PRE-ACT

- SAFE AND COST-EFFICIENT CO_2 STORAGE

Peder Eliasson, SINTEF

4th ACT Knowledge Sharing Workshop

Divani Palace Acropolis Hotel, Athens, 6 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

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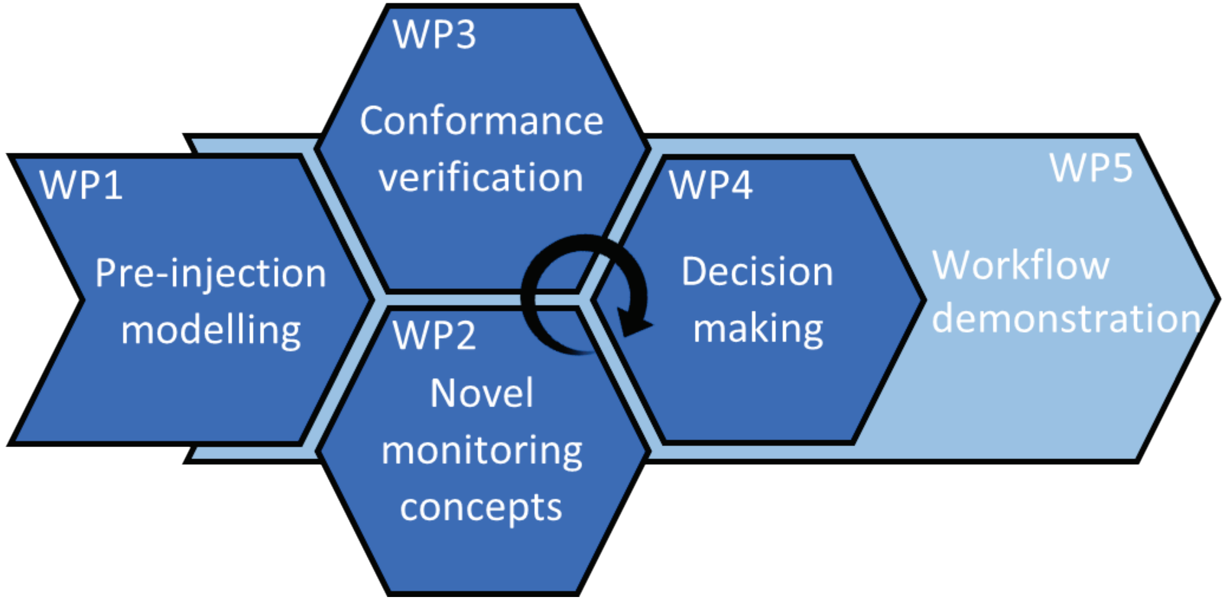
- Methodologies and recommendations for **cost-efficient monitoring, reliable conformance assessment and decision making** (Pre-ACT Protocols)
- North Sea case studies:
  - Smeaheia (SINTEF, Equinor, ++)
  - P18-4 (TNO, TAQA, ++)
  - Endurance (BGS, Shell, ++)
- Workshops with industry, stakeholders,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



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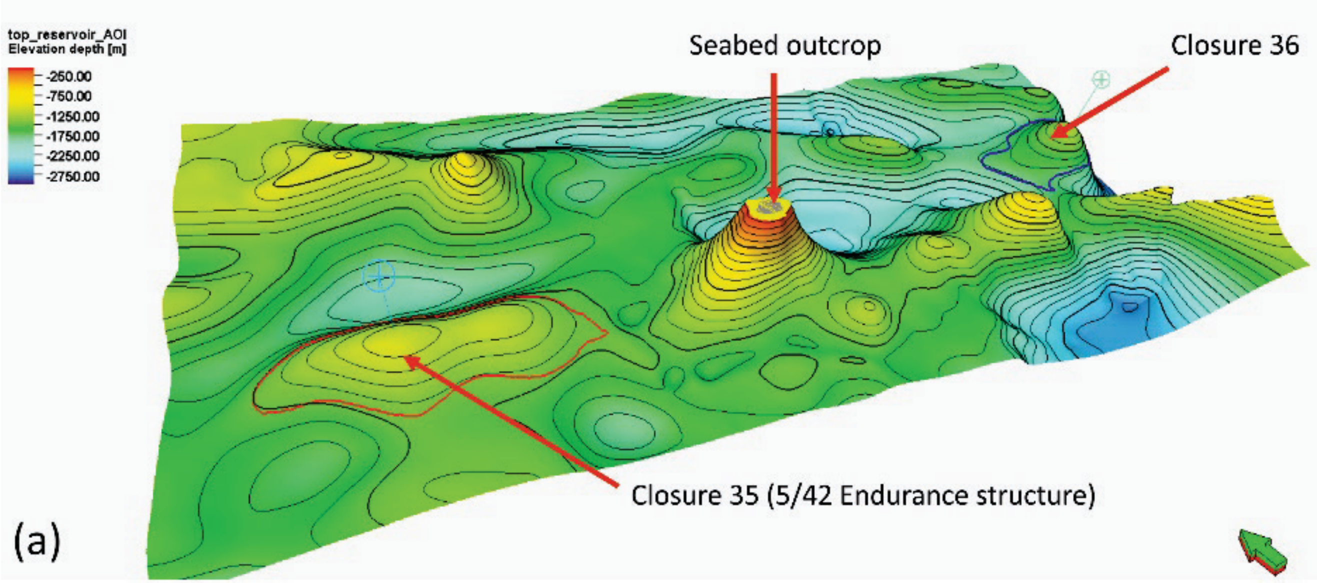

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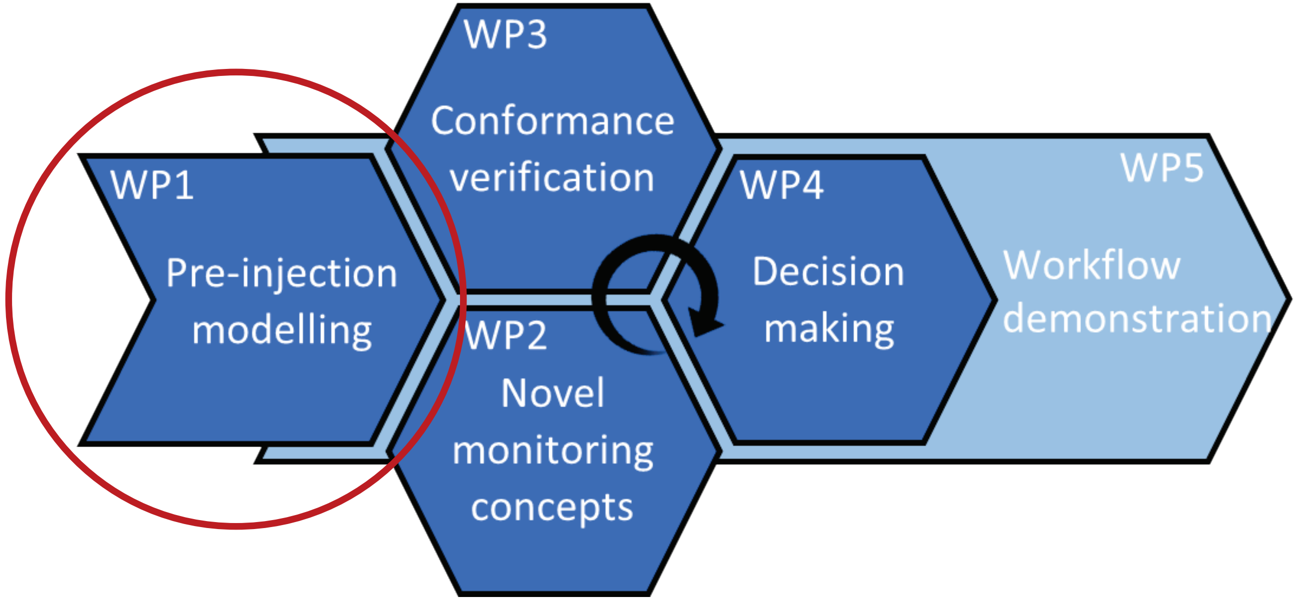
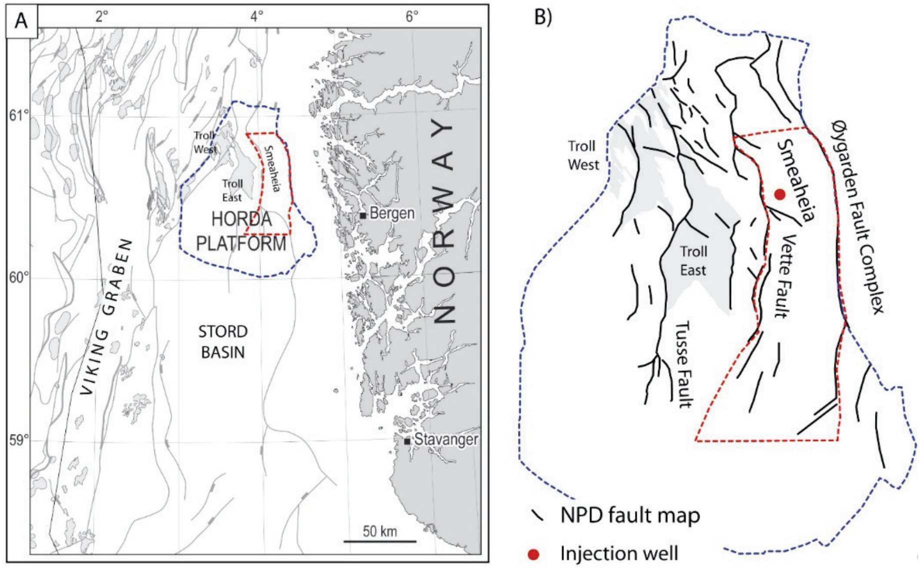
WP1: Pre-injection modelling

- 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

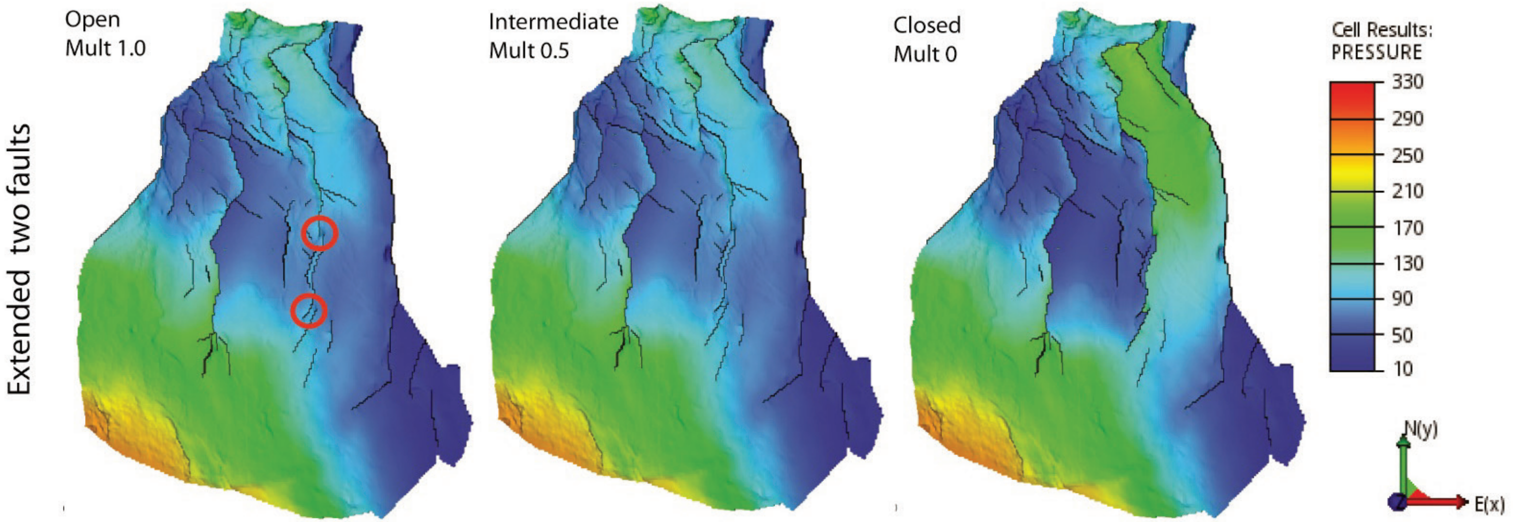


Fault heterogeneity

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



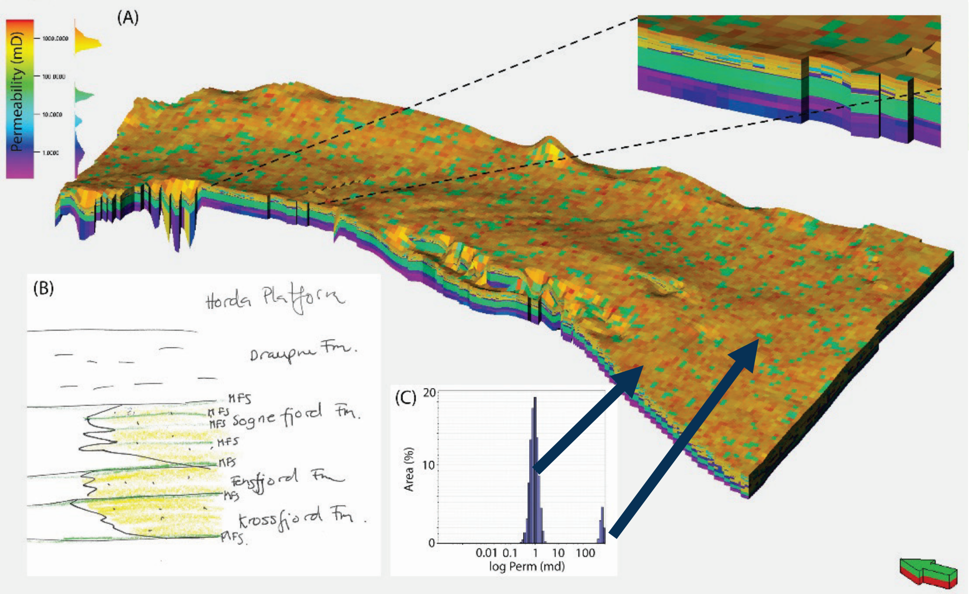
Lothe et al.,(2019)



