Accelerating
CCS
Technologies

SENSE

Assuring integrity of CO_2 storage sites through ground surface monitoring (SENSE)

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Norwegian Geotechnical Institute

https://sense-act.eu/

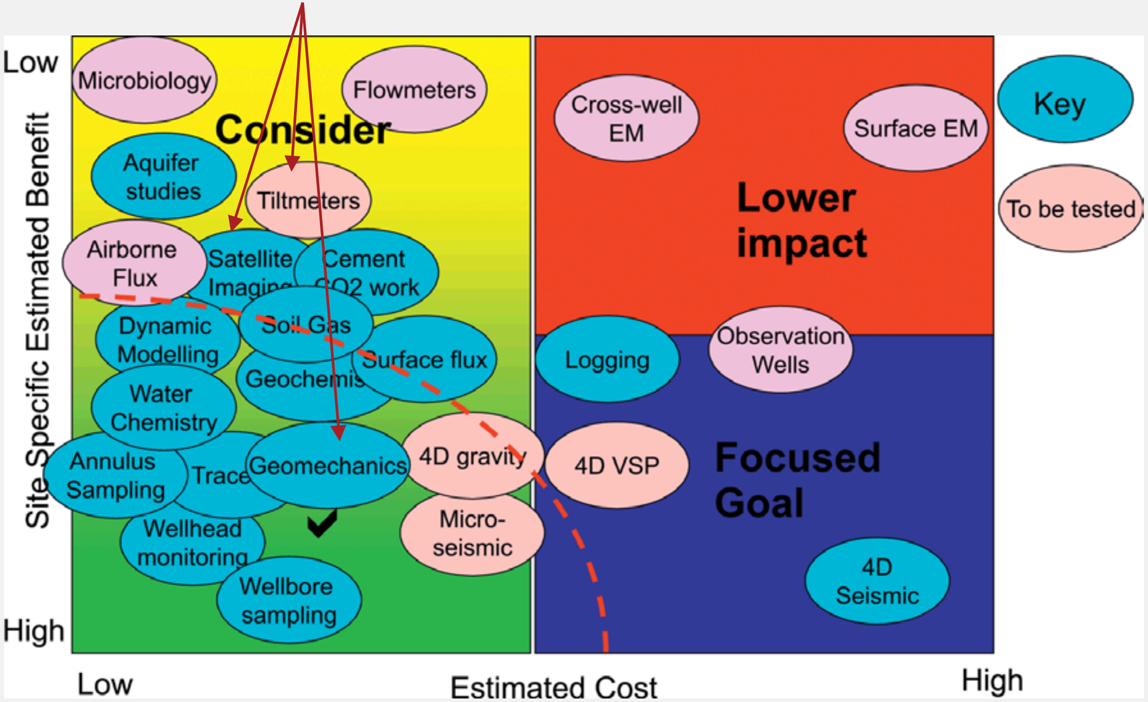
Presentation for CICERO
Jan 11, 2022
Digital meeting

Outline

- Introduction
- Objective of SENSE project
- Case studies and achievements
- Summary

Introduction: monitoring methods for CO_2 storage sites

SENSE focuses on



Ref.: Davis et al. 2019

Introduction: SENSE consortium

equinor

QUAD
GEOMETRICS

NGI

BGS
1835

GEOMAR
Helmholtz-Zentrum für Ozeanforschung Kiel

Lawrence Livermore
National Laboratory

UiO
University of Oslo

ifp Energies nouvelles

RITE
Research Institute of Innovative
Technology for the Earth

ciudad de la energía

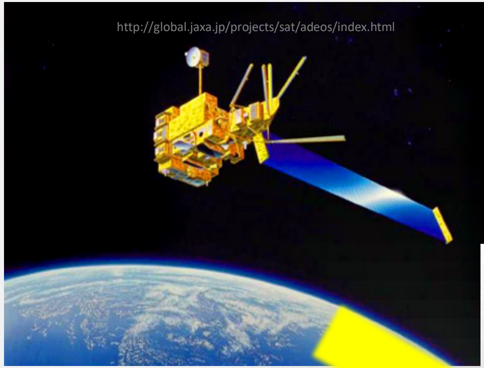
IGME

TEXAS Geosciences
The University of Texas at Austin
Jackson School of Geosciences
Museum of Earth History

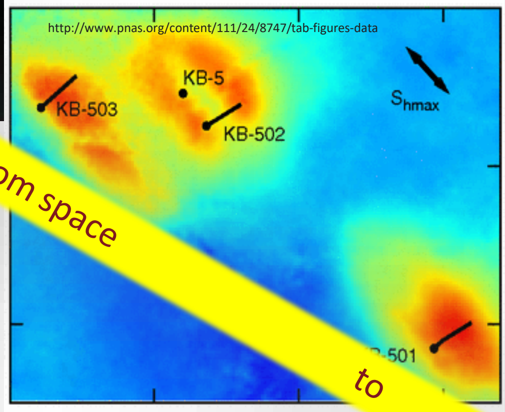
KIGAM

CSIRO

SENSE project concept


http://global.jaxa.jp/projects/sat/adeos/index.html

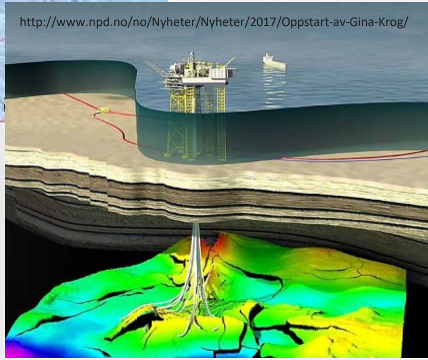
Satellite for monitoring ground motion onshore


http://www.pnas.org/content/111/24/8747/tab-figures-data

Demonstration of concept onshore

Demonstration offshore


http://www.drillingcontractor.org/high-cost-subsea-sector-faces-test-of-economics-35798


http://www.npd.no/no/Nyheter/Nyheter/2017/Oppstart-av-Gina-Krog/

From space to the subsurface

- **Estimation of ground deformation** (via modelling)

- **Measure ground deformation** (satellite for onshore-pressure sensors/fiber optics for offshore)

- **Analyse measured vs estimated deformation**:
- agreement with estimations → OK
- anomaly → **Alert** on performance/integrity issues

Geomechanical modelling, inversion- history matching → subsurface management & **containment assurance**

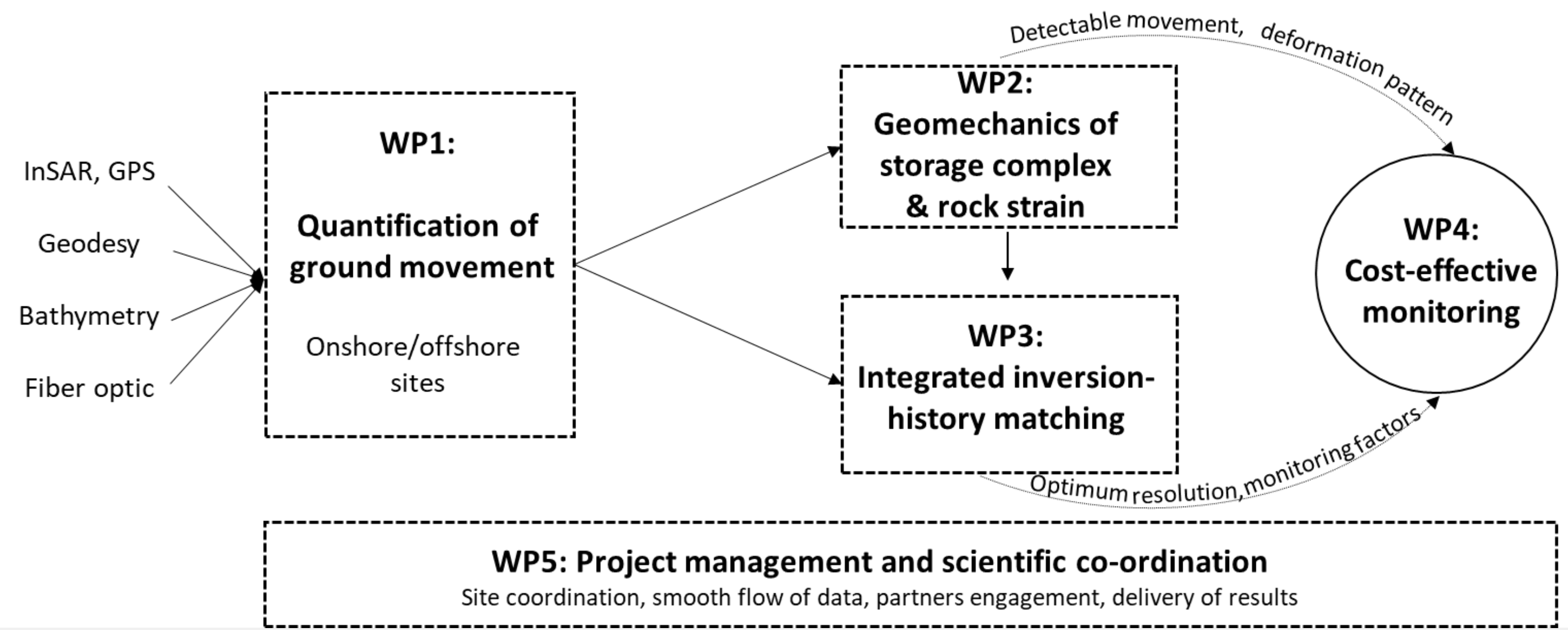
SENSE objective

- Ground motion measurement for **continuous, cost efficient** CO_2 storage monitoring **over large areas**:
  - Demonstrate tools & methods in field cases (onshore, offshore)
  - Optimization of sampling configuration for monitoring ground surface/seafloor
  - Models & inversion to provide information on pressure distribution and hydraulic behavior of subsurface
  - Improvement of geomechanical constraints for storage performance and integrity

