Presentations February 8 - CCS Speed Dating – Storage

- Nils Opedal, SINTEF
- Elin Skurtveit, Norwegian Geotechnical Institute (NGI)
- Anouar Romdhane, SINTEF
- Maximilian Leinenbach, Fishbones AS
- Guttorm Alendal, University of Bergen
- Julian Leander Löw, Geomec
- Tore Lie Sirevaag, NTNU
- Arvid Nøttveit, NORCE
- Tor Harald Sandve, NORCE
- Lars Grande, Norwegian Geotechnical Institute (NGI)
- Bahman Bohloli, Norwegian Geotechnical Institute (NGI)
- Michael Jordan, SINTEF
- Pierre Cerasi, SINTEF
- Elin Skurtveit, Norwegian Geotechnical Institute (NGI)

Nils Opedal

RESEARCH SCIENTIST

CLIMIT SUMMIT

#CLIMITSUMMIT2023
7–9 February

REX-CO_2: Re-using EXisting wells for CO_2 storage operations

Nils Opedal has been working at SINTEF for ten years on various drilling and wells projects. The main interest has been on cement, cementing and cement bonding to wellbore materials. He holds a MSc in Chemical Engineering and a PhD in Surface & Colloid Chemistry from NTNU.

The Research Council of Norway

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REX-CO2
RE-USING EXISTING WELLS FOR CO2 STORAGE OPERATIONS

Nils Opedal @ CLIMIT Summit 2023

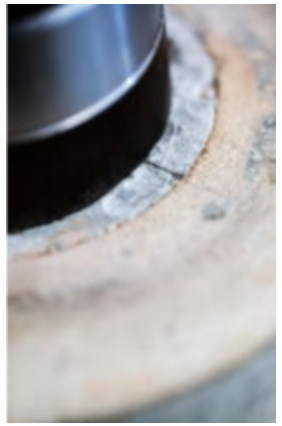
https://rex-co2.eu/index.html

The project REX-CO_2 is funded through the ACT programme (Accelerating CCS Technologies, Horizon2020 Project No. 299681). Financial contributions made from ADEME (FR); RVO (NL); Gassnova and RCN (NO); UEFISCDI (RO); BEIS, NERC, and EPSRC (UK); and US-DOE (USA) are gratefully acknowledged.

REX-CO2
re-using existing wells

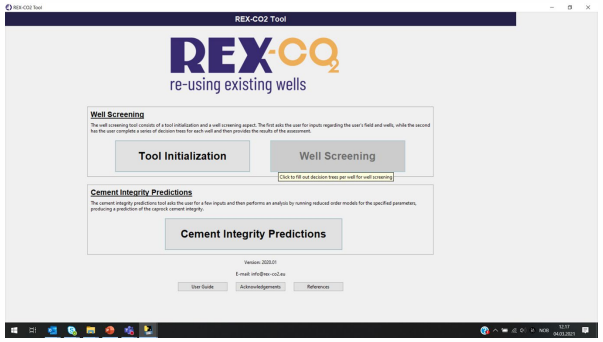
Motivation

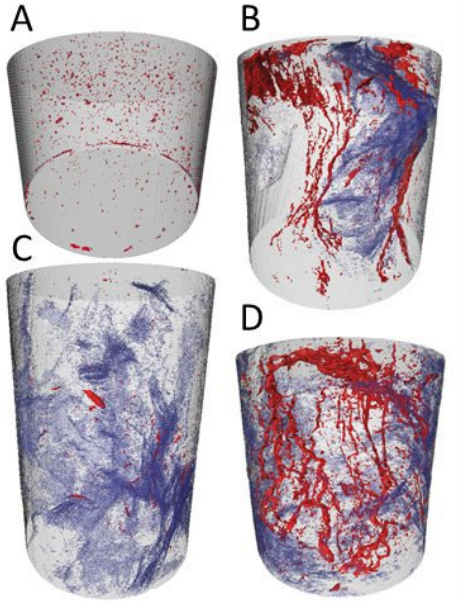
- Mature hydrocarbon fields approach the end of planned life
  - Infrastructure to be decommissioned with tremendous ***efforts & costs***
- Existing wells could present an ***opportunity***
  - Large scale implementation of Carbon Capture Storage and Utilization
  - High cost of drilling new wells
  - Identifying wells suitable for ***continued*** use for CCUS
  - ***Substantial savings*** could be realized by ***re-using*** these wells
  - Well (barriers & materials) must be assessed
- ***No (automated/standardized) qualification process exist***
  - Effective well re-use workflows could increase re-use potential



Objective

- Development of a ***well-screening software tool*** to assess the re-use potential
- Definition of the suitability of wellbore materials and near-wellbore environment
- Investigation of materials and remediation/self healing methods
- Application of the tool to ***national case-studies***
- Development of ***best practice recommendations*** for well re-use
- Ensure efficient implementation of CCUS

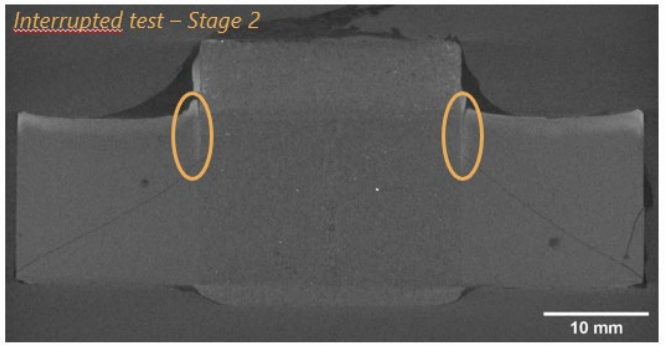




Project outcome

- Assesment tool developed and functional
- Tool used in several ***national case*** studies
- Experimental and numerical investigations on well barrier materials:
  - cement/rock/casing
  - Self healing and remediation methods
- Development of ***best practice recommendations:***
  - Enabling regulators and responsible authorities to ***benchmark proposals*** for well re-use
  - Operators can use ***effective well re-use workflows***
- ***Current discussion on continuation with JIP***

	Out of zone injection	Structural integrity	Well integrity primary barrier	Well integrity secundary barrier	Material compatibility
Well #1					
Well #2					
Well #3					
Well #4					



REX-CO_2

re-using existing wells

Thank you for your attention

The project REX-CO_2 is funded through the ACT programme (Accelerating CCS Technologies, Horizon2020 Project No. 299681). Financial contributions made from ADEME (FR); RVO (NL); Gassnova and RCN (NO); UEFISCDI (RO); BEIS, NERC, and EPSRC (UK); and US-DOE (USA) are gratefully acknowledged.

Elin Skurtveit

STRUCTURAL GEOLOGY

CLIMIT SUMMIT

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7–9 February

Learnings from a naturally occurring CO_2 laboratory in Utah, US

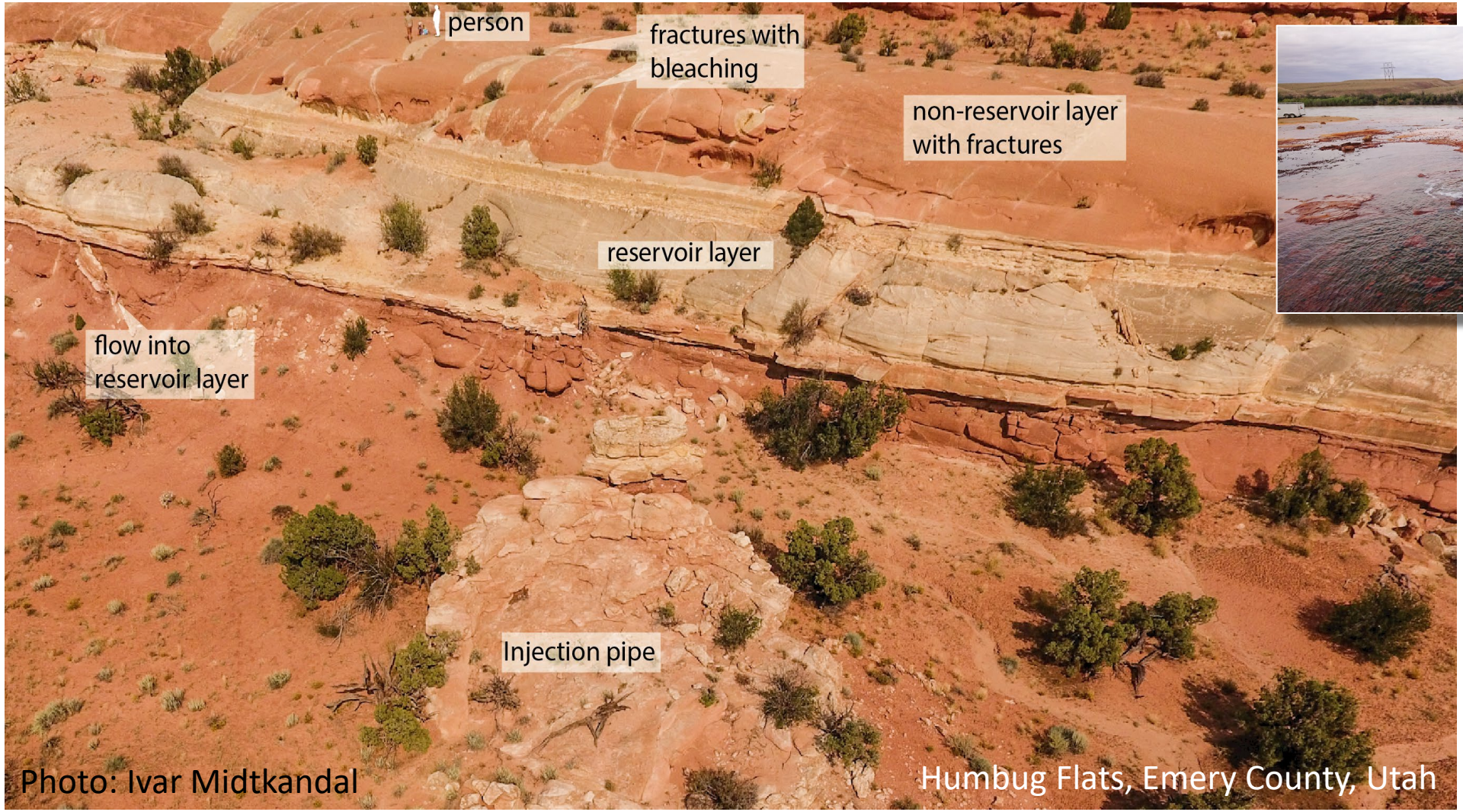
Elin Skurtveit holds a PhD in structural geology, employed at NGI (Norwegian Geotechnical Institute) and an Associate Professor II at University of Oslo, Dept. of Geosciences. Elin follows up several projects related to CO_2 storage and has a passion for integrated research combining geology, geomechanics and rock physics

The Research Council of Norway

GASSNOVA

UiO : University of Oslo

A naturally occurring CO_2 laboratory in Utah

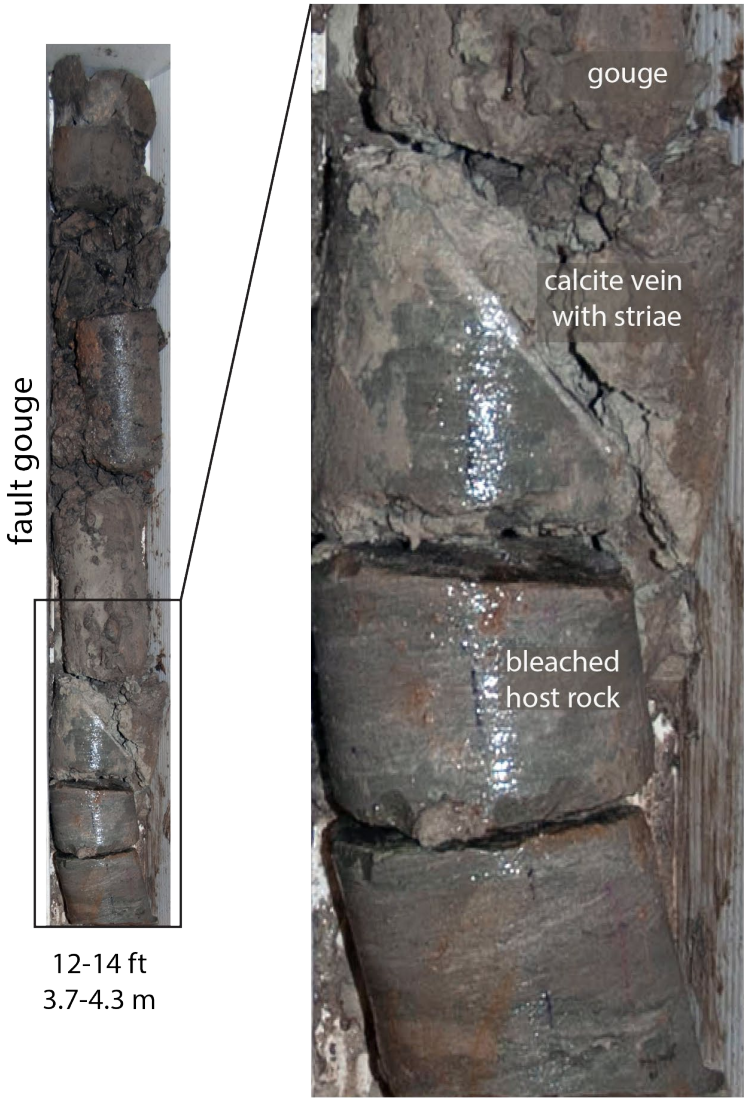


Little Grand Wash Fault, Utah

Research question: What are the thresholds for detecting CO_2 seeps in the subsurface?

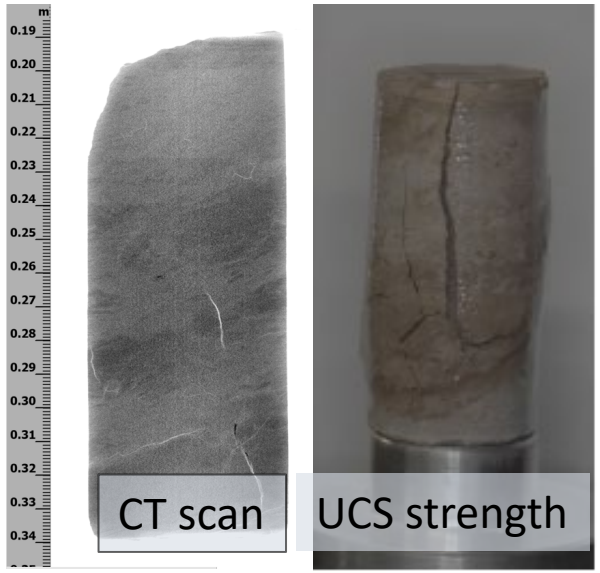
Field-data collection by COTEC members from Western Colorado State University

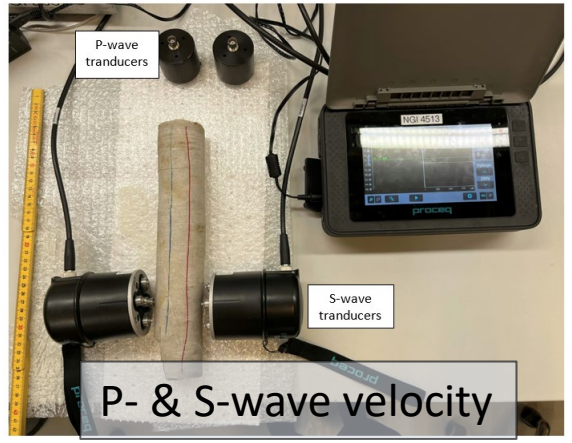
Western State Colorado University



Petrie et al, 2022

NGI

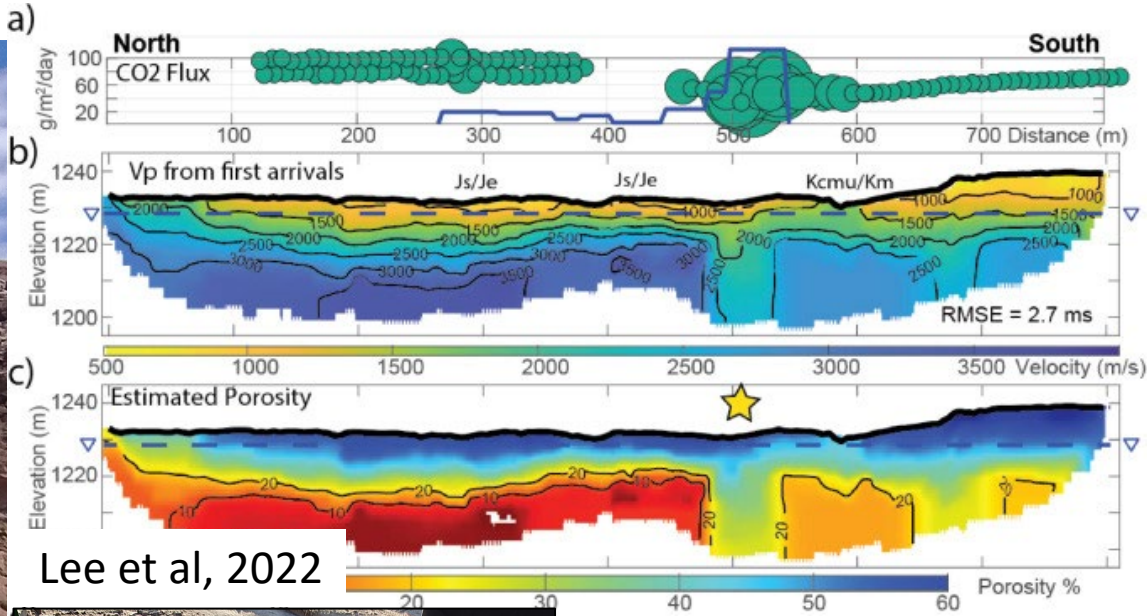




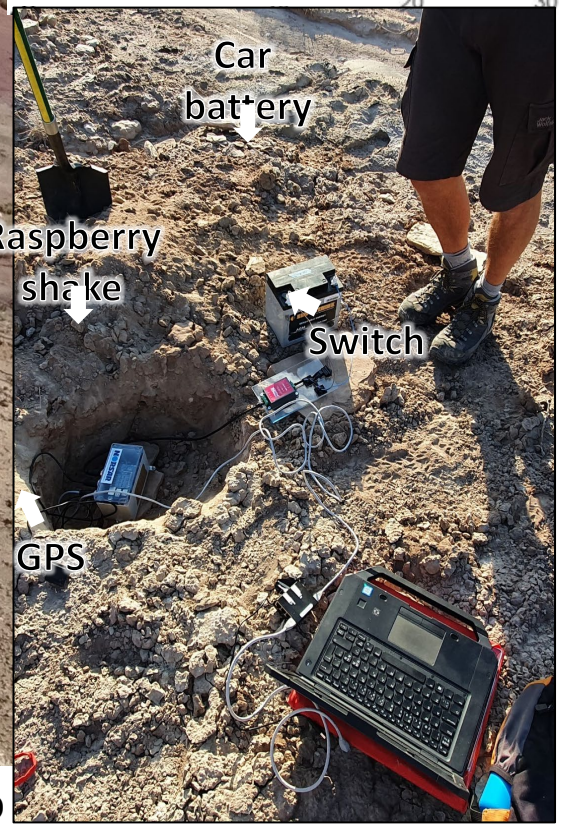
Sample analysis
Faleide, 2022, Skurtveit 2022

Active seismic

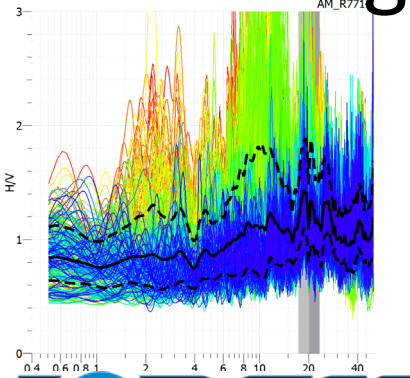
Photo: Ivar Midtkandal



Lee et al, 2022



Passive seismic monitoring

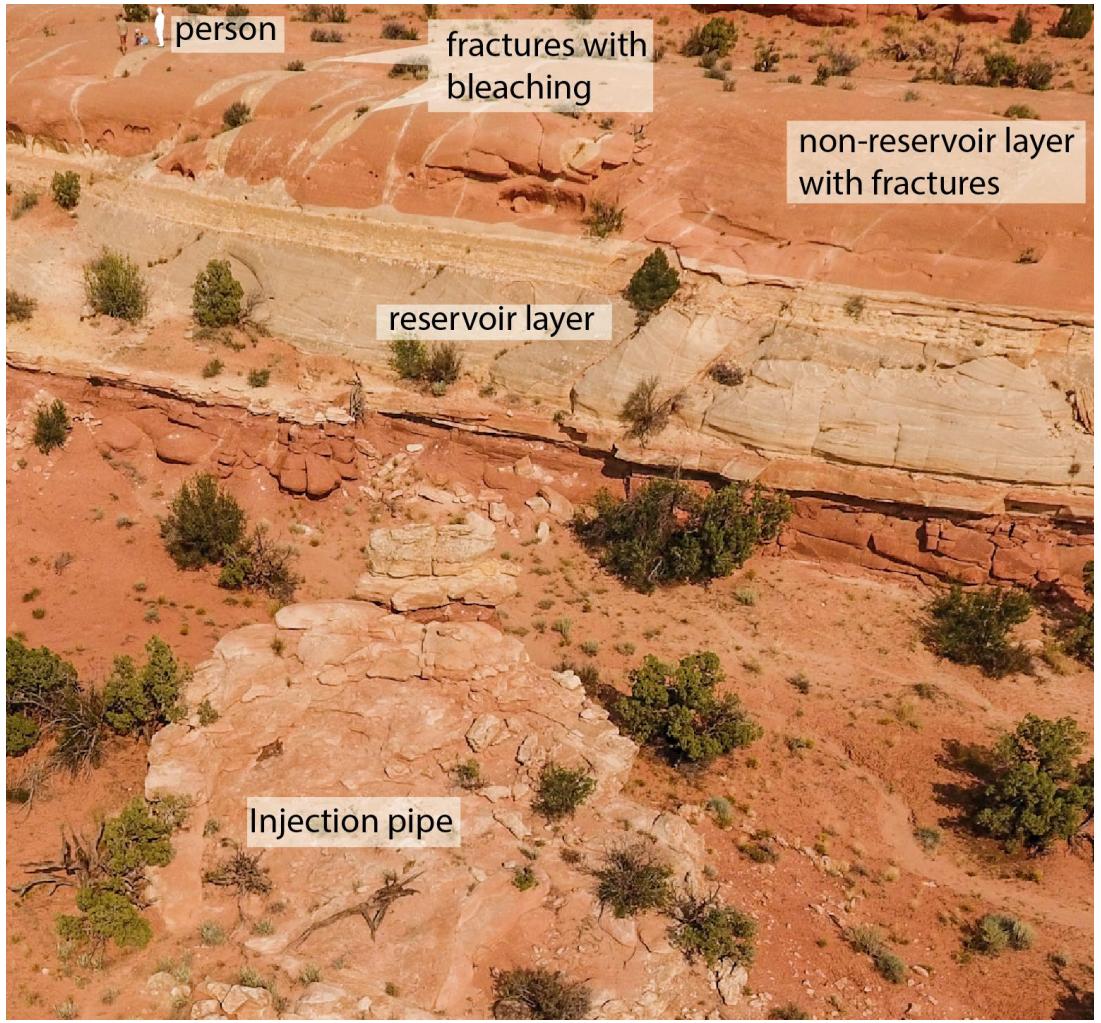


NORSAR

Field-data collection by COTEC members from University of Boise, Idaho

What did we learn?

