PRE-ACT

- FOR SAFE AND COST-EFFICIENT CO_2 STORAGE

Peder Eliasson, SINTEF

CSLF Technical Group Meeting

Chatou, 5 November 2019

Pre-ACT background

- Response to first **ACT** call 2016
- Wanted to identify and address main storage-related challenges for **accelerated deployment of CCS** in collaboration with industry.
- Focus on crucial **storage challenges: capacity, confidence, and cost**
- Least common denominator: **pressure**

Pressure control and conformance management for safe and efficient CO_2 storage - Accelerating CCS Technologies (Acronym: Pre-ACT)

www.sintef.no/pre-act

Pre-ACT approach

- **Answering to industry needs**
- Learning from demonstration, pilot, and field lab data
- Deliverables with focus on industry uptake

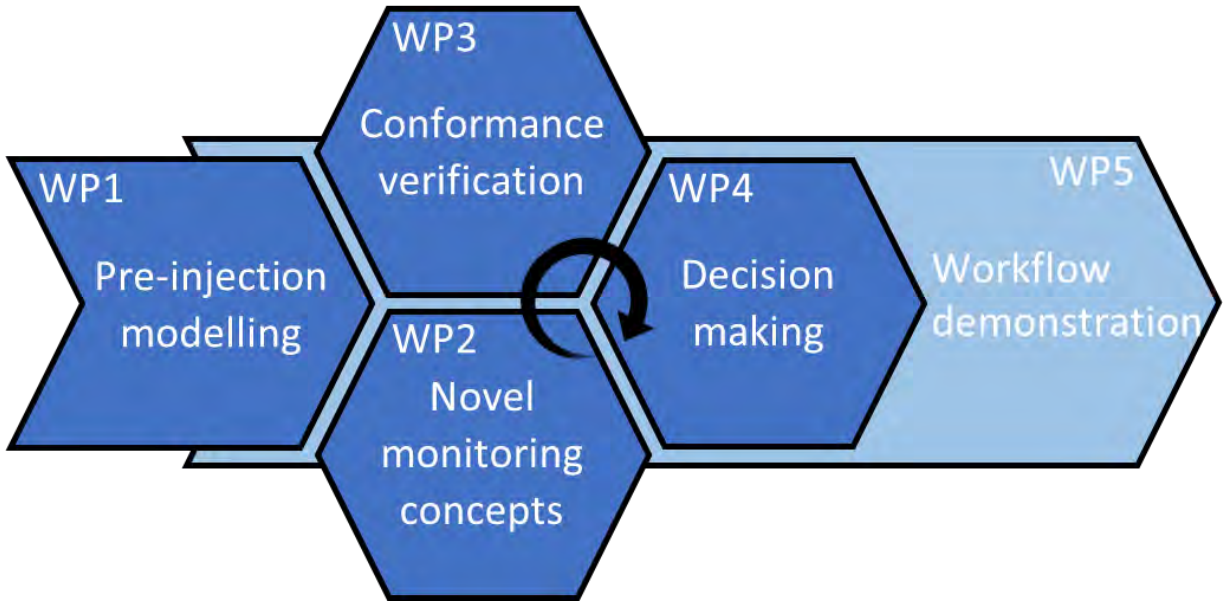
Questions from industrial operators	Pre-ACT approach to answer questions
How can we most effectively extract pressure from direct and indirect measurements?	Experimental setup for pressure and saturation discrimination (WP2)
What is sufficient pressure monitoring?	Novel conformance criteria to limit the required measurement effort (WP3)
How can we quantify site conformance?	Analysis of uncertainty by a closed modelling-monitoring loop (WP3)
How can we detect migrated CO_2 at indicator horizons?	Pressure-sensitive passive-active monitoring concept (WP2)
How can a cost-saving prevention concept be practically implemented?	Effective injection strategies as pressure management (WP1)
How can we measure and verify the stability of a reservoir in the post-closure phase?	Continuous calibration of models with real data under inclusion of geomechanical features (WP1)
Does dispersal of hypersaline pore water require environmental management?	Novel hypersaline hydrodynamic scenario modelling (WP1)

Pre-ACT approach

- Answering to industry needs
- **Learning from demonstration, pilot, and field lab data**
- Deliverables with focus on industry uptake

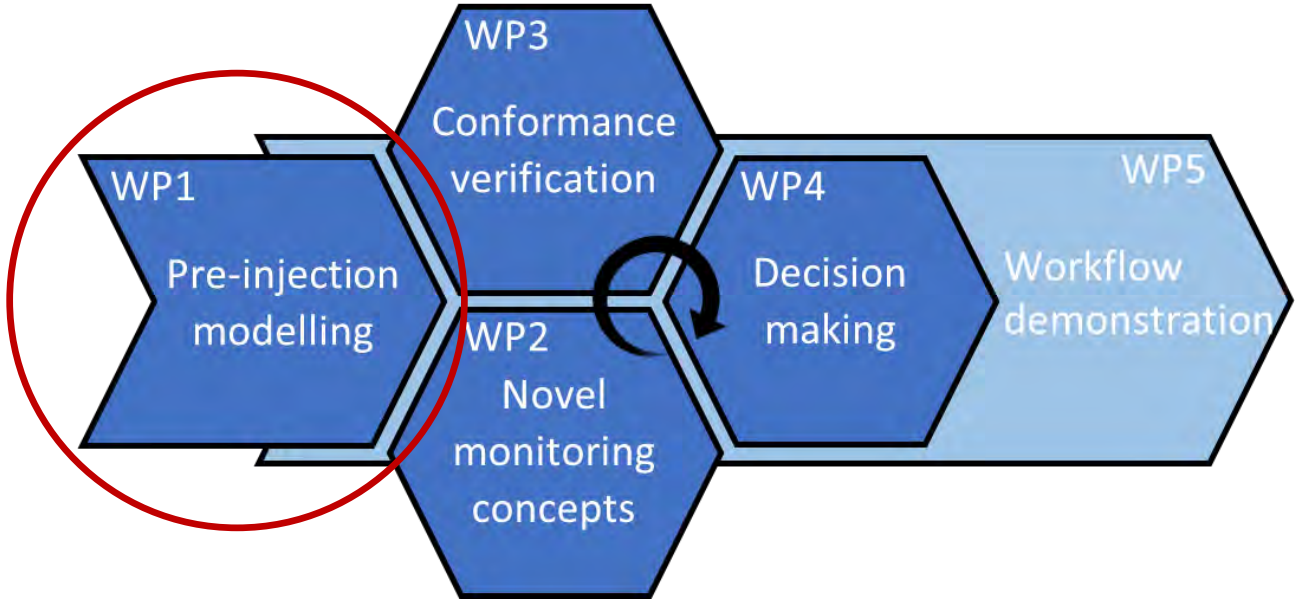
Pre-ACT impact

- Methodologies and recommendations for **cost-efficient monitoring, reliable conformance assessment and decision making** (Pre-ACT Protocols)
- North Sea case studies:
  - Smeaheia (SINTEF, Equinor, ++)
  - P18-4 (TNO, TAQA, ++)
  - Endurance (BGS, Shell, ++)
- Workshops with industry, stakeholders, researchers
- First Svelvik CO_2 Field Lab campaign



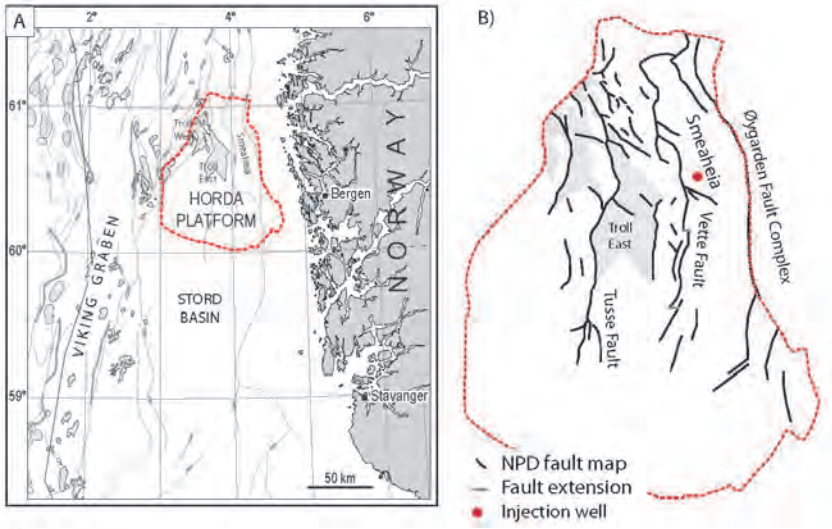
WP1: Pre-injection modelling

- WP leader: Jim White (BGS)
- Study optimal injection planning via effective pressure control
- Focus on understanding propagation and control of pressure increases following injection through a program of modelling and laboratory work

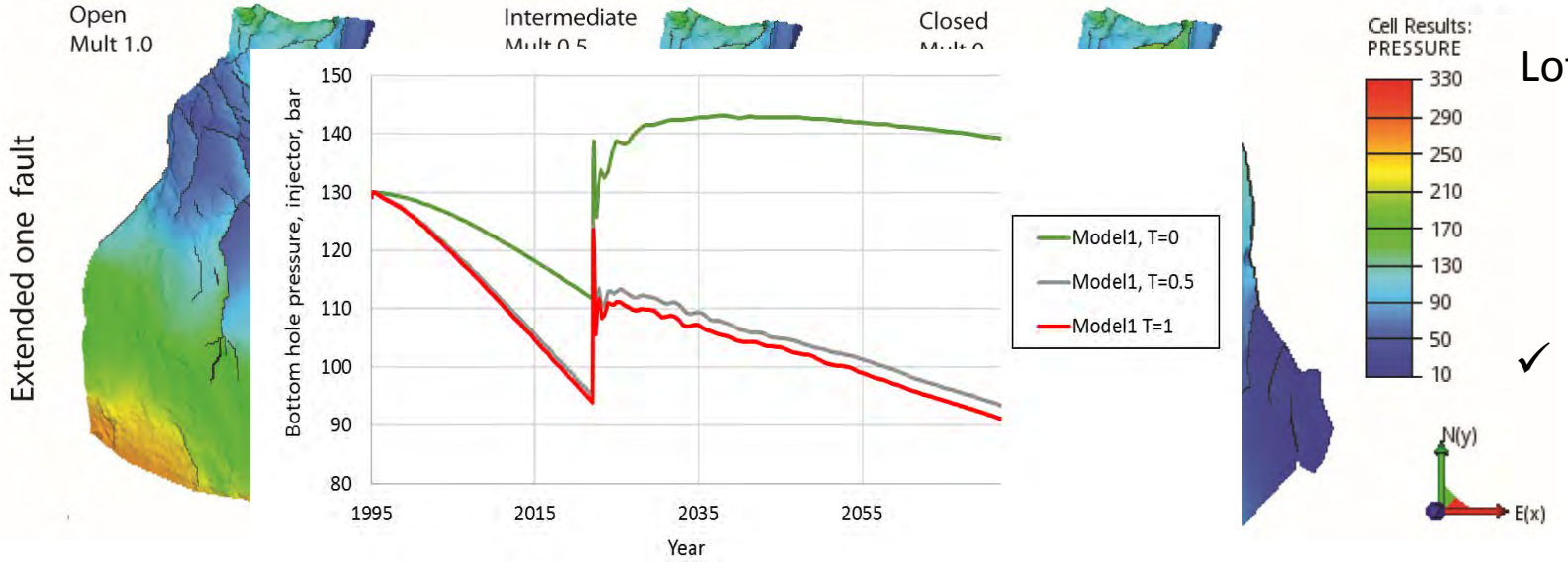


Fault heterogeneity

- Study of the effect of uncertain fault characterisation
- Varying sealing properties in assumed fault relay zones has a major impact on pressure propagation