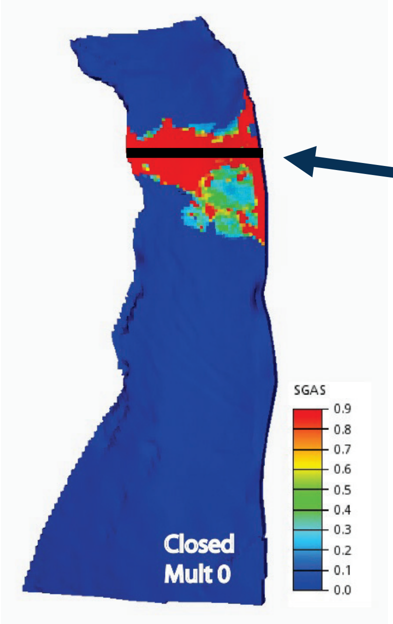
Lothe et al. (2018)

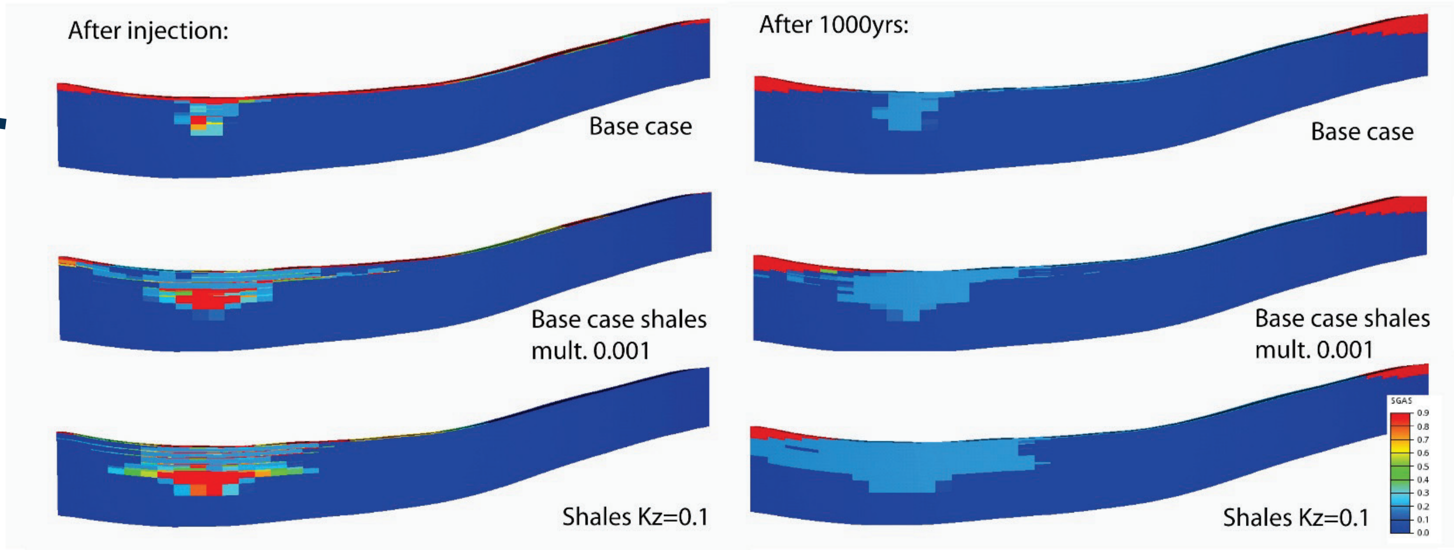
Heterogentities in reservoir

- Study effect of facies related heterogeneities (400x400 m grid block) using 27 layers.
- The base case is a stochastic model with clay layers and localized zones of high permeability.
- CO_2 injection rate is constant at 3 Mt/yr for 50 yrs
- Injected CO_2 migrates rapidly toward east, here with sealing faults
- Tighter clay layers result in more dissolved gas



Base case permeability distribution for the clay-rich layers, with patches of sands.

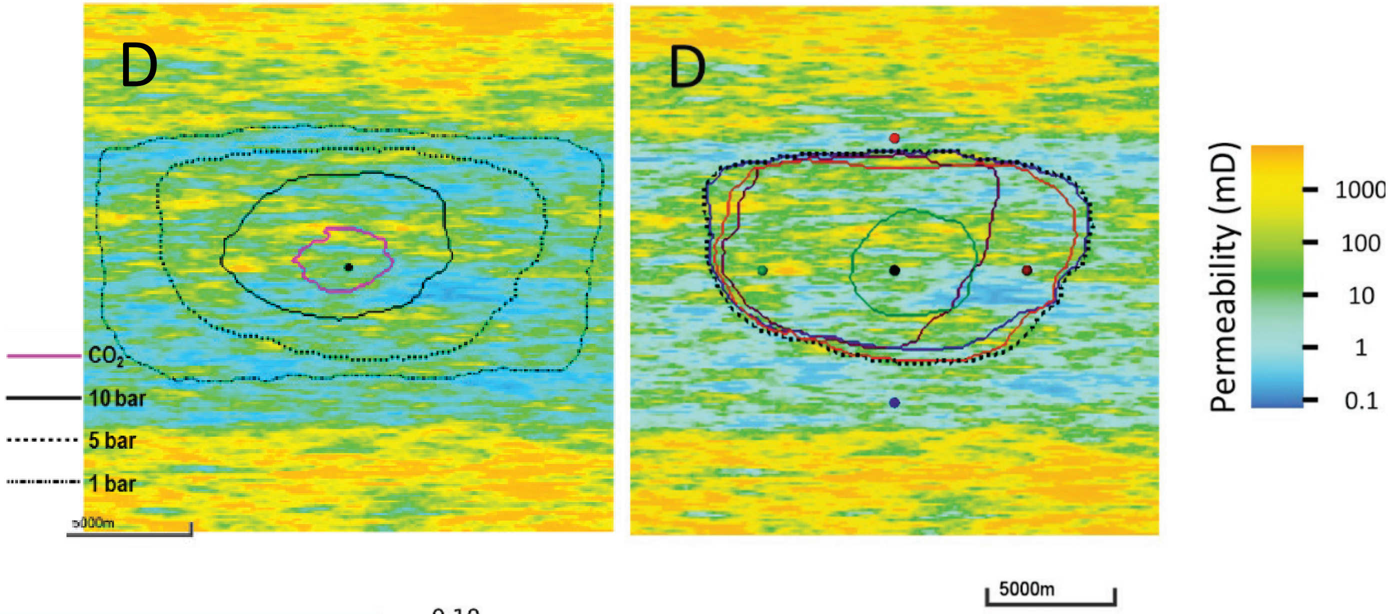


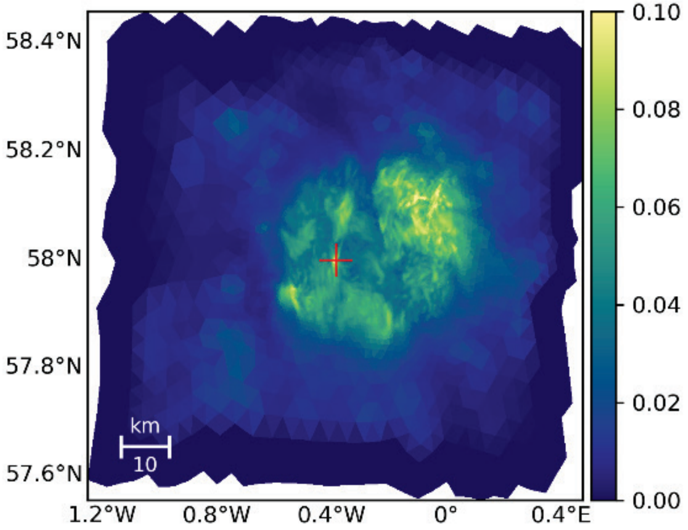


From Lothe et al. (2019)

Pressure control

- Effect of geological heterogeneities on pressure studied
- Four different production well locations compared
- Various orientation and degree of heterogeneity (case D shown here)
- Impact of hypersaline discharge also modelled