- Behaviour of CO_2-charged fluid in rocks in relation to rock type and fracture patterns
- Rock strength, and thereby behaviour, is affected by the history of fluid flow in pores and fractures
- Chemical reactivity between CO_2 and rock is the variant
- Seismic detection and detection levels are affected by fluids and the resultant rock strength. Prediction level increased



For more info: https://www.mn.uio.no/geo/english/research/projects/cotec/index.html

Contact: ivar.midtkandal@geo.uio.no

CO2 containment and monitoring techniques (COTEC)

Project lead: Ivar Midtkandal, UiO

NRC funded; CLIMIT
Timeframe: 2019-2022 (extended due to COVID: 2023)
14 000 000 NOK

Host: University of Oslo
National collaborative partners:
NGI, UNIS, NORSAR

International partners:
Utah State University, Western Colorado State University, Boise State University, Colorado School of Mines

Anouar Romdhane

RESEARCH SCIENTIST

CLIMIT SUMMIT

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7–9 February

Accelerating CSEM technology for efficient and quantitative CO_2 monitoring (EM4CO2)

Anouar Romdhane ($EM4CO_2$ project manager): Research Scientist (Dr. Ing. in geophysics) has 10+ years of experience as a researcher and project manager in geophysics at SINTEF. His research covers CO_2 storage, geophysical modelling and inversion, time lapse monitoring, rock physics inversion, and machine learning.

The Research Council of Norway

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NORWEGIAN CCS RESEARCH CENTRE

Accelerating CSEM technology for efficient and quantitative CO_2 monitoring

CLIMIT SUMMIT– February 2023

Anouar Romdhane (SINTEF), Joonsang Park (NGI), Julien Porté (SINTEF),
Bastien Dupuy (SINTEF) & Kjetil Eide (Allton)

EM4CO2: project facts

- EM4CO2: Accelerating CSEM technology for efficient and quantitative CO_2 monitoring
- Goal: develop and apply a cost-efficient CO_2 monitoring concept using time-lapse CSEM and demonstrate its readiness for the future Norwegian large-scale CO_2 storage project
- CLIMIT KPN

SINTEF

UiO : University of Oslo

NGI

allton

UNIVERSITY OF Southampton

NCCS

CLIMIT

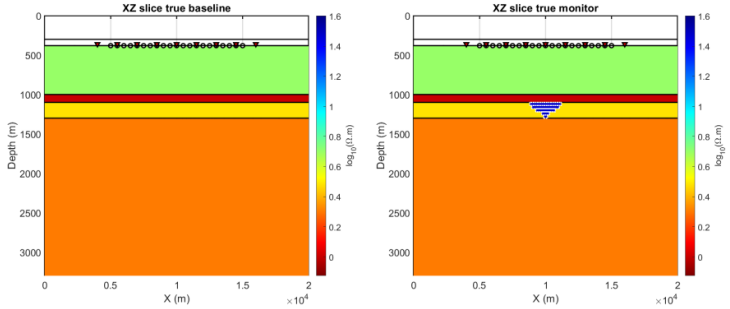
Activities

WP0: Project management/dissemination

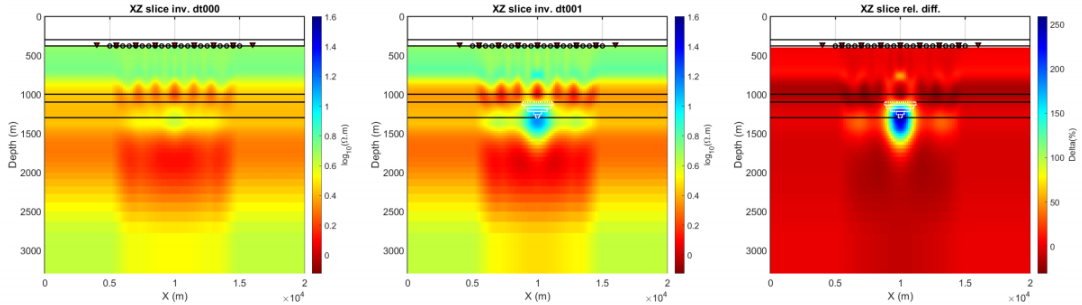
WP1: Optimal survey layout and TL inversion techniques

WP2: Effects of infrastructure on CSEM surveys

WP3: Integration of CSEM with other geophysical data

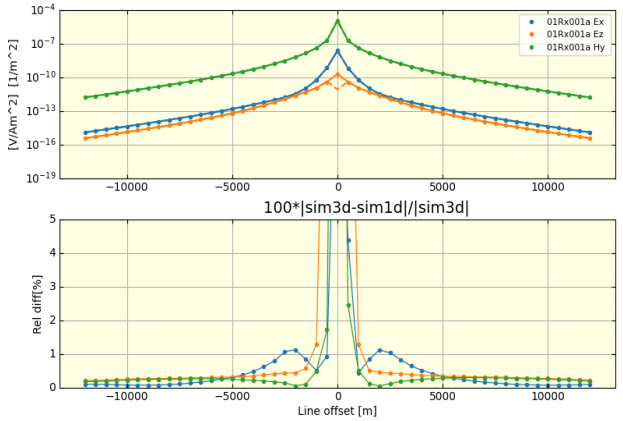


(a) Baseline (b) Monitor

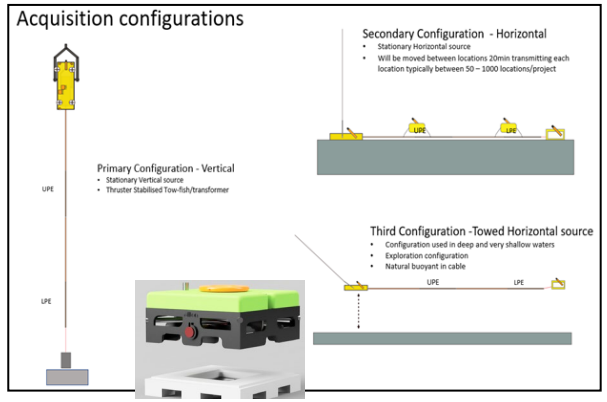


(d) Joint time-lapse: Baseline (e) Joint time-lapse: Monitor (f) Joint time-lapse: : Δ_t Difference (%)

New TL strategy to:
- Mitigate repeatability requirements
- Improve background model imaging
- Reduce acquisition size of monitor surveys



Forward modelling benchmarking (Allton)



Acquisition system development (Allton)

Activities

- WP0: Project management/dissemination
- WP1: Optimal survey layout and TL inversion techniques
- WP2: Effects of infrastructure on CSEM surveys
- WP3: Integration of CSEM with other geophysical data

NCCS

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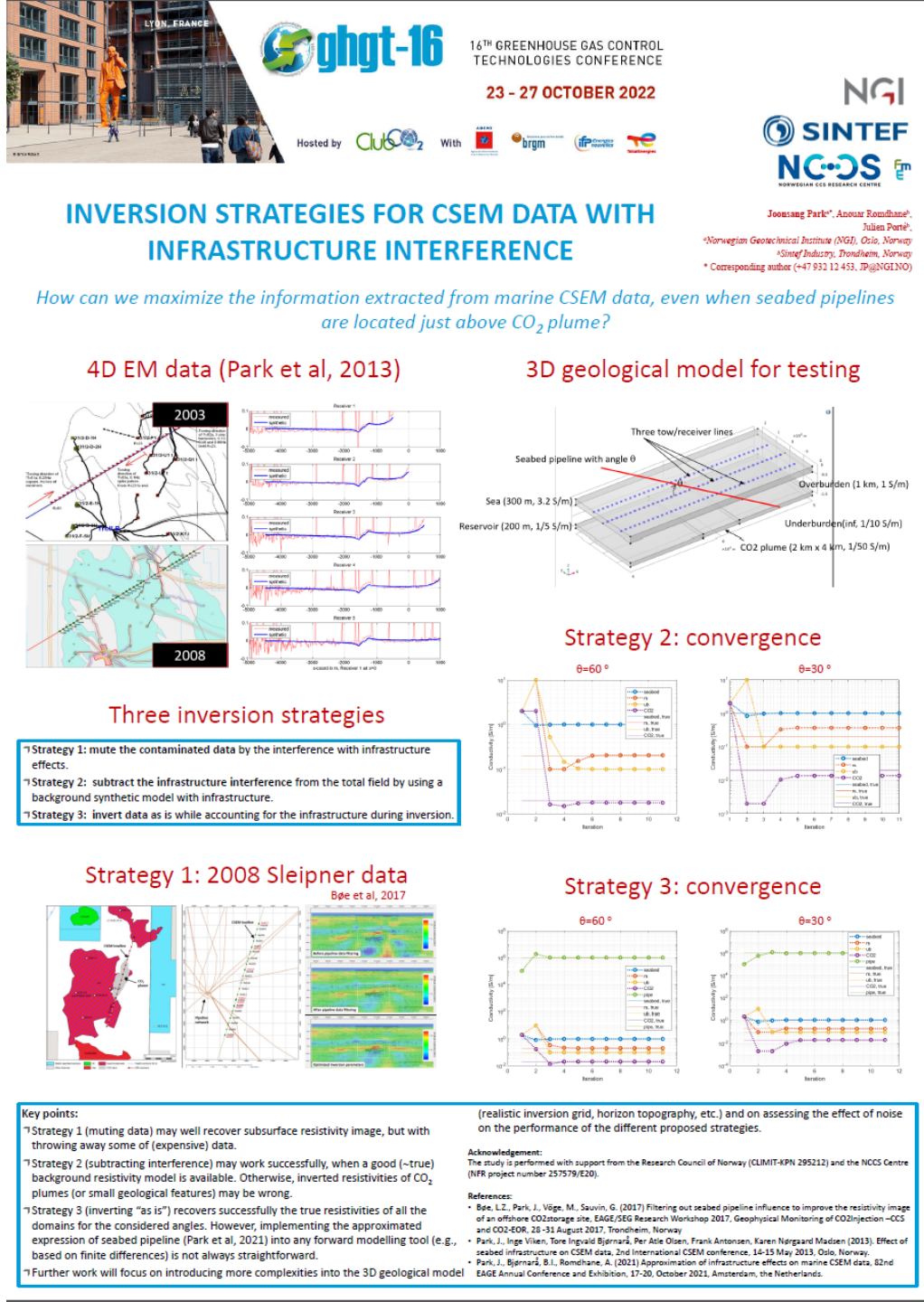

Activities

- WP0: Project management/dissemination
- WP1: Optimal survey layout and TL inversion techniques
- WP2: Effects of infrastructure on CSEM surveys
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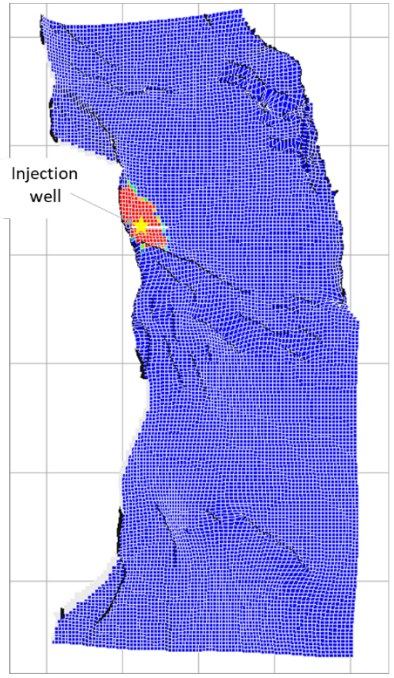
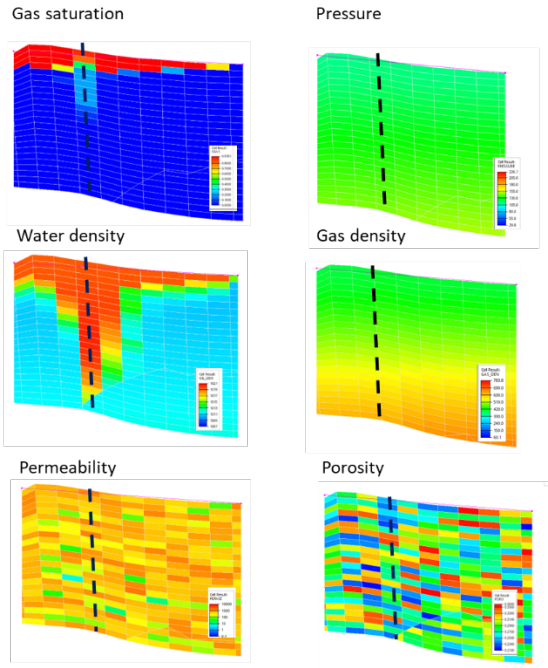
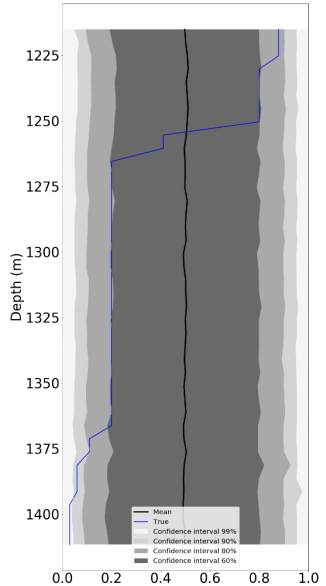
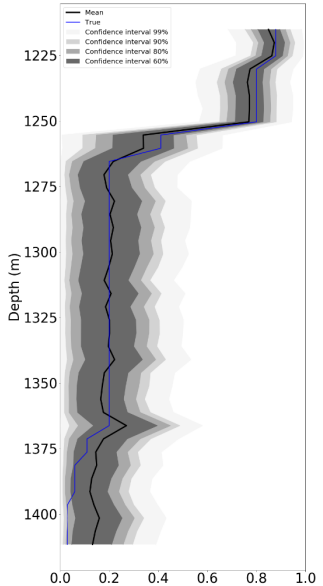






V_P

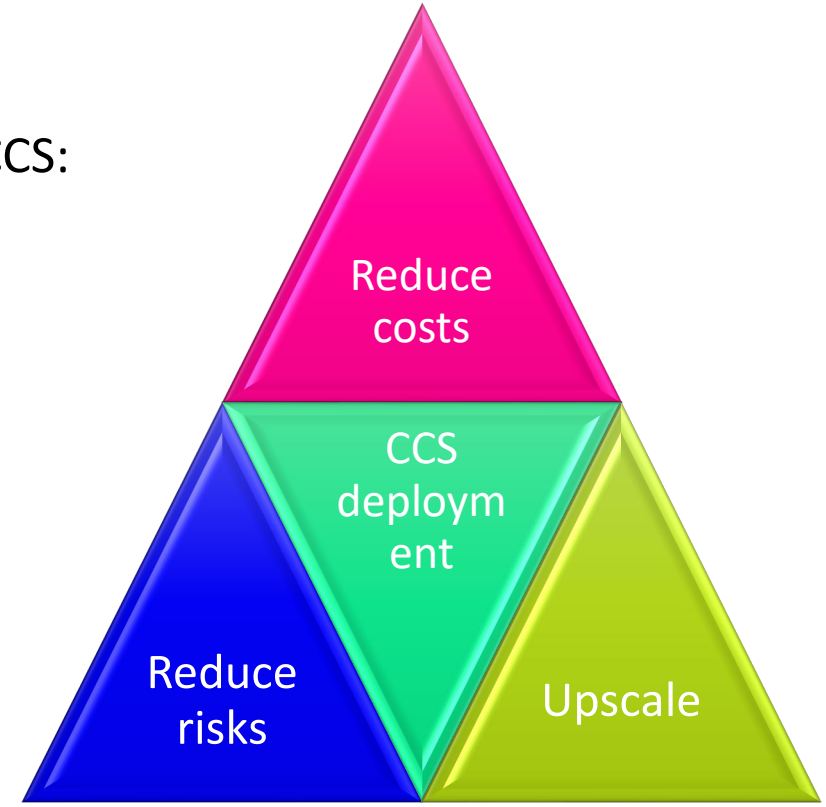


V_P, R_t

Impact

EM4CO2 project addresses key challenges for industrial deployment of CCS:

- Risk reduction:
  - A remote monitoring alternative for carbon storage.
  - Timely detection and verification of volumes.
  - Low-impact operation in complex and sensitive areas.
  - Increase subsurface characterisation reliability and reduce risk of misinterpretation.
- Cost reduction:
  - Optimized acquisition strategies ties directly to acquisition product development.
- Upscaling
  - Flexible/target-oriented monitoring for containment and conformance risk assessment



+ Growth opportunity for service providers working with the technology

Acknowledgment

This work is performed with support from the Research Council of Norway (CLIMIT-KPN 295212) and the NCCS Centre (NFR project number 257579/E20) under the CLIMIT programme. The authors acknowledge the Research Council of Norway and the NCCS partners (https://www.sintef.no/projectweb/nccs/about-us/partners/) for their contribution.

Maximilian Leinenbach

DIRECTOR TECHNOLOGY O&G / GEOTHERMAL

SafeGuard: New technology for long-term monitoring and risk mitigation of CO_2 storage sites

Maximilian Leinenbach is the Director of Technology at Fishbones AS, where he leads the Engineering department. He has over 10 years of experience in product development for the O&G and automotive industries. His current work focuses on research and innovation to drive existing and new Fishbones technologies into a commercial phase.

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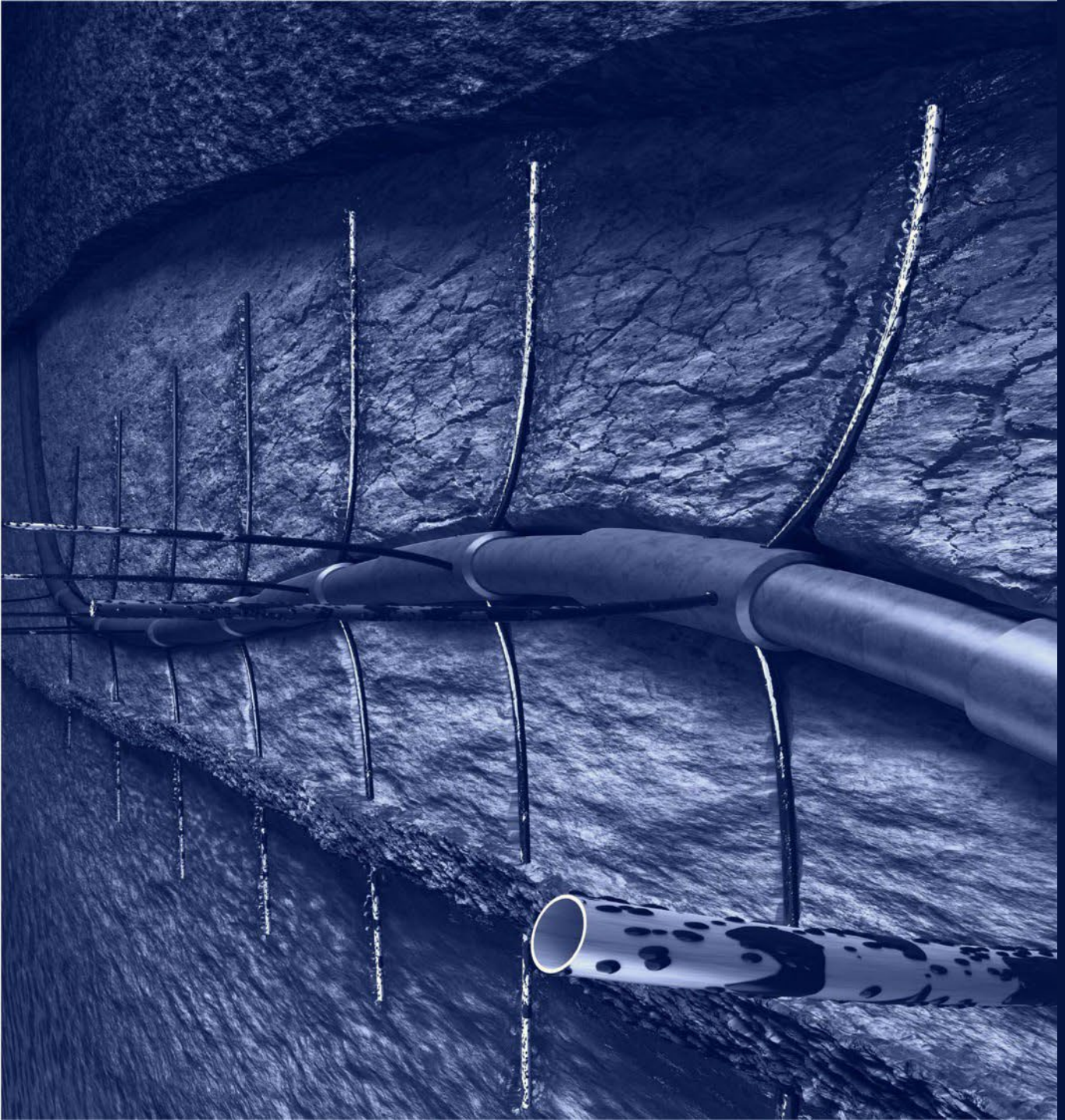


fishbones

CLIMIT

SafeGuard - New well monitoring technology for CCS sites

February 2023

SafeGuard - New well monitoring technology for CCS sites

Introduction

Fishbones technology

- Small diameter laterals jet or drill out from the wellbore, penetrating the reservoir exactly where needed, to enhance hydrocarbon recovery.