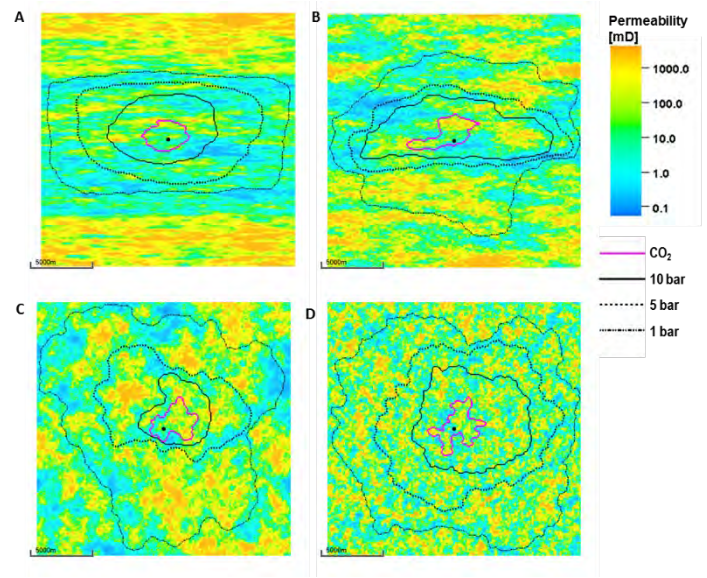
Lothe et al., 2018

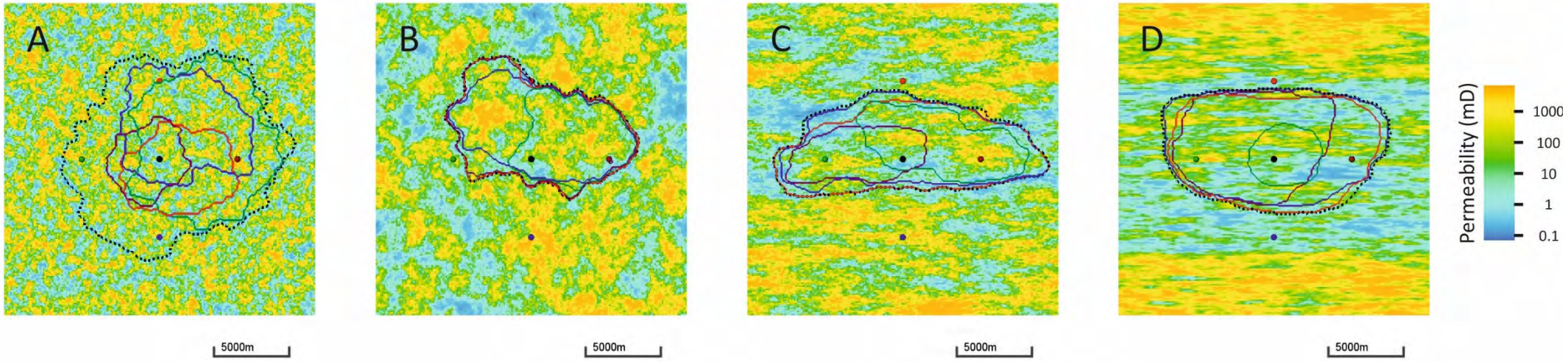


✓ High bottom hole pressure simulated in the Smeaheia area using sealing faults

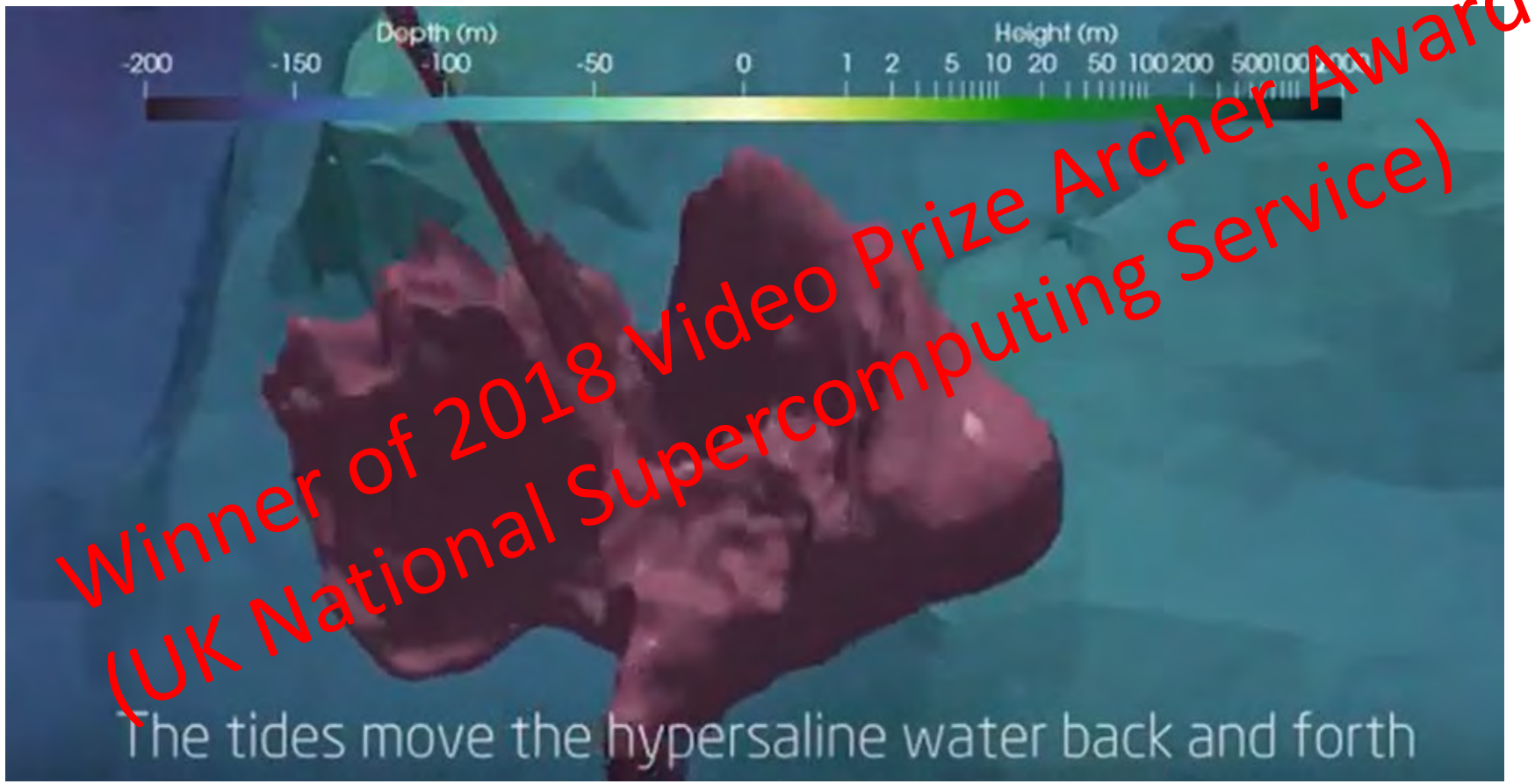
Pressure modelling

- Effect of geological heterogeneities on pressure studied
- Four different production well locations compared
- Various orientation and degree of heterogeneity (A, B, C, D)
- Influence of connectivity on pressure propagation is clear





Impact of hypersaline discharge



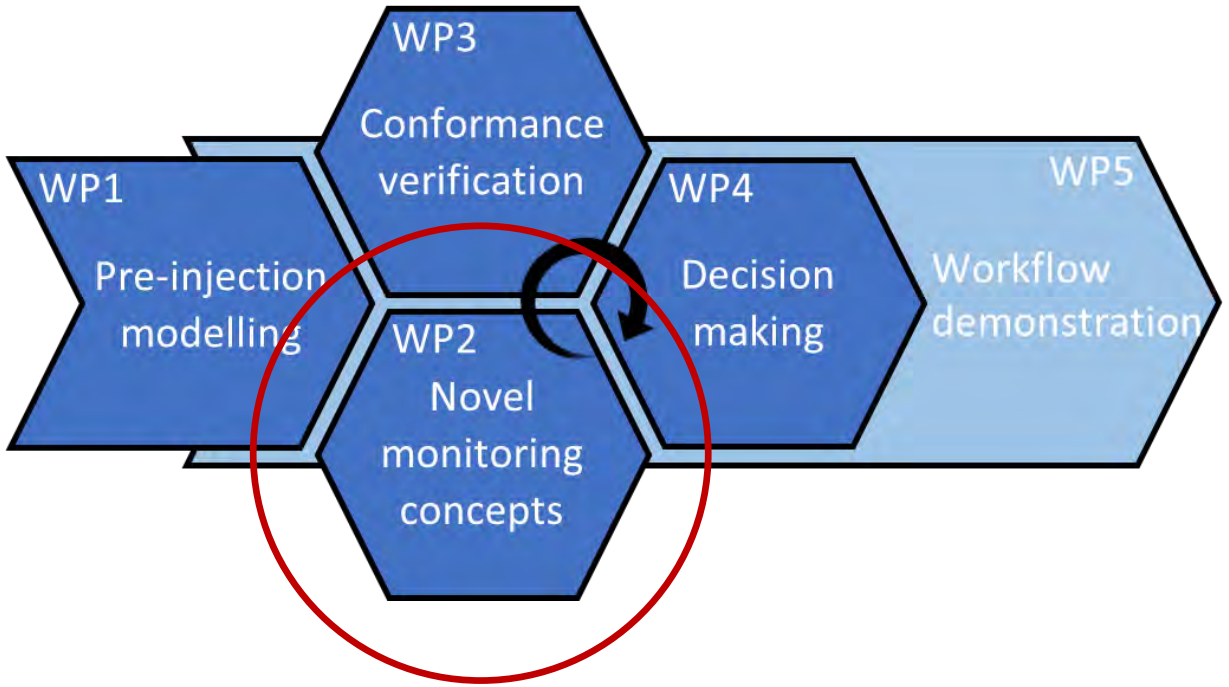
Winner of 2018 Video Prize Archer Award (UK National Supercomputing Service)

http://www.archer.ac.uk/about-archer/news-events/events/image-comp/gallery-2018/

https://youtu.be/EmQv4qk0kUo

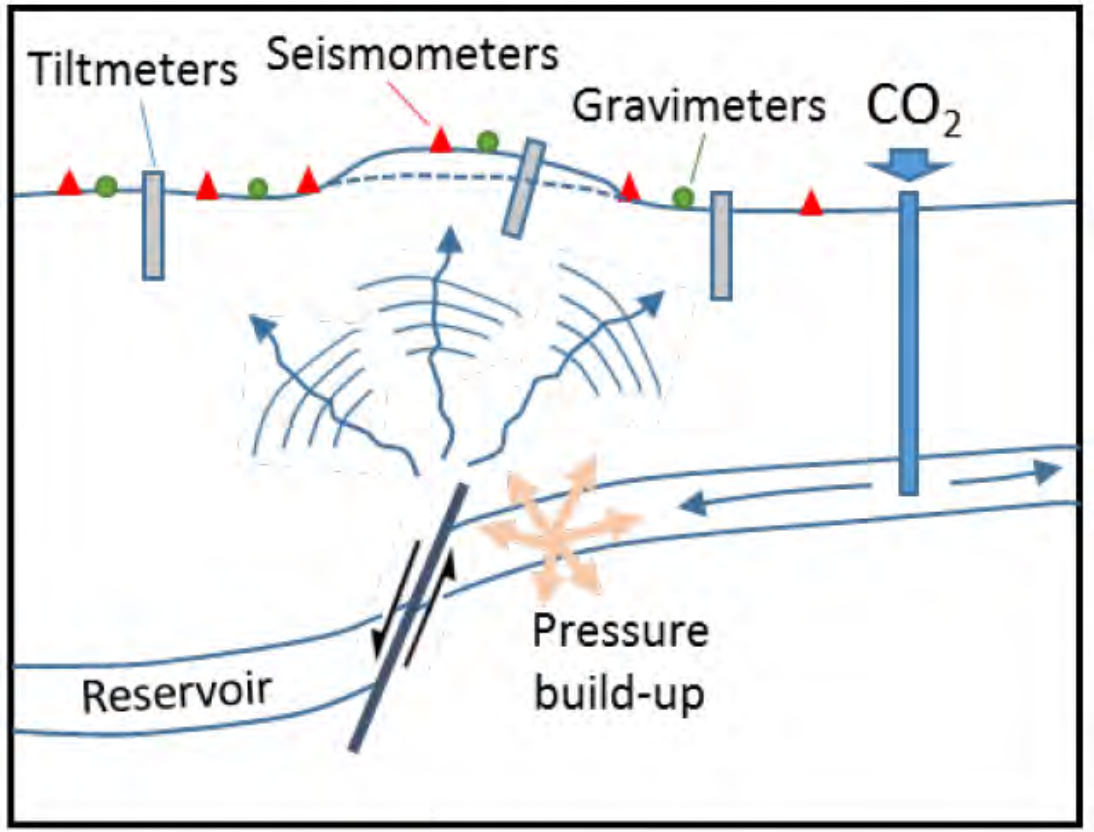
WP2: Novel monitoring concepts

- WP leader: Conny Schmidt-Hattenberger (GFZ)
- Minimize cost and get sufficient information by using passive-active monitoring strategy
- Novel concepts for quantification of pore pressure and saturation
- Methods applied to Svelvik CO_2 field lab



