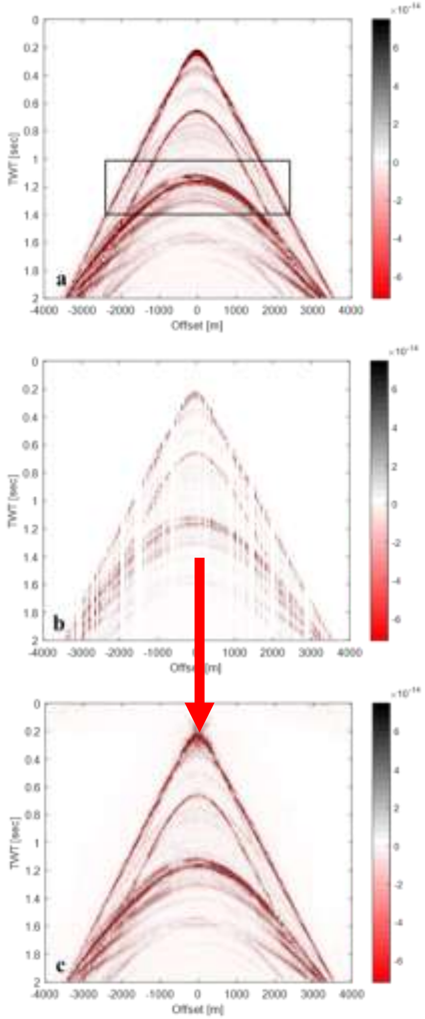
NCOOS

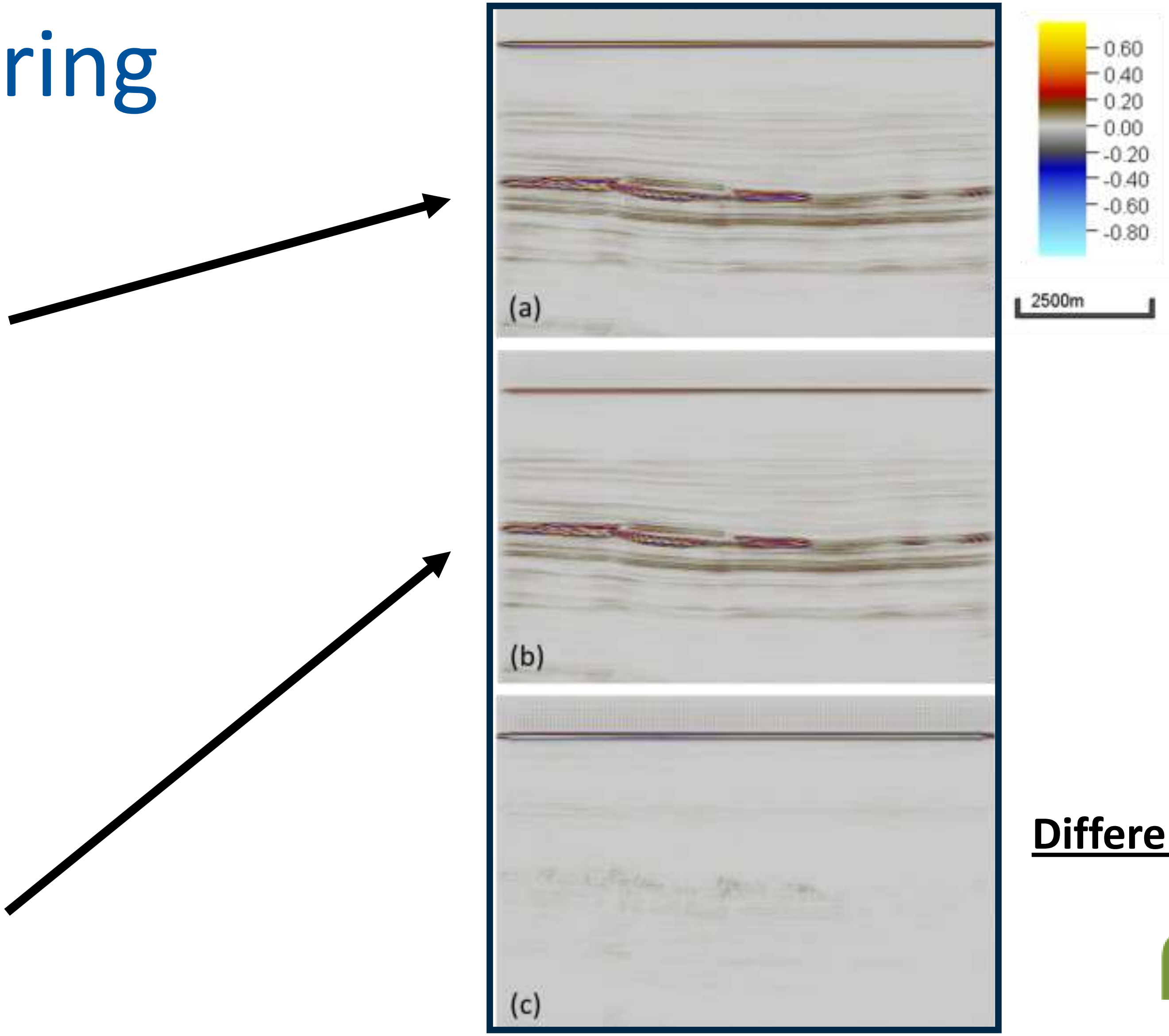
Sparse monitoring

Original

Reduced

Recreated





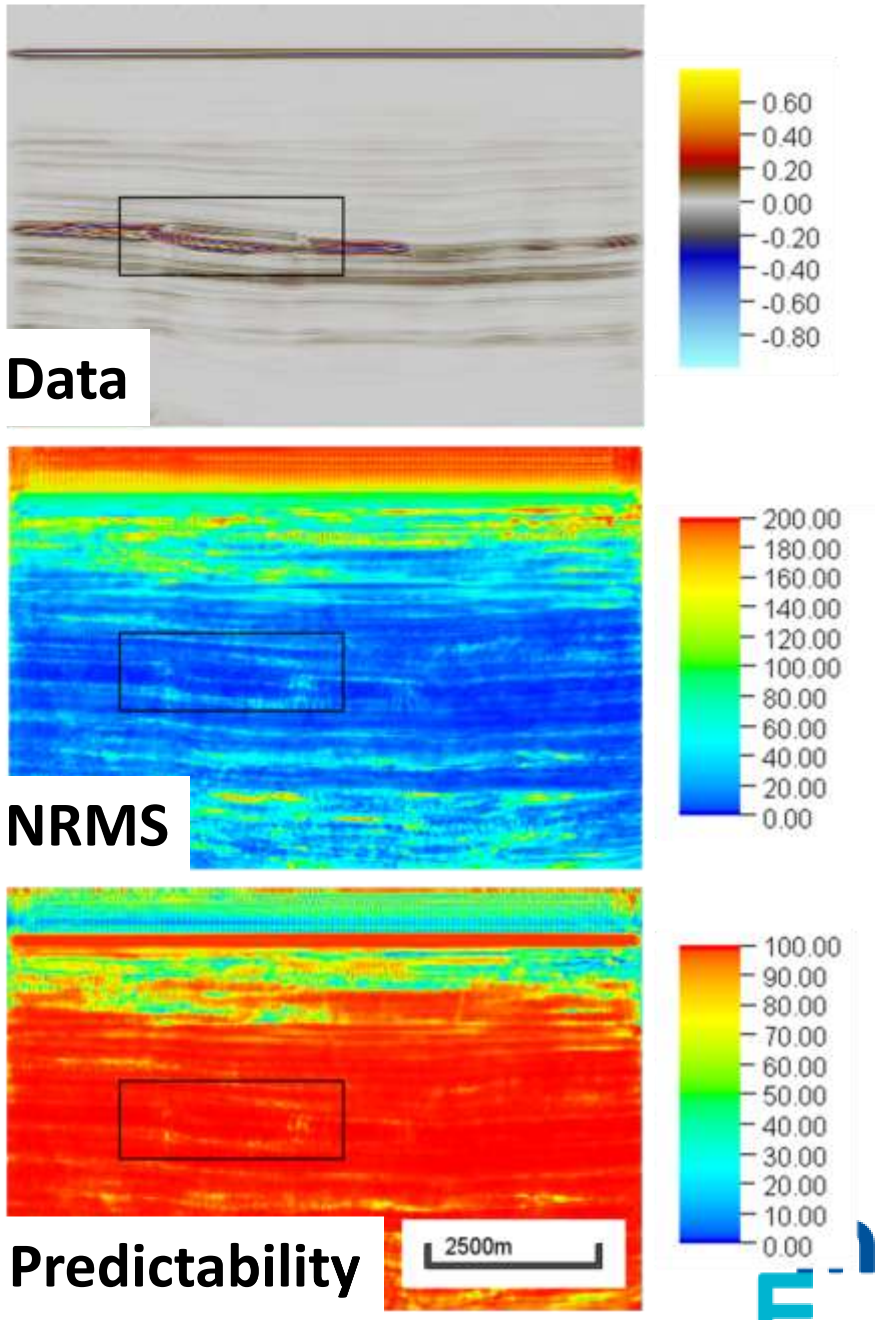
Difference

Quantify difference between datasets

- NRMS is the summation of the difference between two traces (a_t and b_t) in a specified time window divided by the average RMS amplitude of the two input traces:
- $NRMS = \frac{200 \times RMS(a_t - b_t)}{RMS(a_t) + RMS(b_t)}$