Project scope

- Investigate if the technology provided by Fishbones AS can be combined with instrumentation and adapted to serve as permanent and easily accessed well-based monitoring and early warning system for any or all wells penetrating or surrounding a chosen CO2 sequestration site.

Objectives

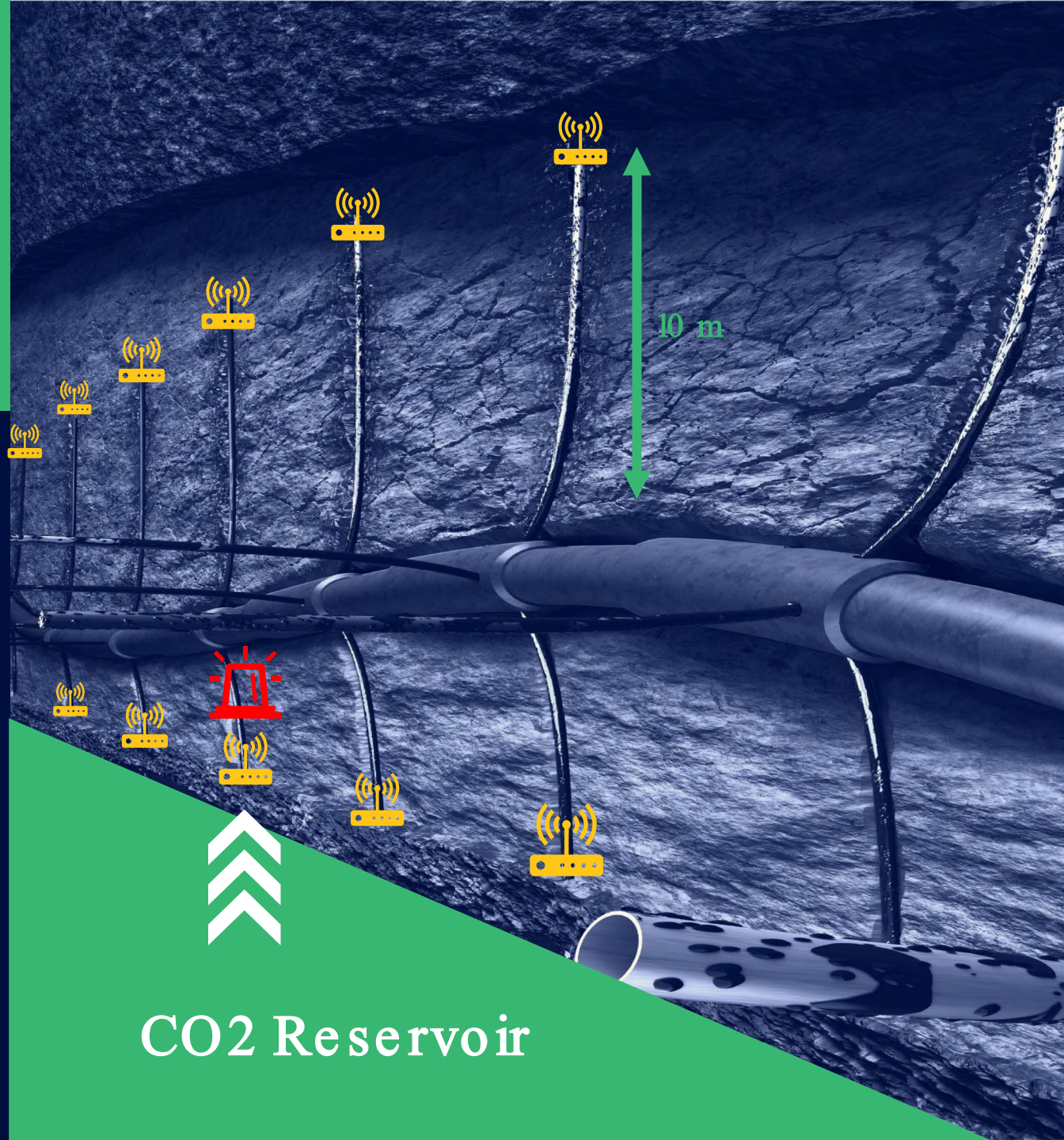
- The project work was split into three work packages:
  - WP-1: Measure pore pressure in shales and sandstones
  - WP-2: In-situ stress measurement
  - WP-3: DAS measurement of acoustic noise in shale fracture flow

➡ Measurements of WP 1-3 need to be inline with analytic expectations and within certain tolerance window

SafeGuard - New well monitoring technology for CCS sites

Concept

- Sensor are attached at the Fishbones Needles
- The monitoring strings placed in new or existing wells with a relevant position close to CCS sites
- The measured change of formation properties can be used for direct leakage detection and as additional data input for numerical models



SafeGuard - New well monitoring technology for CCS sites

Results & Timeline

2019 – 2022
CLIMIT – Safeguard
Successful feasibility for
WP-1 and WP-2

2023
Design small-scale prototypes and establish collaboration to design electronics.
Customer and governmental funding required.

2024
Design equipment for data capturing, storage and retrieval from wellsite.

2025
Functional testing of full-scale prototype

2026
Field trial

THANK YOU

www.fishbones.as
Maximilian.Leinenbach@fishbones.as
+47 909 13 376

Guttorm Alendal

PROFESSOR

CLIMIT SUMMIT

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7–9 February

ACTOM, Act on offshore monitoring

Guttorm Alendal is a professor in applied and computational mathematics at the University of Bergen. His main research focus is on ocean processes, with special focus on transport of tracers and their potential impact on the marine environment, and dynamical systems and epidemiological modelling.

The Research Council of Norway

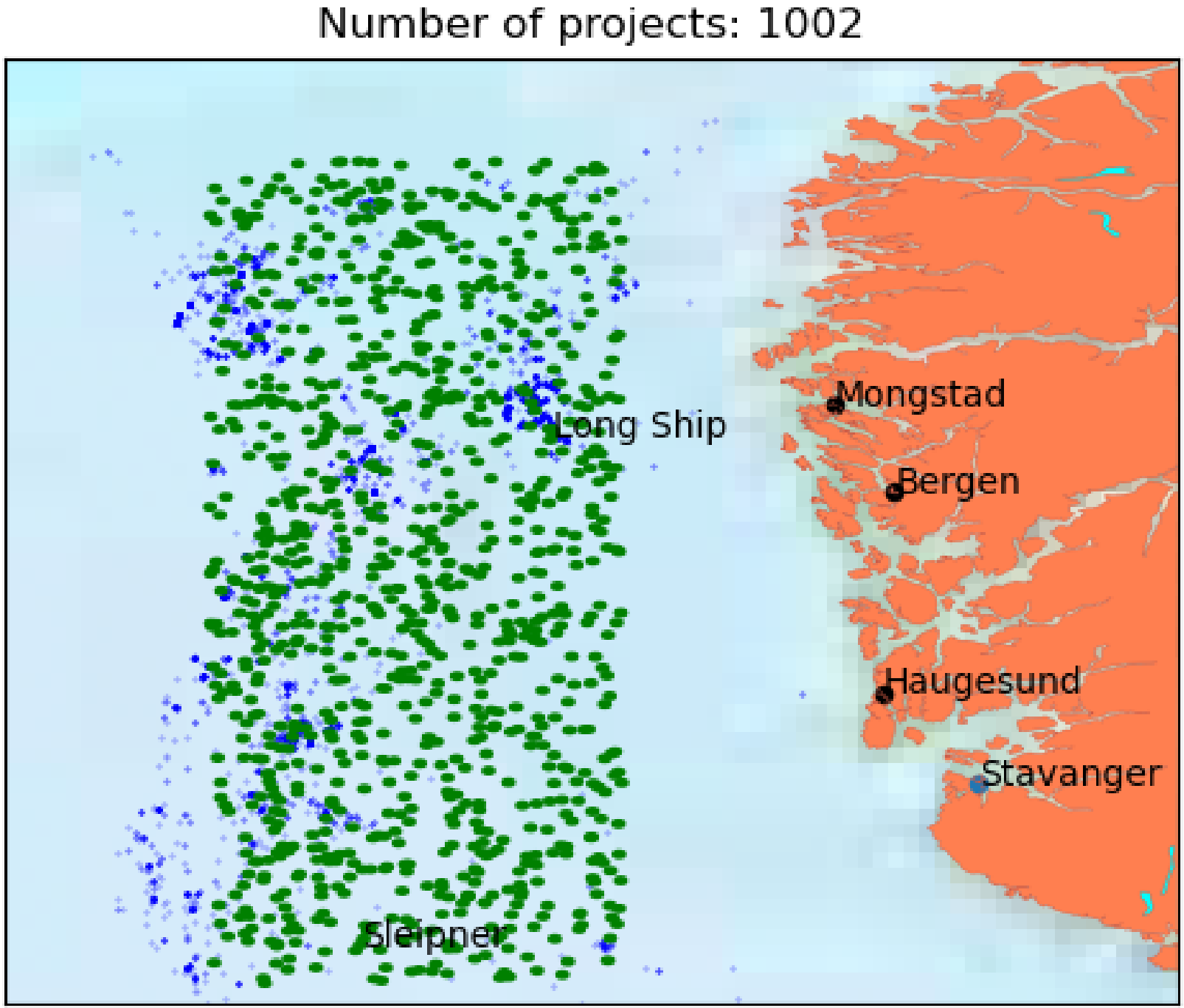
GASSNOVA

ACT on Offshore Monitoring

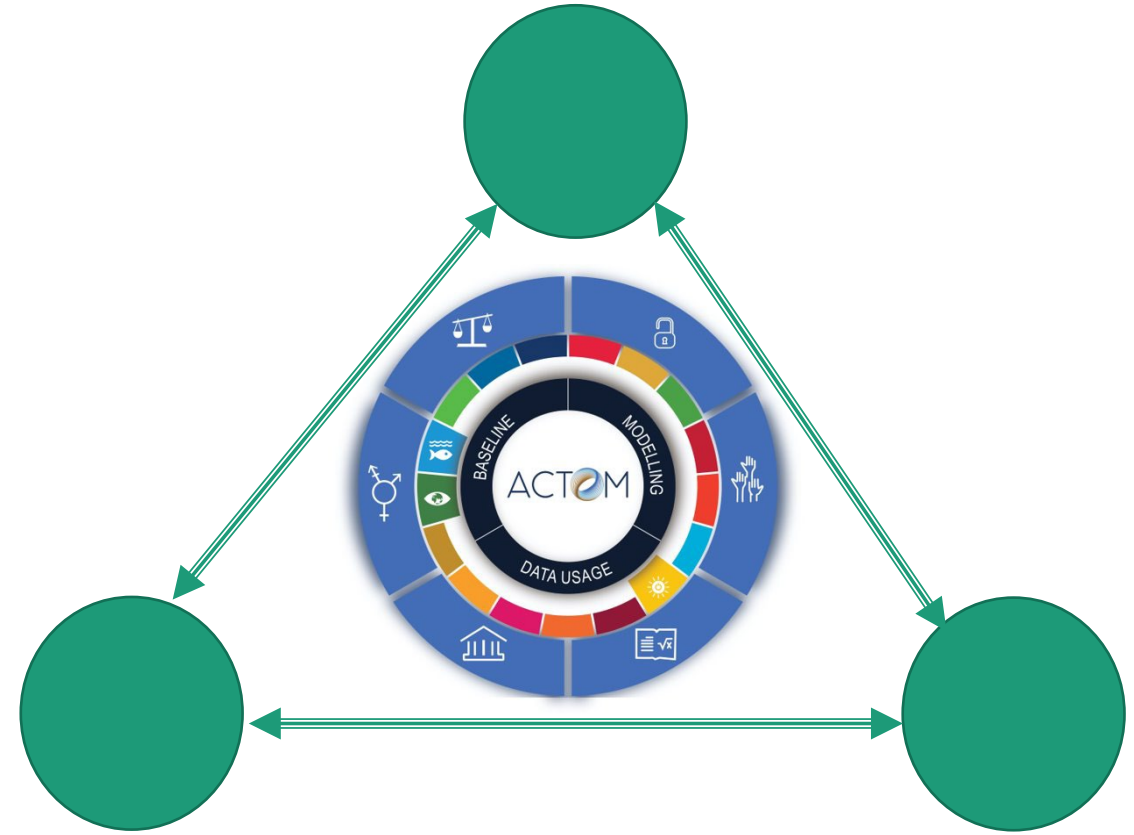
Presented by
Professor Guttorm Alendal,
Department of Mathematics,
University of Bergen

on behalf of the ACTOM team (in random order)
Marius Dewar (PML), Anna Oleynik (UiB), Stefan Carpentier (TNO), Abdirahman Omar (NORCE),
Jerry Blackford (PML), Sufyan El Droubi (University of Dundee), Dorothy Dankel (UiB, now Sintef),
Sigrid Eskeland Schütz (UiB), Darren Snee (PML), Parisa Torabi (UiB), Sarah Gasda (NORCE),
Ketil Fagerli Iversen (UiB, now FFI), Rajesh Pawar (LANL), Bjarte Fagerås (OCTIO), Katherine Romanak (BEG).

Upscaling


Number of projects: 1002
Mongstad
Long Ship
Bergen
Haugesund
Stavanger
Sleipner

Societal values



Legal requirements

Technical capabilities

ACTOM

An ACT-2 project

ACTOM

ACT on Offshore Monitoring

https://actom.w.uib.no

- Advisory board.
  - Philip Ringrose, Equinor
  - Marcella Dean, Shell
  - Eva Halland, NPD
  - Tim Dixon, IEAGHG
  - Jun Kita, MERI
  - Gloria Thurschmid, EBN
  - Charles Jenkins, CSIRO
  - Sallie Greenberg, ISGS

This project, ACTOM, is funded through the ACT programme (Accelerating CCS Technologies, Horizon2020 Project No 294766). Financial contributions made from; The Research Council of Norway, (RCN), Norway, Ministry of Economic Affairs and Climate Policy, the Netherlands, Department for Business, Energy & Industrial Strategy (BEIS) together with extra funding from NERC and EPSRC research councils, United Kingdom, US-Department of Energy (US-DOE), USA. In-kind contributions from the University of Bergen are gratefully acknowledged. Anna Oleynik is funded through the Academia agreement between Equinor and the University of Bergen.

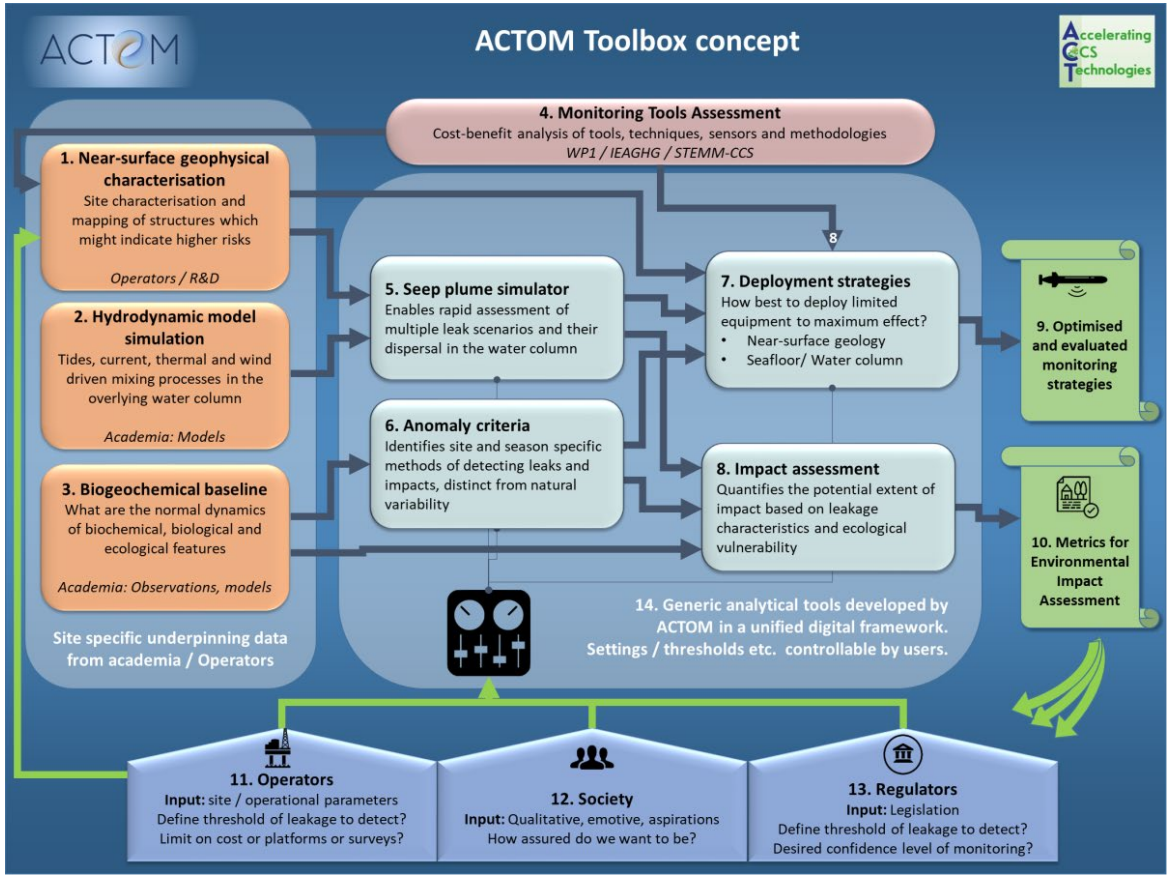
The Research Council of Norway

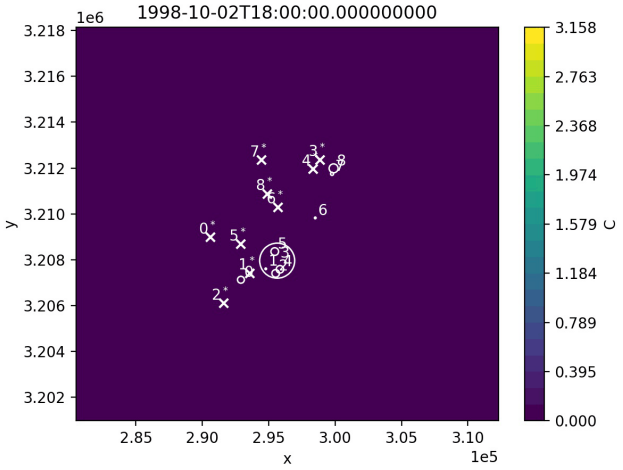
Netherlands Enterprise Agency

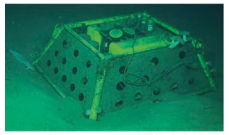
Department for Business, Energy & Industrial Strategy

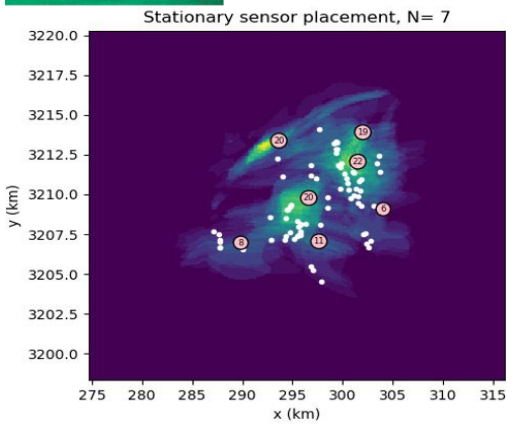
Accelerating CCS Technologies

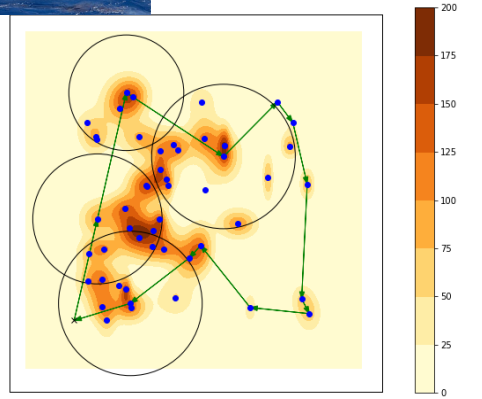
The ACTOM toolbox



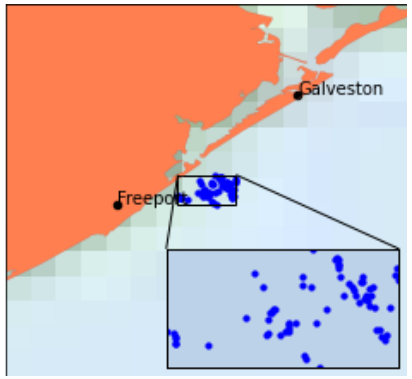


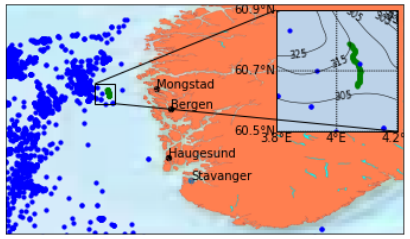


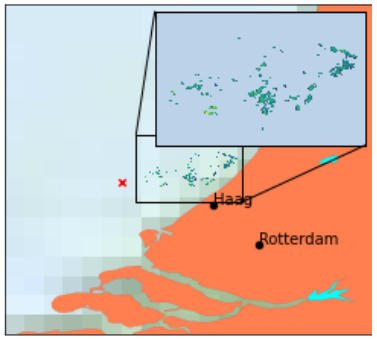




Where are we and where to go?