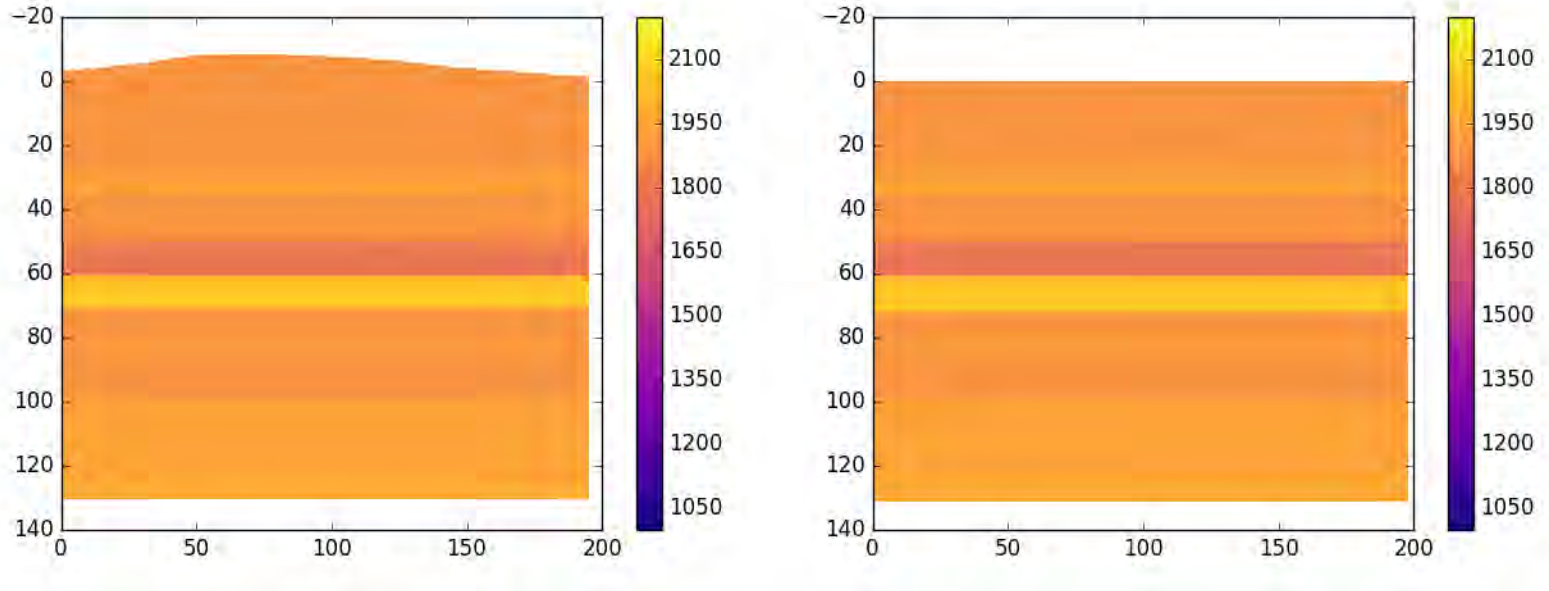
Passive-active monitoring workflow

- Sparse, semi-continuous monitoring, with complementary detailed measurements
- Potentially all geophysical methods are suitable
- Investigation of different passive seismic data types
  - Ambient noise
  - Teleseismic, regional earthquakes, micro-seismicity



Ambient Noise Seismic Interferometry

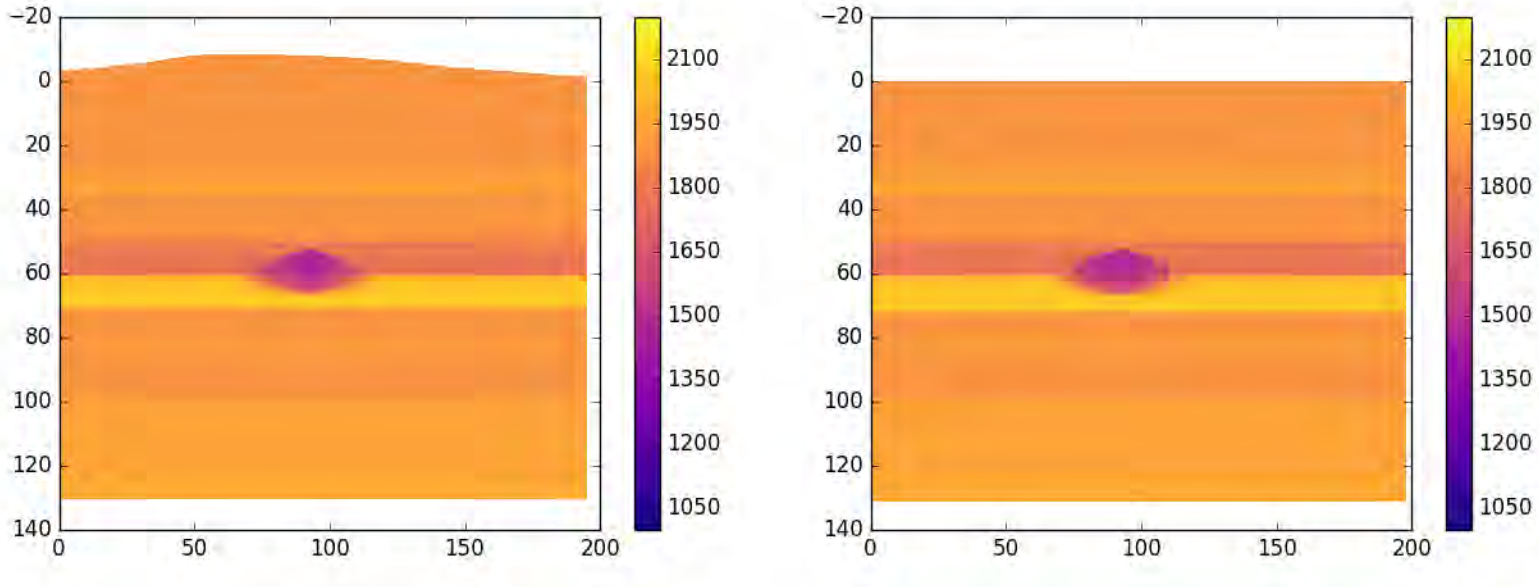
- Vp models (low containment case)



Vp at d_0

Ambient Noise Seismic Interferometry

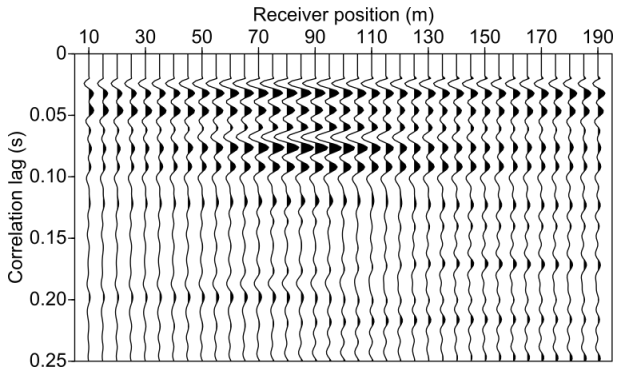
- Vp models (low containment case)



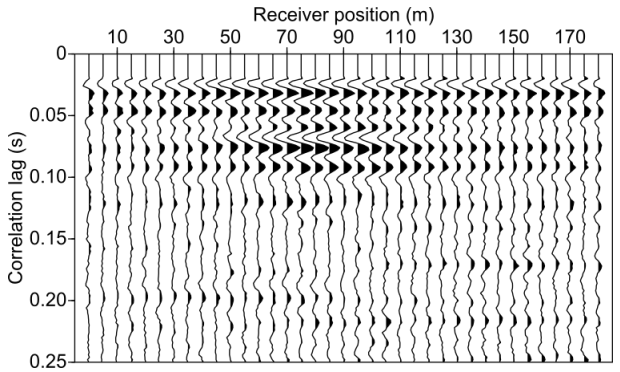
Vp at d_15

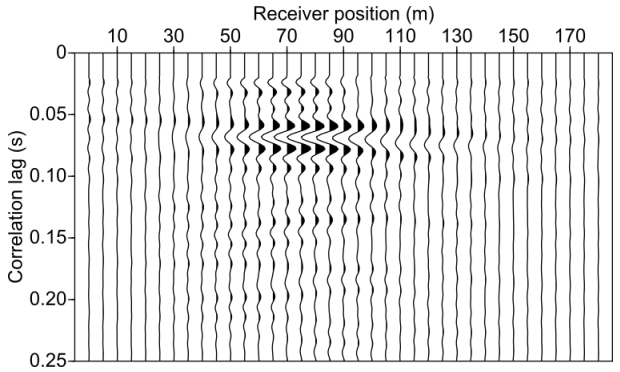
Ambient Noise Seismic Interferometry

- Retrieved auto-correlations (fmax=70)