- Predictability is the summed squared cross-correlation of two traces (ϕ_{ab}) in a time window, divided by the summed product of the trace auto-correlations (ϕ_{aa} & ϕ_{bb}).
- $PRED = \frac{100 \times \sum \emptyset_{ab}(\tau) \times \sum \emptyset_{ab}(\tau)}{\sum \emptyset_{aa}(\tau) \times \sum \emptyset_{bb}(\tau)}$

Quantitative assessment

- The top third of the seismic section shows the lowest repeatability (%NRMS ~120% and %predictability of c. 60%)
- At the level of the CO_2 plume, repeatability is generally very good (%NRMS <20% and %predictability of >90%).



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Conclusions

- Compressive sensing techniques are suitable for pre-stack interpolation of monitoring data
- The high amplitude seismic response, following CO_2 fluid substitution, enhances capability
- Measures of repeatability are high
- Testing on real data is underway

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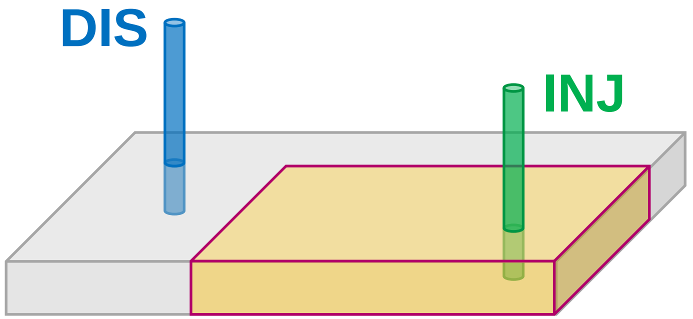
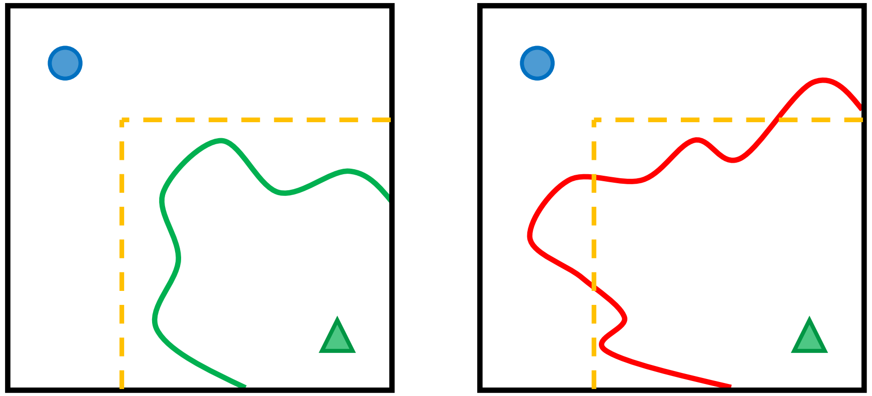
Conformance - synthetic example