- Safe storage of CO2 in long-term

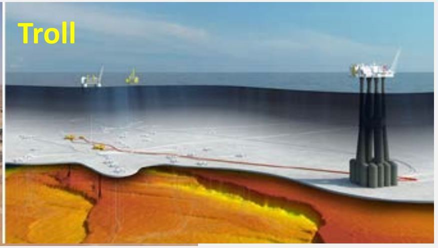
(Early warning in case of unexpected events)

Project Structure



WP1: Measurement of ground deformation-case studies

1. In Salah/Troll Subsidence data
2. Boknis Eck, Offshore Germany
3. Hatfield Moors, onshore US
4. Gulf of Mexico



3. Hatfield Moors, natural gas storage, sandstone, 450 m deep

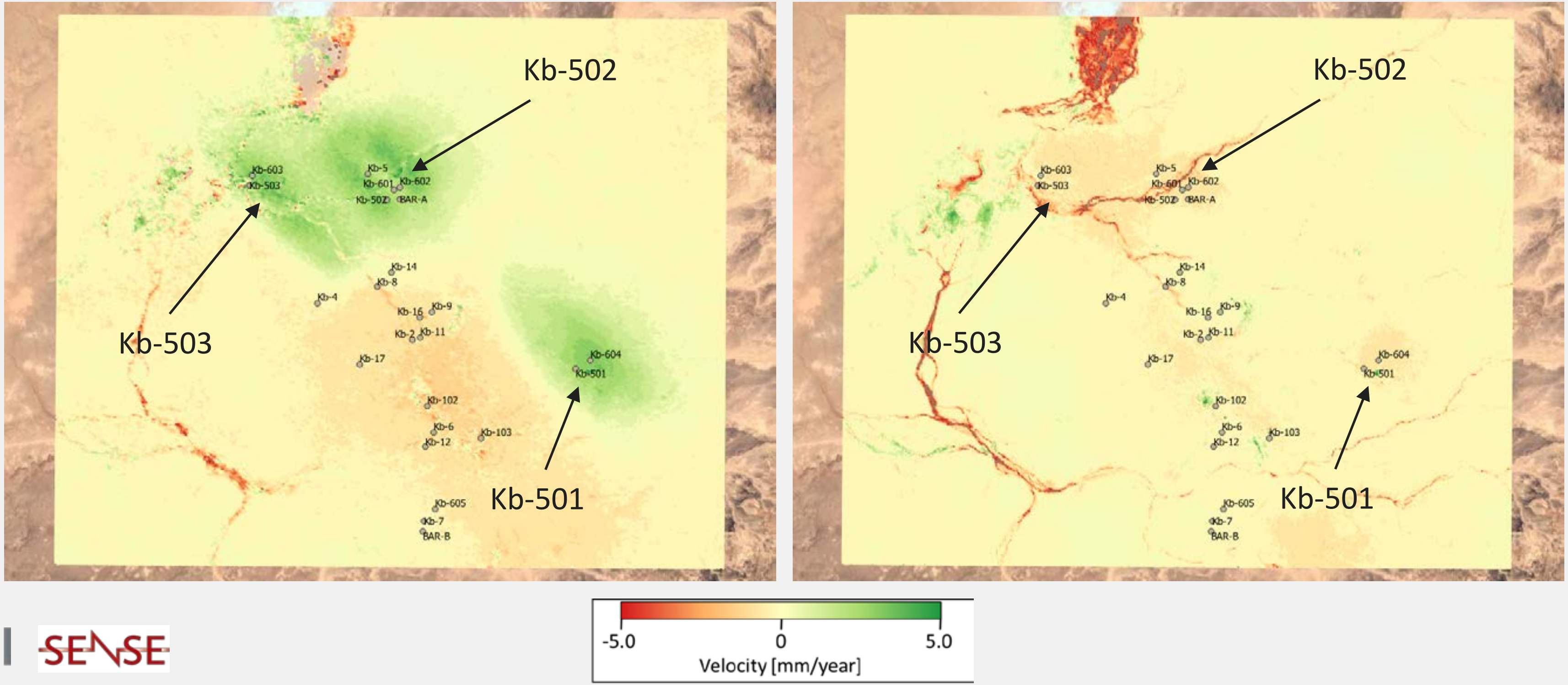
Scottish power: operator

BGS: install reflec./acquire InSAR data

InSalah: Injection vs. Post-Injection Phase

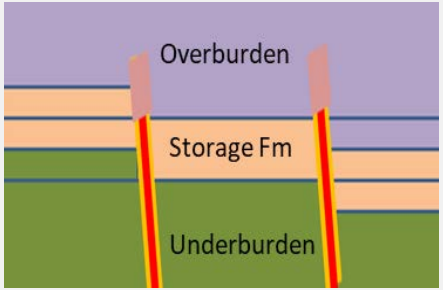
Injection: 2004 – 2010 (ENVISAT)

Post-Injection: 2010 – 2016 (TerraSAR-X)

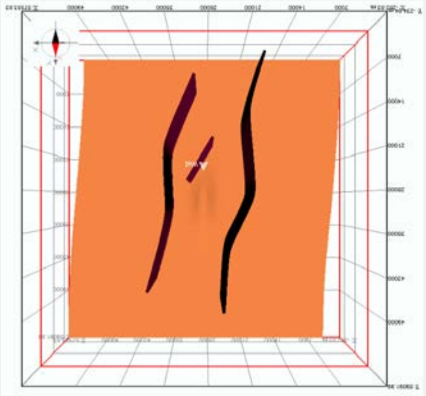


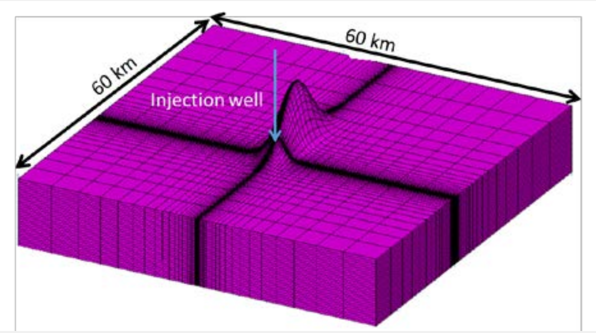
CONCEPTUAL MODELING- IMPACT OF FAULT PERMEABILITY ON GROUND DEFORMATION

- Reservoir at a 1600 m depth, 50 m thick
- 2800 t/d injection, 160 bar/40°C conditions, injection controlled by a 50 bar overpressure
- Injection well: 6 km from anticline summit
- Injection constrained by a max. overpressure [50 bar], max. inj. rate of **2800 t/d** (surface)
- Depth, thickness of storage formation and overburden are scenario-dependent.

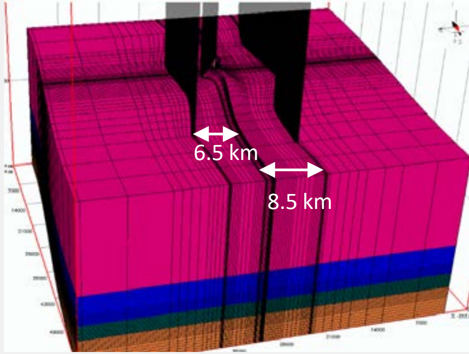


Faults (core and damage zones) with throw





Anticline trap

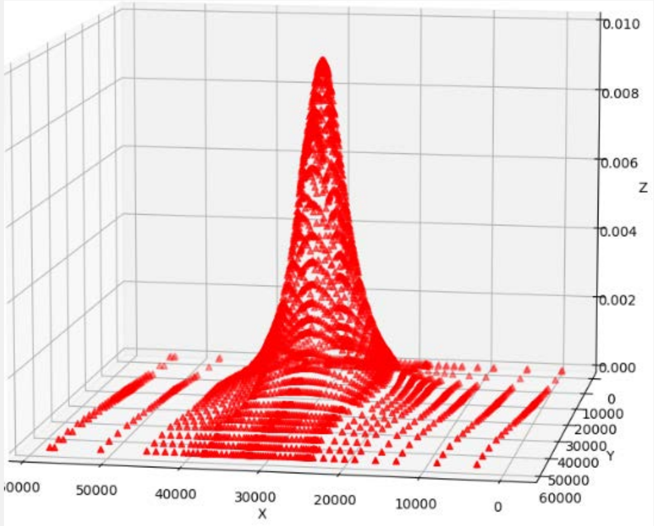


Anticline trap with sealing or draining faults

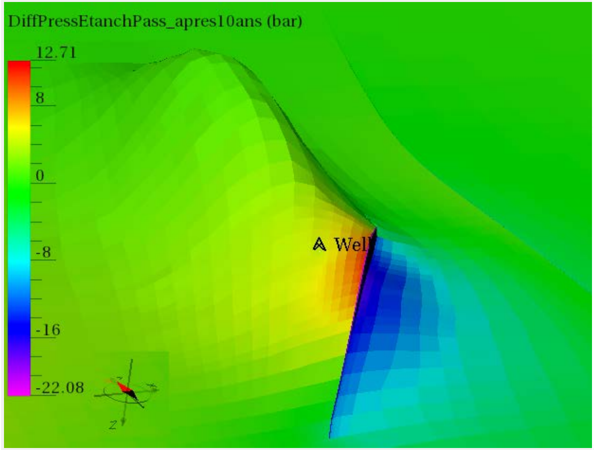
Impact of fault permeability of ground uplift