- Utilize the toolbox for site studies
  - On-going Gulf of Mexico and the North Sea.
- Upscaling
  - Larger areas, several projects.
  - Include other activities offshore, Marine Spatial Planning.
- Extend the toolbox with other features
  - Acoustic signals,
  - Combining platforms.
- Uncertainty quantifications.
  - Signal analysis
    - Anomaly detections.
    - Classification,
  - Decision tool.

Belief/Reality	True	False
True		False positive
False	False negative	

A final webinar February 28; 15-16:30 CET.

Julian Leander Löw

CHIEF OPERATIONS OFFICER

Real-Time Monitoring for Safe Geological CO_2 Storage

MSc in Applied Geoscience from RWTH Aachen University, Germany, BSc in Geoscience from University of Potsdam, Germany
Works with Geomec since 2019, first as technical advisor, since Jan 2022 as COO. Responsible for technical work duties, running operations, as well as sales and marketing.

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GASSNOVA


GEOMEC ENGINEERING
AN ENERGY OPTIMISATION COMPANY
DISCOVER YOUR SUBSURFACE POTENTIAL

Project 309844

Real-Time Monitoring for Safe Geological CO_2 Storage

Research Council of Norway
CLIMIT SUMMIT 2023
February 8th

From Consultancy to SaaS, with Governmental Soft-Funding

Research & Development

We have developed a technical-engineering SaaS for injection wells, *embedding decades of accumulated experience and know-how.*

Disposal Wells (CRI)
Ensuring improved storage capacity, by optimised injection safety. Soft-funded by Innovation Norway (IFU, 2013-14), and in use by ConocoPhillips on NCS.

Pressure-Support Wells (IOR)
Ensuring improved recovery rate, by optimised injection efficiency. Soft-funded by RCN (Demo 2000, 2017-20), and in use by Neptune, Sval and Wintershall DEA on NCS.

CO_2 Storage Wells (CCS)
Ensuring permanent subsurface storage, by enhanced injection efficiency and safety. Soft-funded by RCN (CLIMIT, 2020-23), and with SINTEF as FOU partner.

Establishment & Growth

There are hundreds injection wells on the Norwegian Continental Shelf (NCS); however, there are hundreds of thousands worldwide.

Innovate UK
Technology Strategy Board

Innovasjon Norge

The Research Council of Norway

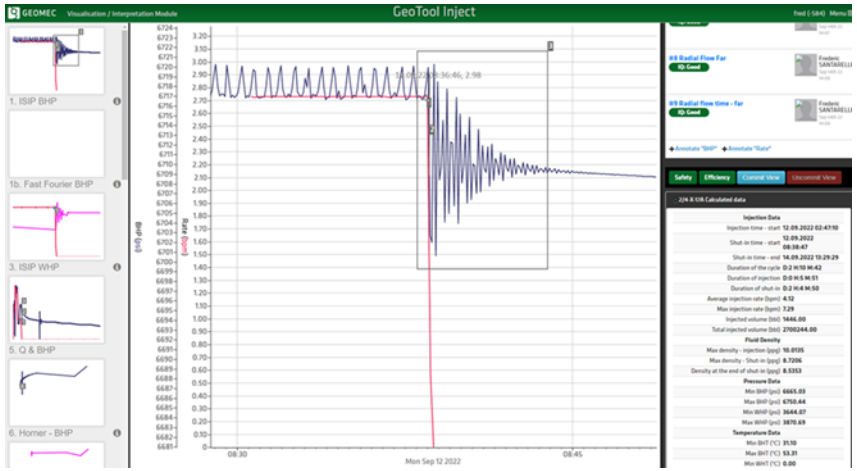
Rogaland Fylkeskommune

Our mission is to be the preferred safety and efficiency provider for IOR and CCS injection wells; and our vision is to minimise the environmental impact and to maximise the recovery rate.

Best Available Practise, for Safe Geological CO_2 Storage

The Industrial Challenge (Subsurface Leakages)

CO_2 will be stored in geological formations, to reduce greenhouse gas emission; however, is the CCS industry fully prepared?



Our IFU and Demo 2000 projects have demonstrated that 1/3 of disposal wells have leakages, and that 80% of pressure-support wells have inefficiencies – what about CO_2 storage wells?

The Industrial Solution (Detection & Prevention)

We are providing a technical-engineering toolbox for injection wells, a data-driven market-approach for safe subsurface storage of CO_2.

Tailored SaaS

For real-time monitoring & analysis, inclusive adapted operational procedures for start-ups and shut-ins, and automated early-warning alarms for zero-leakage tolerance.

Hands-on Support-Team

For regular reporting, operational advising and ad-hoc problem solving (by continuous cycle analysis of and progressive calibration against real-time data).

Digitalised Modelling

For distinguishing between primary and secondary technical-engineering effects (i.e. Joule-Thompson, wellbore storage, and phase transition effects).

“In union there is strength” – Aesop

CCS Speed Dating

- CO_2 injection-data access and/or experience
- Petroleum Engineering products & services
- IT/AI (digitalisation) products & services
- Hardware metering and measurement devices
- Other relevant CCS market-approaches

Geomec SaaS References

- ConocoPhillips
- Neptune Energy
- OKEA
- Sval
- Wintershall DEA

Intellectual Property Notice

Presentation Disclaimer

Tore Lie Sirevaag

PARTNER AND PROJECT MANAGER

CLIMIT SUMMIT

#CLIMITSUMMIT2023
7–9 February

Automating the evaluation of the well barrier

Tore Sirevaag took his Ph.D. in applied ultrasound at NTNU Norway. The doctoral thesis was part of a larger project where we performed and analyzed ultrasonic measurements to evaluate the sealing behind the casings (steel pipes) in oil and gas wells, however, the research is just as necessary in storage of CO_2.

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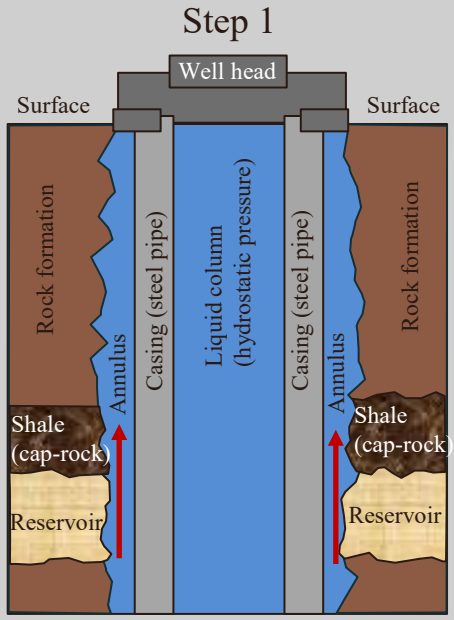
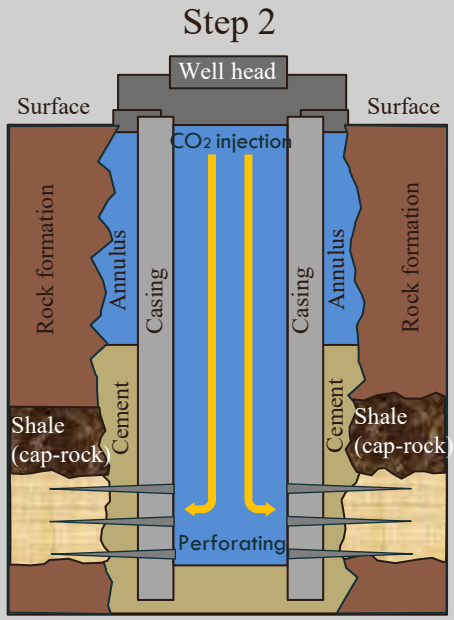
equanostic

CLIMIT SUMMIT 2023

Automating the evaluation of the well barrier (VRI 310010)

By Tore Sirevaag (Ph.D)



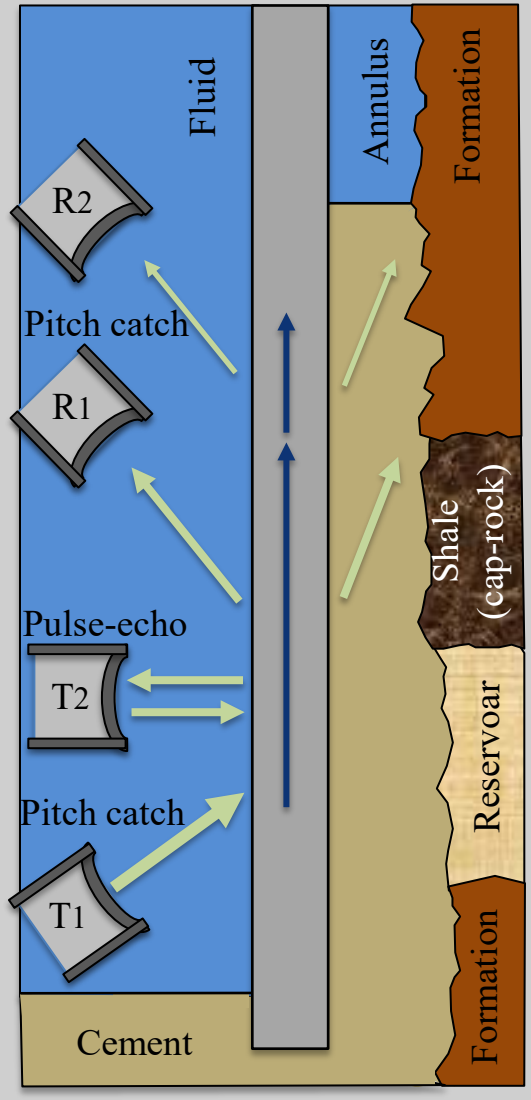


In order to store CO_2 from a deep well:

1) Reservoir and cap rock
2) Casing – prevent formation fluid
3) Cement annulus (space between casing and formation)
4) Perforate and inject

To evaluate the cementing of the annulus, ultrasound is applied.

The challenge however is to verify, through signal processing, that the cement is actually present and is truly sealing of the well



AkerBP

The Research Council of Norway

NORCEM HEIDELBERGCEMENT Group

Apply the strength of modern computers

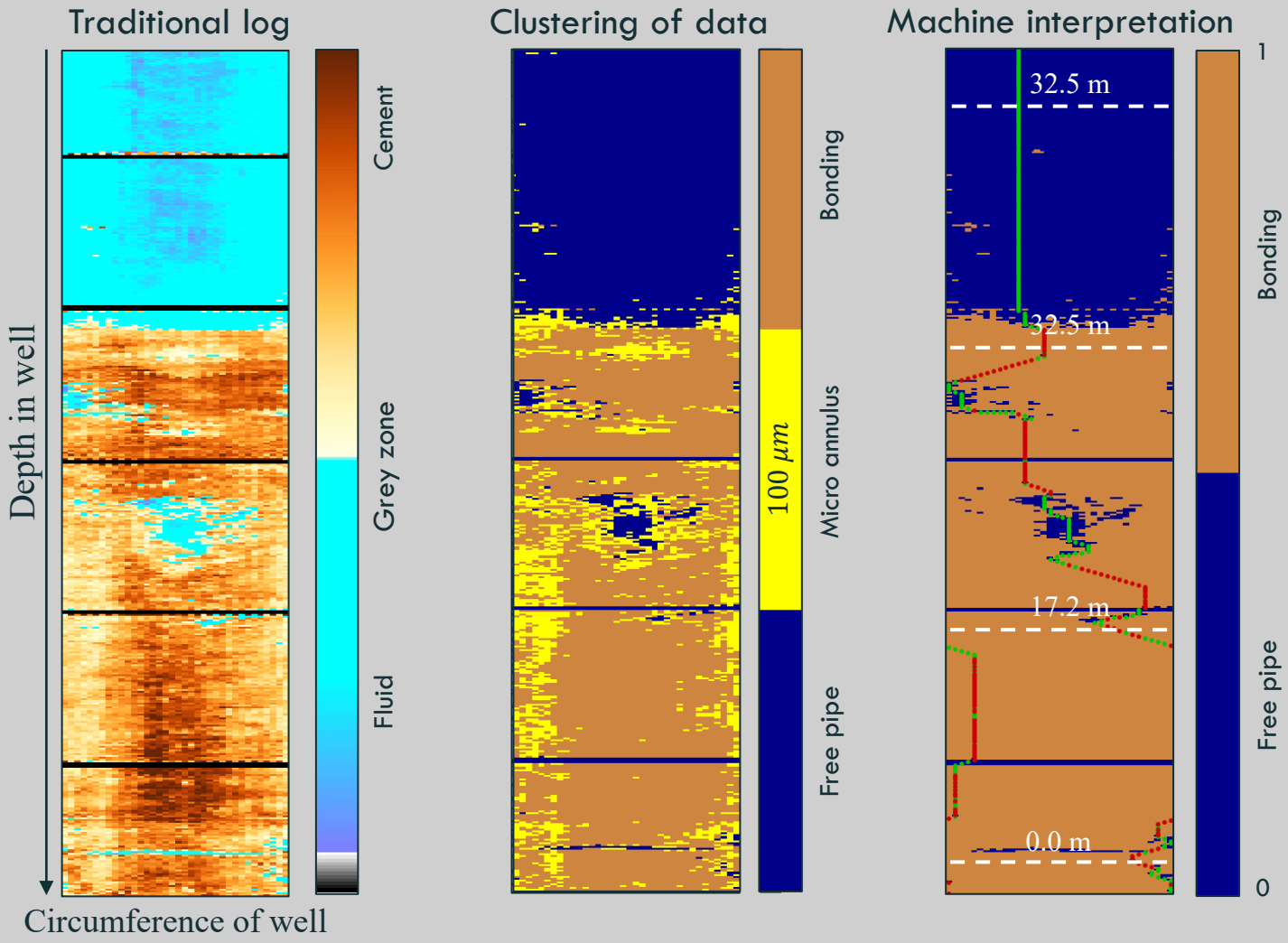
Petrophysical log - 3D data displayed 2D

Traditional processing:
Evaluating physical parameters

Utilizing modern computers:
Clustering, distance measure, correlation

Apply novel physics:
Shape evaluation, signal decomposition, Fourier transform

Automating the interpretation:
Optimization algorithms, barrier estimation

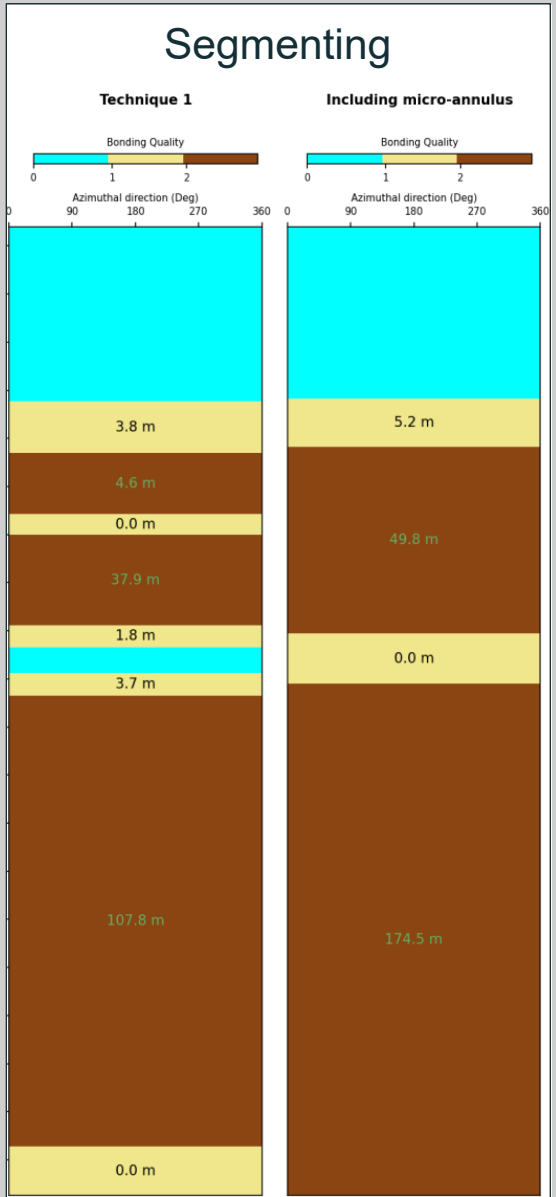


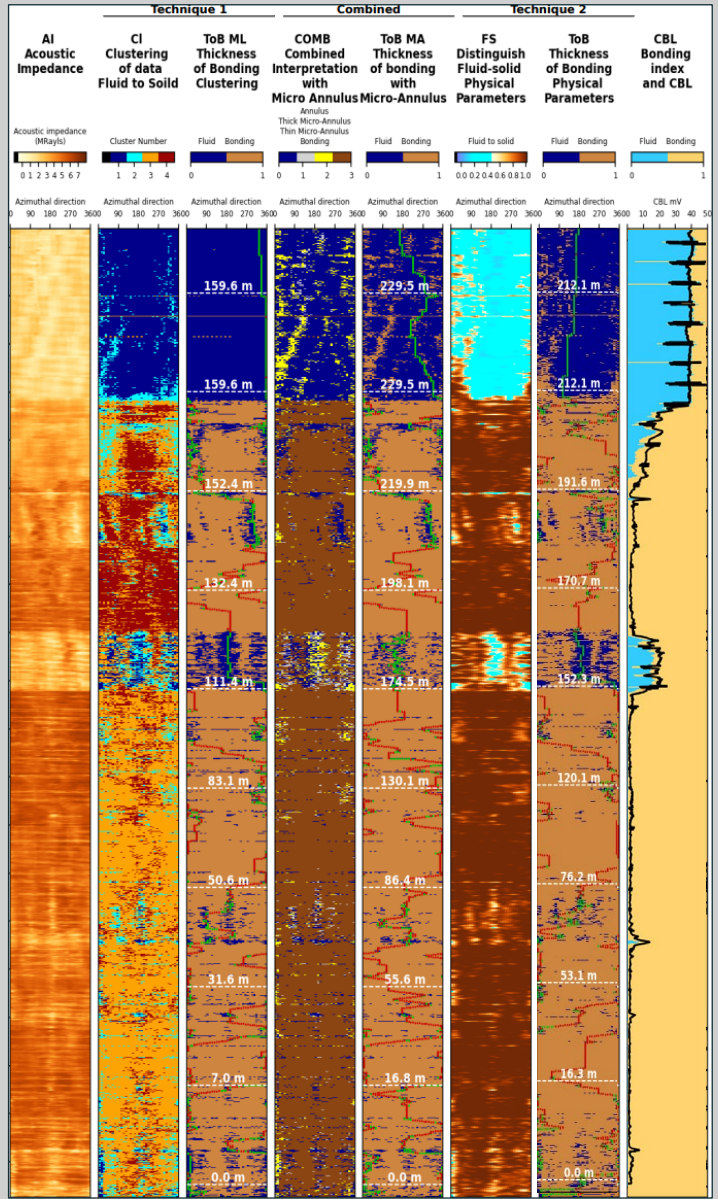
Product - software

Automatically generated reports containing:

- Petrophysical logs
- Segmentation of well
- Summary of results
- Conclusion of annulus integrity
- Web application and software as a service

Zone divided by machine		Annulus information		
Start (MD)	End (MD)	Bonding Quality	Length of bonding (m)	
			Technique 1	Technique 2
1495,2	1601	Poor	0	0
1601	1632,7	Moderate	3.8	5.2
1632,8	1669,7	Good	4.6	5.6
1669,8	1682,2	Moderate	0	0
1682,3	1736,6	Good	37.9	49.8
1736,7	1749,9	Moderate	1.8	0
1750	1779	Poor	0	0
1780	2080	Good	107.8	174.5
Total			**160.2**	**210.4**





Arvid Nøttveit

SPECIAL ADVISOR

ACT2 DIGIMON

Arvid Nøttveit is a strategic advisor for energy at the Norwegian Research Centre (NORCE) based in Bergen and was CEO of its predecessor Christian Michelsen Research for 14 years. He has extensive experience from research in the oil and gas industry, and from managing practical work in drilling, exploration, field development and operations on the Norwegian continental shelf and around the world.