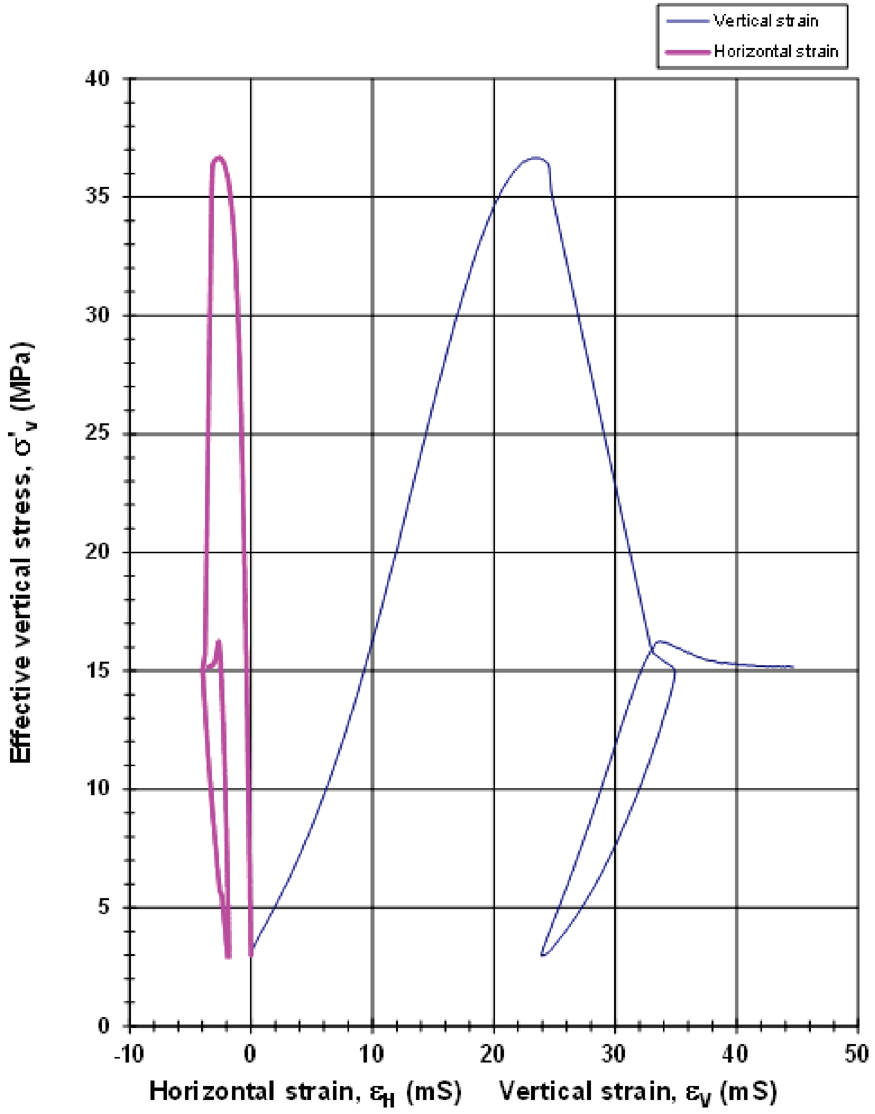




https://youtu.be/EmQv4qk0kUo

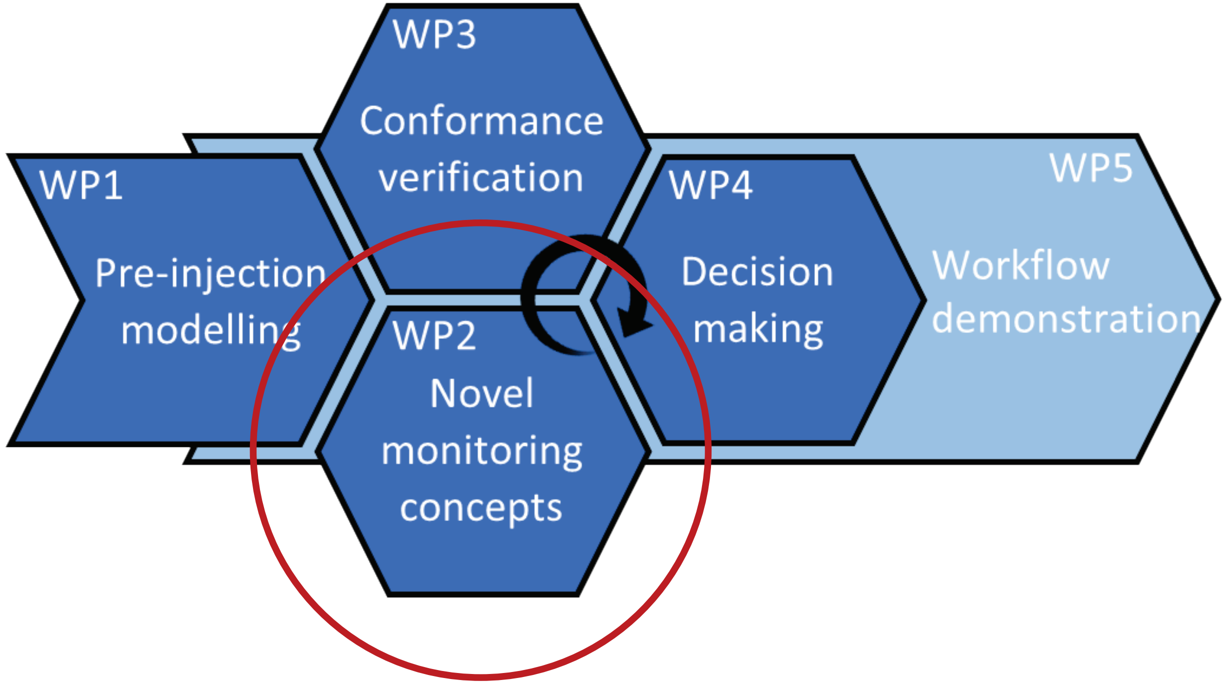
Geomechanical lab studies

- Acoustic Emission tests on-going at NGI
  - First results available
- Thermal stress tests on-going at SINTEF
  - Modelling at TNO



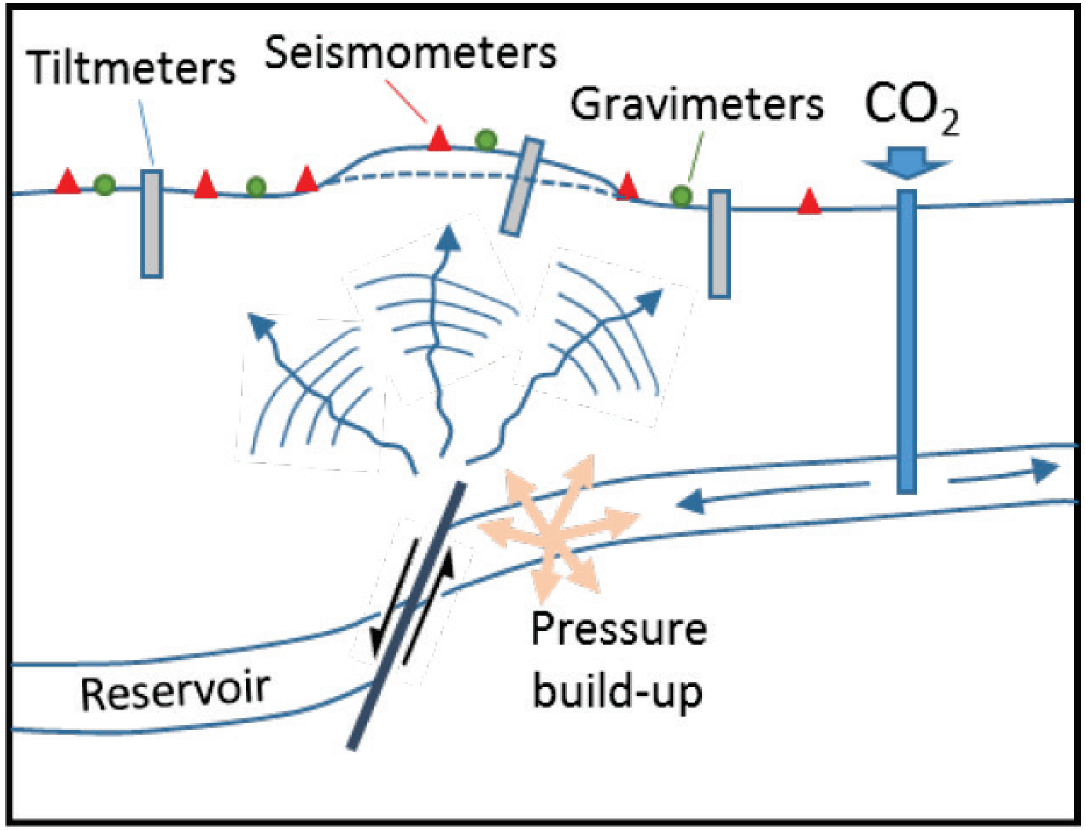
WP2: Novel monitoring concepts

- 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



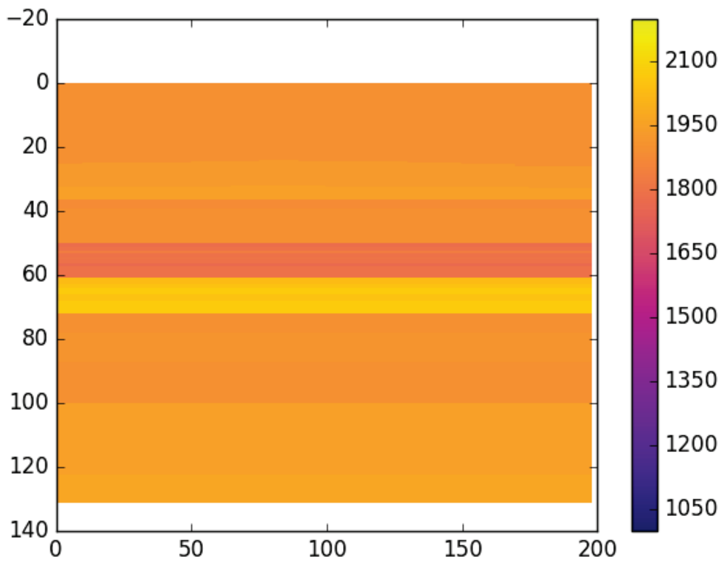
Passive-active monitoring workflow

- 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

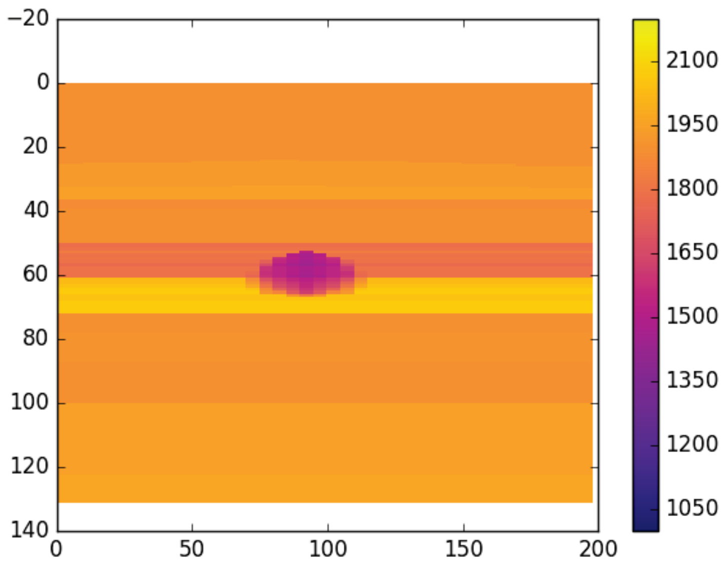


Ambient Noise Seismic Interferometry

- Velocity (v_p) models for low containment case



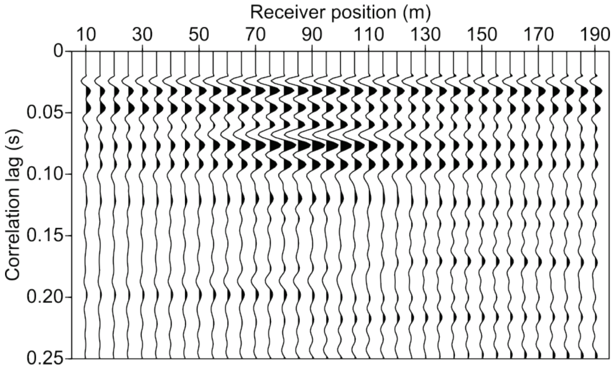
v_p at d_0



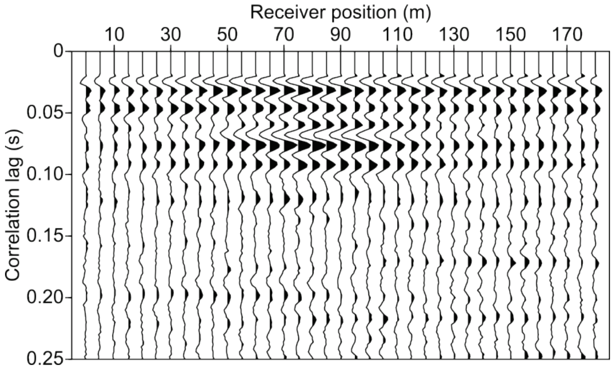
v_p at d_15

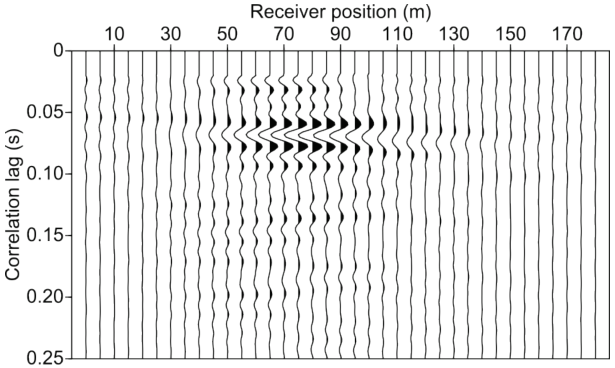
Ambient Noise Seismic Interferometry

- Retrieved auto-correlations (fmax=70)