Anticline trap with sealing or draining faults

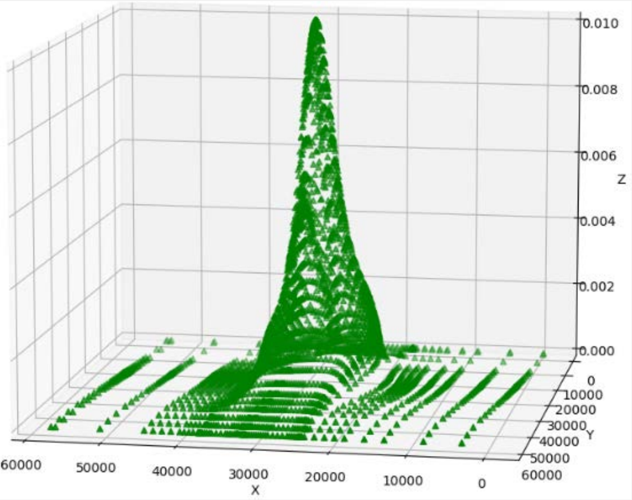
Draining fault



Pressure difference
Sealing – Draining Faults scenarii [bar]

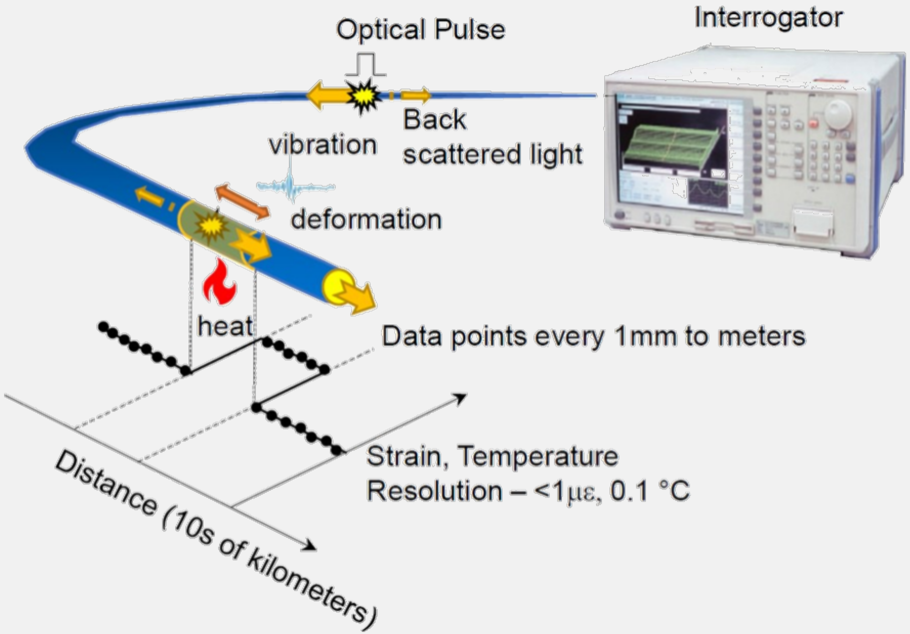


Sealing fault

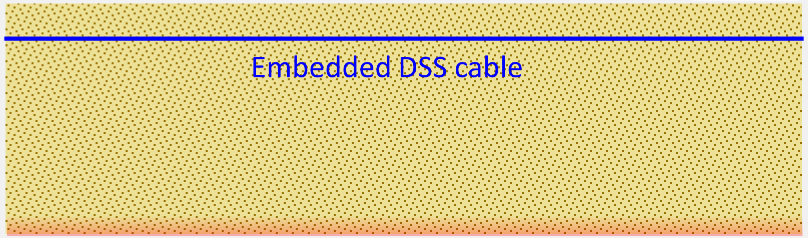


Can we measure mm-scale ground deformation?

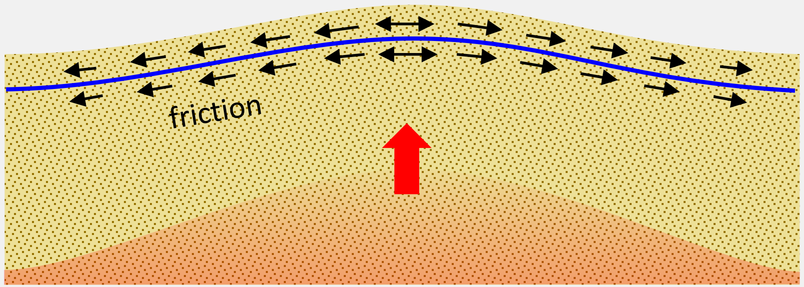
Fiber optics (Distributed Strain Sensing-DSS)



Baseline



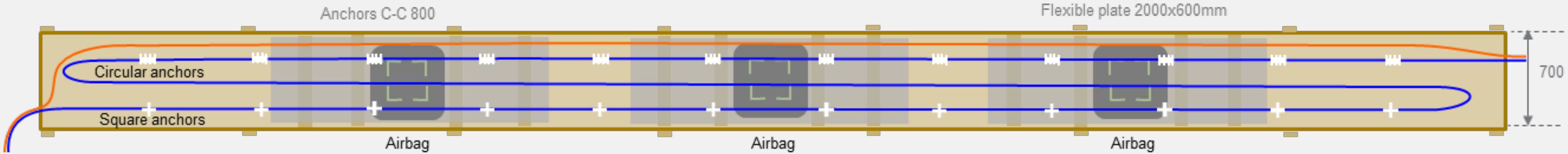
Seabed Uplift



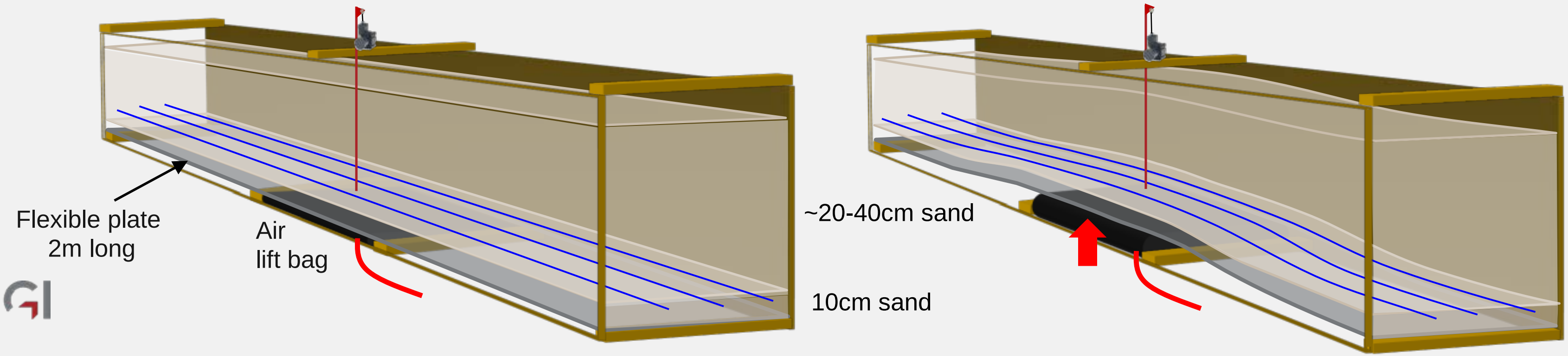
The magnitude of tension (axial strain) along the DSS cable depends on the radial deformation, slope gradient and soil-cable friction

Controlled tests in a sandbox

- Investigate the DSS cable sensitivity to heave deformations
- Investigate the effect of soil-cable interaction (friction) and pre-tensioning
  - Investigate the effect of micro anchors
  - Investigate the effect of overburden
- How to convert and quantify the measured axial strain to radial (vertical) deformations?