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DigiMon

- ACT2 project

CLIMIT Summit 2023

Arvid Nøttveit,

Kirsti Midttømme

8 . FEBRUAR 2023

DigiMon
- ACT2 project

CLIMIT Summit 2023

Arvid Nøttveit,

Kirsti Midttømme

8. FEBRUAR 2023

NORCE (project manager)	TNO
OCTIO Environmental Monitoring	GEOTOMOGRAPHIE GmbH
CRES Centre for renewable energy sources and saving	LLC Lawrence Livermore National Security
UNIVERSITY OF BRISTOL	SILIXA ltd
NTNU	EQUINOR Energy AS
HELMHOLZ – Centre for Environmental Research (UFZ)	REPSOL – Norge AS
SEDONA Development srl	UNIVERSITY OF OXFORD

DigiMon – the project

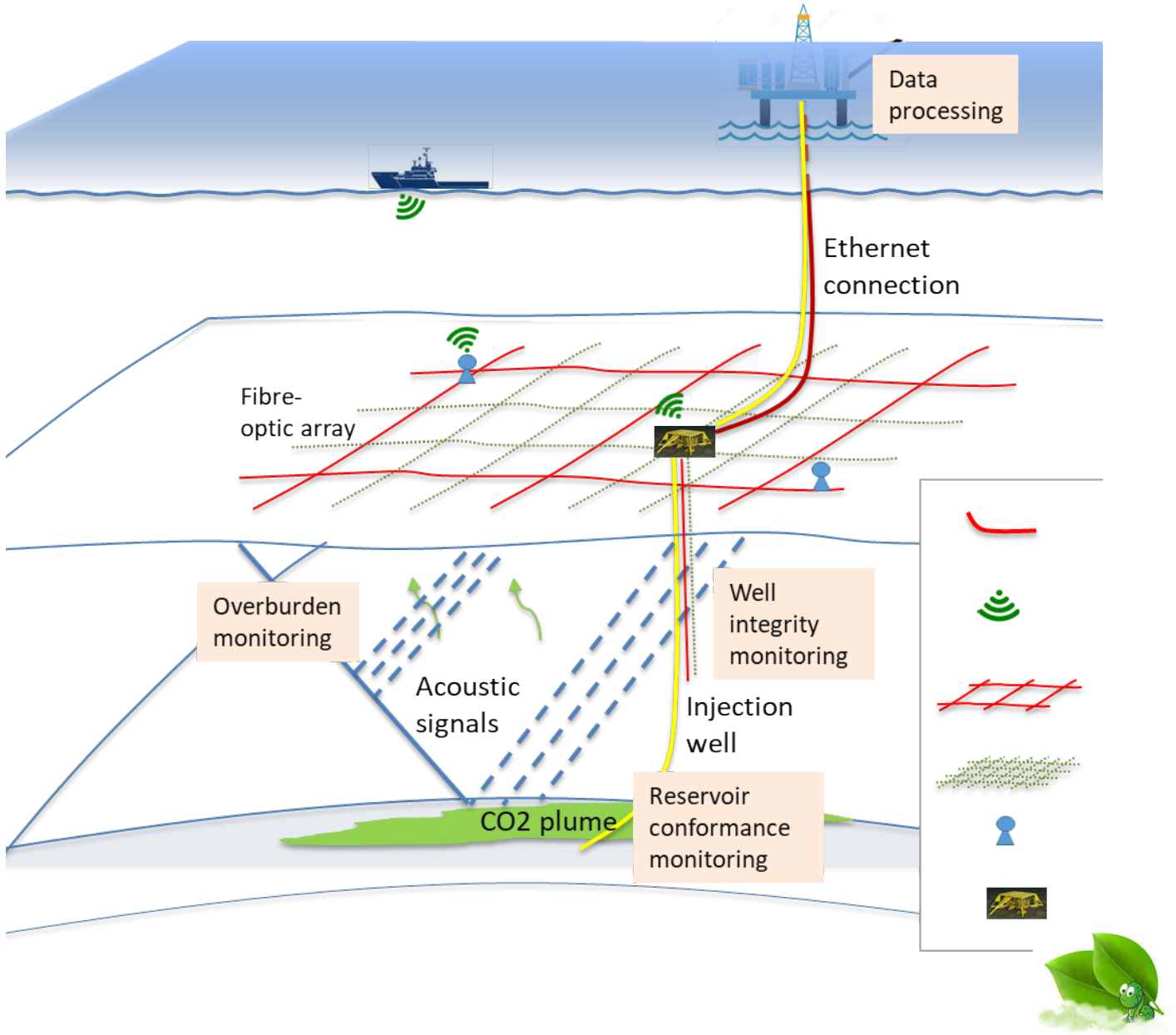
CO2 plume	Well integrity	Overburden
Monitoring the plume movement in the reservoir mainly using remote passive geophysical measurements of changes in saturation and pressure (Conformance monitoring).	Monitoring well integrity, mainly with downhole sensing (Containment and Contingency monitoring).	Monitoring the overburden, including monitoring of above-zone CO2 migration and early detection of CO2 leakage anomalies (Containment and Contingency monitoring).

WP4 Project management (NORCE)

WP1	WP2	WP3
Critical technology elements (Silixa)	Integrating the components (Octio EM)	Designing a human centered monitoring system (TNO)

Interdiciplinary package (IP) 1: Data collection (UoB)

Interdiciplinary package (IP) 2: Dissemination and exploitation (TNO)



System components

- Develop DAS data processing techniques and workflow
  - Microseismic dataset (Antarctica, FRS and FORGE)
  - Dataset for ambient noise interferometry (FRS)
- Determine DAS transfer function
  - Laboratory and field datasets
- Field campaigns
  - FRS, Alberta, Canada dataset - University of Oxford, TNO, Silixa & University of Bristol (2021)
    - Passive & active data, CCS research site (active CO2 injection)
    - Surface and borehole data, straight & helical fibre, reference geophones
  - Svelvik, Norway dataset - Geotomographie, NORCE & Silixa (2021)
    - Field test new SV source
    - Passive & active data, CCS research site (active CO2 injection)
    - Surface and borehole DAS data - straight & helical fibre, hydro- & geophones

Key output

- DAS Processing algorithms and workflows
- Algorithms to aquire and process gravity and deformation data
- “DigiMon toolbox” python library
- Feasibility of using distributed chemical sensing for CO_2 leakage monitoring

Integrating the components

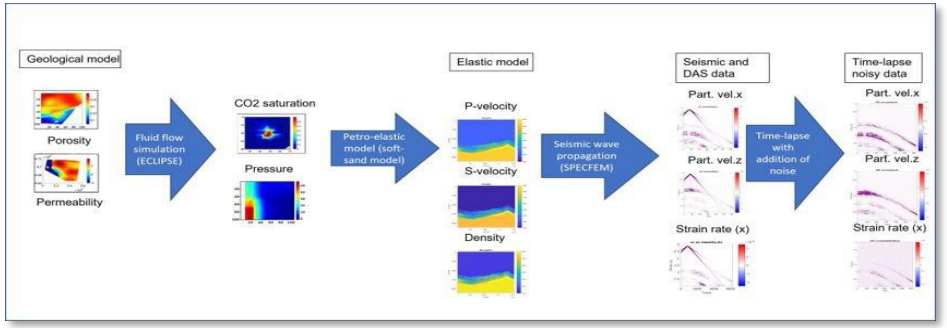
- Technology Readiness Assessment
  - Comprehensive analysis of critical technology components in DigiMon monitoring concept
- Forward and inversion framework set up for selected case Smeaheia, including conventional seismic, DAS, 4D gravity, and seafloor deformation data
  - Investigating the preliminary results on estimation of plume movements using FWI
  - Aim to also invert for the pressure plume including seafloor deformation data
- Optimizing the monitoring solution
  - Accounting for technical, economic and societal requirements

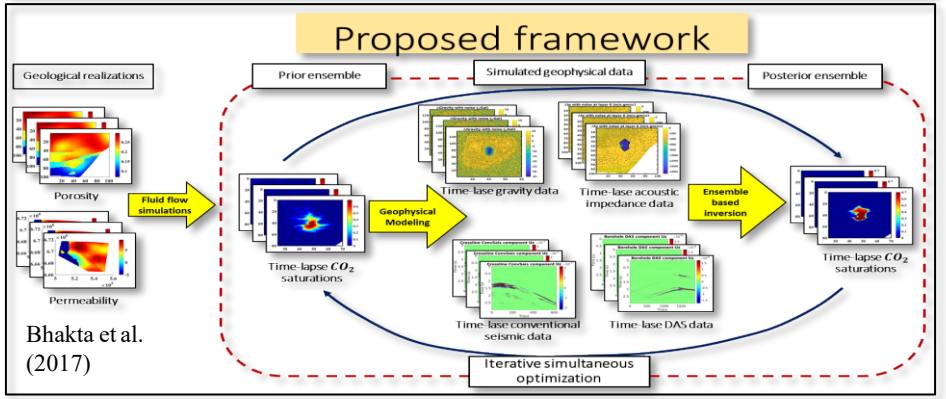
Key output

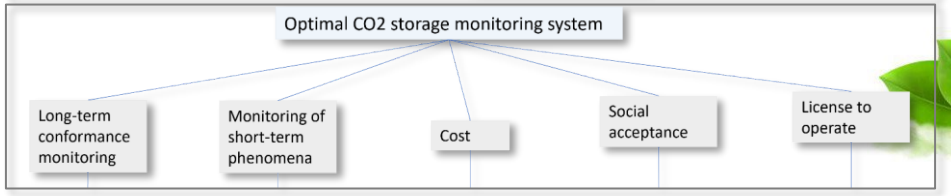
- TRA assessment
- Forward modelling framework
- Inversion framework and methodology
- Optimization of monitoring solution

Application	Class	CTE	TRL	Note
Surface and seabed reflection methods	Seismic reflection surveys	Conventional hydrophone of in case of OBN multi component sensors	9	Mature technology
		DAS	5-6	Recent experiments show good potential
Borehole seismic methods	VSP	Conventional VSP	9	Mature technology
		DAS-VSP	8	Good results only used onshore sofar
	Crosshole tomography	Conventional sensors (Novel SV source)	5-6	In testing phase at different environments
Passive seismic methods	Microseismics	Geophone/hydrophones	9	Mature technology
		DAS	7-8	Operational but not applied
	Ambient Noise Interferometry	Geophone/hydrophones	4-5	
		DAS	4-5	
Microgravity	Microgravity at the seafloor	Point-based, mobile, microgravity sensors	9	Mature technology
Seafloor deformation	Measurements at the seafloor	Pressure sensors	9	Mature technology
		Tiltmeters	4	Good results, only used for other applications sofar
		DSS	4-5	Good results, only used for other applications sofar
Downhole Pressure sensing	Measurements in well	Conventional pressure sensors	8-9	Commercially available but lack long term use in CCS
		DPS	5-6	
Temperature sensing		DTS	9	Mature technology
Chemical sensing		Conventional sensors	9	Mature technology
		DCS	3	

NORCE





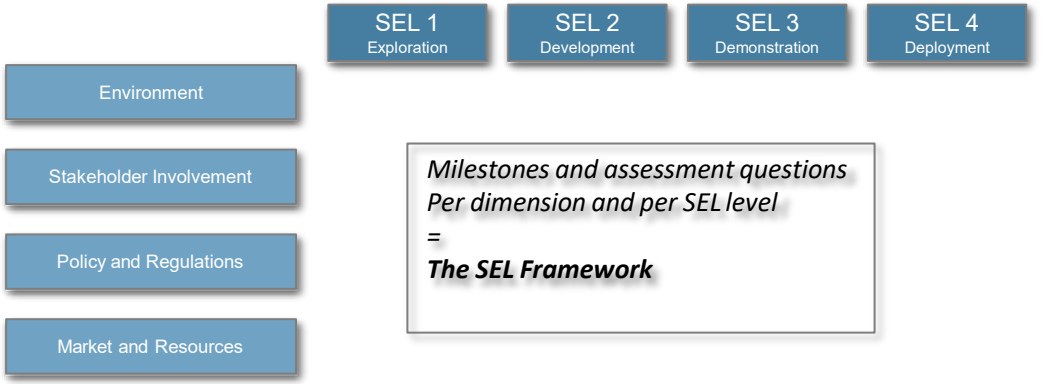


Societal relevance and communication

- Development of SEL methodology for CCS/ CO2 monitoring purpose
  - Calibration with TRL scale
- National and local assessments in 4 countries
  - Germany
  - Greece
  - Norway
  - Netherlands
- Survey among general public related to local developments; in-depth interviews with CCS experts
  - Alignment between SEL and TRL in most countries, except Germany
  - Misalignment increases the risk in deployment of new projects

Key output

- Insights in public perspective on CCS
- Insight in public perspective on CCS monitoring
- CCS experts' perspectives on societal requirements for CCS and CCS monitoring > link SEL dimensions
- Overarching narrative: comparison between countries: overall perspective on CCS and CCS monitoring.



Basic Principles observed	Technology Concept formulated	Experimental proof of concept	Technological validated in a lab	Technology validated in relevant environment	Technology demonstrated in relevant environment	System prototype demonstration in an operational environment	System completed and qualified	Actual system proven in operational environment
TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TRL 9

SEL 1	SEL 2	SEL 3	SEL 4
Exploration - An idea is studied from various perspectives, i.e. technological, environmental, , stakeholder, market, legal, political	**Development** - Further development of the idea by taking into account the societal conditions of relevant stakeholders, policy and regulations, financial resources, required knowledge on impact on society, etc. Actions taken to create financial, stakeholders, policy and regulatory – support.	**Demonstration** - Innovation is demonstrated with the support of relevant stakeholders, policy and regulations and financial commitment. Societal bottlenecks that arise in this phase are coped with. An improved societal innovation is the result.	**Small scale Implementation** – Innovation is embedded in society: support of relevant stakeholders, sound societal business case, supportive policy and regulations and continuous financial commitment.

	Greece	the Netherlands	Germany	Norway
TRL (estimated)	2	5	6	7
SEL (outcome assessment)	1	2	1	3
Comparison SEL-TRL link	in line	in line	not in line	in line

Next steps

- CETP proposal: Risk-based framework for assessing CO2 storage monitoring (RamonCO)
  - NORCE led consortium - collaboration: Germany, Greece, Netherlands, Norway, Romania, US

- Multi-physics, field scale inversion for constraining uncertainties related to monitoring of storage complexes
- Societal and environmental concerns in risk assessment and governance strategies
- Value of Information (VoI) analysis of CO2 storage conformance

Thank you for your attention!

The Digimon, project no 299622 is supported by the ACT international initiative http://www.act-ccs.eu/about-us and funded by GASSNOVA (NO), RCN (NO), BEIS (UK), Forschungszentrum Jülich (DE), GSRT (GR), RVO (NL), UEFISCDI (RO), DoE (US), Repsol Norge (NO) and Equinor (NO)

Tor Harald Sandve

SENIOR RESEARCHER

CLIMIT SUMMIT

#CLIMITSUMMIT2023
7–9 February

HPC-simulation software for the gigatonne storage challenge. OPM-Flow

Tor Harald Sandve is a senior researcher in NORCE (Norwegian Research Centre). He holds a PhD in applied mathematics and is one of the key developers of the OPM Flow reservoir simulator where he recently contributed a dedicated CO_2 storage module.

The Research Council of Norway

GASSNOVA

OPM Flow: HPC-simulation software for the gigatonne storage challenge.

CLIMIT summit 2023

Tor Harald Sandve (Norce), Sarah Gasda (Norce), Atgeirr Rasmussen (Sintef), Kai Bao (Sintef), Alf-Birger Rustad (Equinor) , Eduardo Barros (TNO), Goncalves Machado, C. (TNO)

OPM Flow: HPC-simulation software for the gigatonne storage challenge.

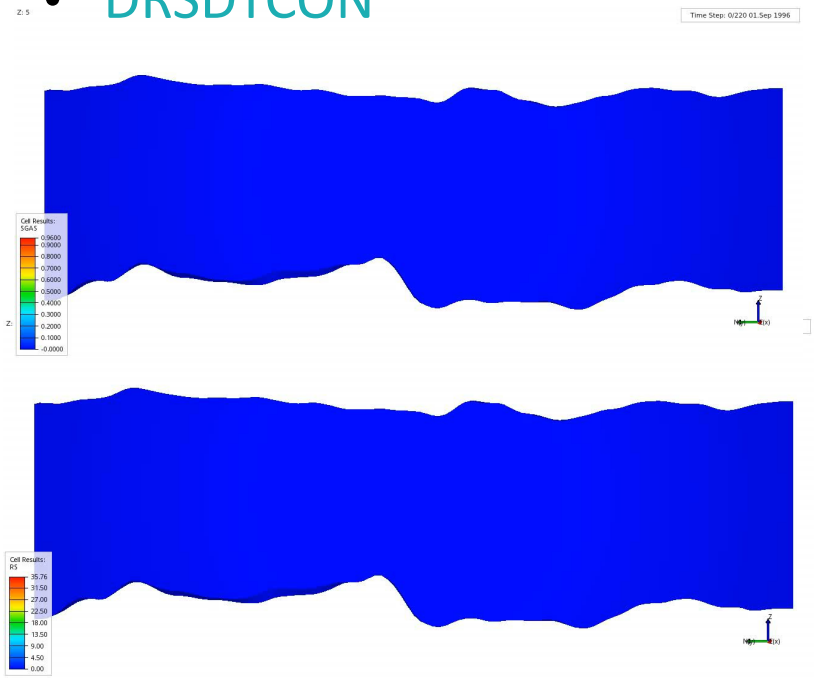
OPM Flow – an open-source reservoir simulator

- Easy-to-use, fast and scalable
- Open source, free to download and use
- Tested on several field scale models
- Compatible with standard industry I/O formats
- Dedicated CO2STORE module
- Upscaled convective mixing (DRSDTCON)

Examples

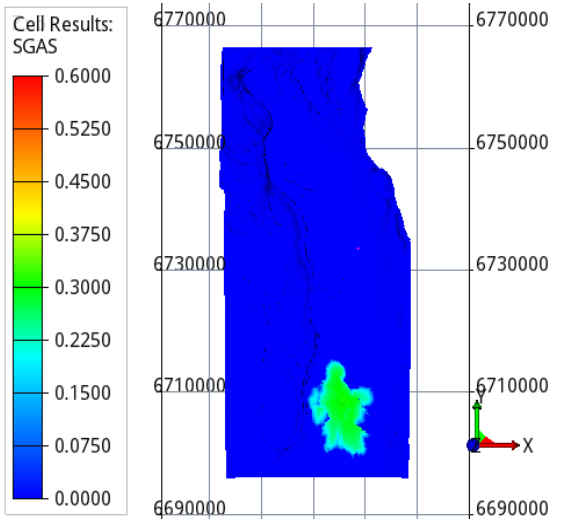
Sleipner

- https://CO2datashare.org/dataset/sleipner-2019-benchmark-model
- DRSDTCON

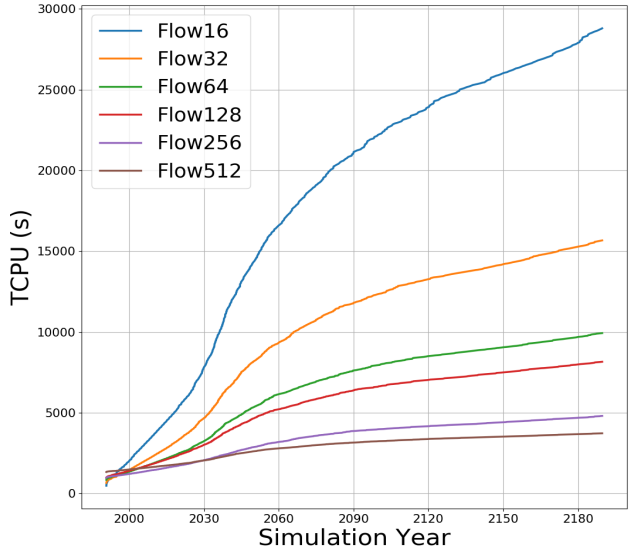


Smeaheia

- 9 million active cells
- Model provide by Equinor for testing purpose



Simulation results in 2100



Simula eX3 HPC infrastructure

* Sandve, T. H., Gasda, S. E., Rasmussen, A., & Rustad, A. B. (2021). Convective Dissolution in Field Scale Co2 Storage Simulations Using the OPM Flow Simulator. In *TCCS–11. CO2 Capture, Transport and Storage. Trondheim 22nd–23rd June 2021 Short Papers from the 11th International Trondheim CCS Conference*. SINTEF Academic Press.

Sandve, T. H., Rustad, A. B., Thune, A., Nazarian, B., Gasda, S., & Rasmussen, A. F. (2022, April). Simulators for the Gigaton Storage Challenge. A Benchmark Study on the Regional Smeaheia Model. In *EAGE GeoTech 2022 Sixth EAGE Workshop on CO2 Geological Storage* (Vol. 2022, No. 1, pp. 1-5). European Association of Geoscientists & Engineers.

OPM Flow: HPC-simulation software for the gigatonne storage challenge.

Goals towards 2024

- Faster and improved scalability on larger clusters
- CO_2 storage in depleted hydrocarbon fields
- Validation and improved robustness of field scale simulations with dissolution and dynamic temperature change

OPM
OPEN POROUS MEDIA

https://opm-project.org/

Lars Grande

SENIOR ENGINEER

CLIMIT SUMMIT

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AddStorage-Analogue-site data-driven study for characterization and monitoring of deep CO_2 storage sites

25 Year experience from geomechanical assessments for oil and gas production and for CO_2 storage in Norway and Internationally. Main work area is geomechanichal characterization of petroleum and CO_2 sites by integration of geology data, petrophysical logs and geomechanical laboratory data and ground stresses.

The Research Council of Norway

GASSNOVA

Analogue-site data-driven study for characterization and monitoring of deep CO_2 storage sites (AddStorage)

CLIMIT SUMMIT 8th February 2023

NGI, UiO, SINTEF

Contact info: Lars.Grande@ngi.no

AddStorage - A CLIMIT-Demo project sketch

Title: Analogue-site data-driven study for characterization and monitoring of deep CO_2 storage sites (AddStorage)

CLIMIT Idea study 2022 (Project-621305)

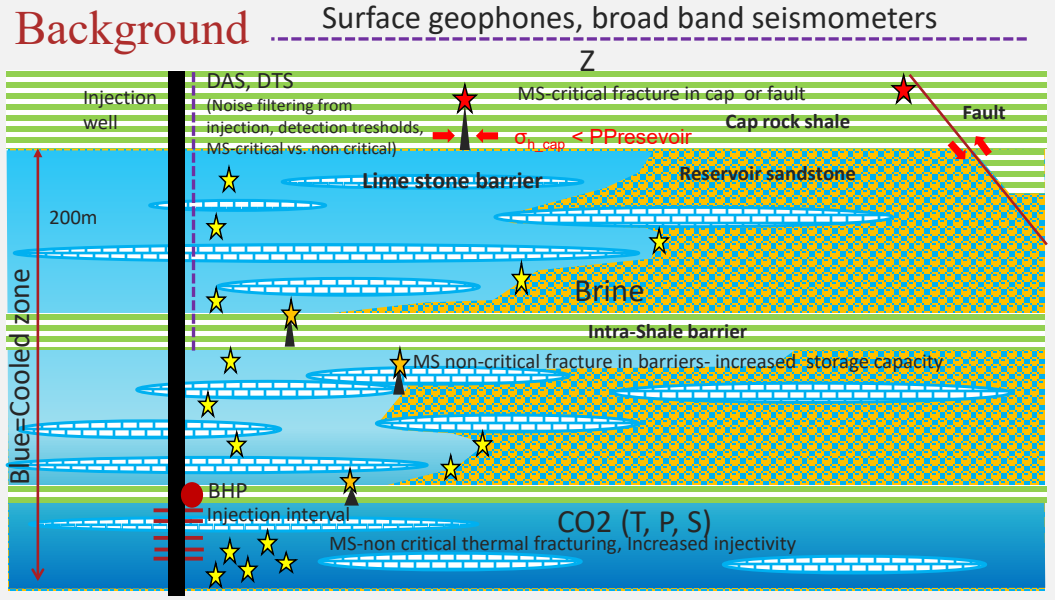
- Deliverable-CLIMIT DEMO full proposal
- Aquistore CCS pilot (Canada) evaluated in idea study
- Status: Need Sponsoring partner support

Objective full proposal- 2 year 2023-2025

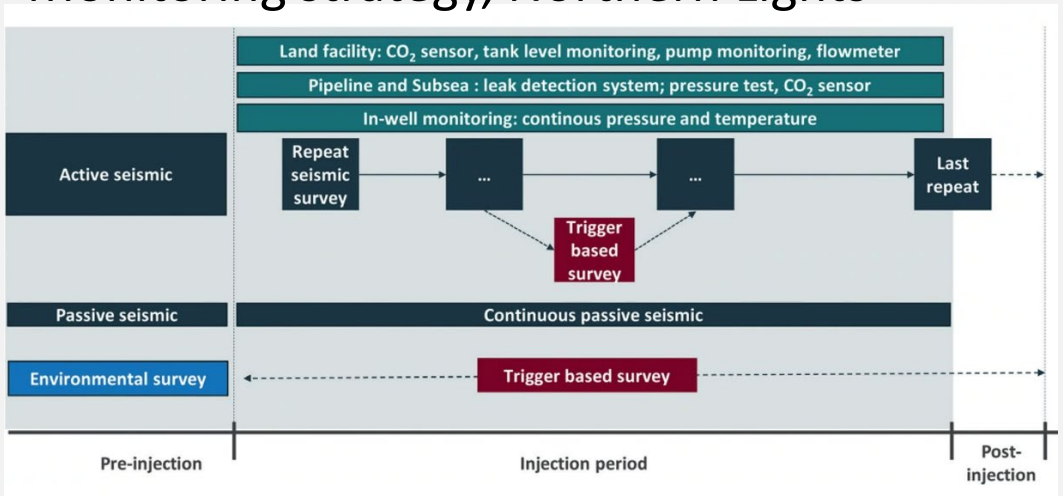
- Test and calibrate a predictive THM-D tool (Thermo Hydro Mechanical- Dynamic) for analysing rock strains, flow and 4D seismic response of thermally influenced zone in deep storage candidates, for safely-managed large-scale CO_2 injection operations.
- Testing and calibration based on datasets acquired at the **Analogue CO_2 injection sites,** including active CO2 storage pilots and producing fields with water injection).