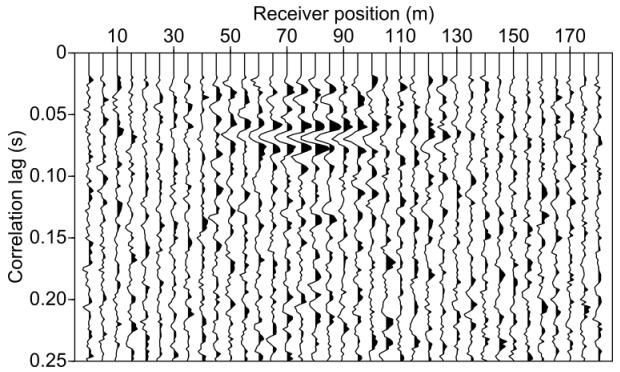


d_15





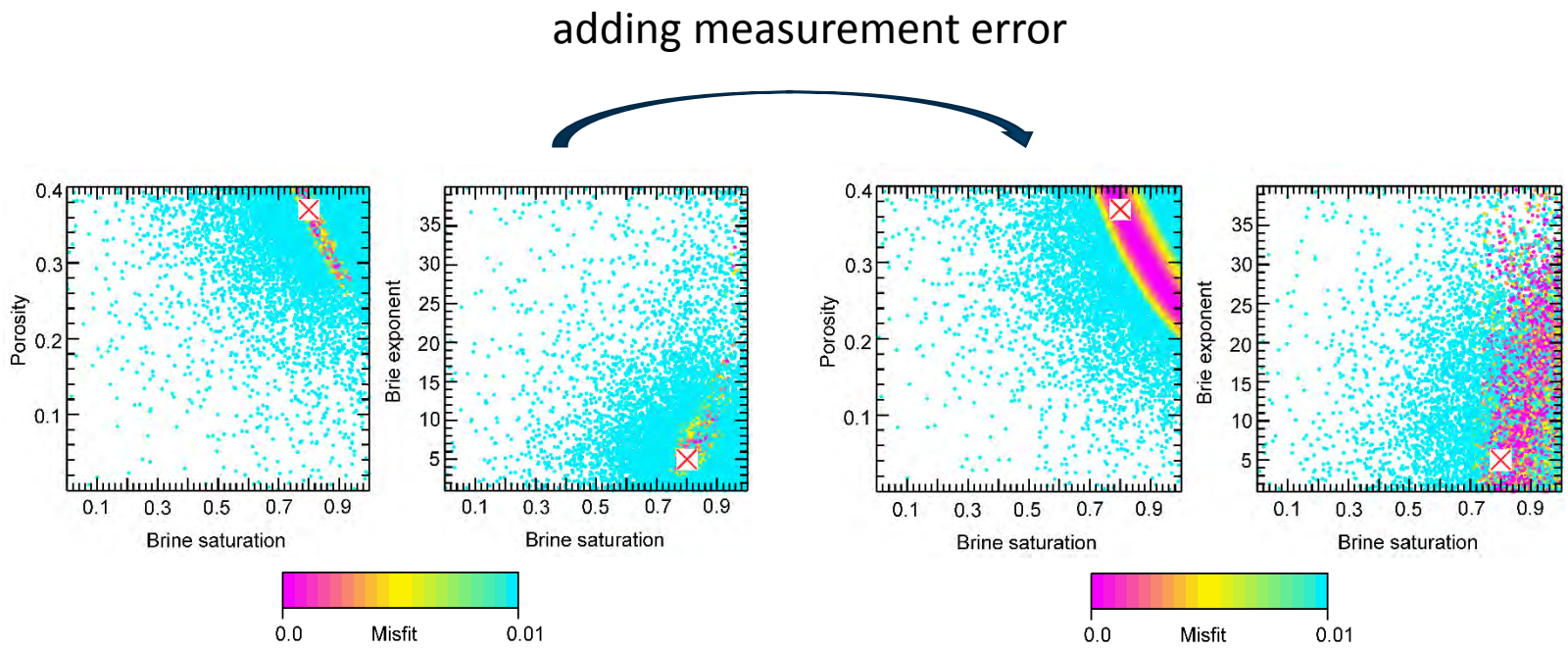
(d_15 - d_0) x 2



with random noise

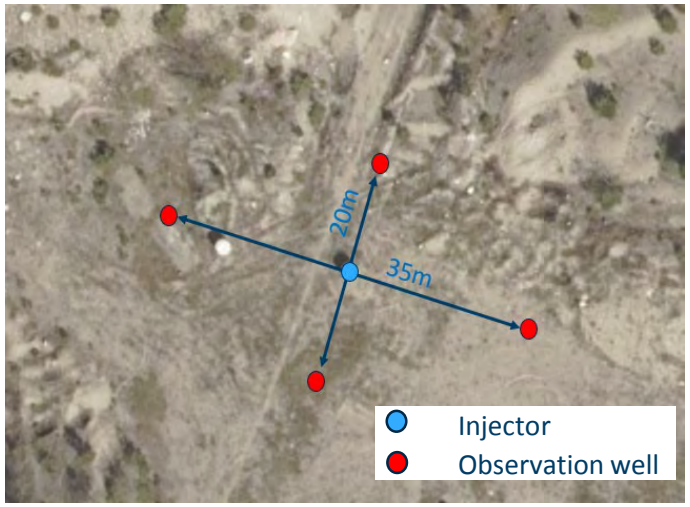
Rock physics inversion

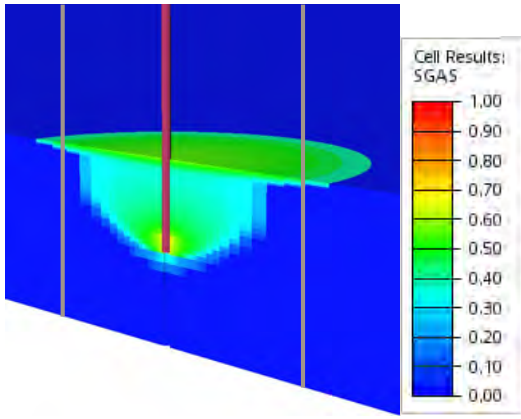
- An integrated methodology for **quantitative CO_2 monitoring** using a Bayesian formulation (accounting for uncertainty) has been developed
- Multiple data sets used to quantify e.g. pressure and saturation

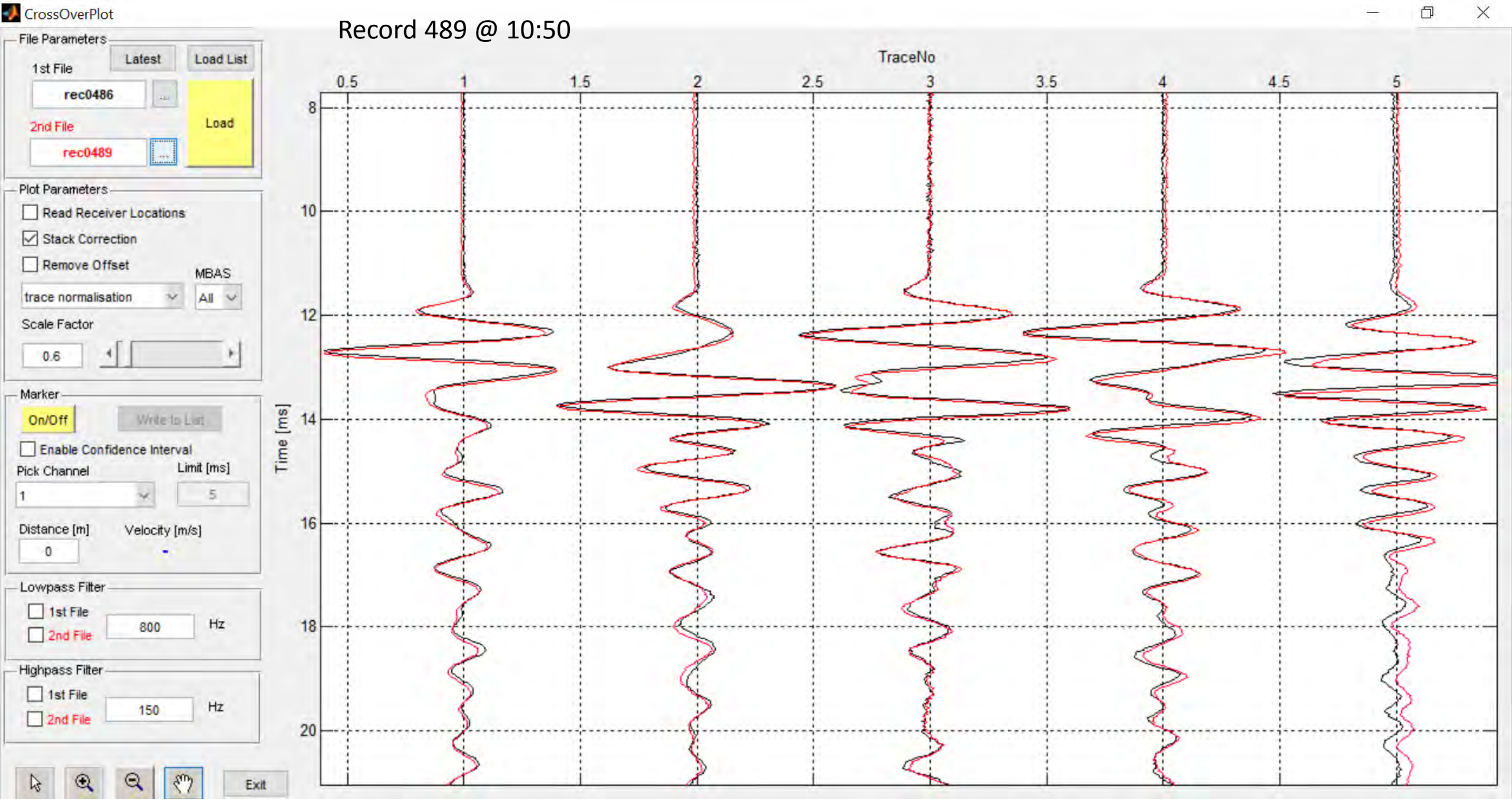


Svelvik CO2 Field Lab

- Unique laboratory for development and testing of technologies for quantitative monitoring of CO2 storage
- 1 Injection well, 4 observation wells
- Cross-hole seismic and ERT, in-situ pressure measurements, DAS, DTS, DSS
- Pre-ACT data for pressure-saturation discrimination and quantification
  - First brine injection for pressure change alone
  - Then CO_2 injection for combined saturation and pressure change