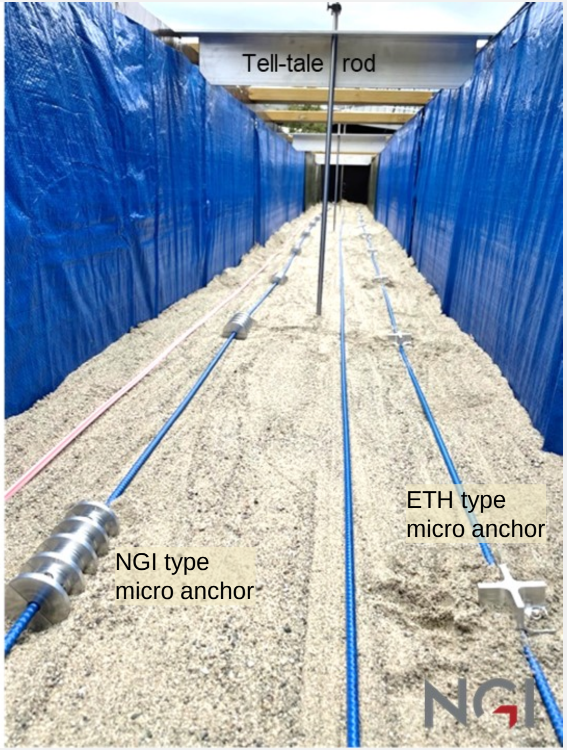


Plane view of 10.5m long sandbox with embedded DSS cable and 3 lifting points



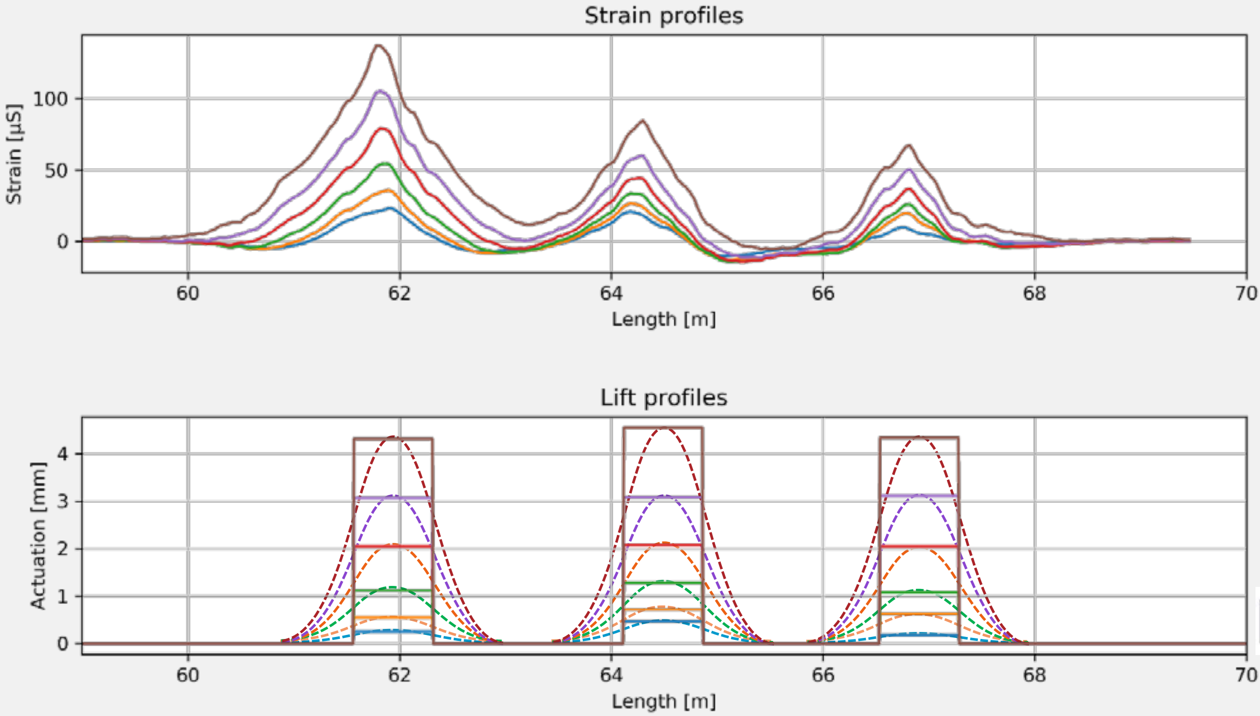
Controlled tests in sandbox - NGI

Test arrangement



Controlled tests in sandbox

Example of results – small deformations - without micro anchors



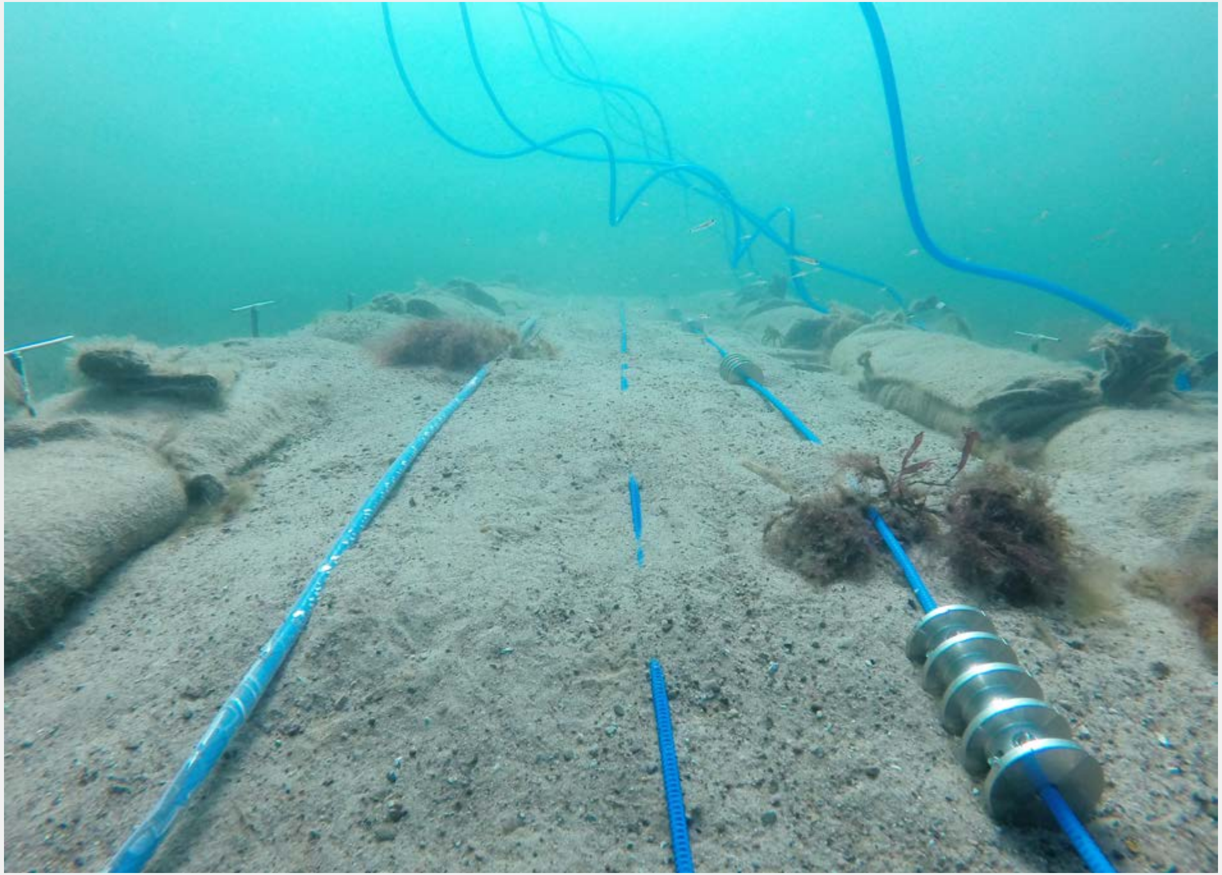
Sensitivity <0.2mm heave over 2m length

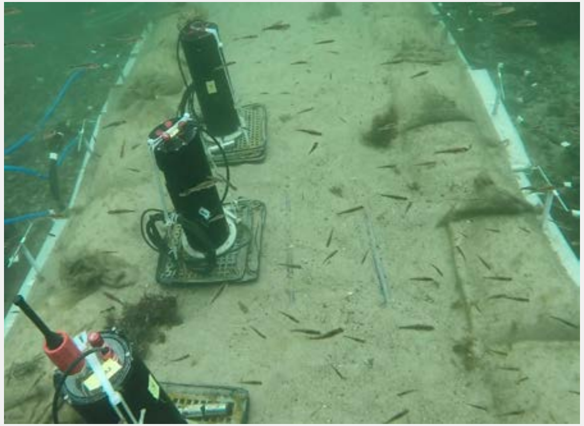
DSS Cable test at Boknis Eck-Germany

SENSE GEOMAR NGI RITE Research Institute of Innovative Technology for the Earth

Test area with adjustable "seabed"