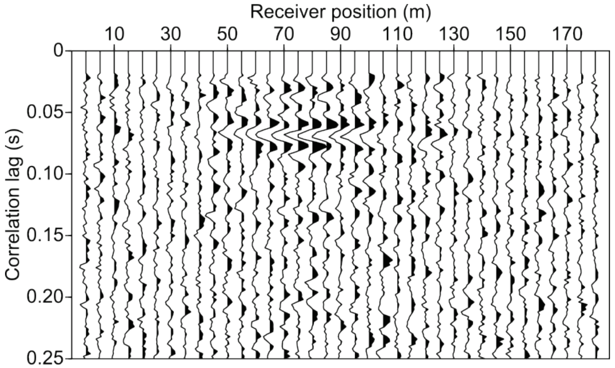


d_15





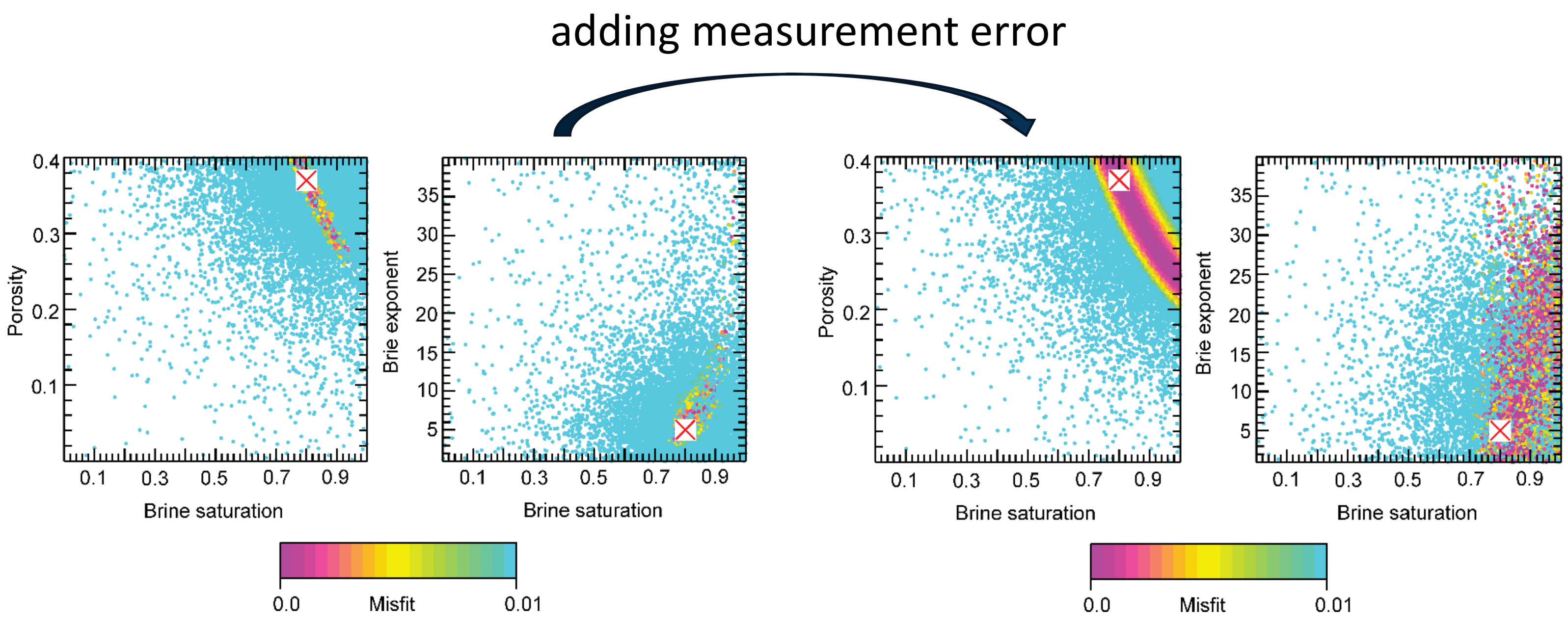
(d_15 - d_0) x 2



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



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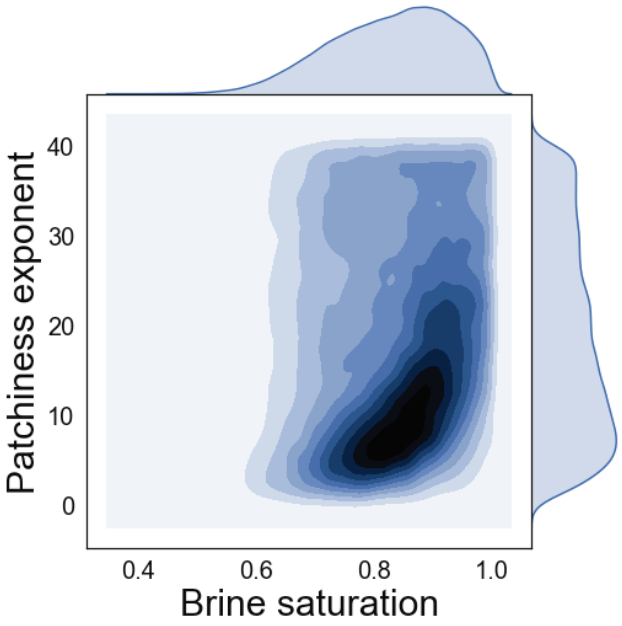
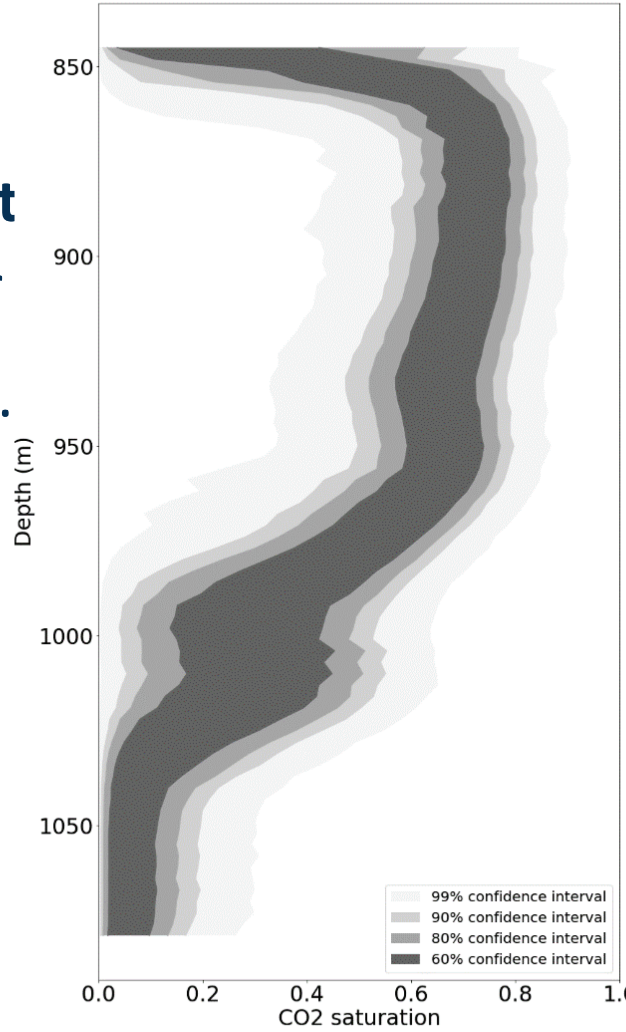
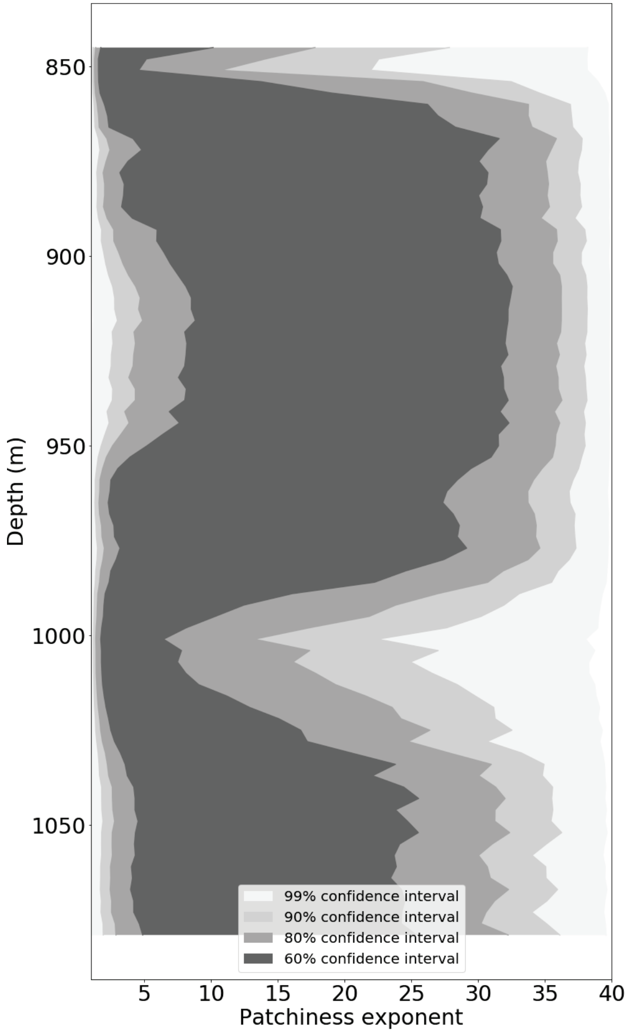


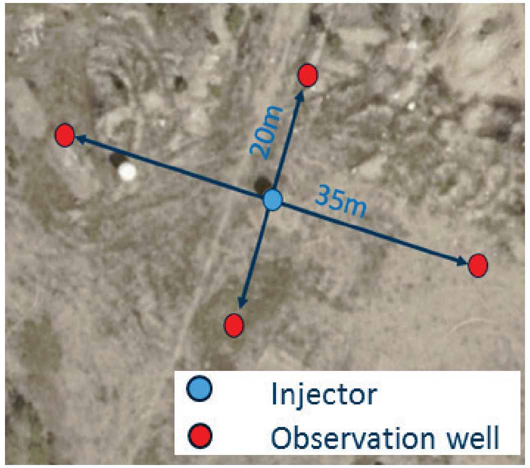


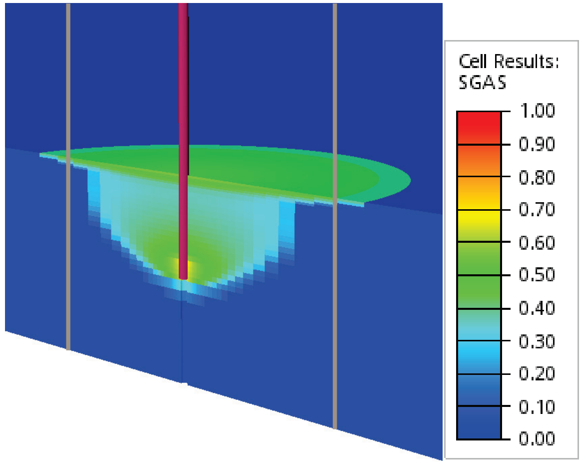


Dupuy et al. (presentation at Petroleum Geostatistics 2019)