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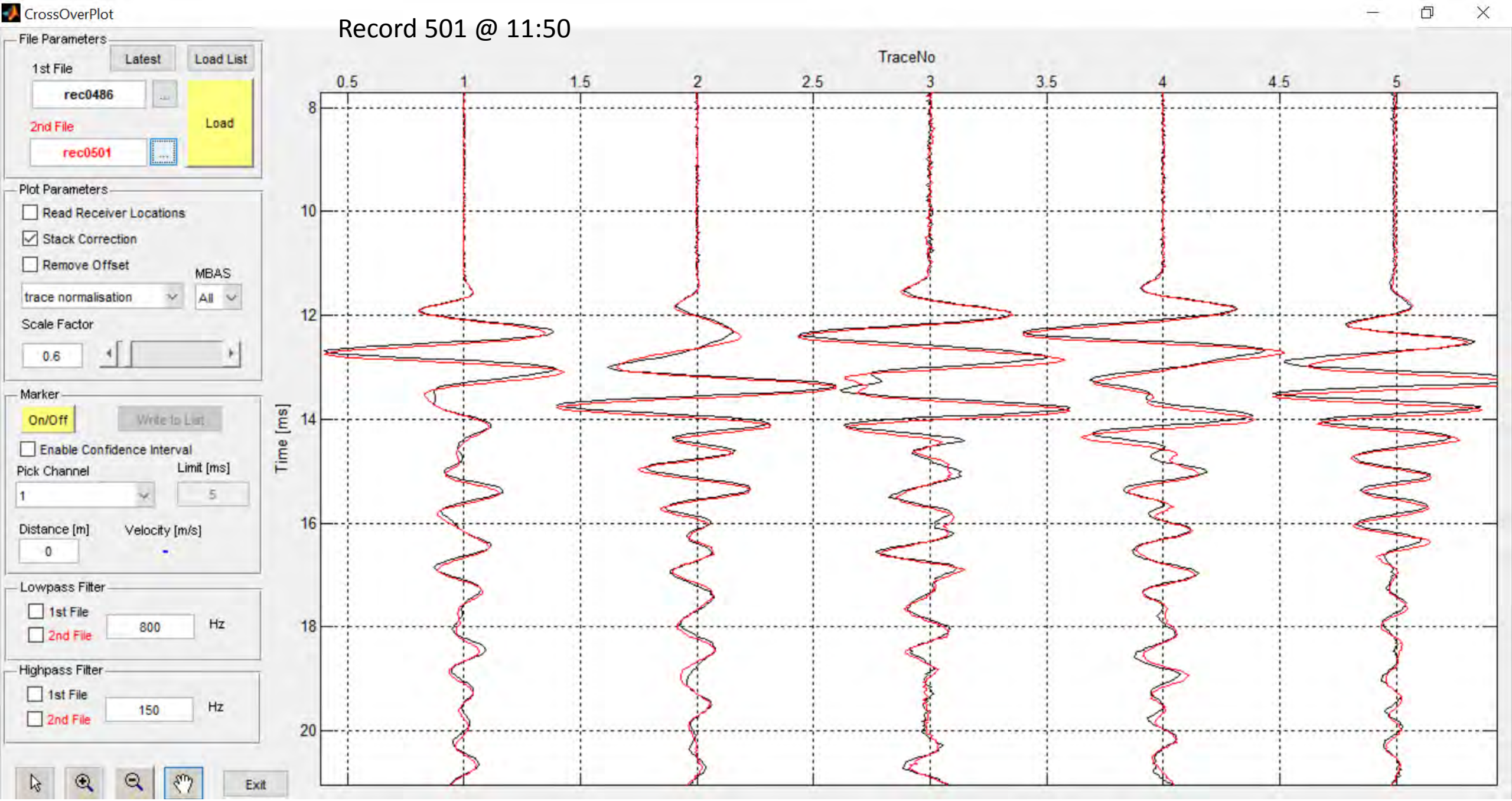
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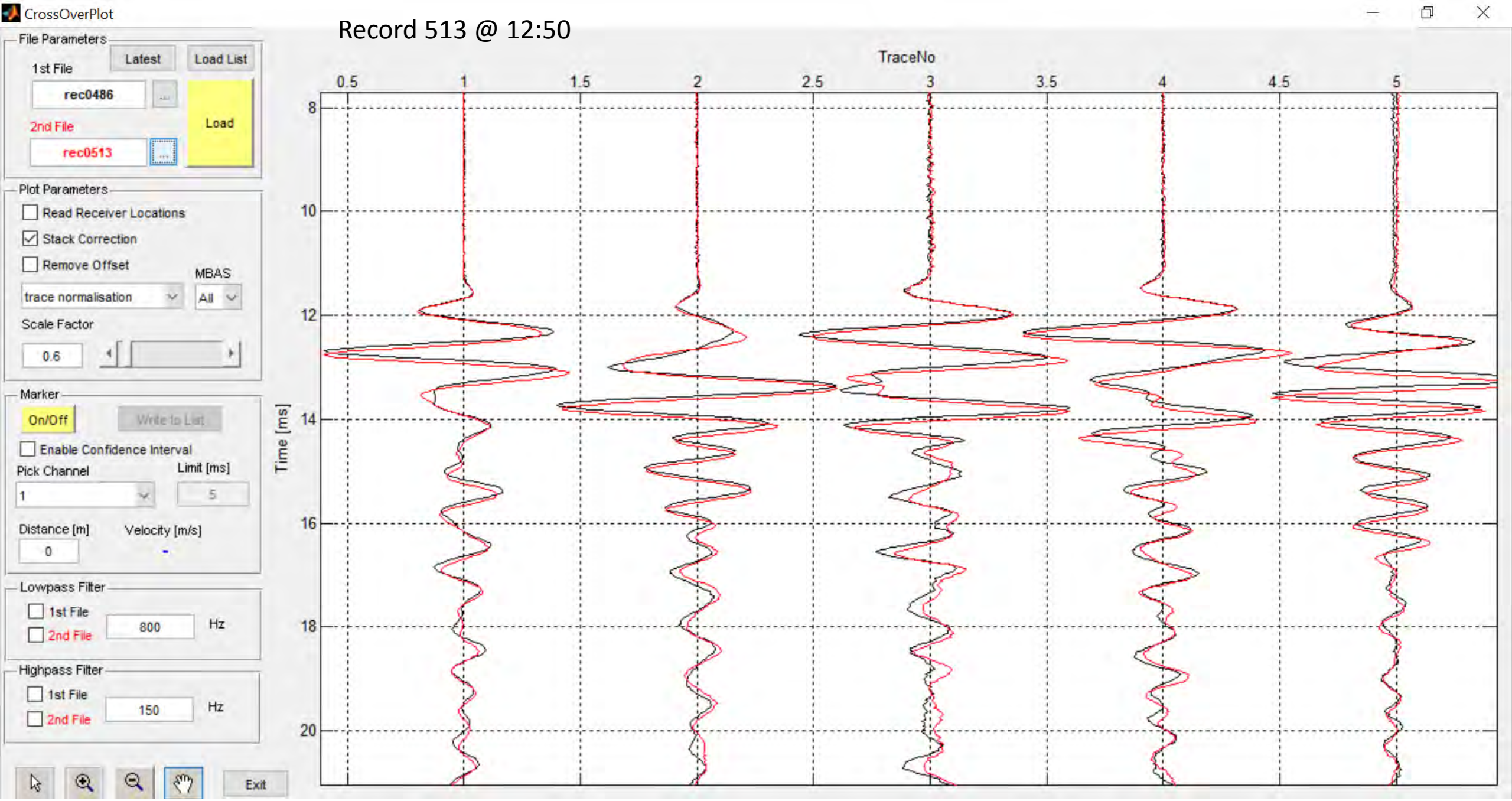
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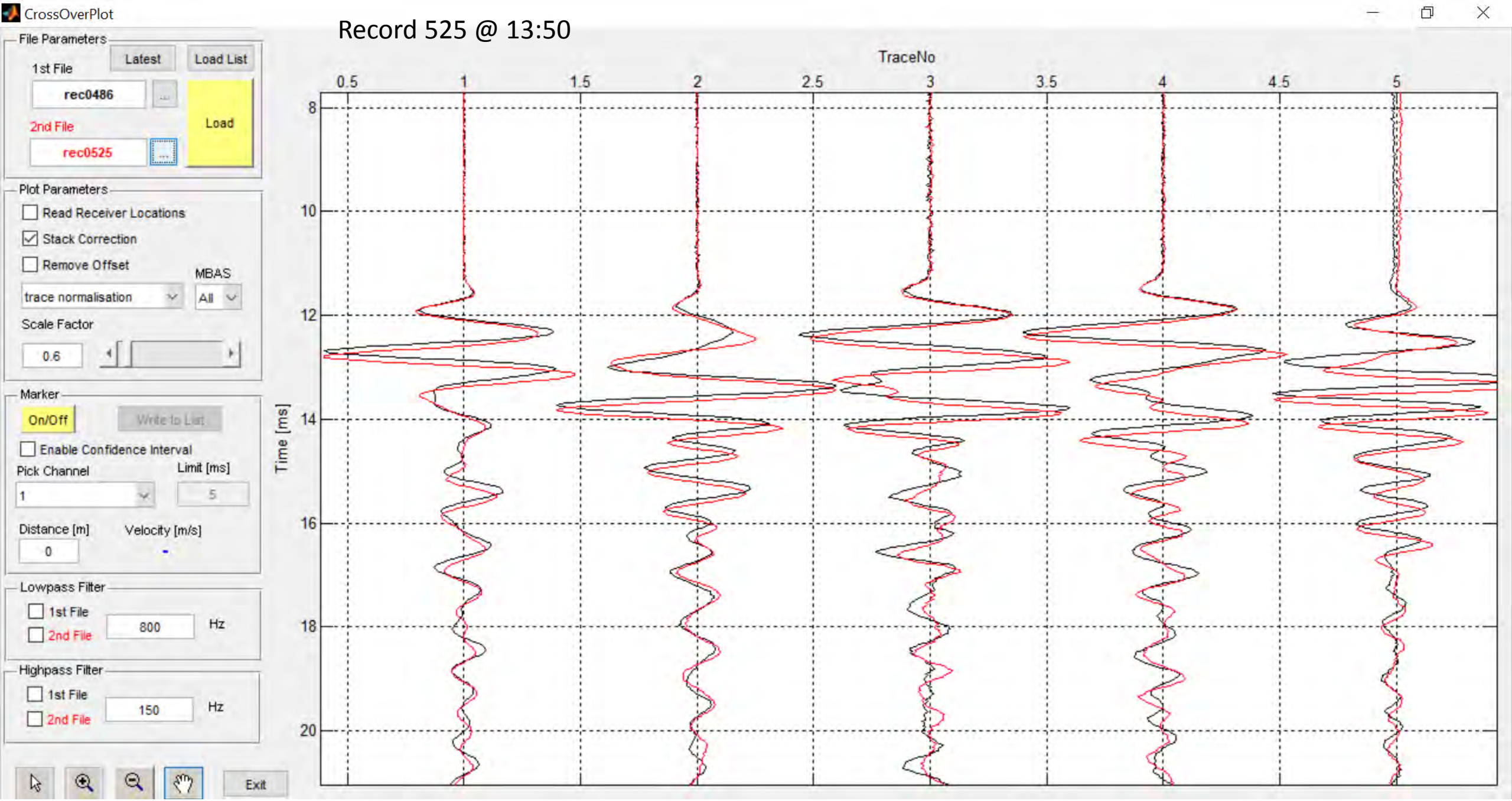
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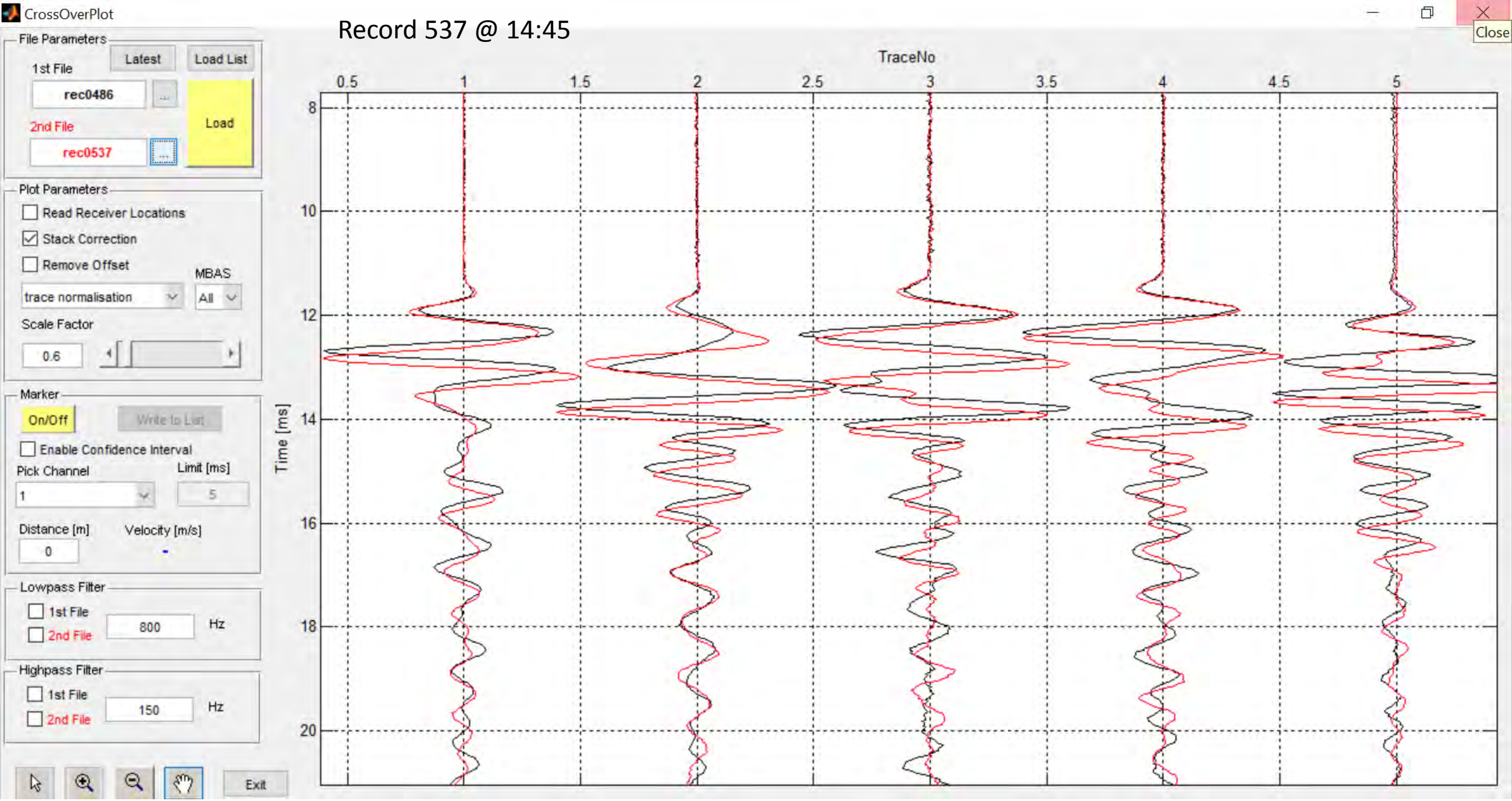
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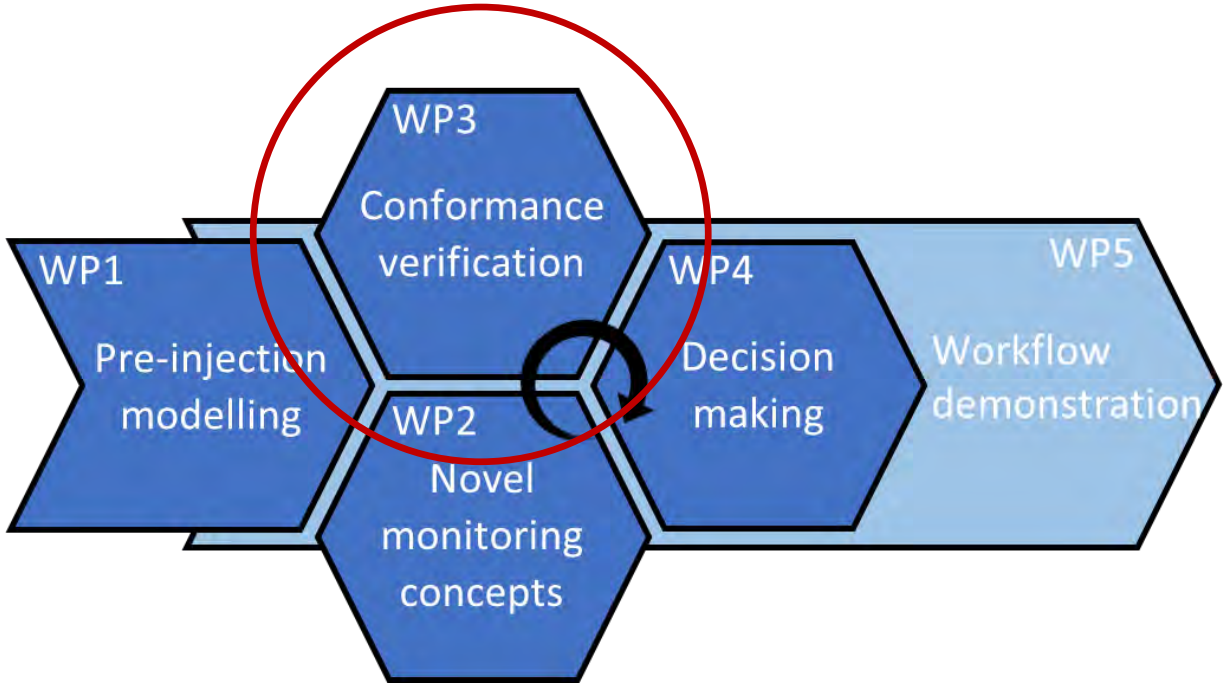
WP3: Conformance verification

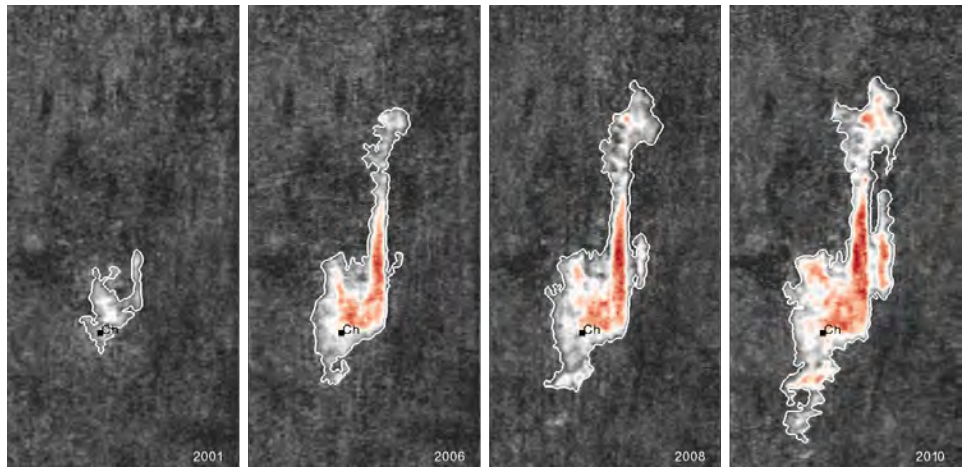
- WP leader: Stefan Carpentier (TNO)
- Construct a *workflow* integrating *multiple data types* and *uncertainties* for assessing *industrial scale* CO_2 storage site *conformance*
- Definition of 'conformance', confidence levels
- Optimal workflow and monitoring plan for determining conformance and making decisions



Saturation, pressure, and conformance

- Large scale CO_2 injection generates widespread changes in the subsurface.
- The consequences can be imaged or appraised with active and passive geophysical measurements and downhole monitoring.
- But what controls the size and scale of the subsurface anomalies?
- And what can a point measurement say about the entire storage reservoir?
- How can limited geophysical measurements demonstrate conformance of a storage site?