DSS Cable test at Boknis Eck

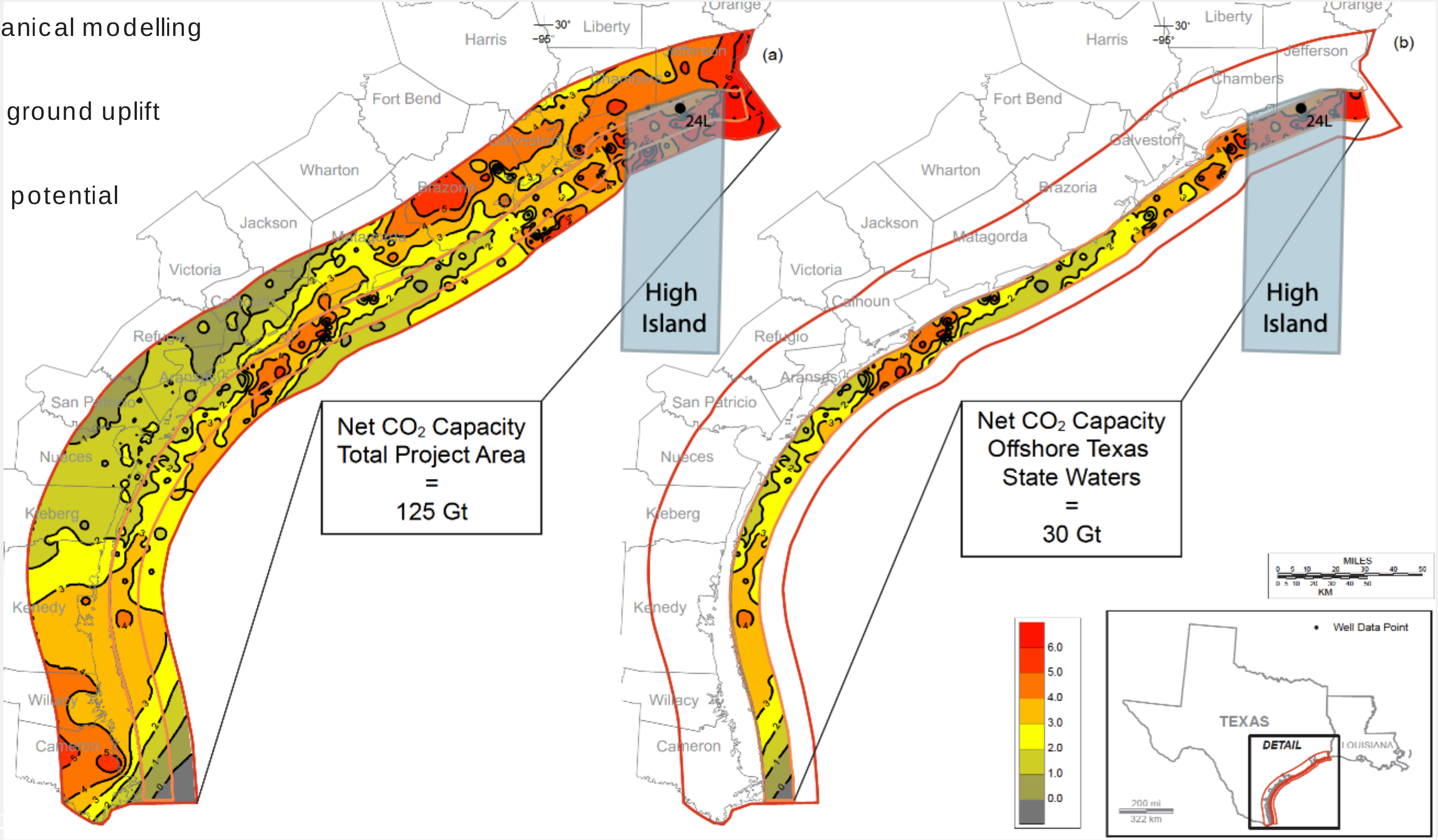




The nearshore tests were less controlled, but similar ground deformation sensitivity as in NGI’s sandbox was demonstrated