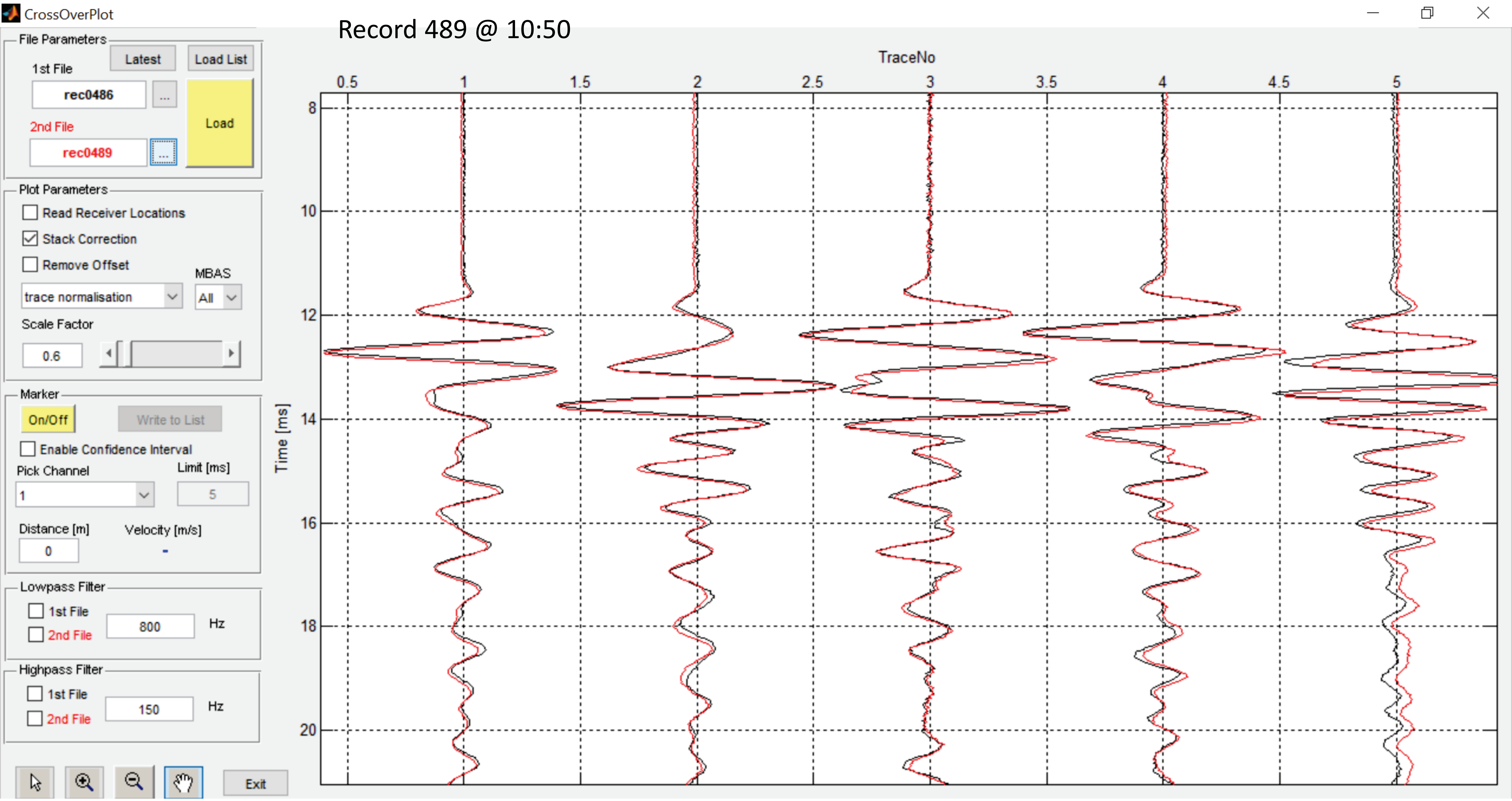
Svelvik CO_2 Field Lab

- 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





Record 489 @ 10:50



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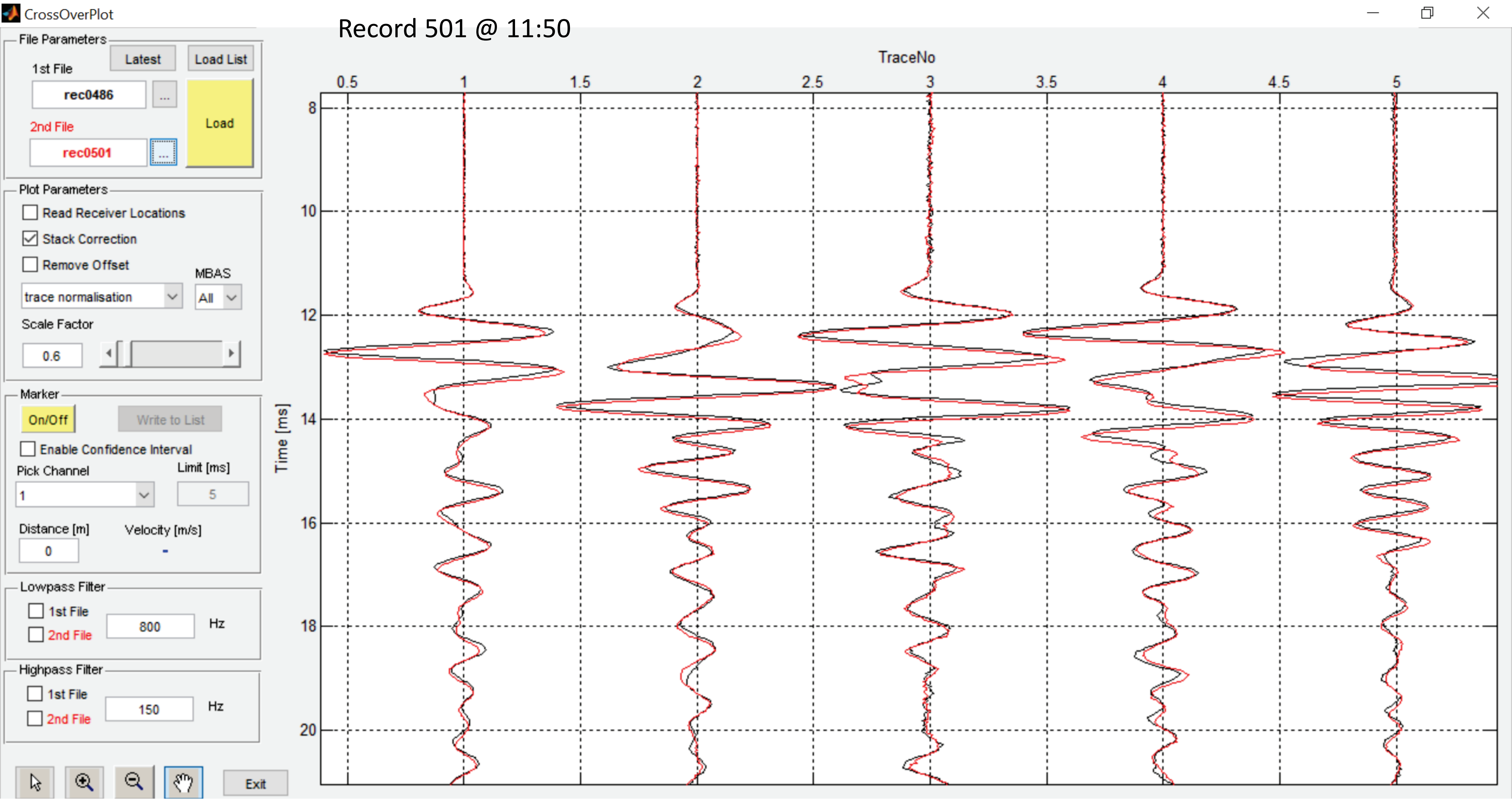

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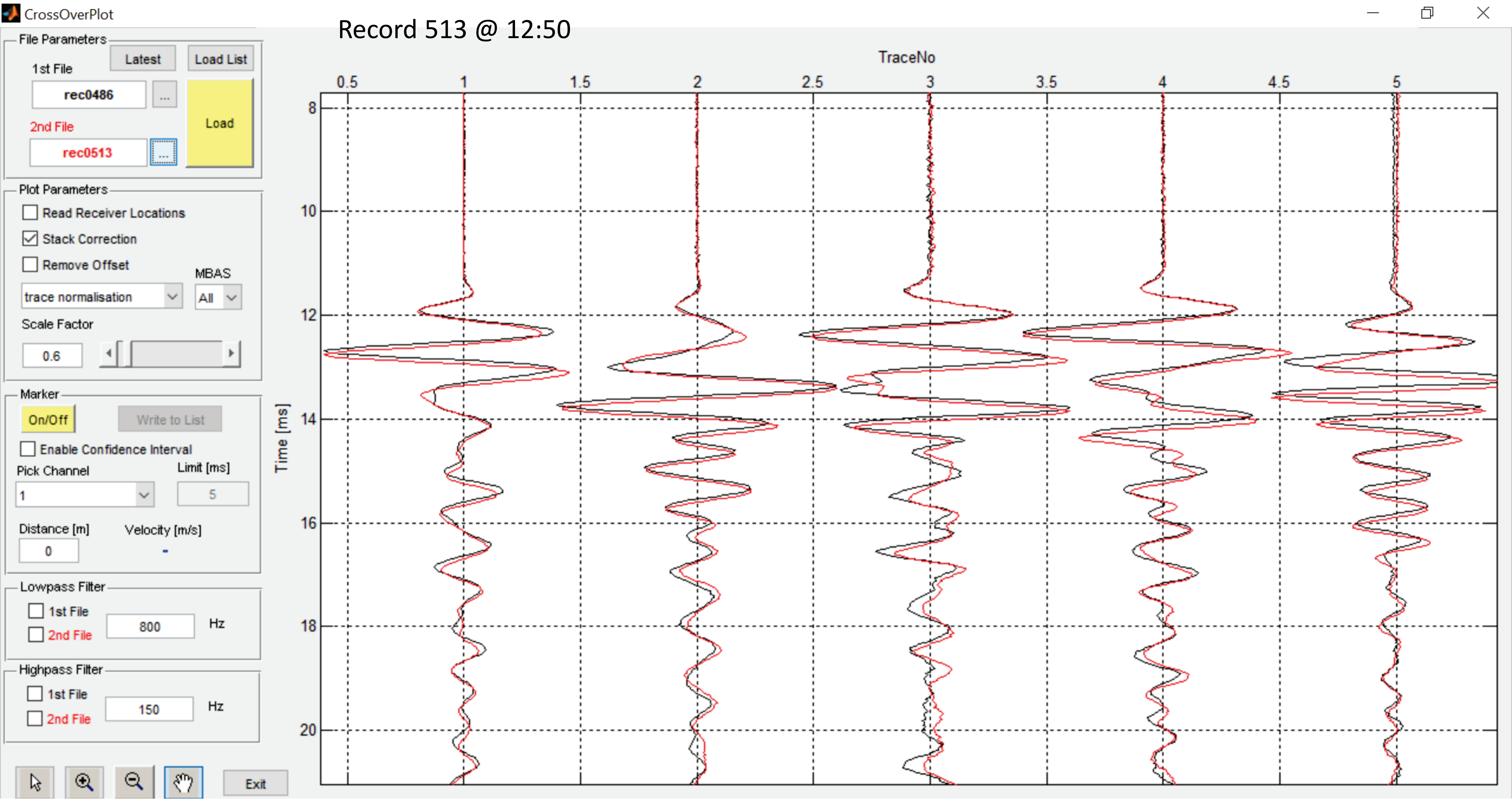

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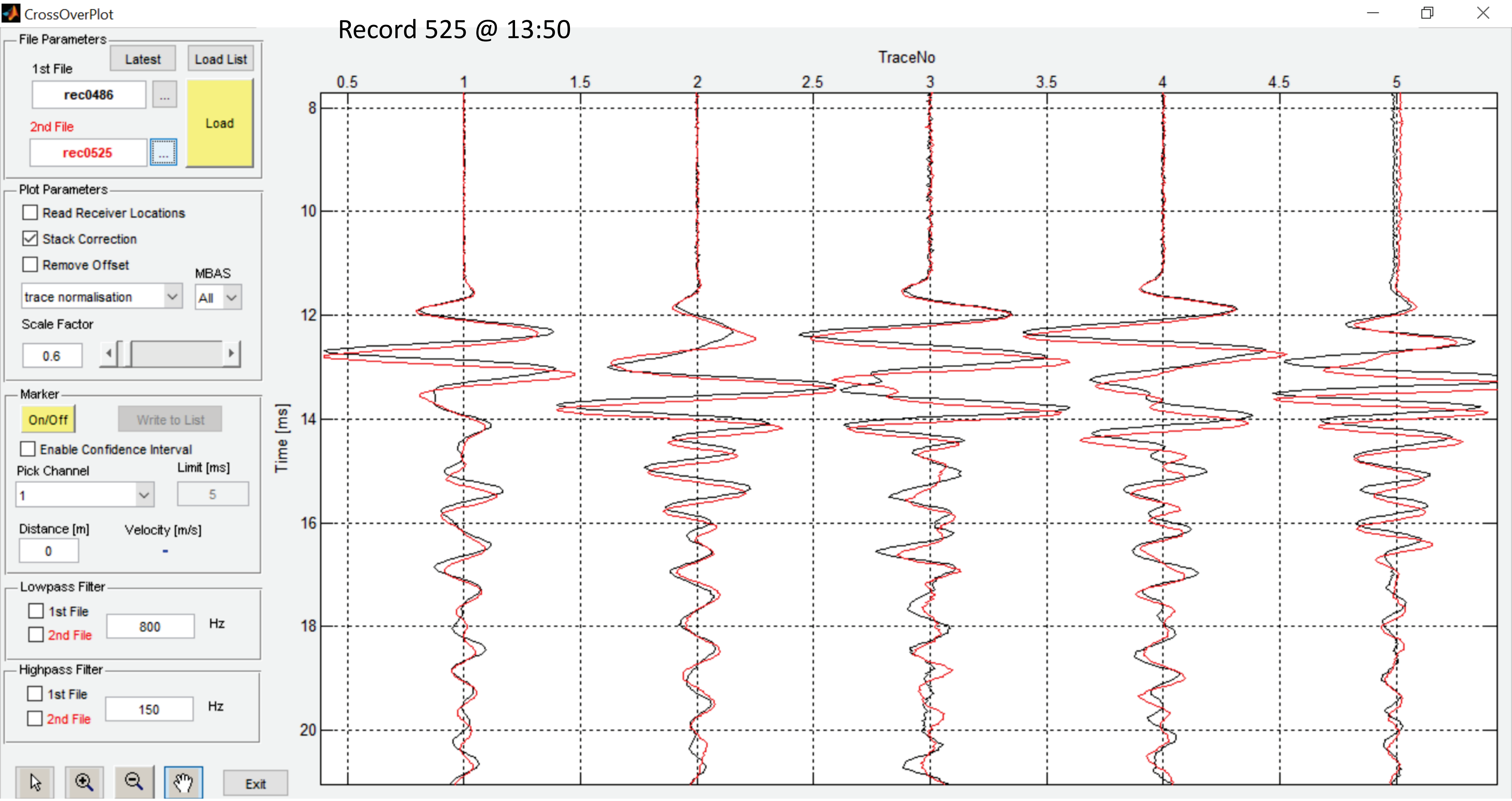