NGI

Complex THM-D system



Monitoring strategy, Northern Lights



Furre et al., 2020 (First Break)

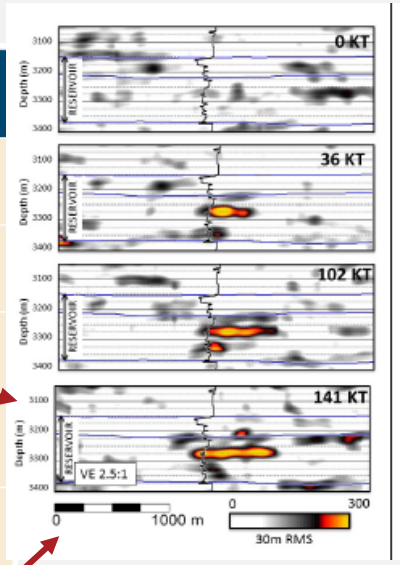
AddStorage - CLIMIT Idea study data review

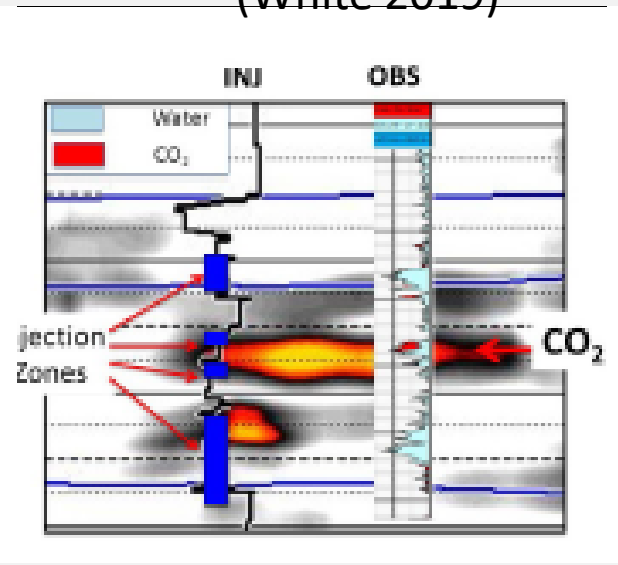
Aquistore, 7 years extensive monitoring experience

	SURFACE	SHALLOW SUBSURFACE	DOWNHOLE INSTRUMENTATION	SEISMIC
MONITORING TECHNOLOGIES	Tiltmeters	Piezometers	Fibre-optic distributed temperature systems (DTS)	Cross-well seismic tomography
	InSAR Satellite Interferometry	Groundwater chemistry monitoring	Fibre-optic distributed acoustic system (DAS)	Broadband seismography
	Electromagnetics	Soil-gas monitoring	Fluid recovery system	Permanent 630 geophone areal seismic array
	GPS	Multi-species atmospheric surveys	Pressure gauges	Time-lapse 3D seismic imaging
	Gravimeters		Temperature gauges	Continuous passive microseismic monitoring
			Pulsed neutron decay and cross dipole sonic logging	Vertical seismic profiling (VSP)
			Borehole gravity	Accurately controlled, routinely operated signal system (ACROSS)
			Bubble tube system	
PURPOSE OF MONITORING	Surface deformation	Groundwater and soil gas changes	Geophysical logging to measure changes from injection	CO_2 plume location
		Near-surface atmospheric changes	Cross-well electrical and seismic tomography	Induced seismic activity
			Rock-fluid properties	Geological changes
			Reservoir fluid chemistry	

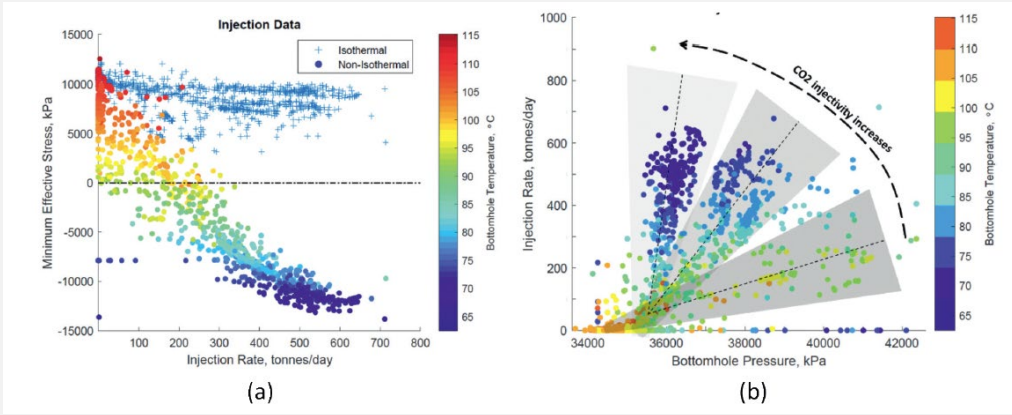
(Movahedzadeh et al., 2021)

4D seismic- 5 repeated 3D datasets (White 2019)





Injection pressure, temperature and rate- Indication of thermally induced fractures (TIF)

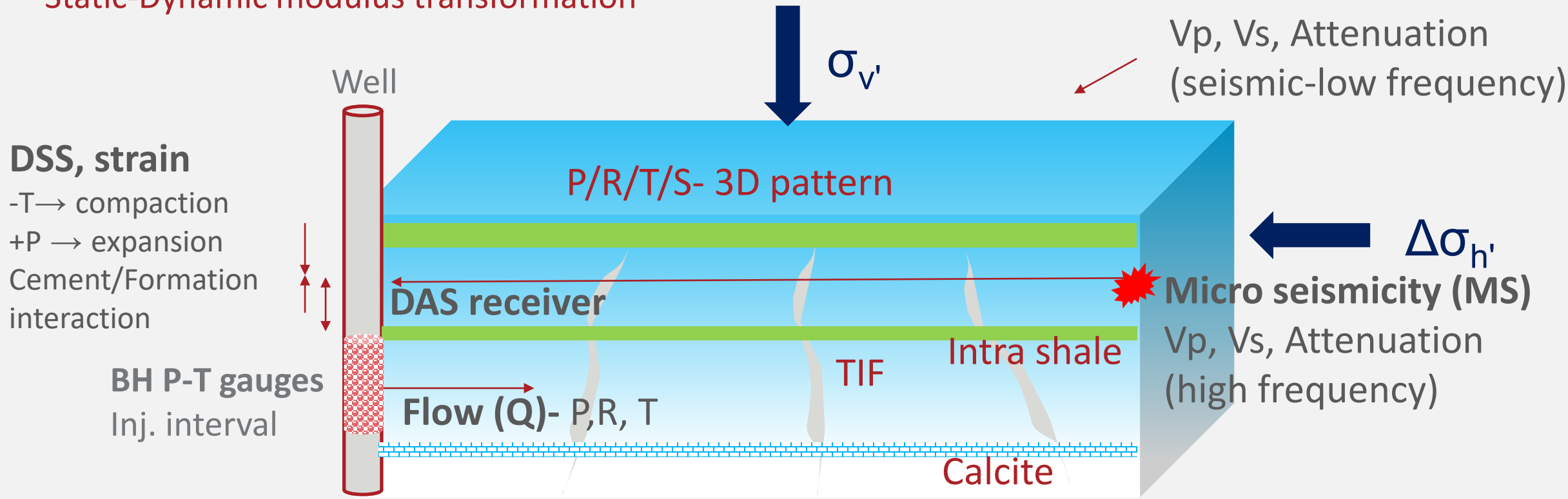


AddStorage - A CLIMIT-Demo project sketch

WP1. Rock physics **(NGI, UiO)**
WP2. Site characterization **(NGI, UiO, SINTEF)**
WP3. THM-D static and dynamic model in COMSOL **(NGI)**
WP4. Calibration through monitoring **(NGI, UiO, SINTEF)**

Complex THM model

- Anisotropy (intrinsic-geological variations)
- Flow (Q); Pressure/Rate/Temperature (P/R/T) and saturation (S)
- Stress dependent modulus and velocity anisotropy, E/Vp/Vs
- Thermally Induced Fractures (TIF)
- Static-Dynamic modulus transformation



NGI

#onsafeground

Further information, contact
Lars.Grande@ngi.no

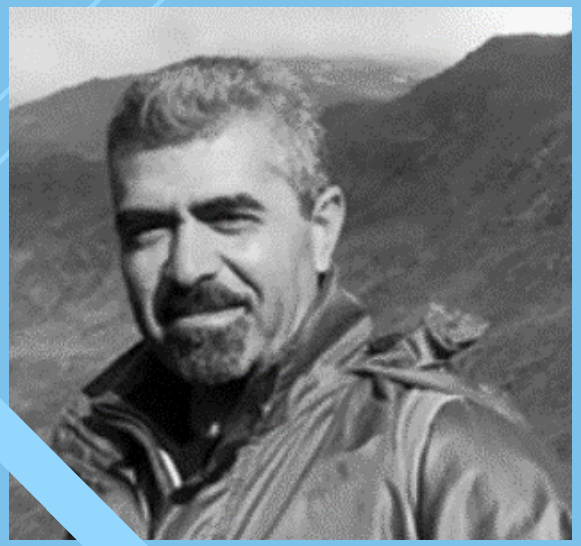
Bahman Bohloli

SENIOR SPECIALIST IN GEOMECHANICS

CLIMIT SUMMIT

#CLIMITSUMMIT2023
7–9 February

Value of ground deformation for monitoring CO_2 storage sites



Bahman Bohloli is a Geomechanics Specialist with 20 years of experience on energy and CCS projects from both academia and industry. He is currently working for Norwegian Geotechnical Institute in Oslo with focus on underground storage of CO_2 and hydrogen.

The Research Council of Norway

GASSNOVA

https://sense-act.eu/

CLIMIT SUMMIT,
7-9 February 2023, Larvik

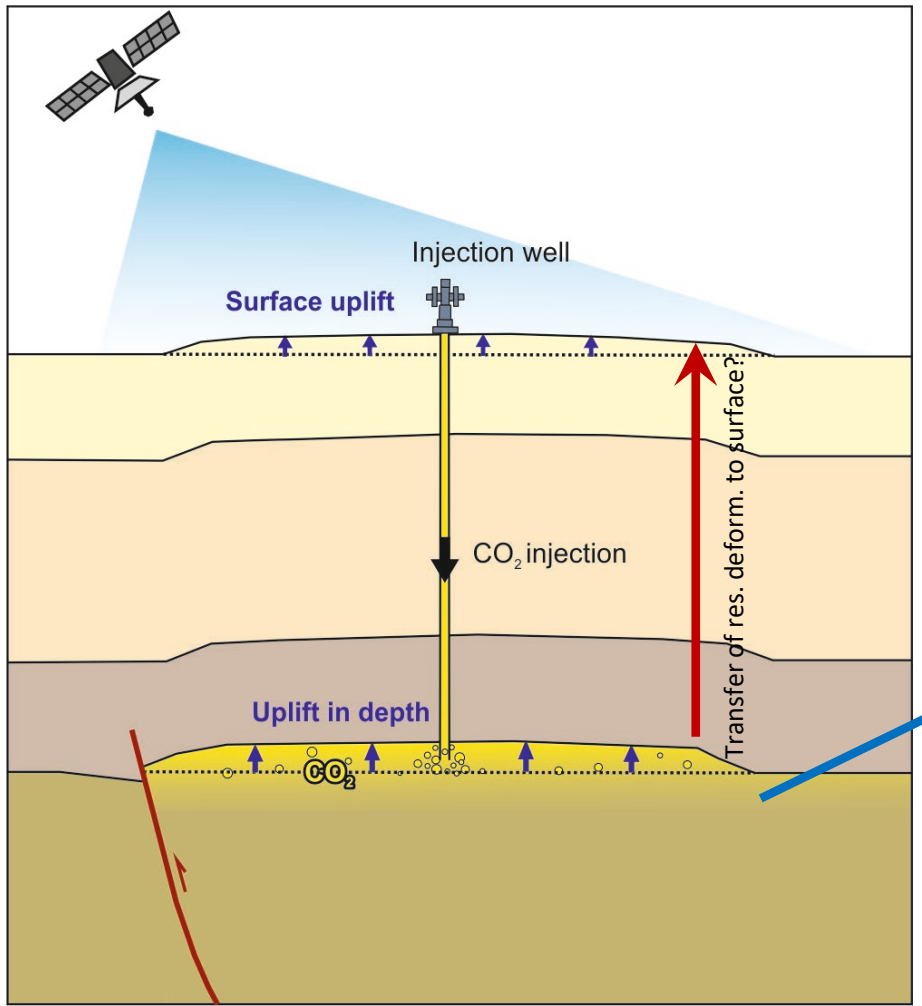
Value of ground deformation for monitoring CO_2 storage sites (SENSE project)

Bahman Bohloli (Norwegian Geotechnical Institute -NGI)

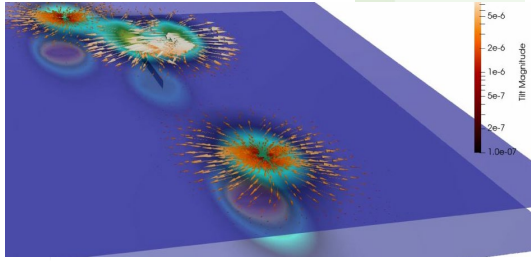
With contribution from: Joonsang Park, Tore I. Bjørnarå, Per M. Sparrevik, Malte Vöge, Regula Frauenfelder, Jean-Remi Dujardin, Henrik Meland, Nazmul H. Mondol, Ola Eiken, Christian Berndt, Jens Karstens, Sarah Bouquet, Audrey Estublier, Andre Fourno, Jeremy Frey, Yeon-Kyeong Lee, Yong-Chan Park, Ceri Vincent, Joshua White, Ziqiu Xue

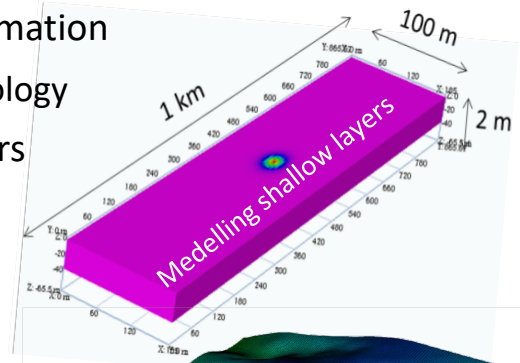
SENSE project narrative

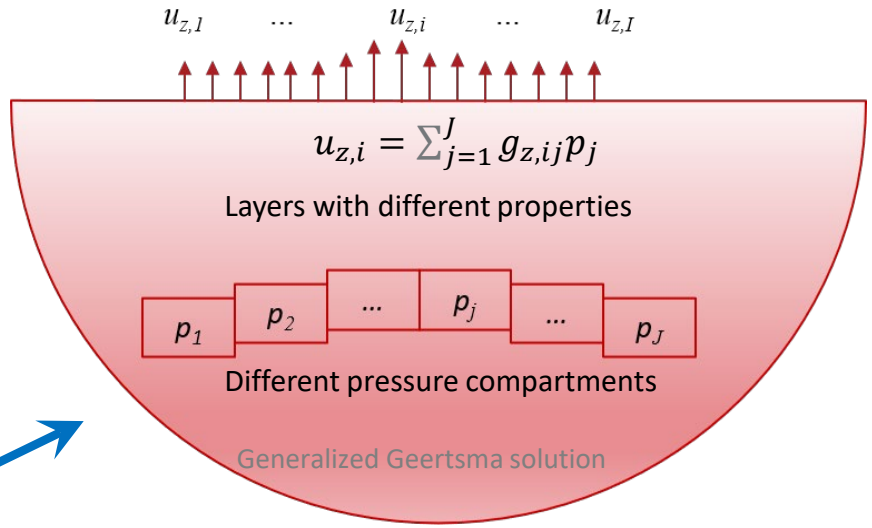
- **Objective**: use ground uplift as a parameter to monitor performance and integrity of storage complex.



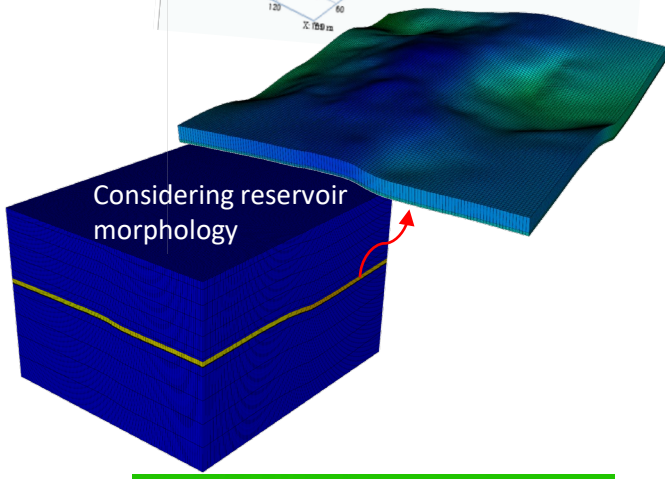
- **Methodology and Achievenments**
  - **Introduced a new analytical solution** for ground deformation
  - **Modelling uplift** with/without faults, considering morphology
  - **Developed** & **tested DSS fiber optics** & pressure sensors
  - **Developed InSAR data processing wokflow**.

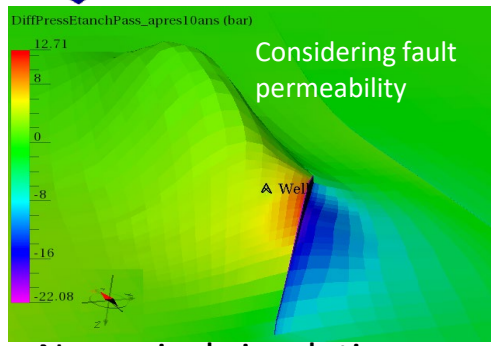






Geertsma Generalized Solution (Park et al. 2021) *for **first-order, fast calculation of ground uplift***





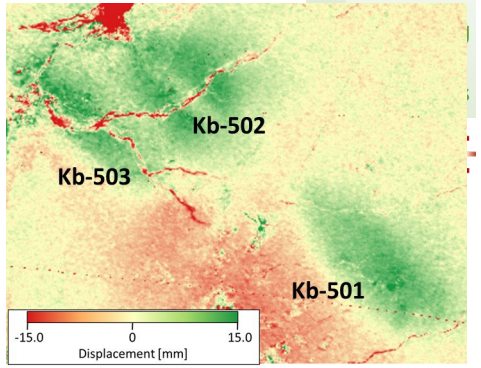
Numerical simulations

SENSE project narrative (Cont'd)

- **Methodology and Achievements**
  - **Introduced a new analytical solution** for ground deformation
  - **Modelling uplift** with/without faults, considering morphology
  - **Developed** & **tested DSS fiber optics** & pressure sensors
  - **Developed InSAR data processing wokflow**.