Case Study: Gulf of Mexico-Lawrence Livermore National Lab

- Geomechanical modelling
- estimating ground uplift
- monitoring potential

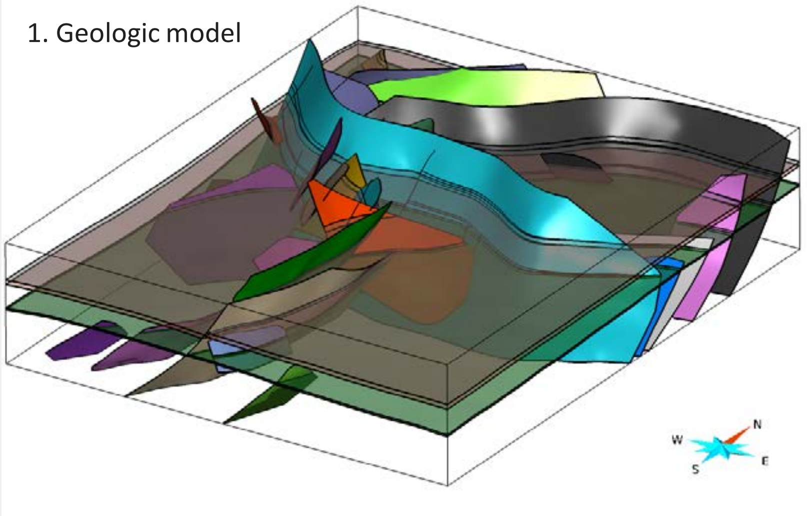


Lawrence Livermore National Laboratory

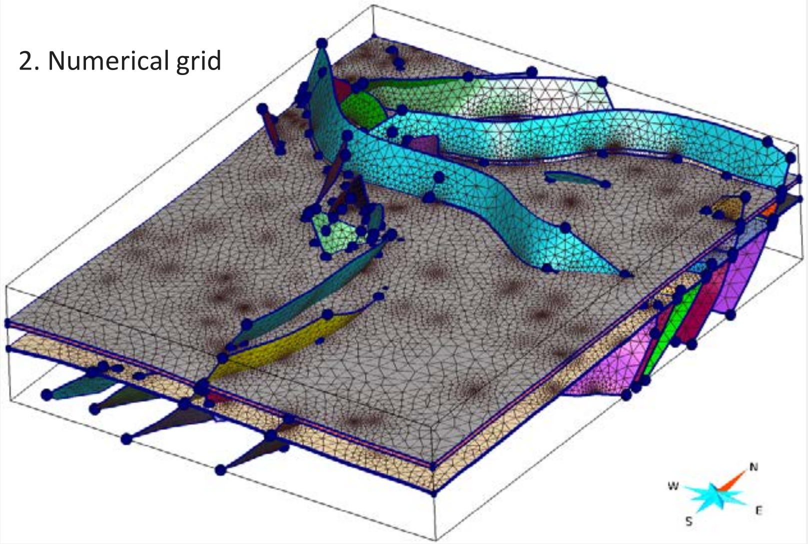
Image credit: D

GoM model

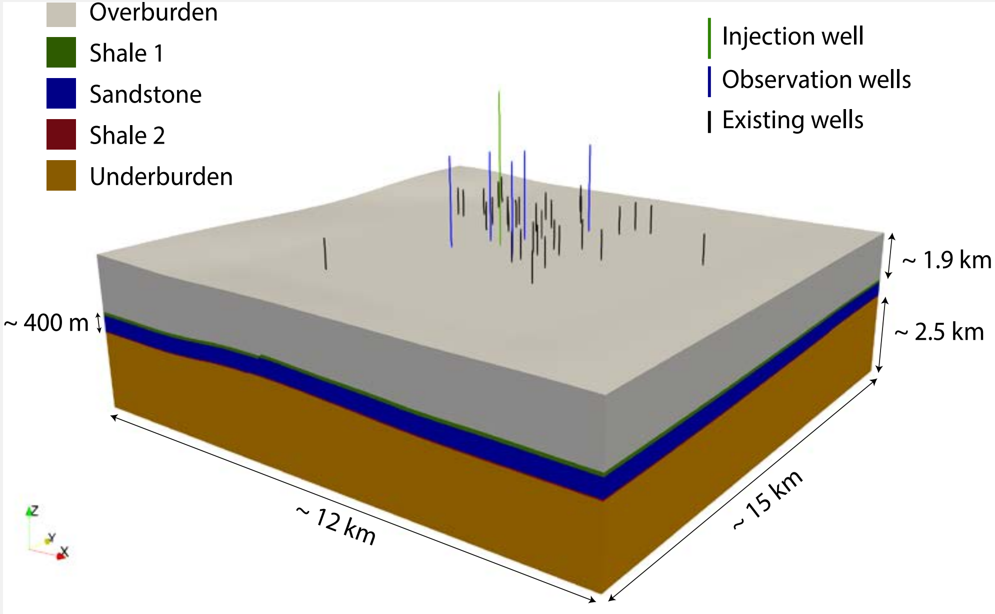
1. Geologic model



2. Numerical grid



3. Geomechanical model



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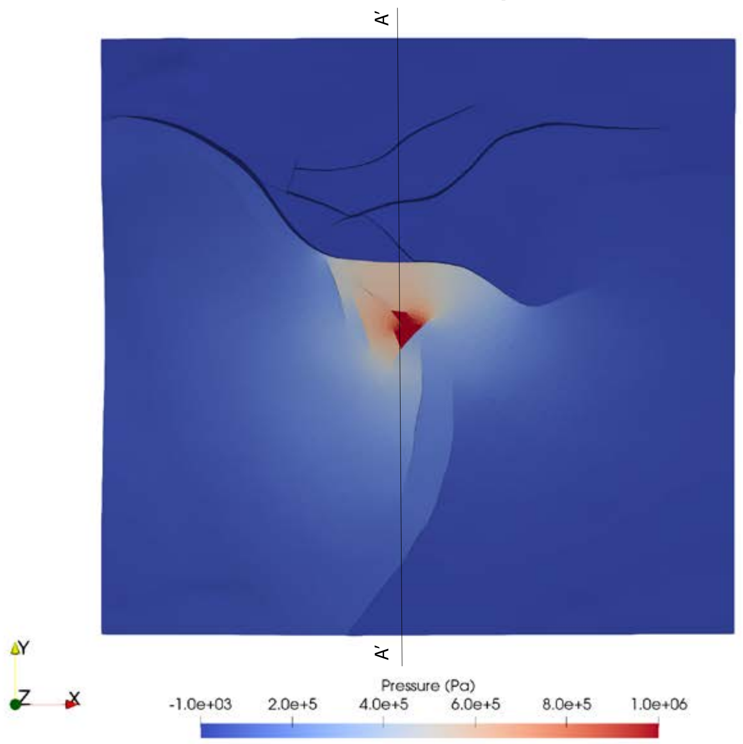
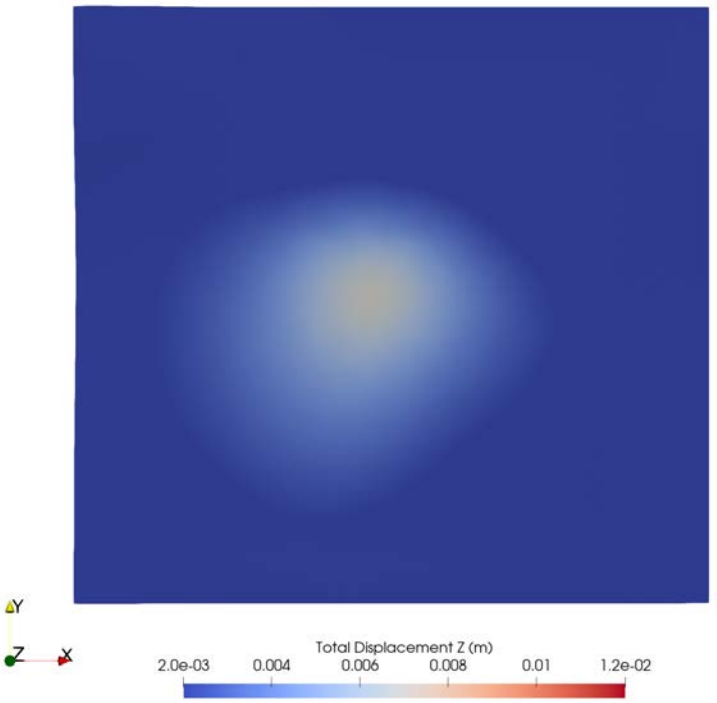
Seabed uplift

Reservoir excess pressure



seabed displacement



Lawrence Livermore National Laboratory

Image credit: DNV

[Julia Camargo et al., *in prep*]

Predict monitoring observations

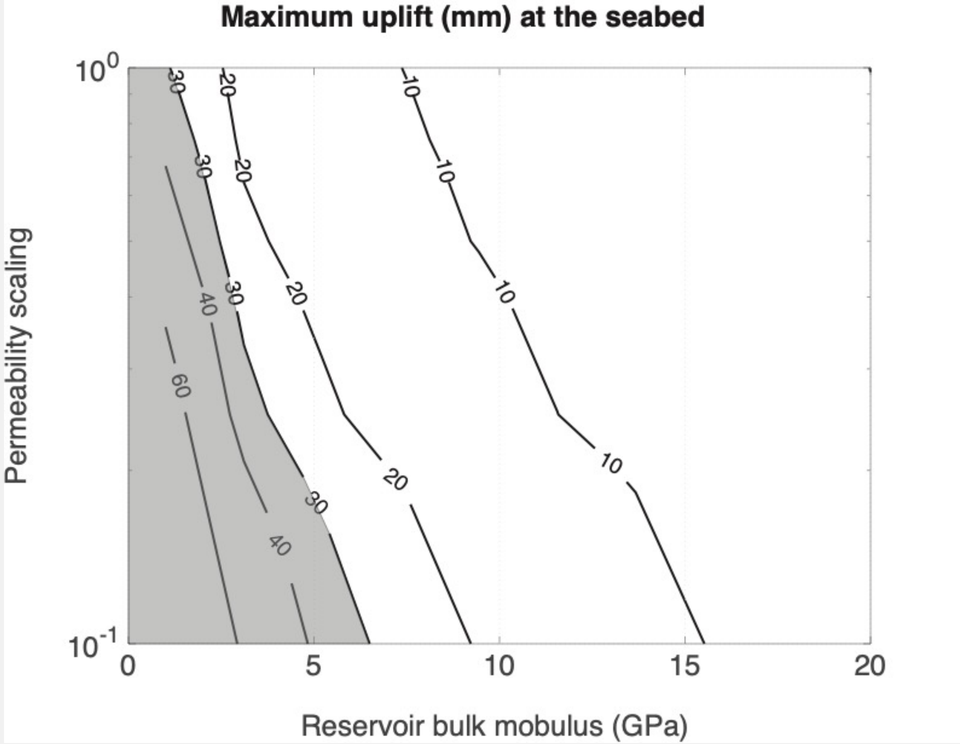


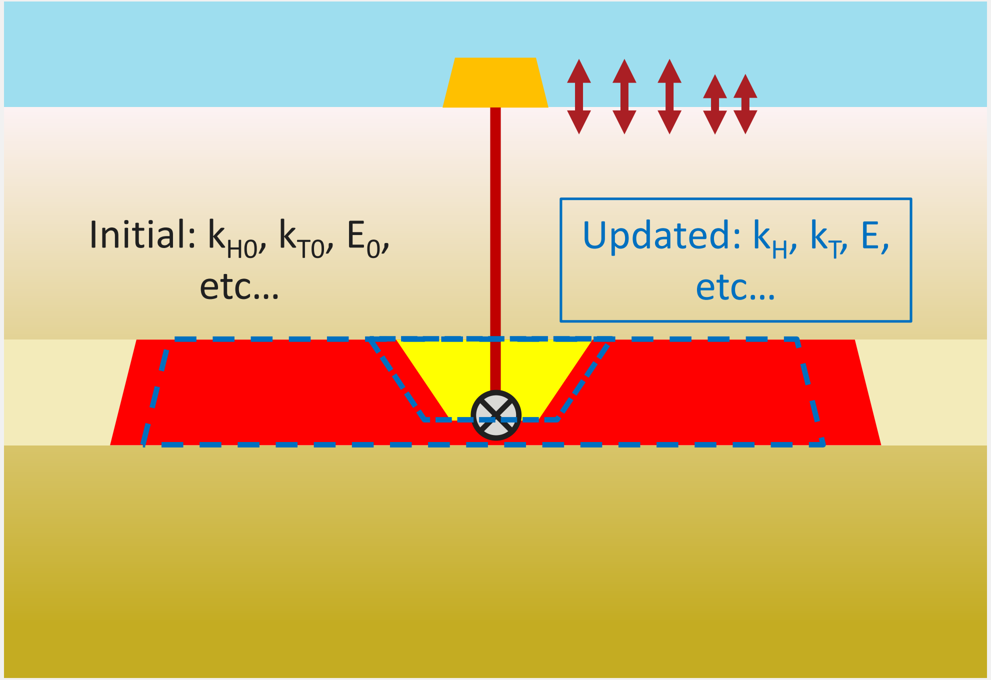
Figure: Sensitivity to property uncertainty

Conclusion:

Both fiber optic and ocean-bottom-pressure sensors could likely provide useful monitoring of GoM storage sites.