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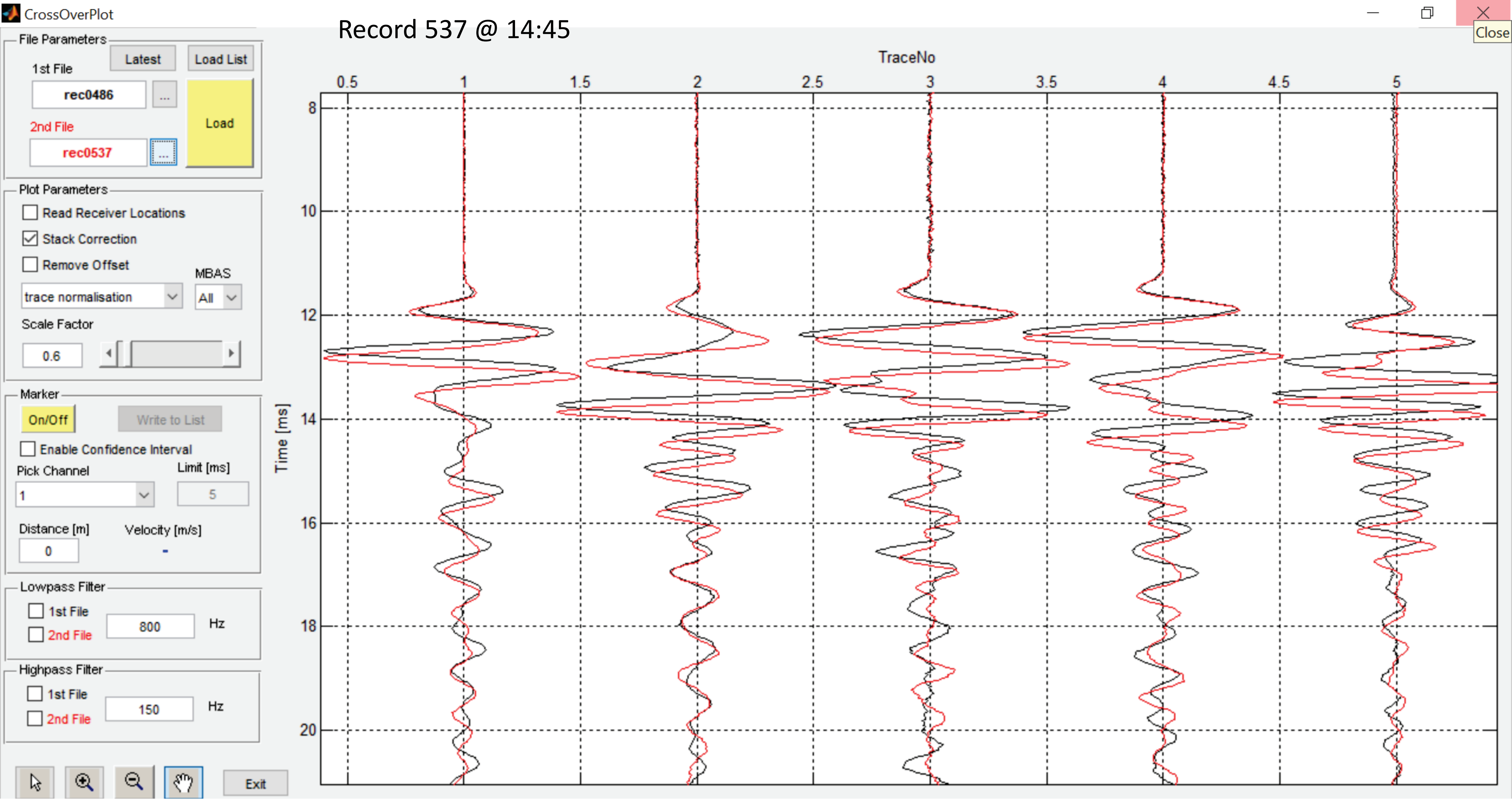
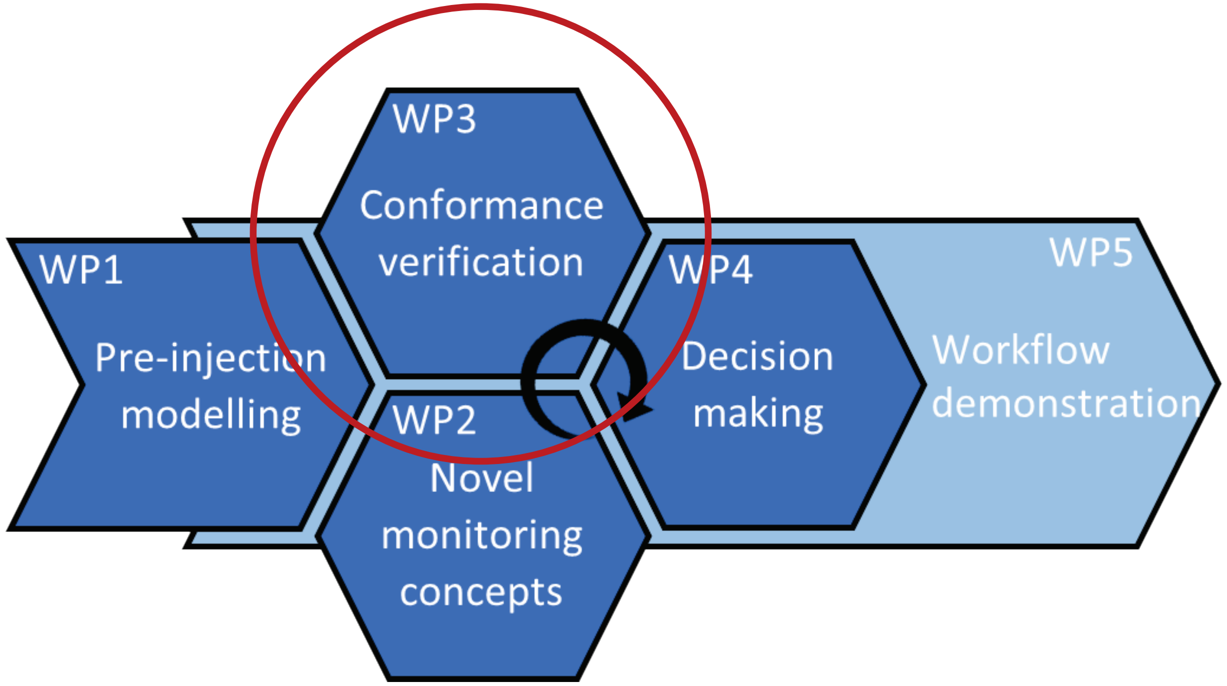
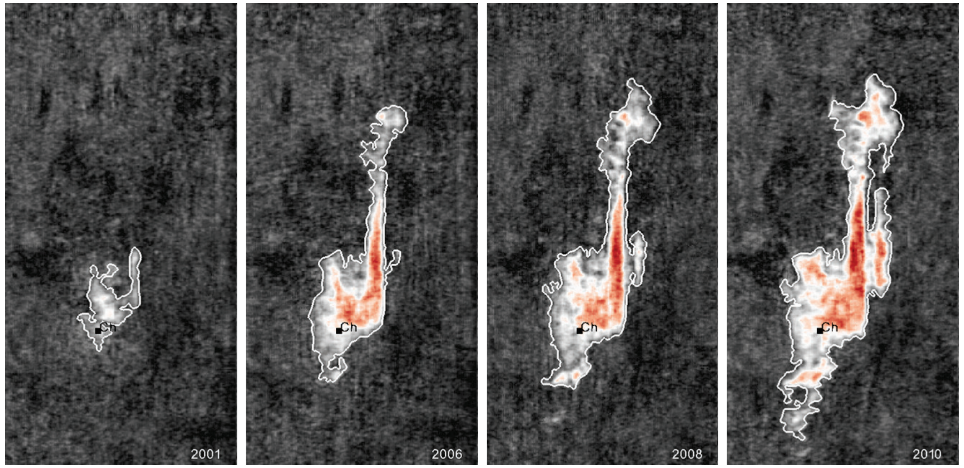


WP3: Conformance verification

- 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



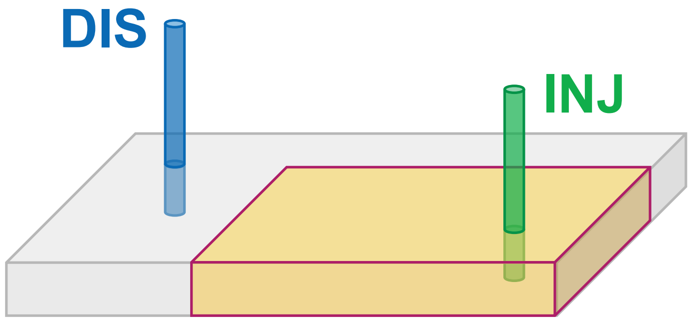
Conformance: history matching

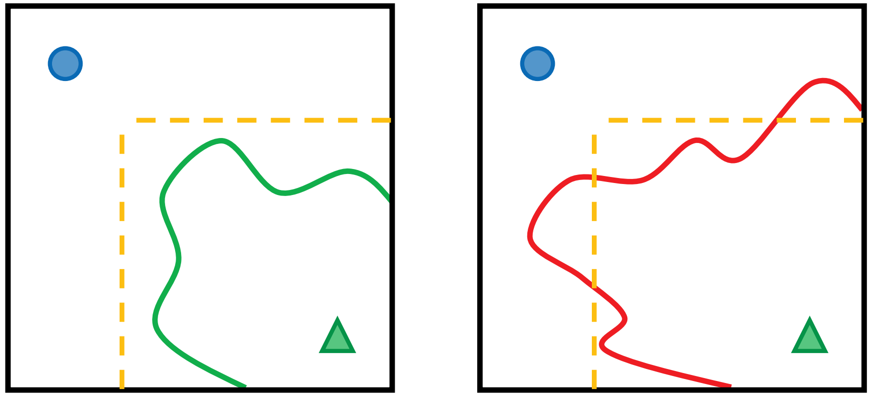


- CO_2 migration can be accurately imaged with geophysical data.
- Flow simulations, based on the best estimates of reservoir parameters, allow prediction to be made.
- But results do not always match!

Conformance and value-of-information

- Injected CO2 must remain within regulatory/safety bounds
  - Quantity of interest: conformance verification at the end of injection period (t = T)

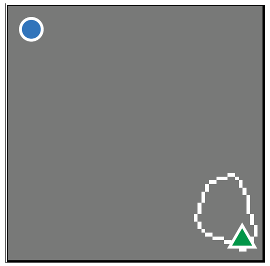




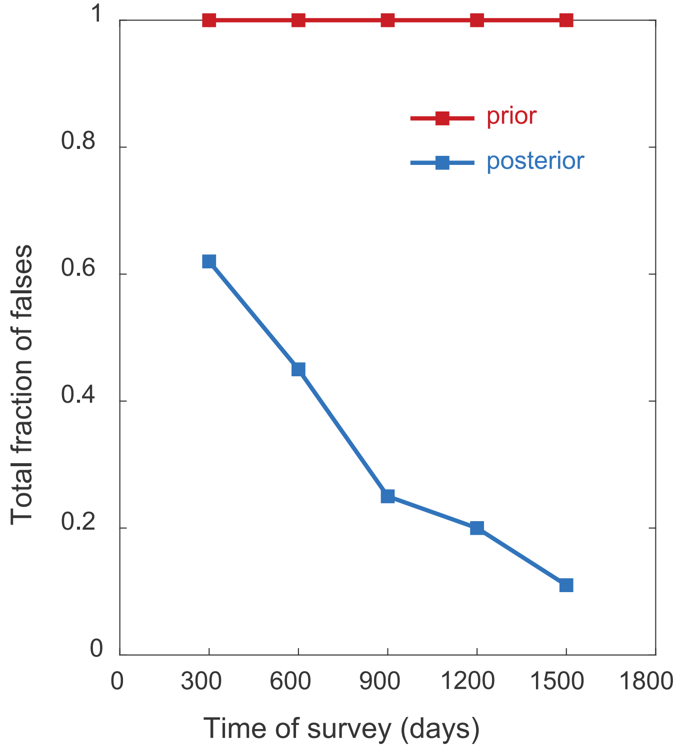
- Monitoring alternatives:
  - Time-lapse survey during interval t = [0,T]
  - How to design the configuration of such a survey?
  - Which configuration is most useful for conformance verification at t = T?