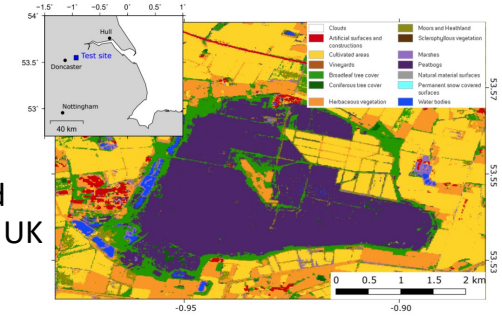
InSAR

In Salah

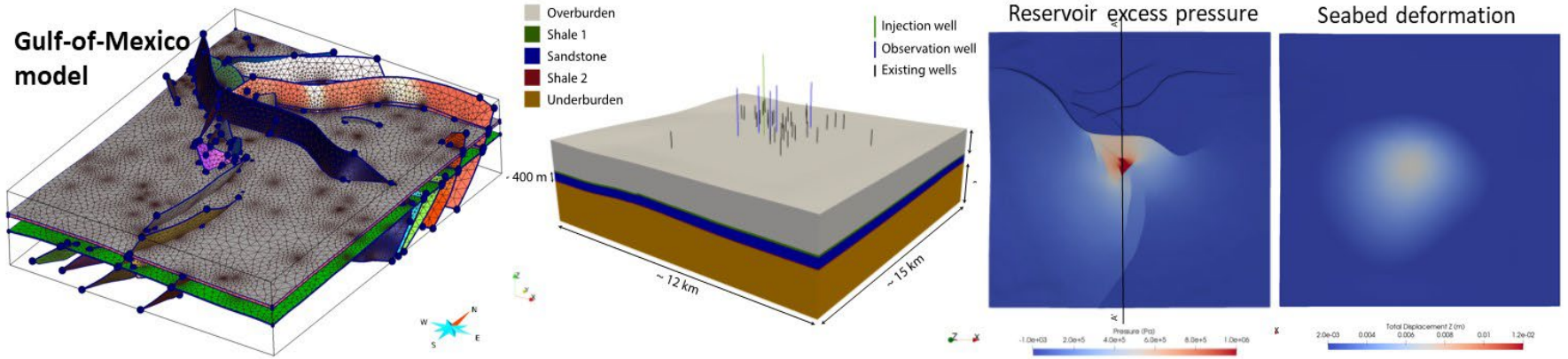


InSAR

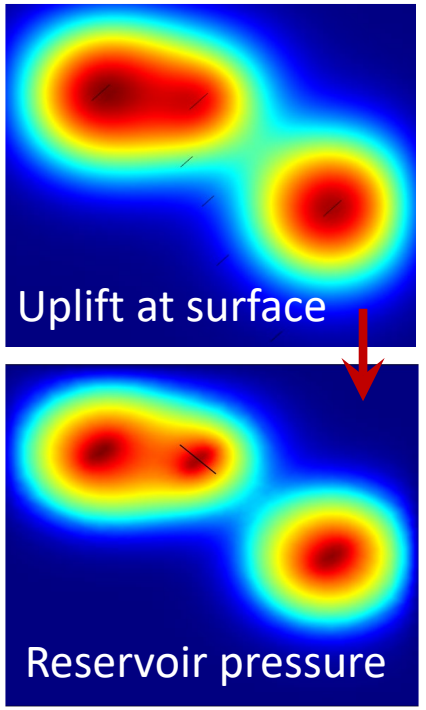
Hatfield Moors, UK



Ground uplift estimation

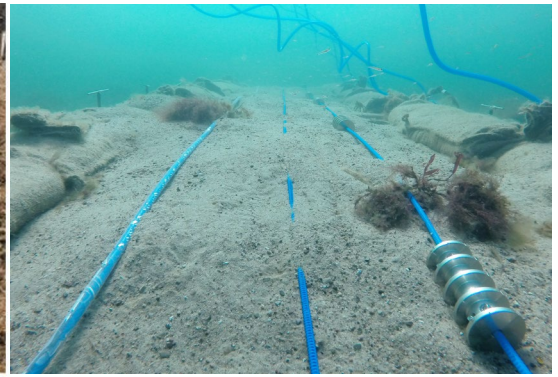


Machine learning



Large scale lab tests

Field scale



Offshore tests

Testing DSS fiber optics

Conclusions

- We suggest first-order estimation of ground uplift using the Generalized Geertsma solution (accounts for reservoir geometry, thickness, anisotropy). If considerable uplift → perform numerical simulations.

- Geomechanical modelling of real-life and synthetic cases shows the shape of deformation reveals sealing & draining behaviour of faults in reservoir/caprock.

- Experiments shows Distributed Strain Sensing (DSS) fiber optic cables:

- Provide good coupling with soil when embedded about 40 cm underground-no anchors
- Can detect deformations of ca. 1µ strain across cables
- Can work well for monitoring deformation hotspots.

Thank you!

https://sense-act.eu/

SENSE (Assuring integrity of CO_2 storage sites through ground surface monitoring) project No. 299664, has been subsidized through ACT (EC Project no. 691712) by Gassnova, Norway, United Kingdom Department for Business, Energy and Industrial Strategy, Forschungszentrum Jülich GMBH, Projektträger Jülich, Germany, The French Agency for the Environment and Energy Management, The United States Department of Energy, and State Research Agency, Spain. Additional support from Equinor and Quad Geometrics and permission to use data from the Krechba Field by In Salah Gas JV are appreciated.

Michael Jordan

SENIOR RESEARCHER

CLIMIT SUMMIT

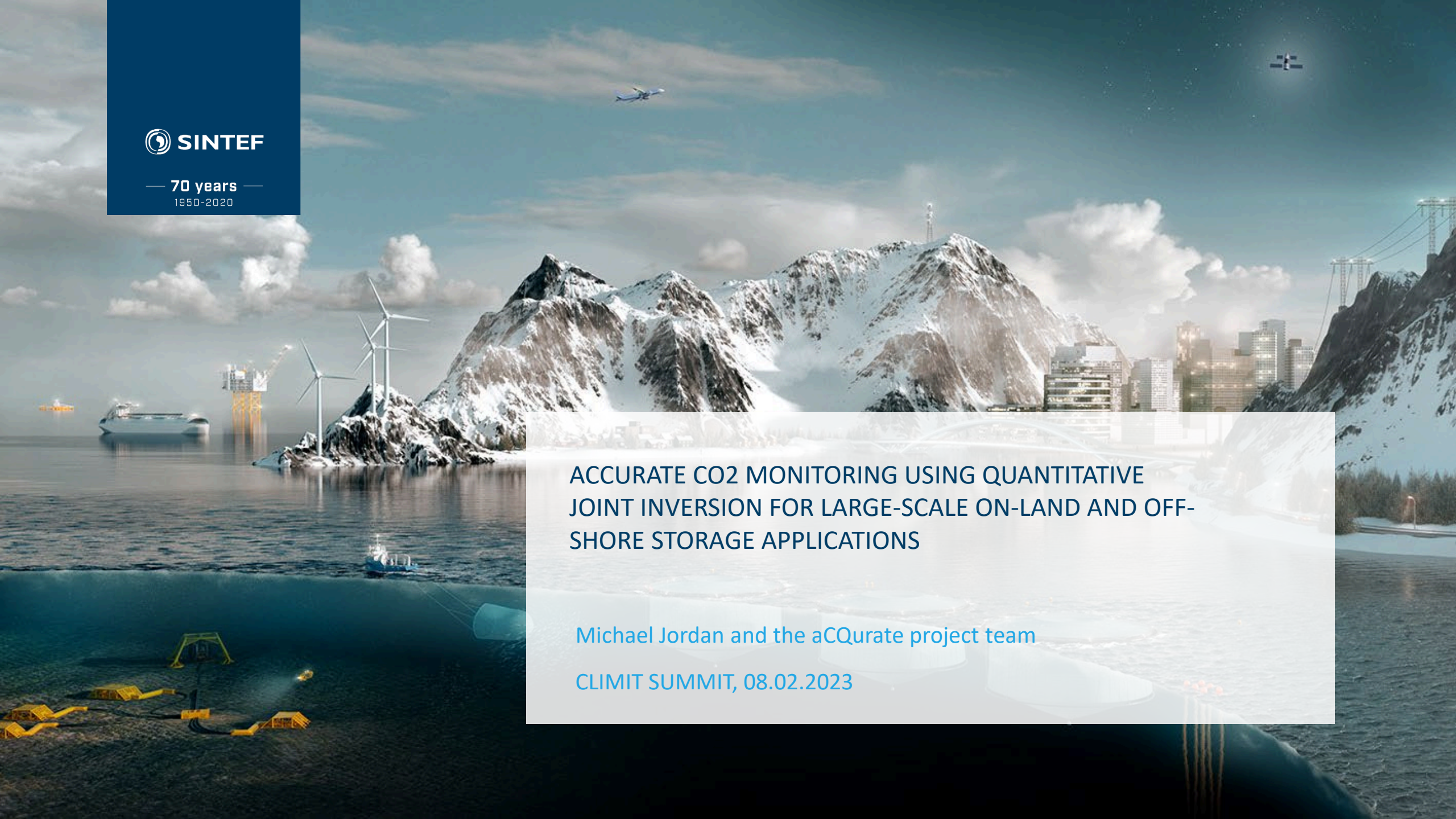
#CLIMITSUMMIT2023
7–9 February

Accurate CO_2 monitoring using quantitative joint inversion for large-scale on-land and off-shore storage applications

Michael is a senior research scientist at SINTEF, Norway, mostly working with monitoring of CO_2 storage. He has over 20 years of experience in development and application of methods for imaging and monitoring of the subsurface and combining different data types, e.g., through joint inversion.

The Research Council of Norway

GASSNOVA



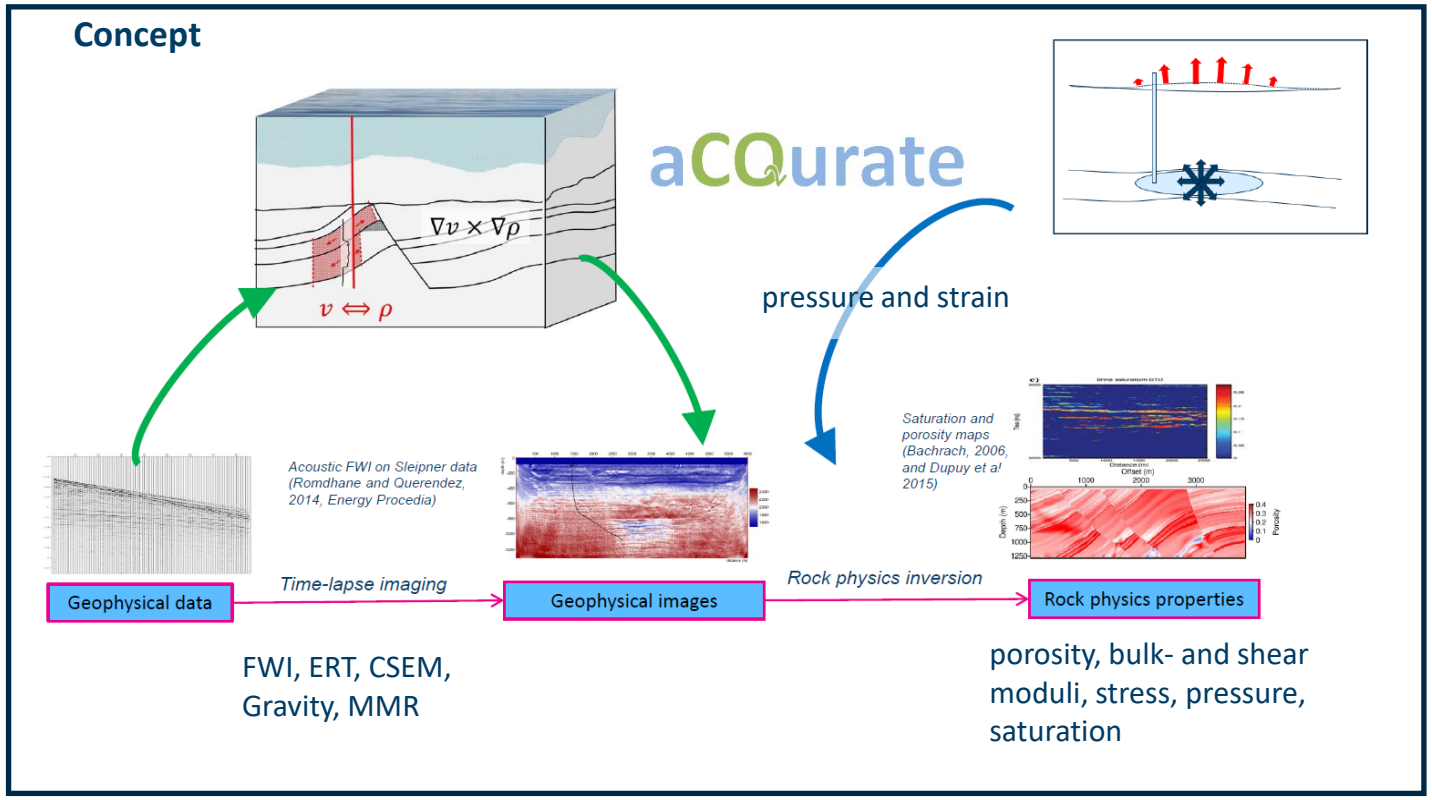
ACCURATE CO2 MONITORING USING QUANTITATIVE JOINT INVERSION FOR LARGE-SCALE ON-LAND AND OFF-SHORE STORAGE APPLICATIONS

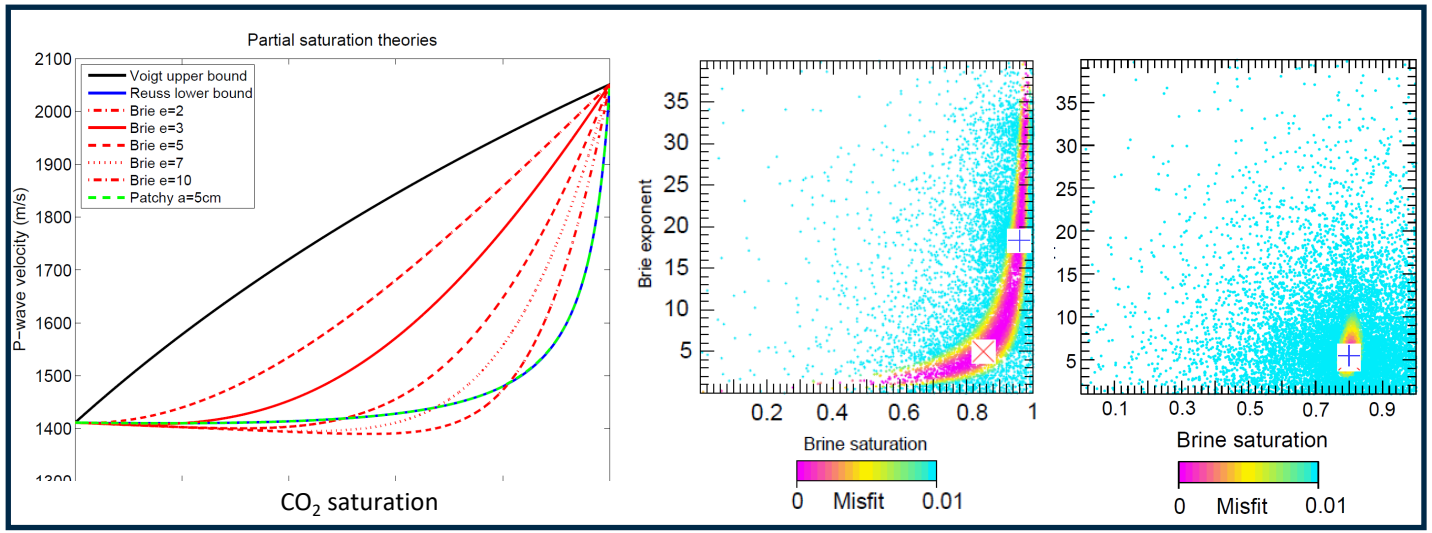
Michael Jordan and the aCQurate project team

CLIMIT SUMMIT, 08.02.2023

Background

- Regulatory requirements for CO_2 storage operations:
  - Containment
  - Conformance
- Operational requirements:
  - Safe and efficient storage
- Requires quantitative monitoring of reservoir parameters
  - pressure, saturation, or strain in the overburden

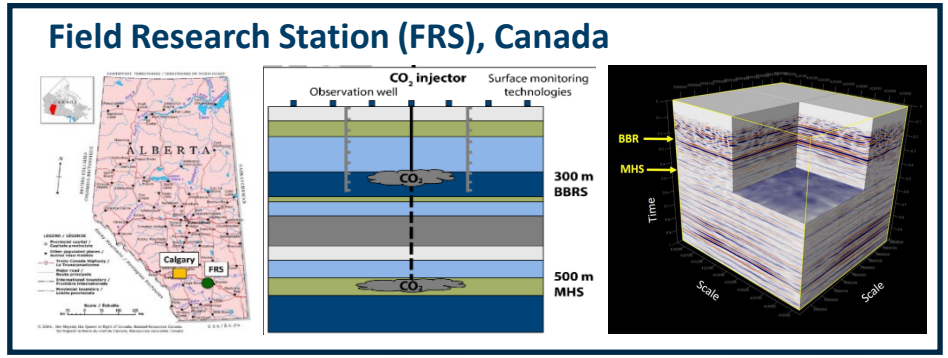


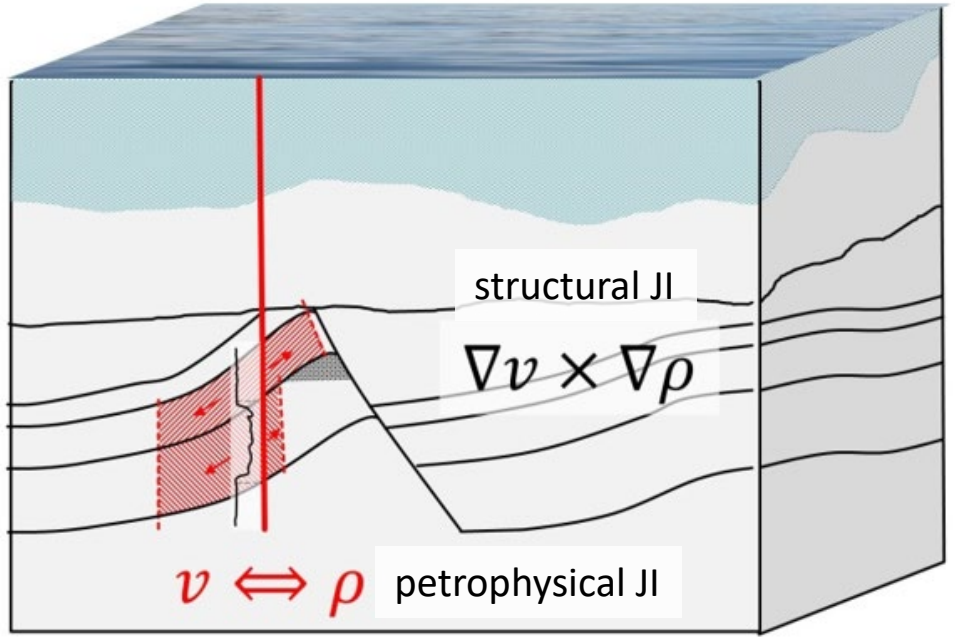


The aCQurate project

Metrics:
- Project completed (2017-2022)
- Total budget: 28,1 MNOK
- Gassnova Funding : 14,7 MNOK

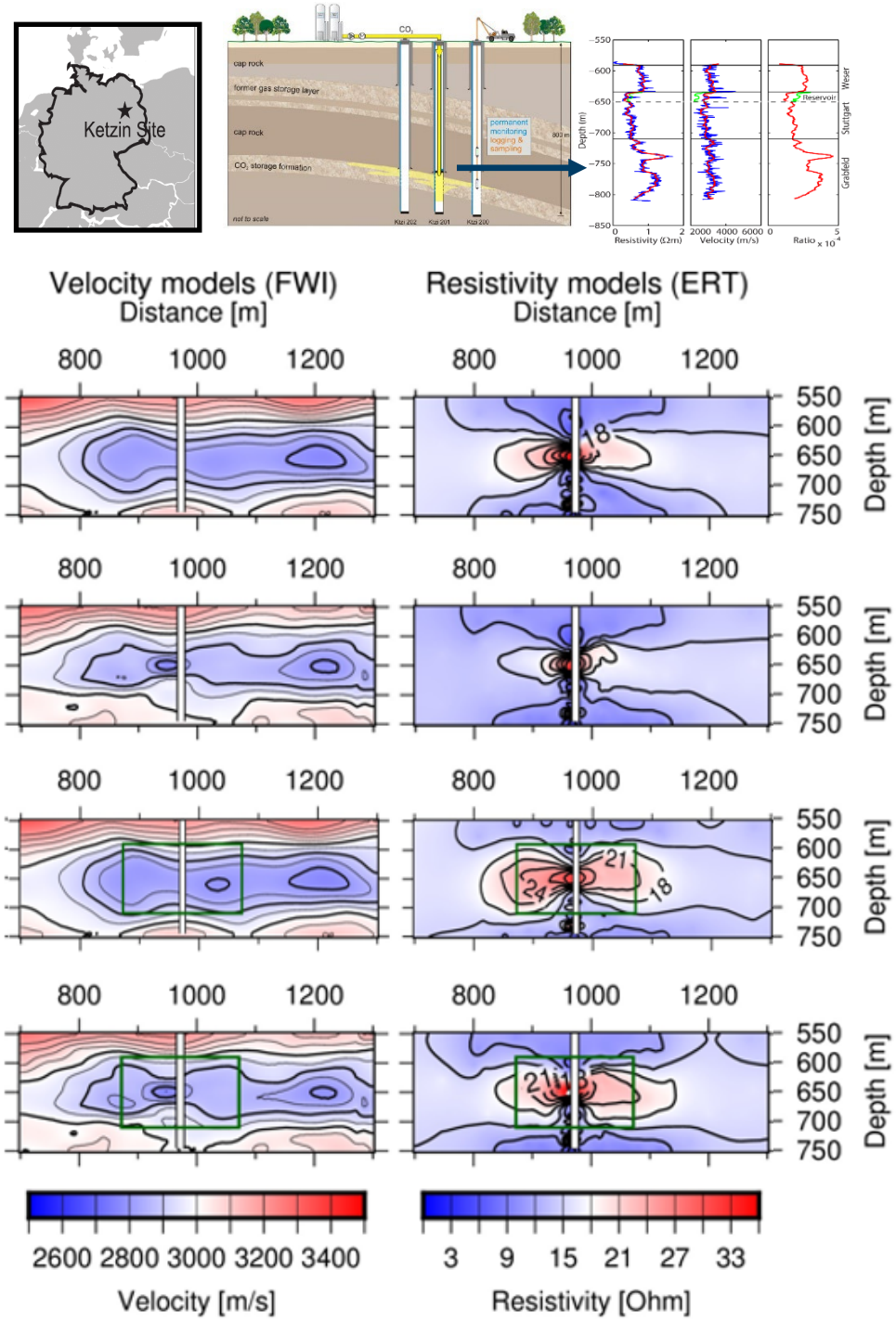
- Aim: Quantitative monitoring of reservoir parameters
- Create a method (software) to reliably integrate relevant CO_2 monitoring data:
  - Advanced hybrid structural-petrophysical joint inversion
    - Methods relevant for CO_2 storage
    - Large-scale and high resolution
    - On-shore (FWI, ERT, gravity, uplift)
    - Off-shore (FWI, CSEM, gravity, uplift)
    - Quantitative





aCQurate results

- Hybrid joint inversion method successfully implemented and tested
  - Tested various data type combinations and geometries at CaMI.FRS and Ketzin sites (surface, downhole, X-well, VSP)
    - Stable results and improved images compared to independent inversions
    - Both methods benefit from joint inversion
    - Hybrid JI combines benefits from structural and petrophysical JI
  - Resulting models can be used for quantification of reservoir parameters
  - Implemented methods: seismic (FWI,X-well, VSP), ERT, CSEM,MMR, gravity
    - Modular design; external 3rd party codes can be linked



SINTEF

70 år

1950-2020

Teknologi for et bedre samfunn

Pierre Cerasi

SENIOR SCIENTIST

CLIMIT SUMMIT

#CLIMITSUMMIT2023
7–9 February

SNOWPACCS – Challenges with post-mortem investigation of well integrity at Mont Terri

Pierre Cerasi is a Senior Scientist at the Formation Physics group at SINTEF. He holds a PhD in Physics from the University of Paris and has 20 years of experience in petroleum-related rock mechanics. Over the last decade, he has focused his interests on geomechanics of carbon storage.