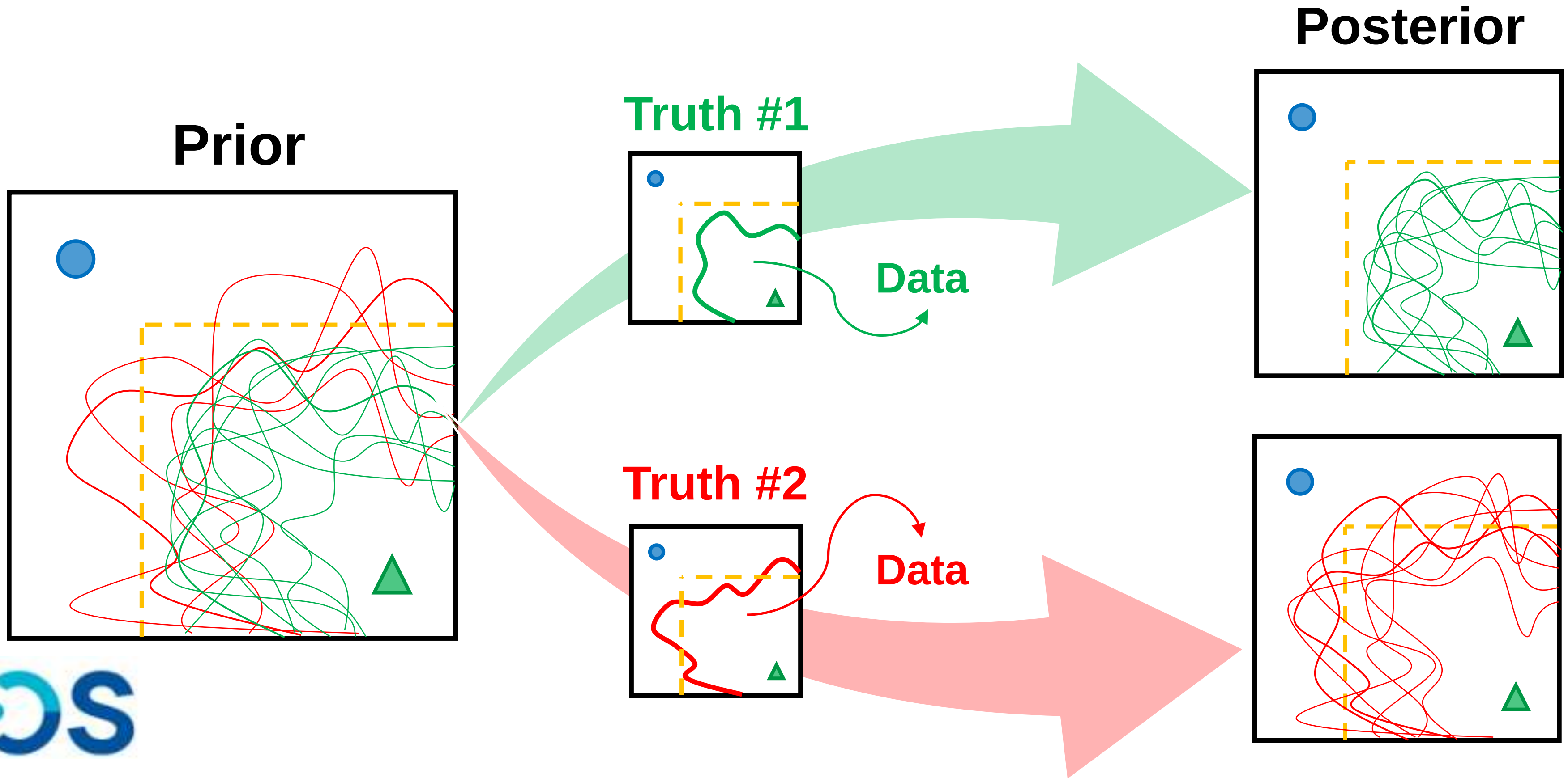
- Use of data for conformance assessment – injected CO_2 must stay within regulatory bounds