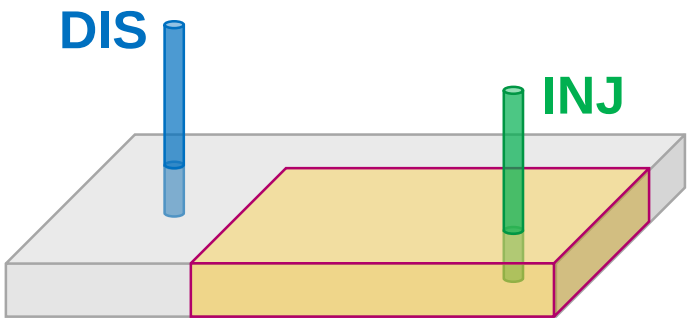
Conformance: history matching

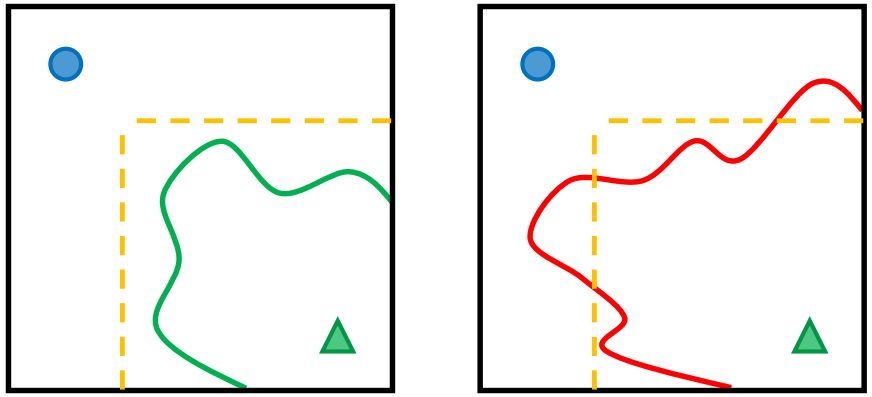


- CO2 migration can be accurately imaged with geophysical data.
- Flow simulations, based on the best estimates of reservoir parameters, allow prediction to be made.
- But results do not always match!

Case study

- Injected CO_2 must remain within regulatory/safety bounds
  - Quantity of interest: conformance verification at the end of injection period ($t = T$)



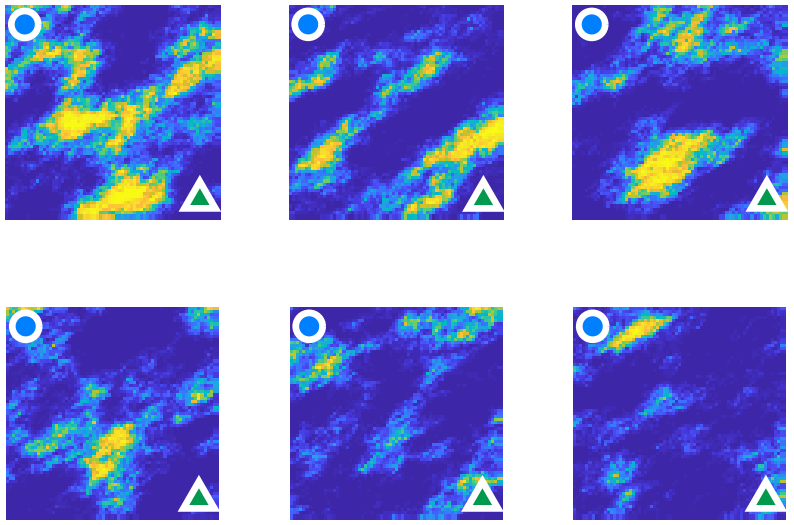


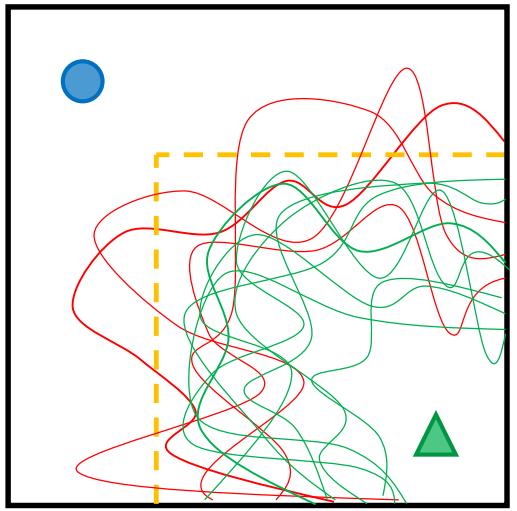
- Monitoring alternatives:
  - Time-lapse survey during interval $t = [0,T]$
  - How to design the configuration of such a survey?
  - Which configuration is most useful for conformance verification at $t = T$?

Value of information

Geological uncertainty

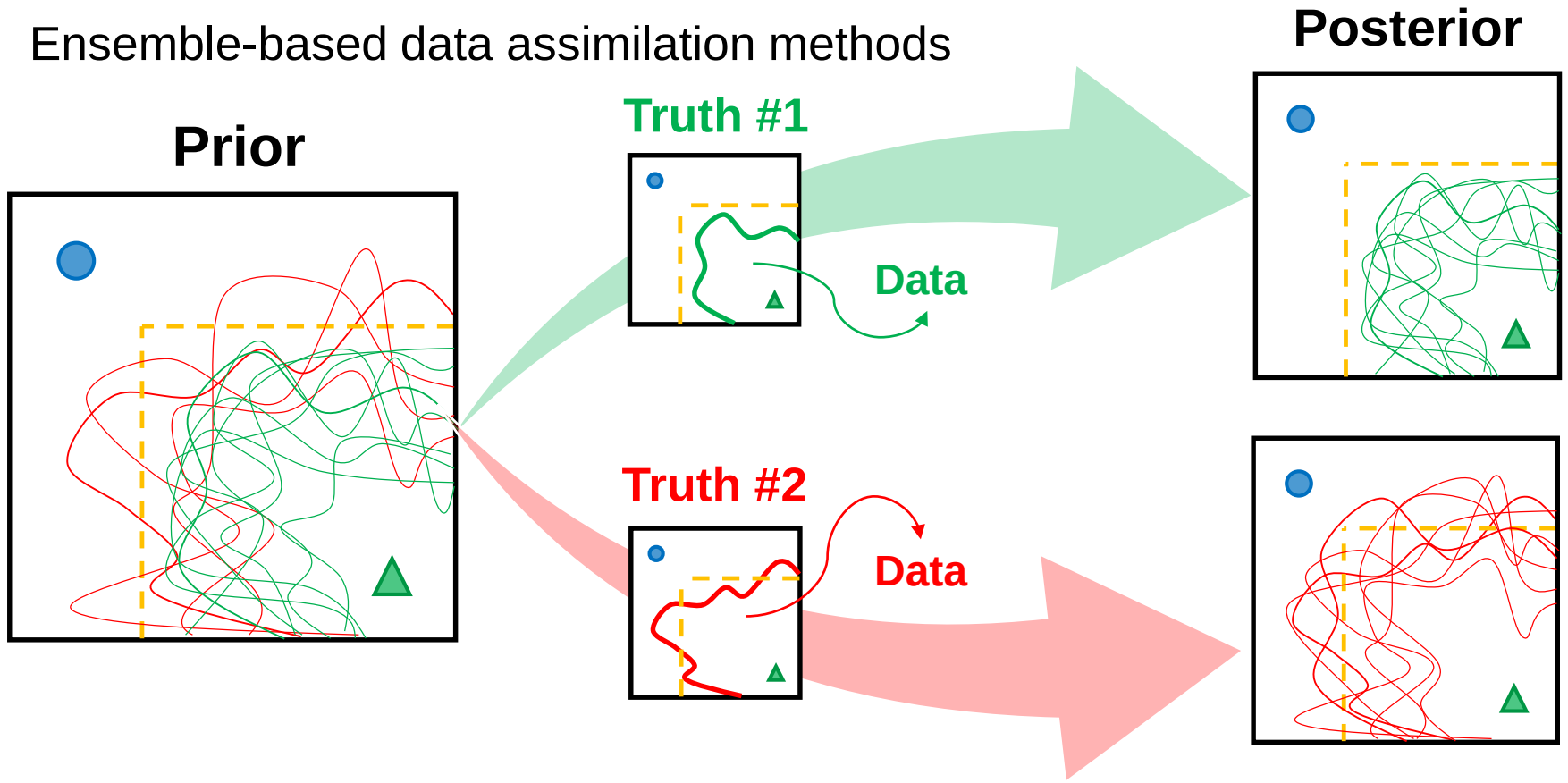
- Geological structures influence propagation of CO_2 plume (e.g., heterogeneities in rock properties)
  - Ensemble of model realizations to characterize geological uncertainty
  - Ensemble of model predictions → Probabilistic conformance assessment