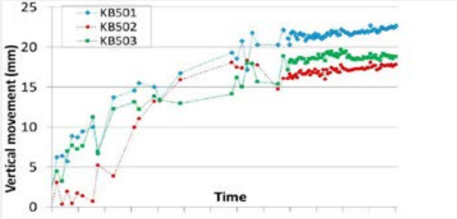
Image credit: DNV

History matching and inversion

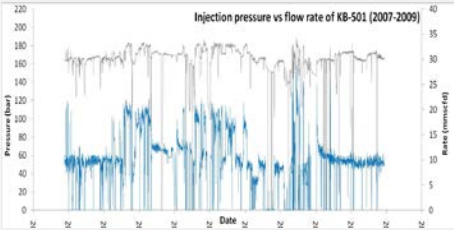


Initial: k_{H0}, k_{T0}, E_0, etc…

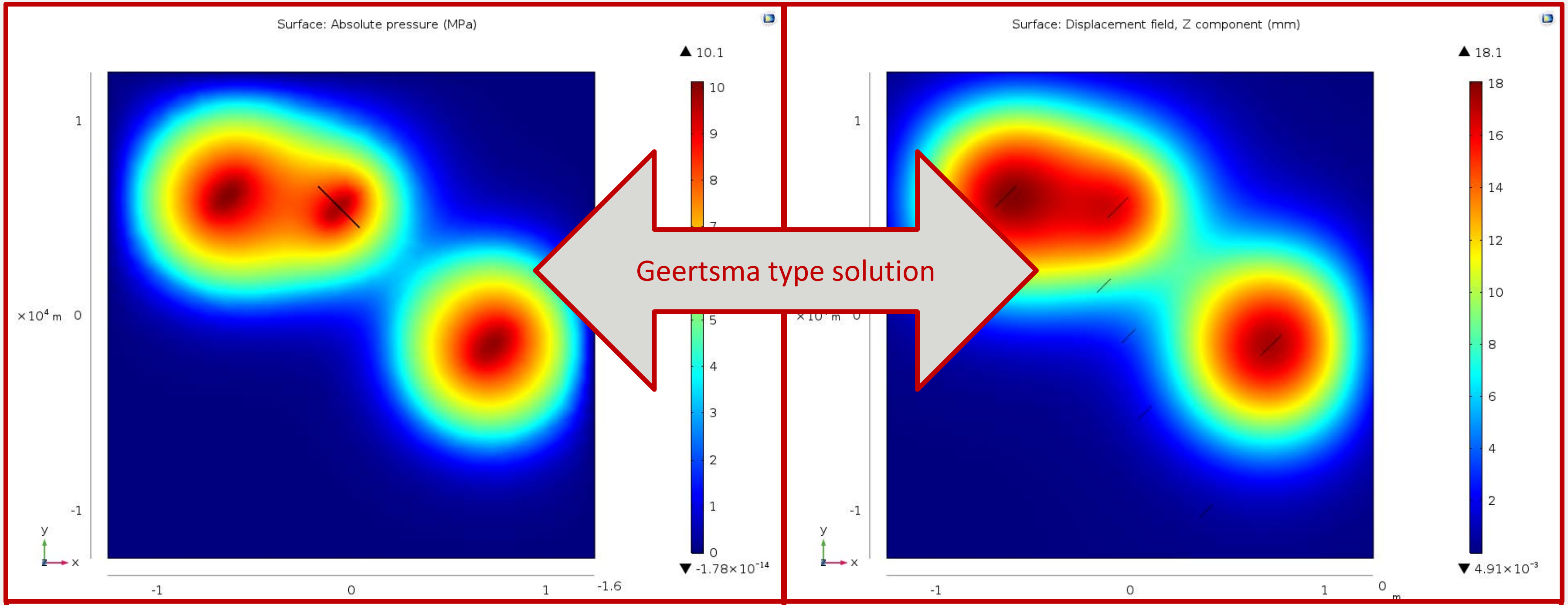
Updated: k_H, k_T, E, etc…



“with survey cost issue”



Background and Motivation (In Salah experience)

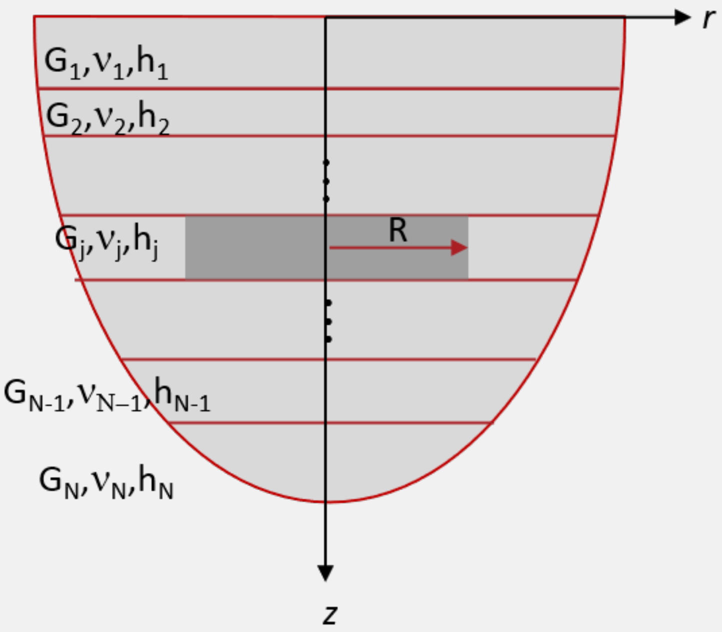


Geertsma type solution

reservoir pressure change

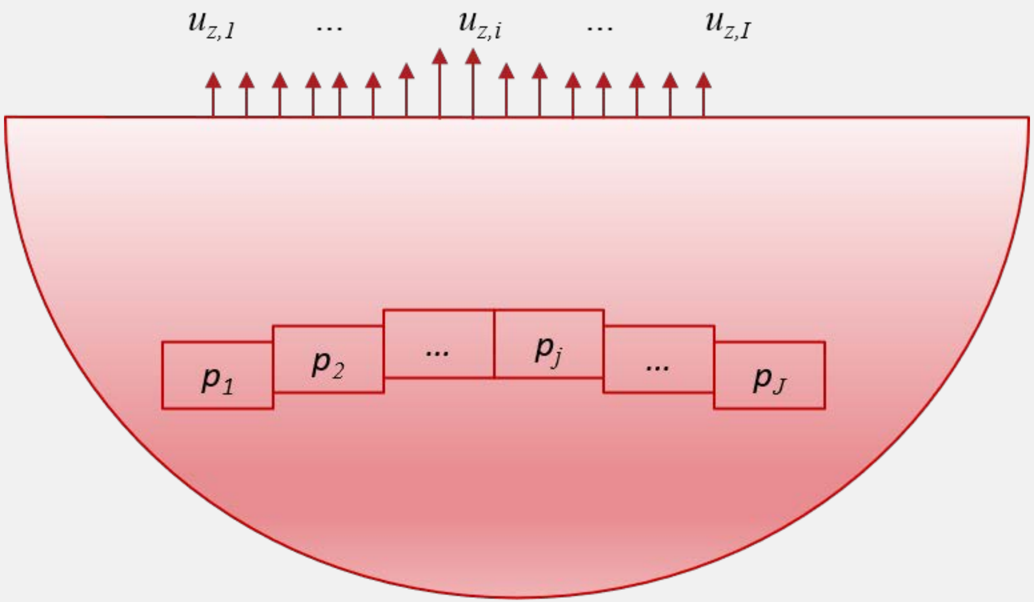
surface heave

Generalized Geertsma solution from SENSE



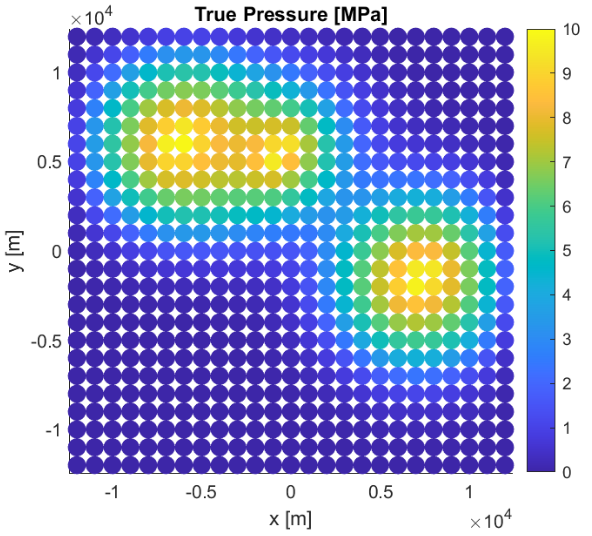
- Any number and thickness of layers can be simulated.
- We can calculate deformation and stress at any layer for «static» pressure or temperature distribution applied at any layer.
- Any boundary condition is available e.g. rigid basement (e.g. Tempone et al., 2010).
- Matlab and Python scripts are implemented.
- Anisotropy medium model can also be considered i.e. $G_h/G_v \neq 1$. (Park et al. 2021)

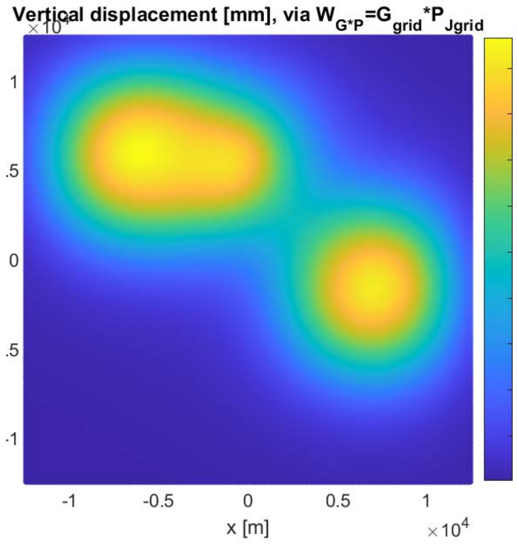
For realistic pressure distribution

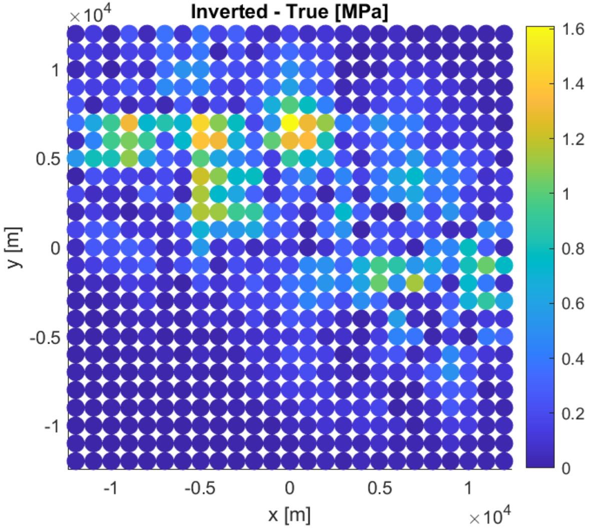


- $u_{z,i} = \sum_{j=1}^{J} g_{z,ij} p_j$
- $\mathbf{U}_z = \mathbf{G}_z \mathbf{P}$
  - $\mathbf{U}_z = \left[u_{z,1}, u_{z,2}, \dots\ u_{z,i}, \dots, u_{z,I}\ \right]^T,$
  - $\mathbf{P} = \left[p_1, p_2, \dots, p_j, \dots, p_J\ \right]^T,$
  - $\mathbf{G}_z = \begin{bmatrix} g_{z,11} & \cdots & g_{z,1J} \\ \vdots & \ddots & \vdots \\ g_{z,I1} & \cdots & g_{z,IJ} \end{bmatrix}$
- $\mathbf{P} = \mathbf{G}_z^{-1} \mathbf{U}_z$