Conformance: History matching

- Incorporate data measured during CO_2 injection to update model realizations
  - Ensemble-based data assimilation methods



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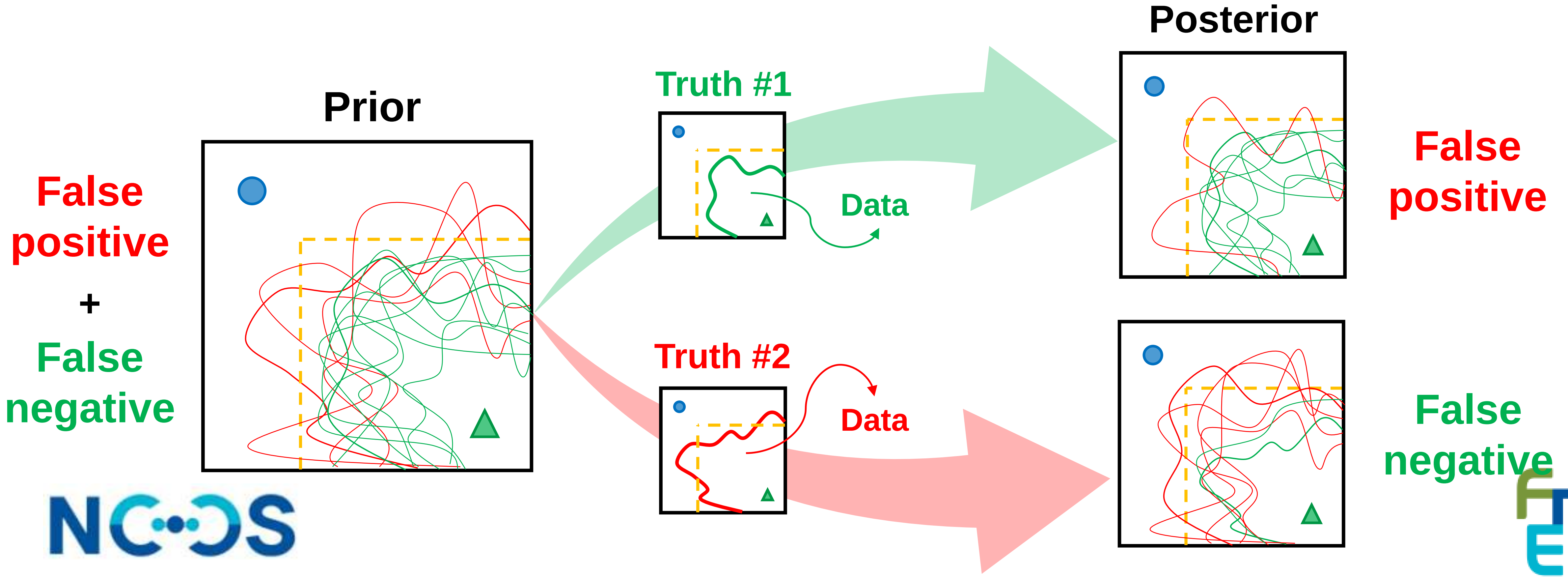

Survey characteristics

- Varying time of acquisition

  t_{survey} = {300, 600, 900, 1200, 1500} days