Value of information

Survey considerations

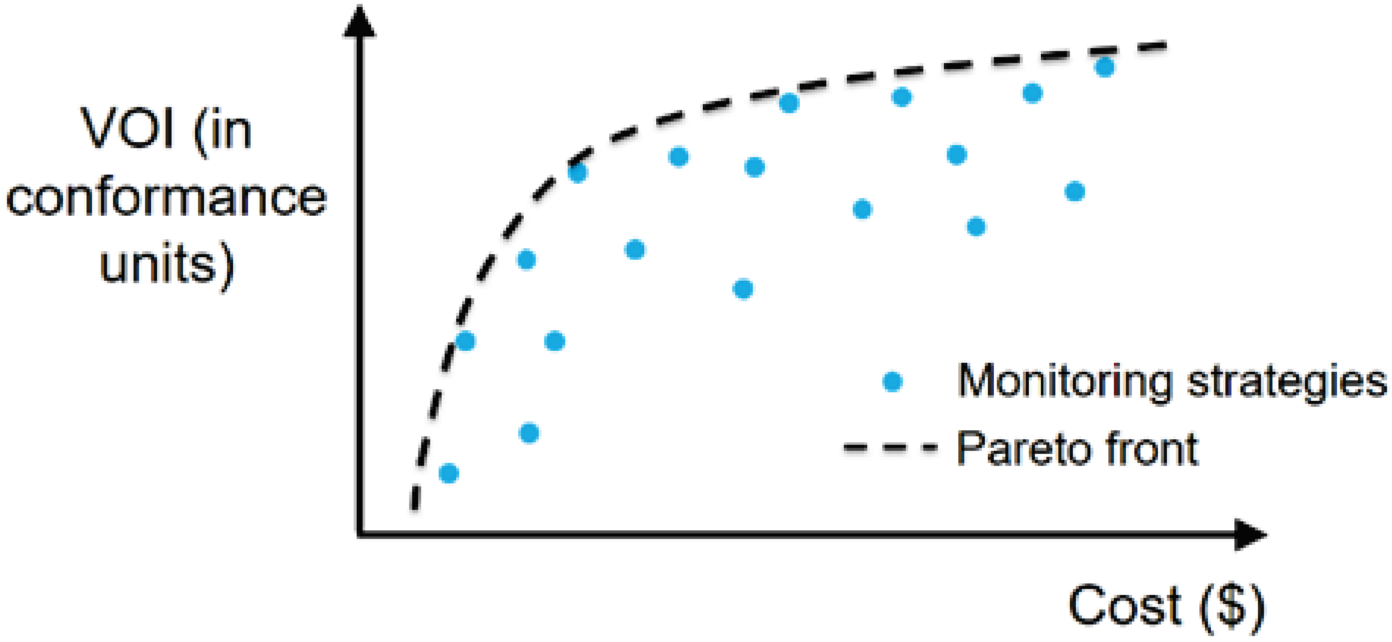


- Varying time of acquisition



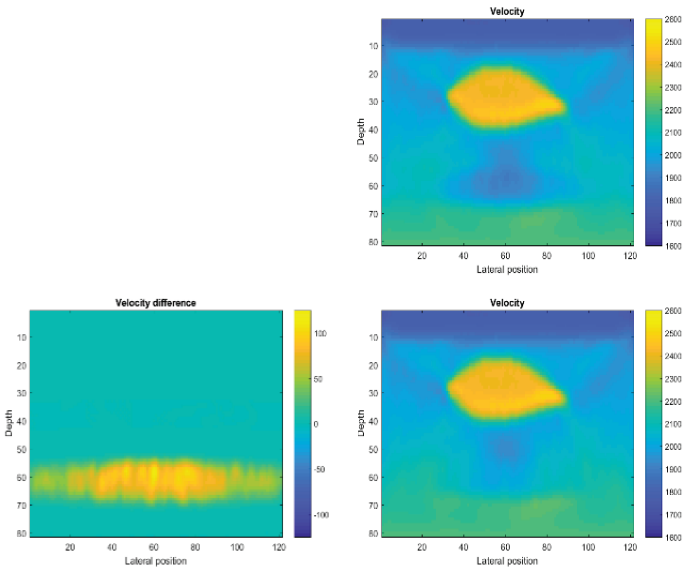
Value-of-information

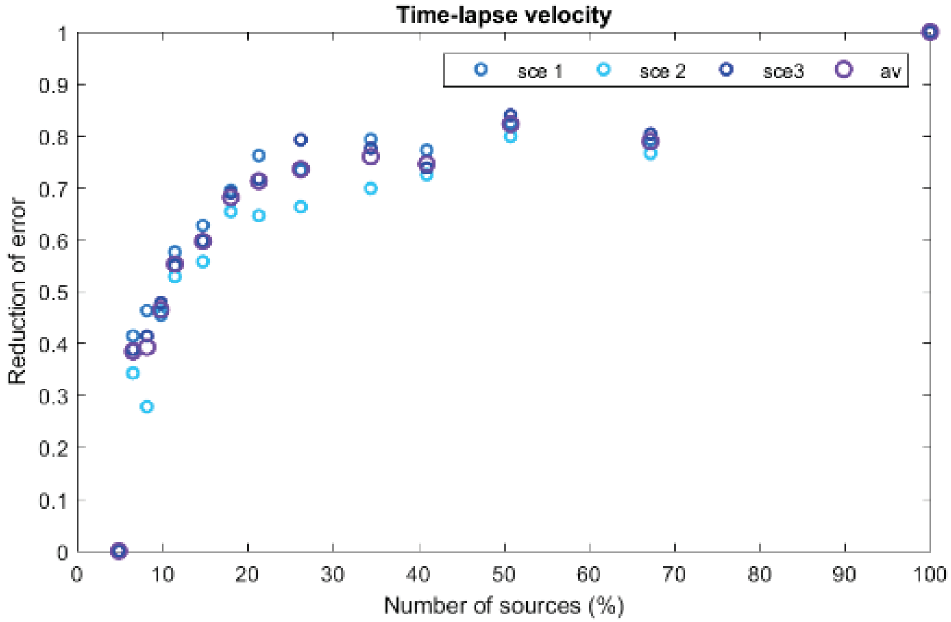
- **Expected gain** (in conformance units) and **deployment costs** ($) associated with each configuration in the search of the best **trade-off**
- **Impact on CCS industry:** More cost-effective monitoring surveys through 1) lower survey effort and 2) faster turnaround leads to 3) earlier decision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



Value-of-information

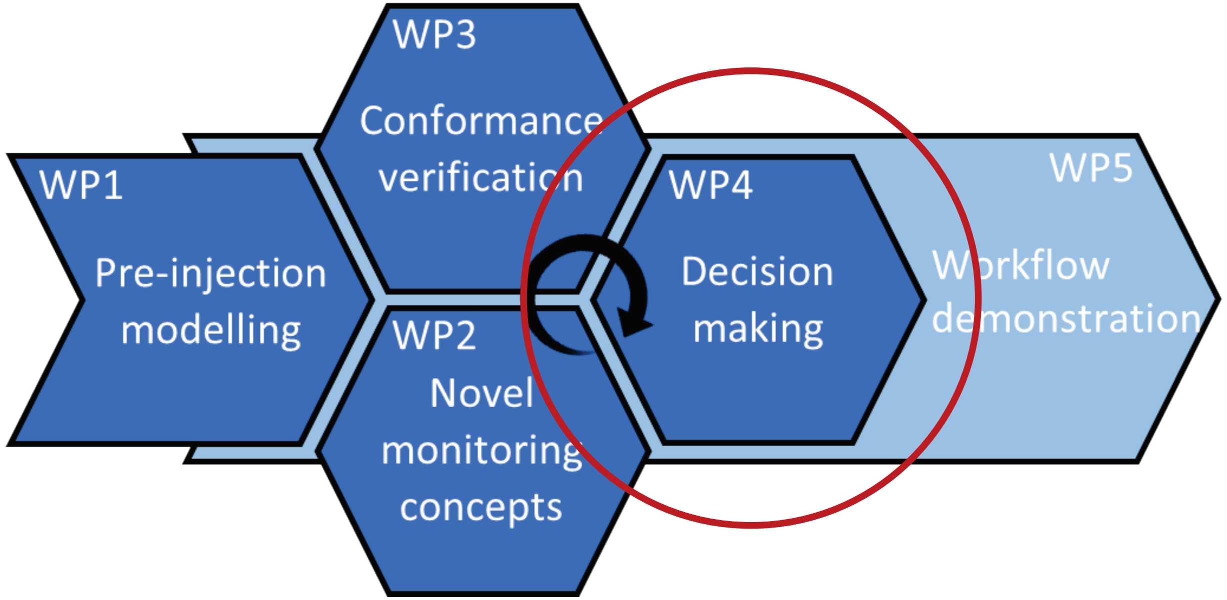
- **<u>Expected gain</u>** (in conformance units) and **<u>deployment costs</u>** ($) associated with each configuration in the search of the best **<u>trade-off</u>**
- **Impact on CCS industry:** 80% result for 20% effort (enough for well-informed decisions)