Effects of heave data noise via synthetic data



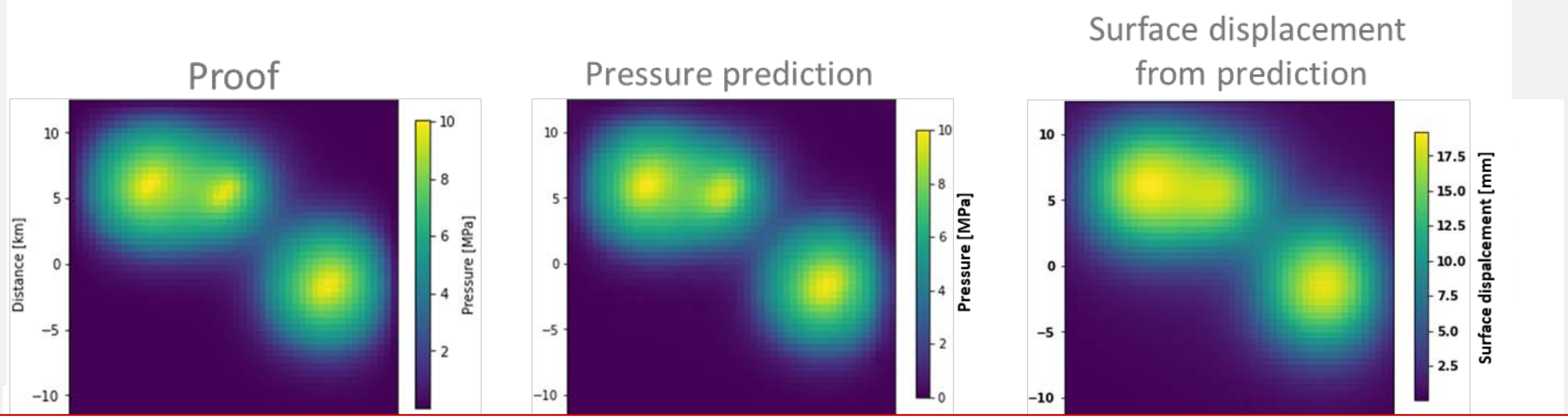




$$\mathbf{G}_z\ \mathbf{P} = \mathbf{U}_z$$

$$\mathbf{G}_z^{-1}\mathbf{U}_{z,3\%} = \mathbf{P}$$

Highlight: ML-based inversion (pressure-deformation pattern training)



Proof

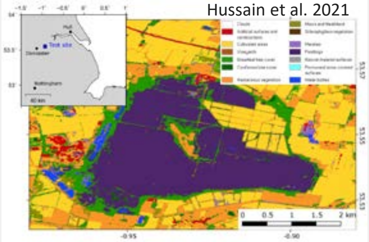
Pressure prediction

Surface displacement from prediction

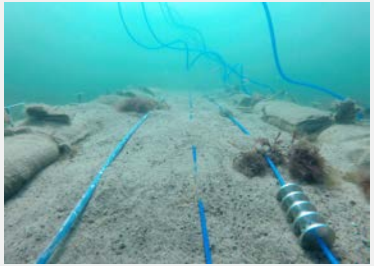
With this framework, we will look into to optimize number of data points or survey layout so that we can minimize the cost, which can be critical for the offshore applications!

Summary

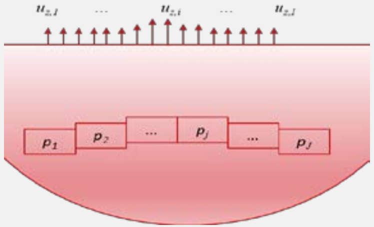
- **Automatic InSAR data processing:** a routine for automatic change detection-BGS has developed and applies to Hatfield Moors gas storage site → **reduces errors & provides timely** and **inexpensive access to InSAR.**


Hussain et al. 2021

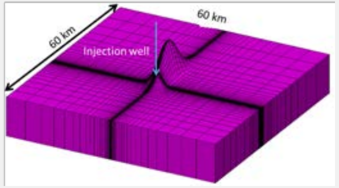
- **Fiber optics- monitor static ground movement:** Field experiments performed by RITE in Kyoto, Japan. NGI is doing tests in Oslo, will test later in offshore Germany (September 2021) → **continuous seafloor monitoring.**

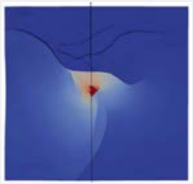


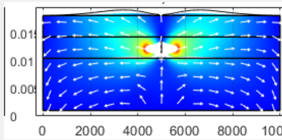
- **Fundamental mathematical solution** for calculating ground movement (subsidence or uplift)-considering inhomogeneous, arbitrary number of layers (NGI & Quad Geometrics)



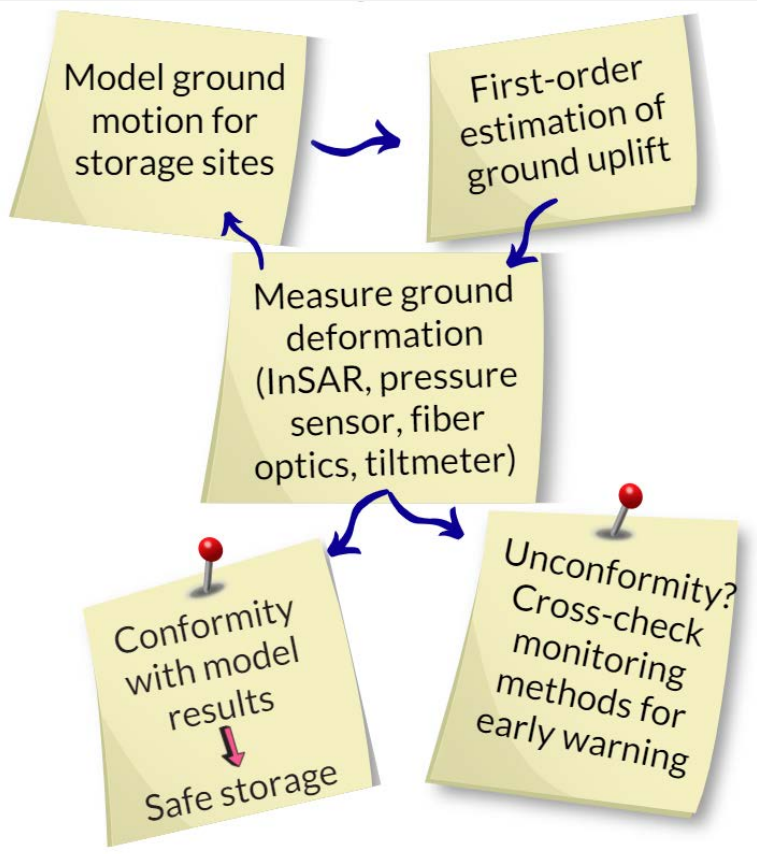
- **Advanced numerical simulation & inversion codes:** for ground deformation (IFPEN, CSIRO, KIGAM, LLNL, UT Austin, IGME, CIUDEN, NGI)







Summary: ground motion monitoring workflow



Accelerating CCS Technologies

Monitoring CO_2 Storage Sites
SENSE Webinar #2 - 25 January 2022

SENSE

a) Ground deformation monitoring using fiber optics

By Dr Ziqiu Xue, Chief Researcher, Research Institute of Innovative Technology for the Earth (RITE-Japan); General Manager (Technical Division), Geological Carbon Dioxide Storage Technology Research Association

RITE
Research Institute of Innovative Technology for the Earth

Geological Carbon Dioxide Storage Technology Research Association

b) Ground deformation monitoring onshore and offshore

By Mr Per Sparrevik, Technical Expert (Norwegian Geotechnical Institute (NGI- Norway) and Dr Jens Karstens, Postdoc Researcher, GEOMAR (Germany)

NGI

GEOMAR
Helmholtz-Zentrum für Ozeanforschung Kie

Event Information:

When: 25 January 2022 at 11:00-12:00 Central European Time (CET)
Where: Online via Teams
Registration via link: please see https://sense-act.eu/
Welcome to join us and hear about the latest advances on CO_2 storage site monitoring & SENSE project

Acknowledgement

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.