The Research Council of Norway

GASSNOVA

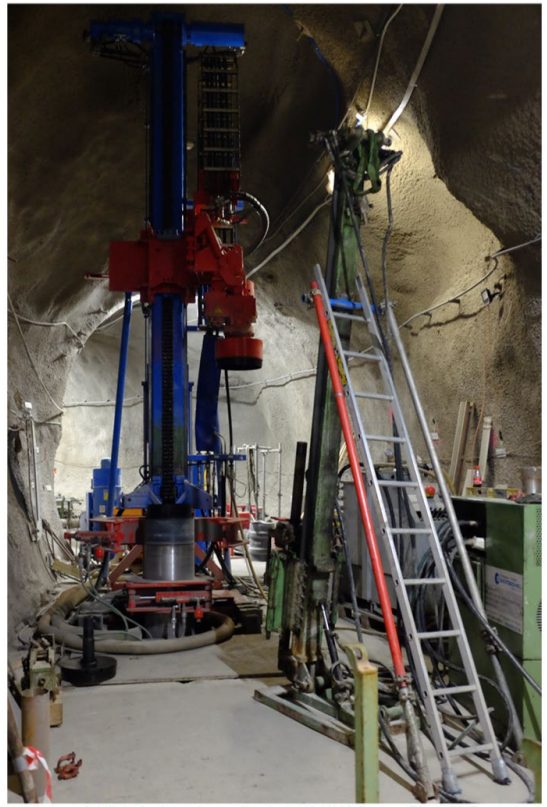
SNOWPACCS

The hidden value of insufficiently preserved shale material

Technology for a better society

SNOWPACCS – Swiss Norwegian Post-Mortem Analysis of Mont Terri CCS well

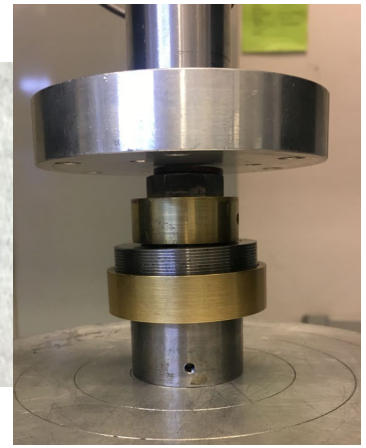
- **Gassnova-sponsored** project at SINTEF, with swisstopo as partner in Switzerland
- Original **objectives**:
  - Help evaluate performance of remediation fluids by overcoring a Mont Terri well and test well pieces for mechanical strength
  - Test SINTEF logging tool in blind test of remediated fractures
- New **goals**, due to failure of intact overcoring:
  - Test hypothesis that non-preserved cores (allowed to dry and crack) can still be useful for rock characterisation
  - Reference testing on preserved core plugs available at SINTEF
- Research **question**:
  - Can the in-situ properties of shale material be recovered by studying the effect of saturation-desaturation cycles on measured properties?
- **Plan**: perform as much as possible same small sample mechanical tests on preserved and unpreserved shale, for same levels of saturation

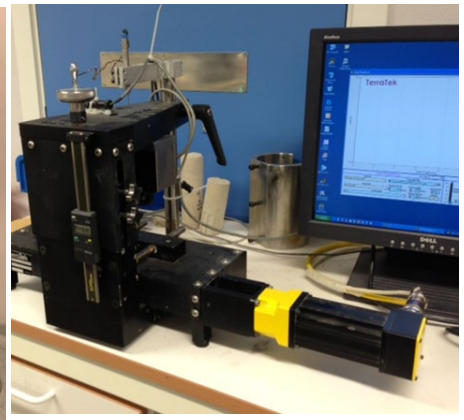


Installation of drill rig for lateral sampling hole 131/102.5 mm. (Photo V. Regard)

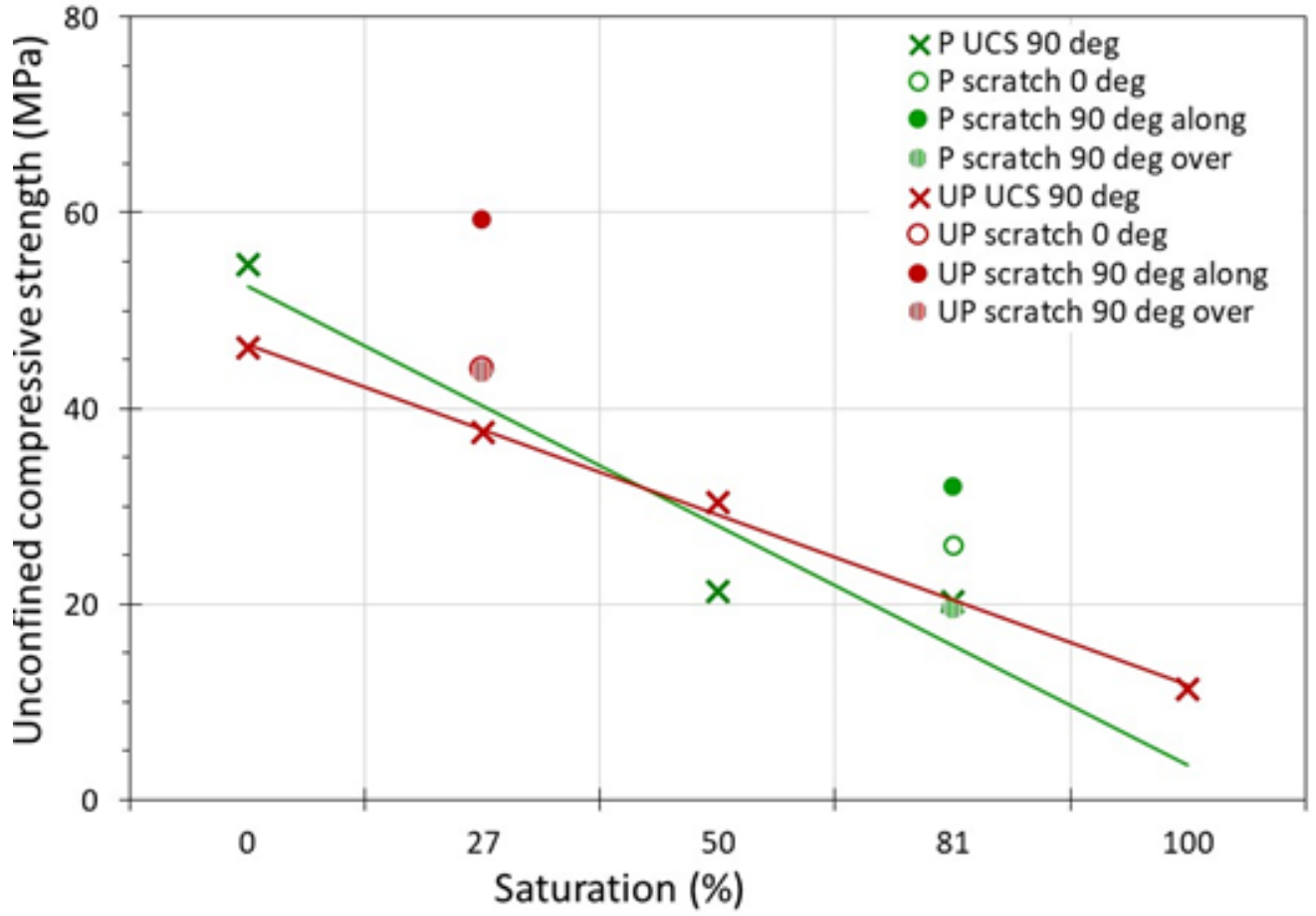
Fig. 1 OPA and cement both have gone at 8.65 m depth (in target section and well below grout packer, naked 120 mm steel casing of completion is visible on the right hand side. Depth indication on the photo is irrelevant, as it was not calibrated (Photo S. Schefer)

Results from measurement campaign





- Both **intact/preserved** shale cores and **dry/damaged** shale cores taken up and down saturation levels and tested mechanically (UCS, scratch, small sample testing)
- **Strength** values align remarkably well, given usual sample-to-sample variability



Conclusions

- Original project plans needed to be modified due to overcoring abandonment
- An alternative experimental programme was proposed, based on the received core fragments
  - Illustrates possible workflow for commercial CCS operations with less costly core taking and laboratory testing procedures
  - Suggests fundamental steps to "rehabilitate" old or non-preserved caprock samples with aim to develop correlations to be used when no reference plugs are available

SINTEF

Technology for a better society

Elin Skurtveit

STRUCTURAL GEOLOGY

CLIMIT SUMMIT

#CLIMITSUMMIT2023
7–9 February

In-situ stress and failure prediction for CO_2 storage sites

Elin Skurtveit holds a PhD in structural geology, employed at NGI (Norwegian Geotechnical Institute) and an Associate Professor II at University of Oslo, Dept. of Geosciences. Elin follows up several projects related to CO_2 storage and has a passion for integrated research combining geology, geomechanics and rock physics

The Research Council of Norway

GASSNOVA

SHARP Storage

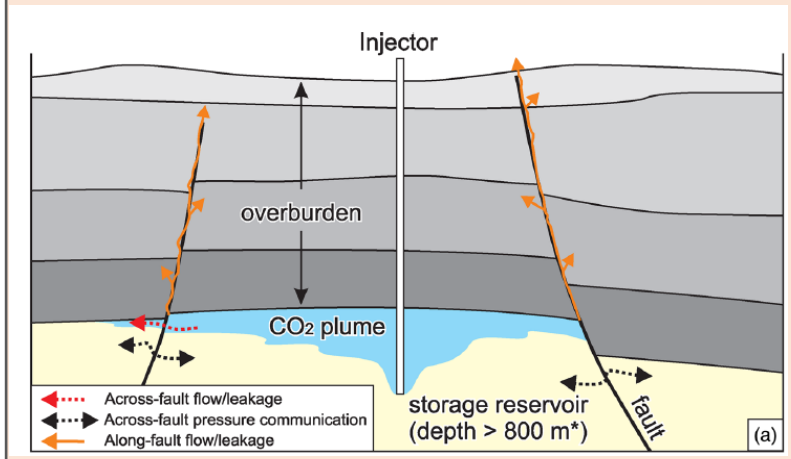
In-situ stress and failure prediction

Climit Summit, Larvik, Feb 8th, 2023

Elin Skurtveit, NGI, SHARP project coordinator
SHARP team: https://sharp-storage-act.eu/

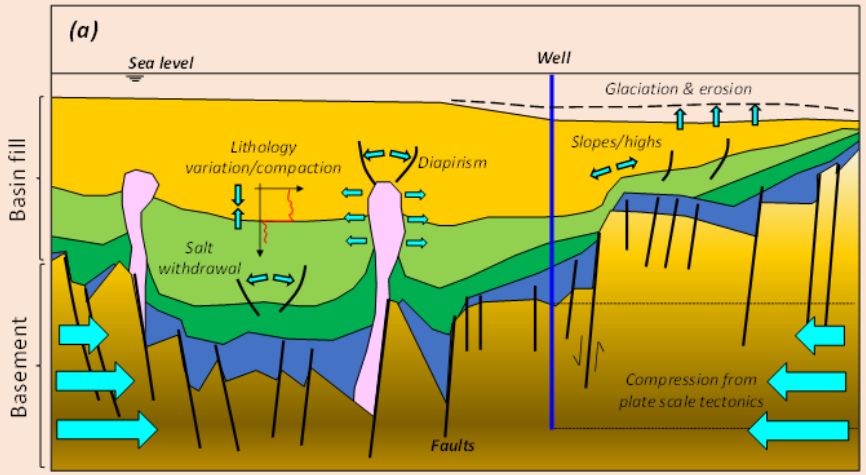
Challenges

Containment risk



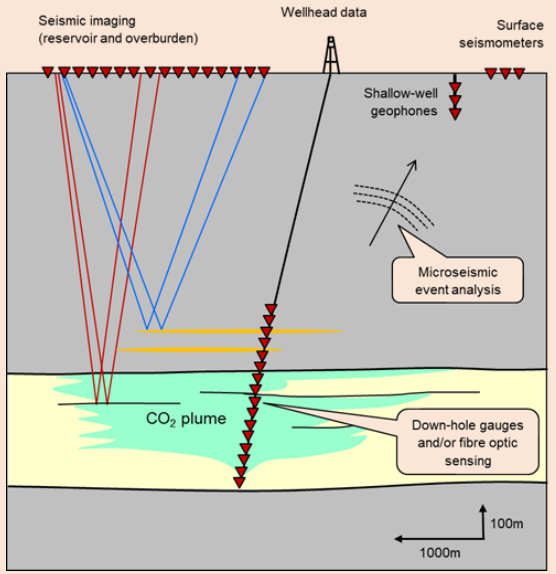
- Uncertainties
- Pressure/temp changes
- Seismicity

Stress - strain - failure



- Tectonics
- Local stress
- Glacial loads
- Failure mode

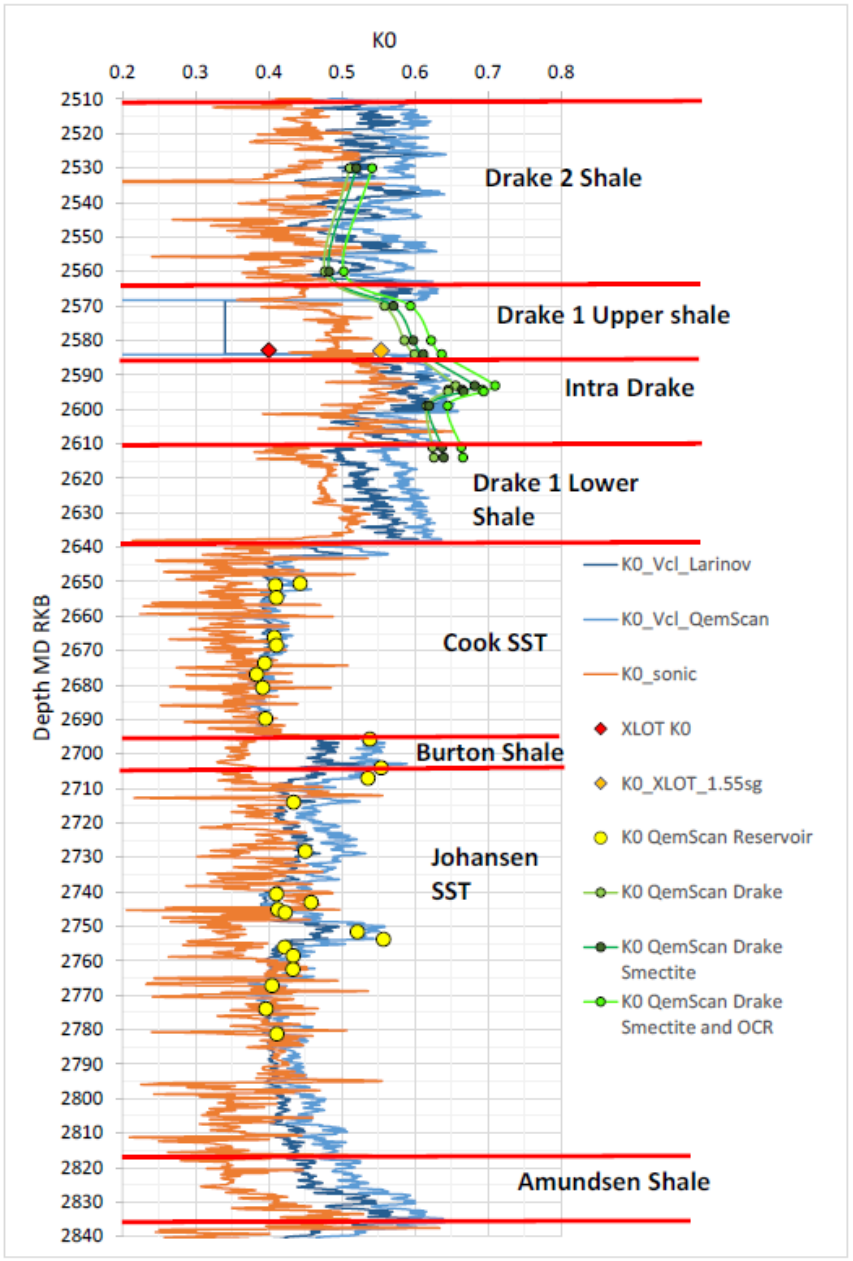
Monitoring



- Targeted
- Right time – right place
- Cost efficient

SHARP Storage

Accelerating CCS Technologies



New method: Stress estimation from clay content and mineralogy

- K_0 = stress ratio – horizontal/vertical effective stress
- Application for log data (v_{shale}) and mineralogy (Qemscan) for Eos well
- More detailed understanding of stress variation with depth (lithologies)

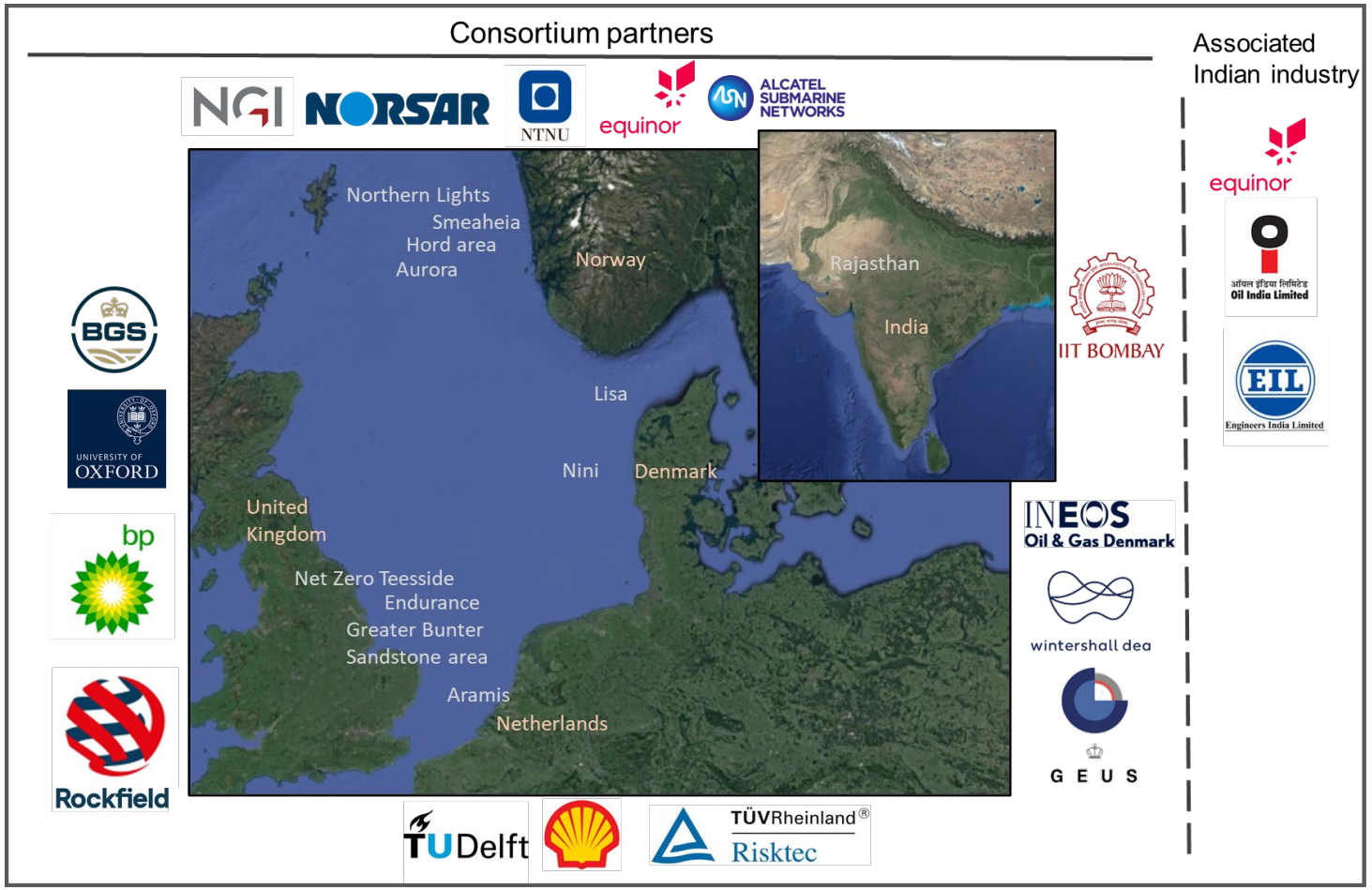
SHARP Storage

Grande et al., 2022 GHGT https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4286343

Accelerating CCS Technologies

SHARP Consortium

- **Norway:** NGI, Equinor, Norsar, NTNU, Alcatel (ASN)
- **UK:** U.Oxford, Rockfield, BGS, BP
- **Denmark:** GEUS, INEOS, WintershallDea
- **Netherlands:** TU Delft, Risktec, Shell
- **India:** IIT Bombay, Equinor, EIL, Oil India, Shell



SHARP Storage

Accelerating CCS Technologies