History matching

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



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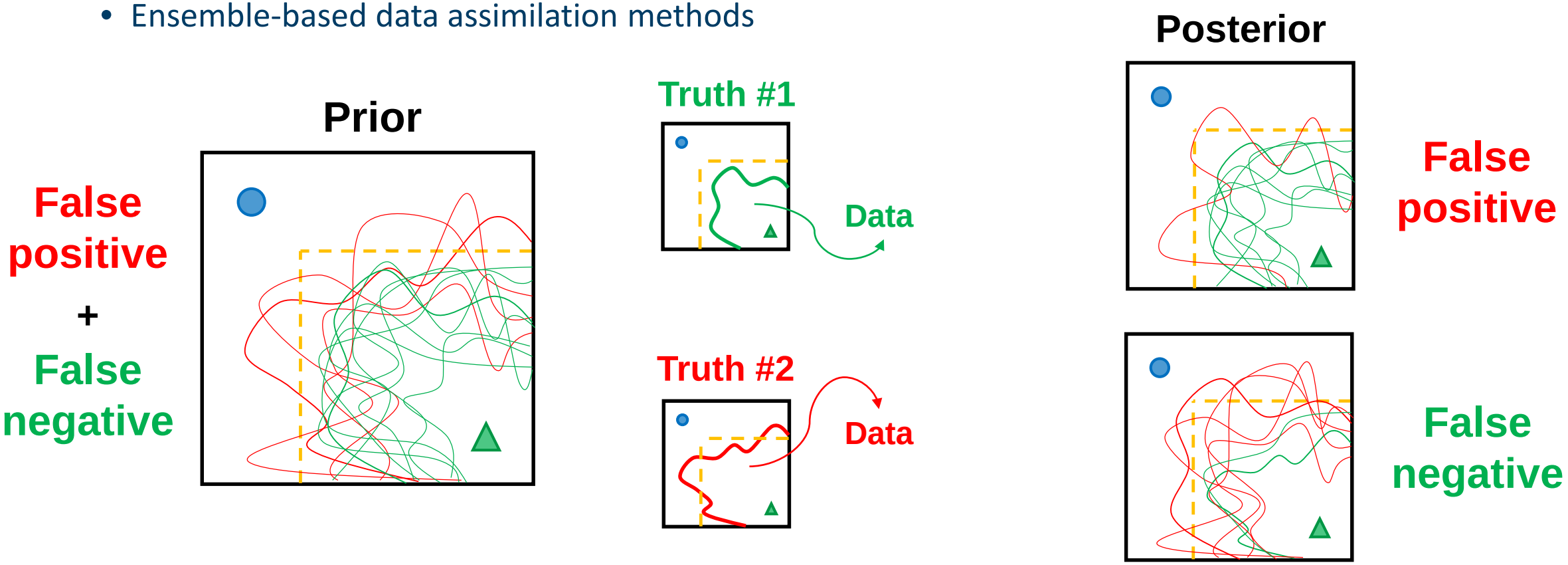
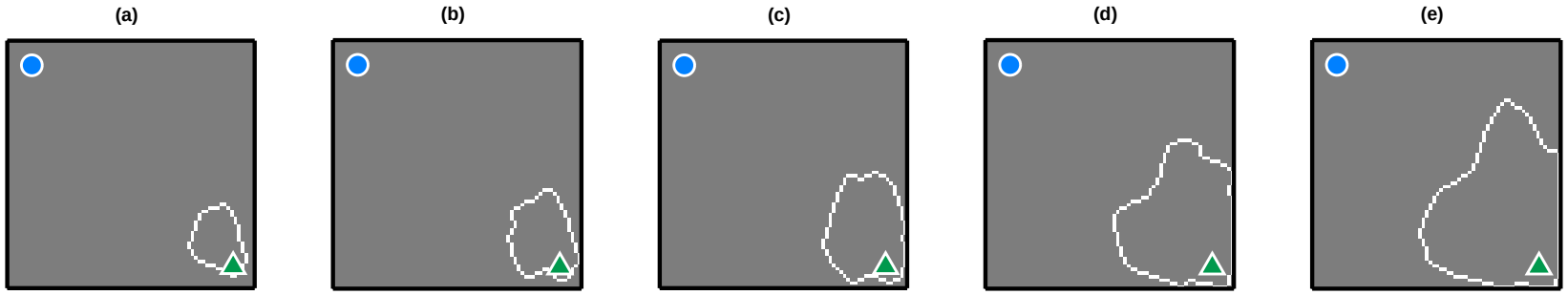
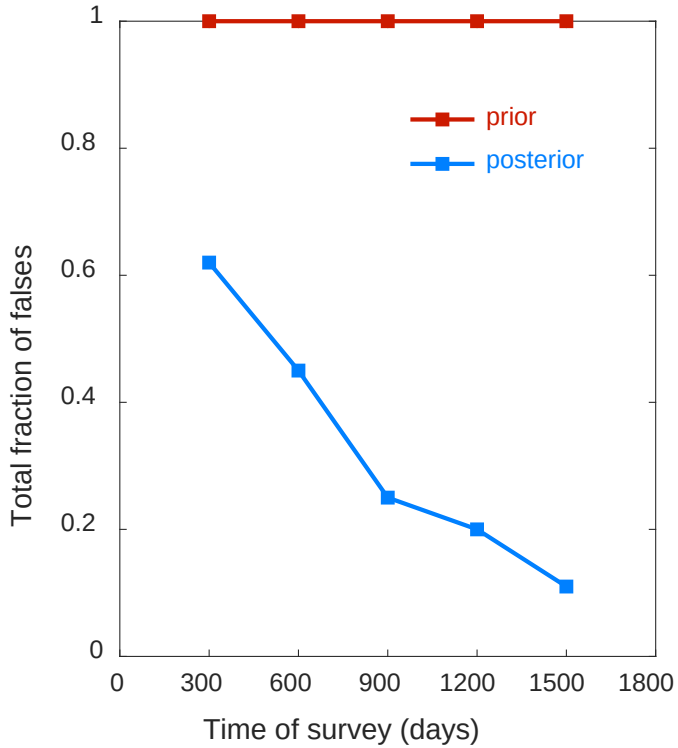


Survey considerations

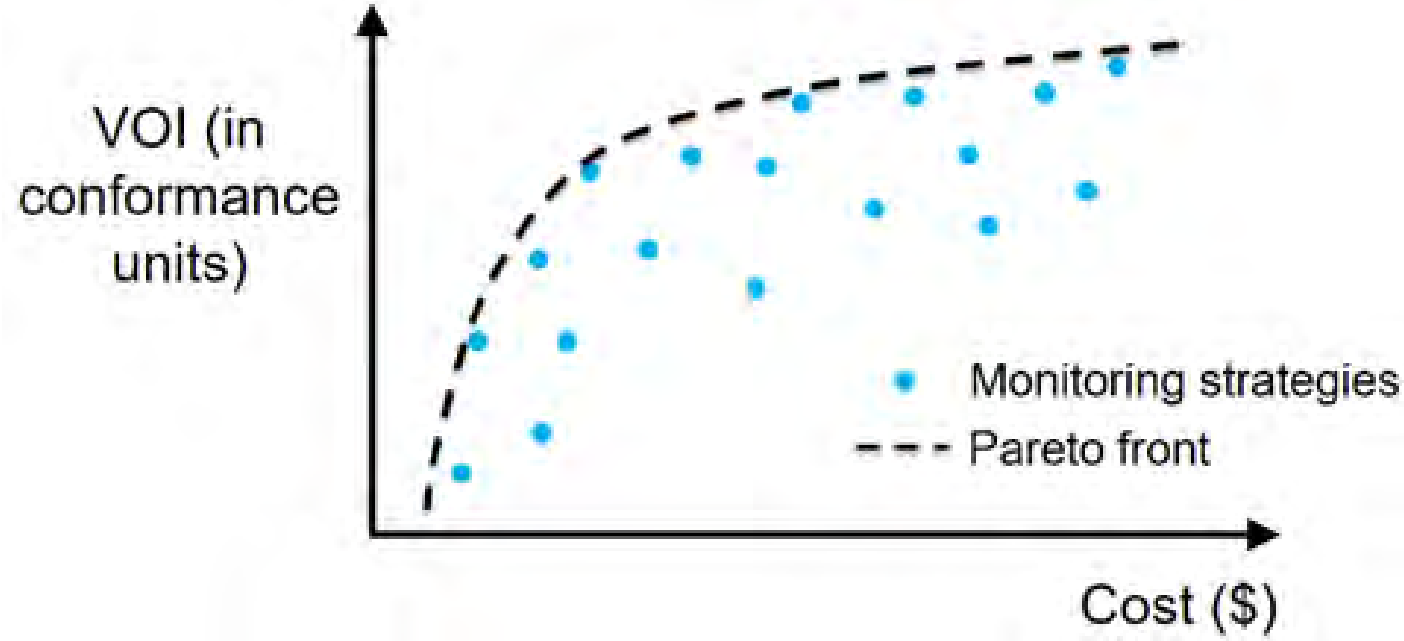


- Varying time of acquisition



Value-of-information

- **Expected gain** (in conformance units) and **deployment costs** ($) associated with each configuration in the search of the best **trade-off**
- **Impact on CCS industry:** More cost-effective monitoring surveys through 1) lower survey effort and 2) faster turnaround leads to 3) earlier decision making and 4) more grip on uncertainties



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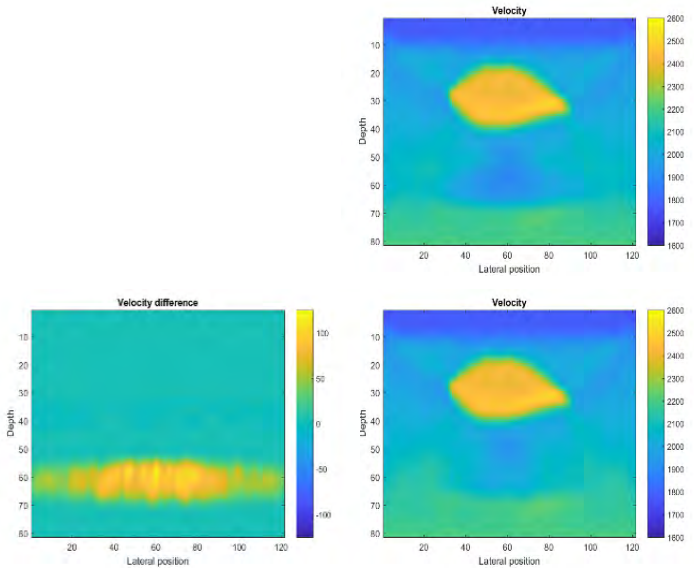
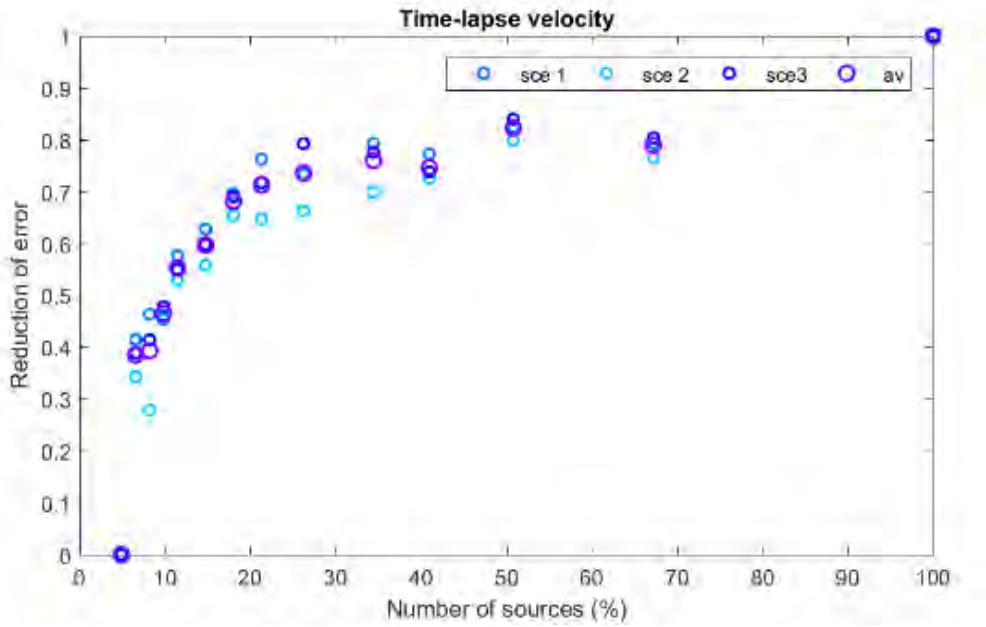
- **Expected gain** (in conformance units) and **deployment costs** ($) associated with each configuration in the search of the best **trade-off**
- **Impact on CCS industry:** 80% result for 20% effort (enough for well-informed decisions)