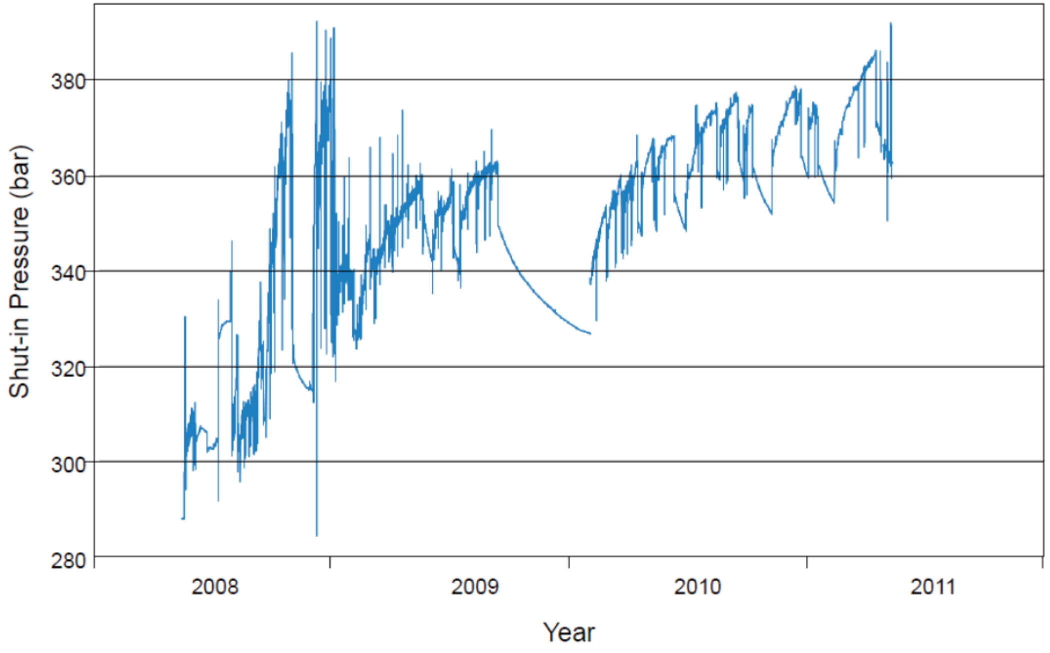
WP4: Decision making

- 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

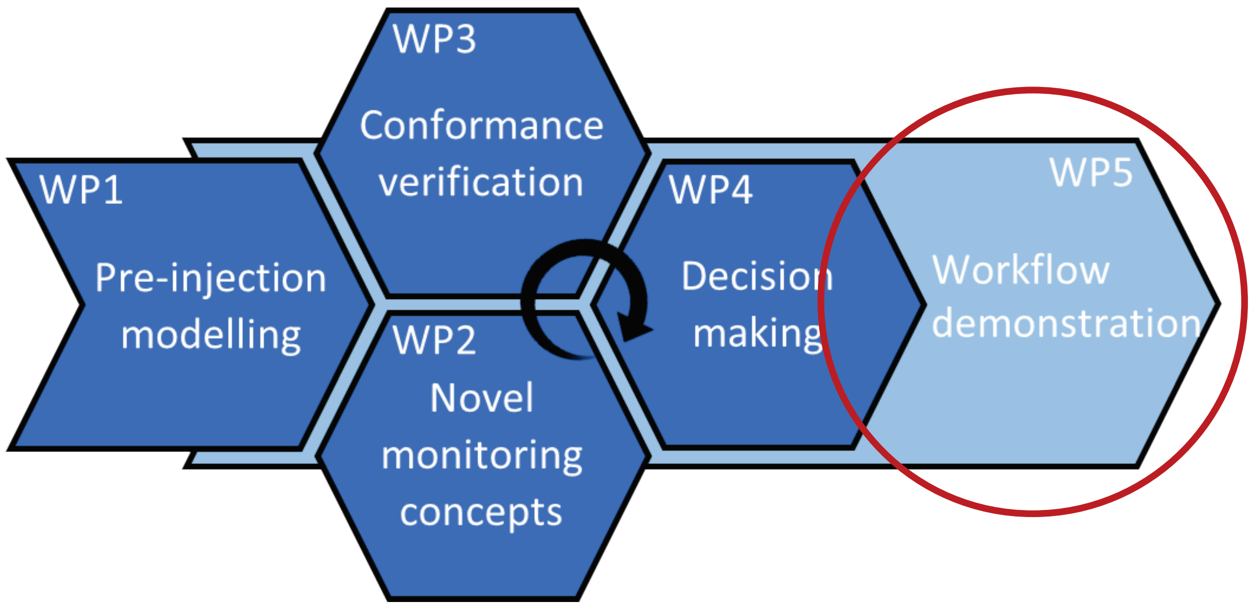
- What does a failed conformance test signify?
- Monitoring data indicates that the storage site behaviour cannot with sufficient certainty be said to be consistent with predictions
- Predictions of future storage site behaviour should show safe containment (by "definition")
- A failed conformance test therefore means that we are not sure that the site develops in a manner that ensures containment of injected CO2



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.

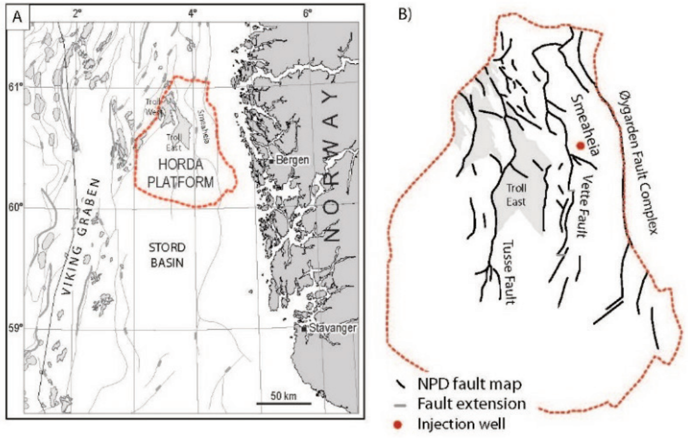
WP5: Workflow demonstration

- 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.

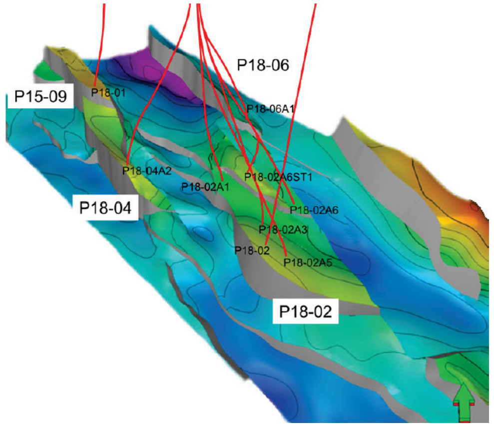


Workflow demonstration

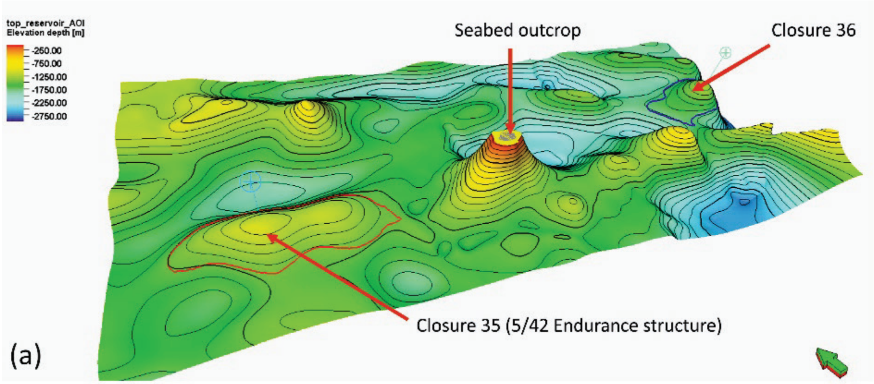
- **Smeaheia case** (SINTEF, Equinor)
  - Effect of gas Troll production on regional pressure depletion
  - Base injection plans to account for uncertainties
  - Develop a monitoring plan addressing changing baseline
- **P18-4** *(TNO, TAQA)*
  - Base-line injection plans will be tested and optimised
  - 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)



Dissemination (organized workshops)

- Pre-ACT kick-off days at Sem Gård, Norway, 7-9 November 2017.
  - **Open workshop** about **and a field trip** to the ECCSEL **Svelvik CO2 Field Lab**. Participation from Pre-ACT, NFR, Gassnova, NPD, UiO, Uppsala University, Aker Solutions, smaller vendors and several research institutes.
  - Pre-ACT kick-off meeting
  - Pre-ACT WP4 **workshop on decision-making**

Dissemination (organized workshops)

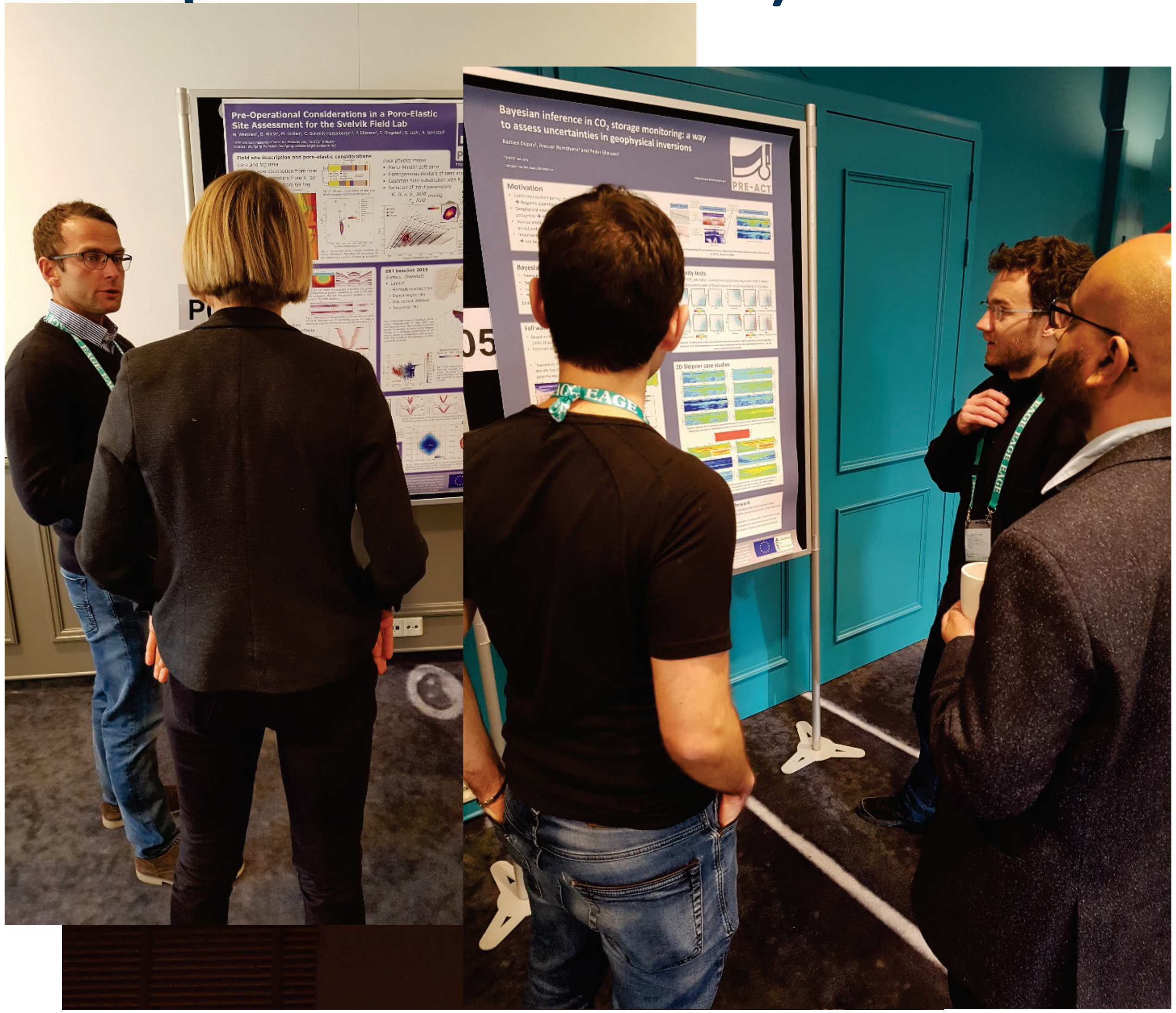
- WP2/WP3 meeting with **public workshop on "Quantitative measures of site conformance"** (20-21 February 2018, Utrecht). External participation from EBN (NL) and NPD (NO).
- Pre-ACT Annual Meeting (19-20 November 2018, Utrecht)
  - Annual meeting
  - **CO2 monitoring/conformance workshop** (semi-public). Common lunch with the ACT ECOBASE project. Participants from other ACT projects (Elegancy and DETECT) and projects such as ENOS, the Field Research Station (FRS), and ICO2P.

Dissemination (other workshops)

- CO_2 GeoNet poster (May 2018)
- Otway Stage 3 Peer Review panel participation
- Invitation to meet US federal- and state-government delegation
- Input and poster at Accelerating CCUS Intl. Conference (Edinburgh, Nov 2018)
- Presentation at "NCCS workshop on fault derisking" (Feb 2019)
- Presentations at two ACT Knowledge Sharing Workshops (Oct 2017, Nov 2018)
- Presentations at two EERA-CCS steering committe meetings (Dec 2017, Dec 2018)
- Presentation at "EU CCS Storage Research Projects Science-Policy Showcase" (Sept -19)
- Presentation CSLF Annual Technical Group Technical Meeting (Nov 2019)

Dissemination (conference presentations)

- 1 poster at EAGE Conference and Exhibition (Copenhagen, 2018)
- 1 poster at SEG annual meeting (Anaheim, 2018)
- 1 poster at European Meeting of Environmental and Engineering Geophysics
- 3 presentations/posters at GHGT-14 (Melbourne, 2018)
- 6 presentations/posters at 5th Geological Storage Workshop (Utrecht, 2018)
- 1 presentation at EAGE ws Practical Reservoir Monitoring (Amsterdam, 2019)
- Presentations at SEG and Petroleum Geostatistics



Dissemination (publications)

- 16 publications, proceedings papers, and extended abstracts (until midterm)
- Links on Pre-ACT website

- Weinzierl, W., Lüth, S., Rippe, D., Schmidt-Hattenberger, C., & Wiese, B. (2018, June). Rock Physics Driven Workflow for Pressure and Saturation Control in Quantitative CO2 Monitoring. In *80th EAGE Conference and Exhibition 2018*. https://doi.org/10.3997/2214-4609.201801150
- Weinzierl, W., Wiese, B., Lüth, S., Rippe, D., & Schmidt-Hattenberger, C. (2018). Preinjection AVO conceptual modeling for the Svelvik CO2 field laboratory. In *SEG Technical Program Expanded Abstracts 2018* (pp. 2800-2804). Society of Exploration Geophysicists. https://doi.org/10.1190/segam2018-2989649.1.
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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
  - Open for anybody to participate
- 4th meeting (TBD, February 2020)

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

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