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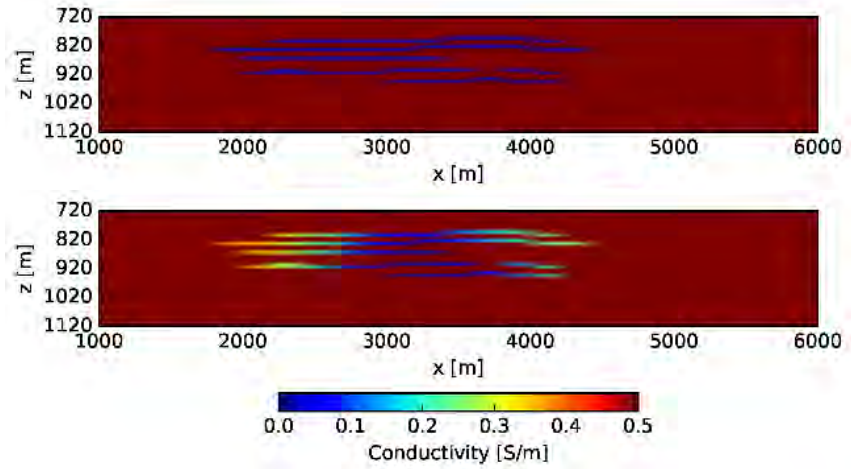
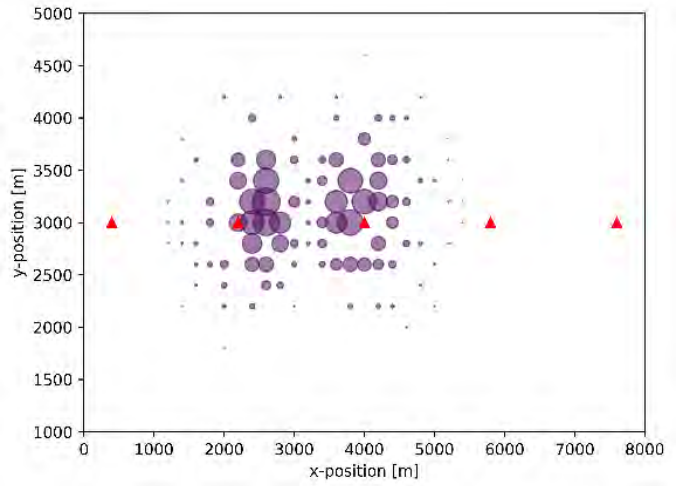
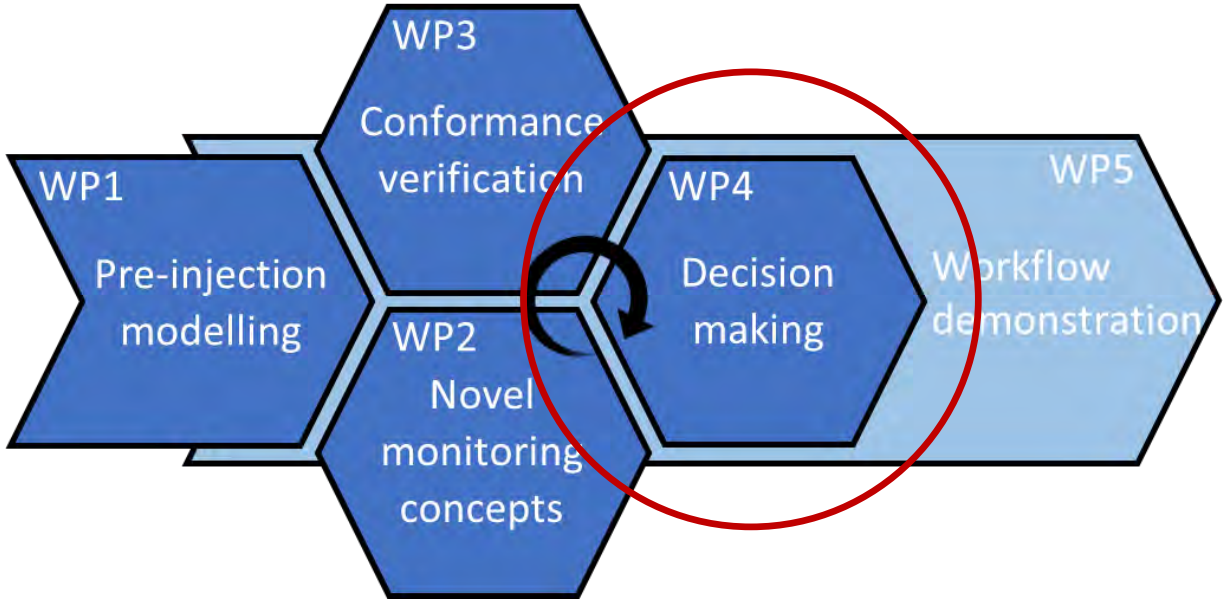




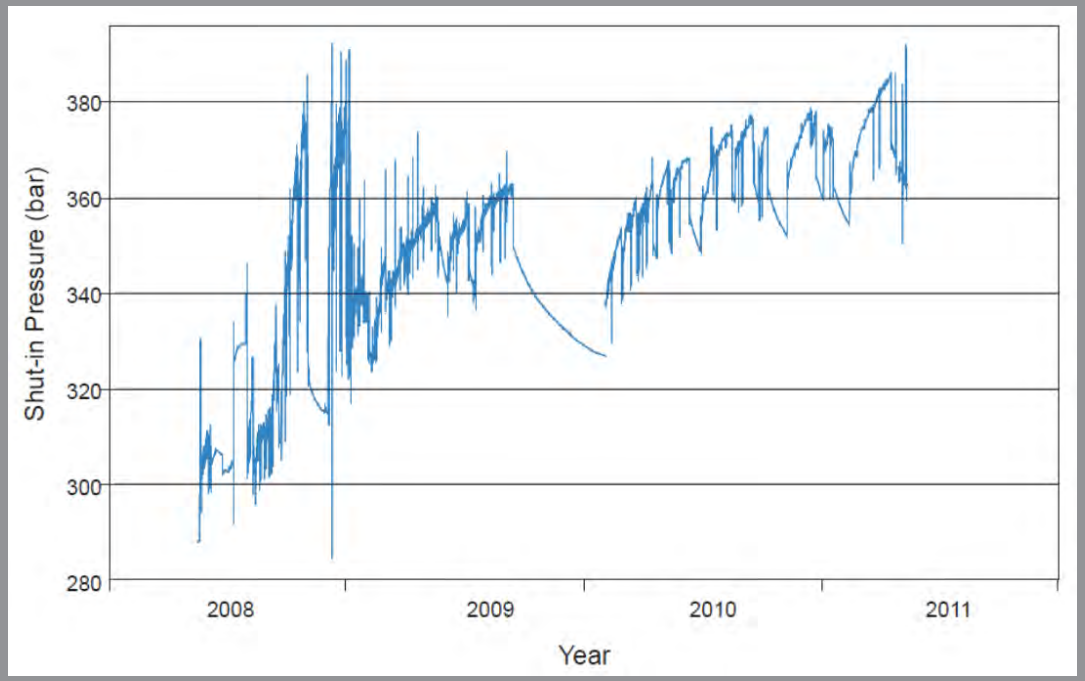
WP4: Decision making

- WP leader: Alv-Arne Grimstad (SINTEF)
- Investigate and describe procedures that should be set in motion if a conformance test has failed
- Enable knowledge-based decision-making
- Explore consequences of possible actions



WP4 Context

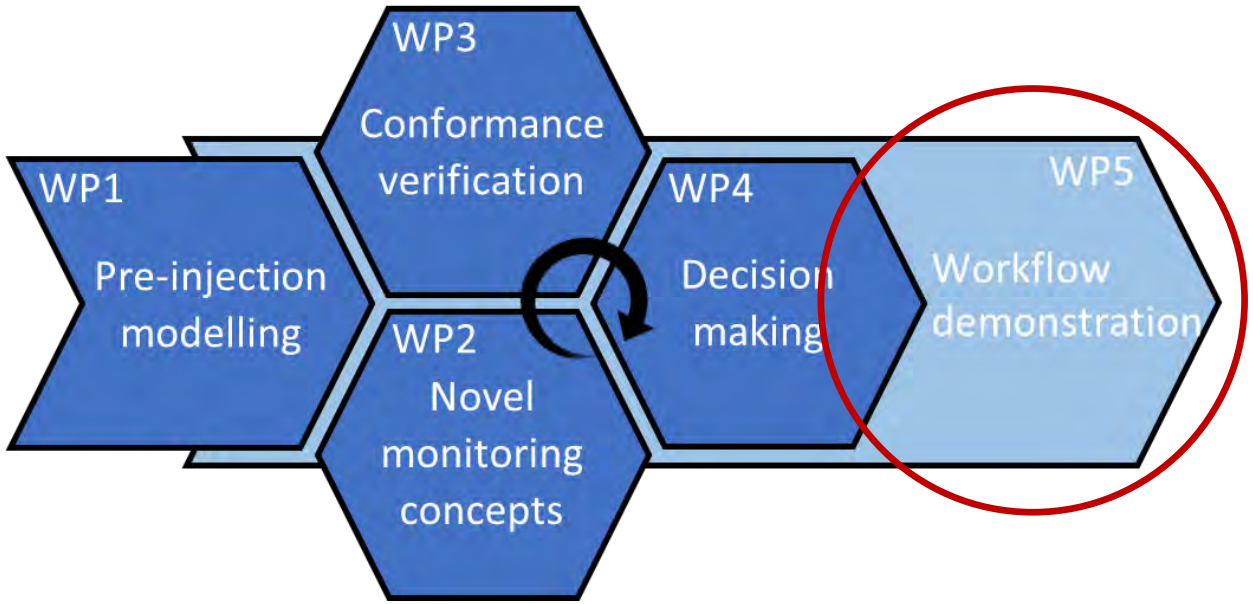
- What does a failed conformance test signify?
- Monitoring data indicates that the storage site behaviour cannot with **sufficient certainty** be said to be consistent with predictions
- Predictions of future storage site behaviour should show safe containment (by "definition")
- A failed conformance test therefore means that we are **not sure** that the site develops in a manner that ensures containment of injected CO_2



Development of shut-in pressure at Snøhvit Tubåen. Predicted exceed of estimated fracture reactivation pressure (390 bar) led to change of injection plan.
From Hermanrud et al, 2013; Figure 6.

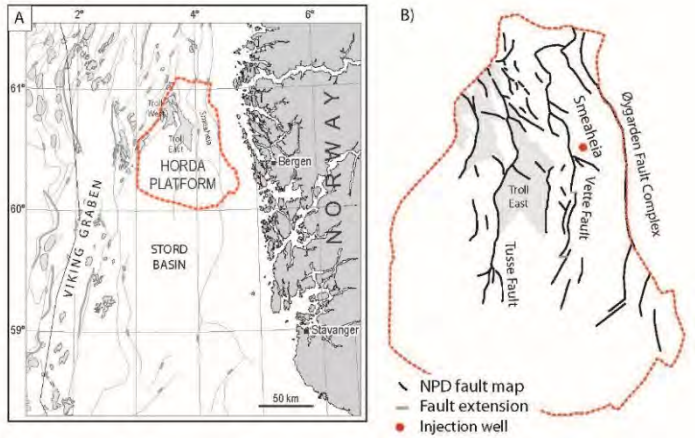
WP5: Workflow demonstration

- WP leader: Ane Lothe (SINTEF)
- Demonstrate value of project results through **application of the methodology developed in WP1–WP4** to storage scenarios at realistic sites
- **Communicate the results to stakeholders**: authorities, regulators, policy and decision makers, politicians, etc.

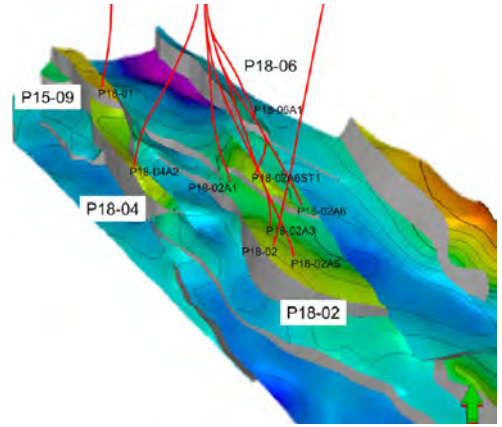


Workflow demonstration

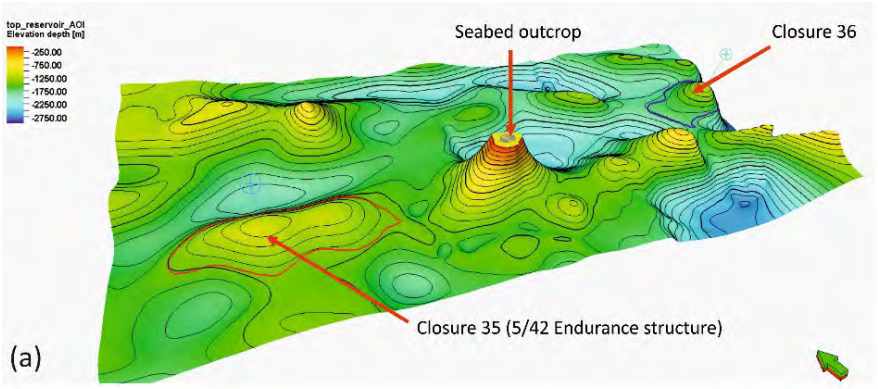
- **Smeaheia case** (SINTEF, Equinor)
  - Effect of gas Troll production on regional pressure depletion
  - Base injection plans to account for uncertainties
  - Develop a monitoring plan addressing changing baseline
- **P18-4** *(TNO, TAQA)*
  - Base-line injection plans will be tested and optimised
  - A monitor plan will be designed
- **Endurance** (BGS, Shell)
  - Case study based on pressure linked injection operations
  - Focus on water extraction and boundary limits to control injection and extraction rates
- **Snøhvit** (SINTEF, Total)
  - Extra case being discussed



Lothe et al. (2018)



Arts et al. (2012)



Stakeholder workshops

- 1st meeting in Trondheim, 10 April 2019
  - "First government exploitation permit for CO_2 storage at the Norwegian Continental Shelf"
- 2nd meeting in Brussels, 10 October 2019
  - "Mission: Safe and cost-efficient CO2 storage for European industry"
- 3rd meeting in "Oslo", 14 November 2019
  - Svelvik official opening
- 4th meeting (TBD, February 2020)

www.sintef.no/projectweb/svelvik-co2-field-lab

Acknowledgements

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