



# Assuring integrity of CO<sub>2</sub> storage sites through ground surface monitoring (SENSE)

Overview & Status

Bahman Bohloli-Project Coordinator

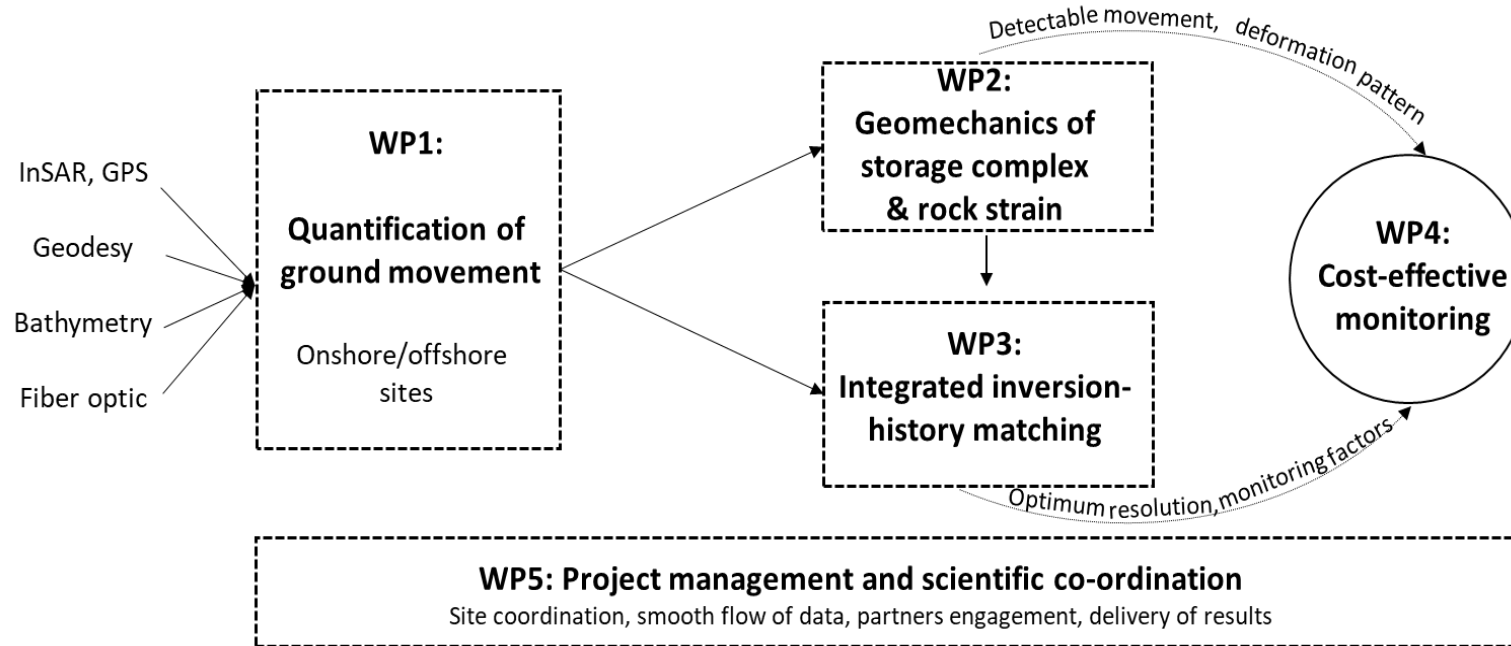
Mid-term review meeting

17 June 2021

# Outline

- Project structure & organization
- Objectives
- Highlights
- Deviations
- Financial status
- Dissemination

# Project Structure & organization



Structure of SENSE project

## • Implementation

- Consortium meetings:
  - 6-monthly (presentation of progress)
- Steering Committee meeting:
  - 6-monthly (decision making)
- WP-lead meetings:
  - 2-monthly (regular monitoring of activities)
- WP internal meetings:
  - Frequently (weekly/monthly-on need)

# SENSE Objectives

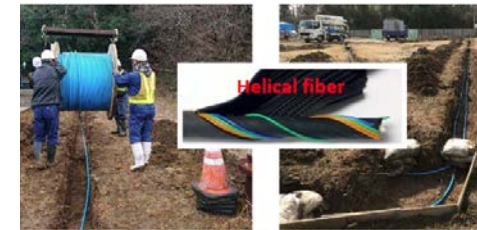
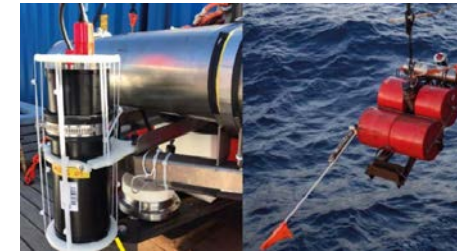
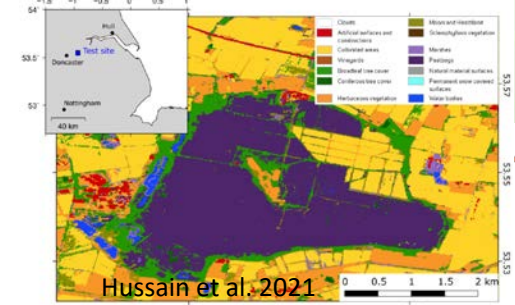
- Ground movement detection for continuous, cost efficient CO<sub>2</sub> storage monitoring over large areas:
  - Demonstrate tools & methods in field cases (onshore, offshore)
  - Optimization of sampling array configuration for tools monitoring ground surface/seafloor
  - Models & inversion to provide information on pressure distribution and hydraulic behavior of subsurface



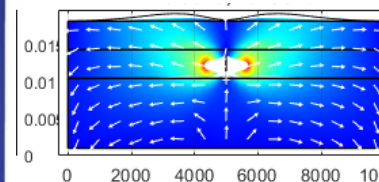
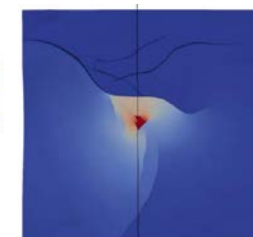
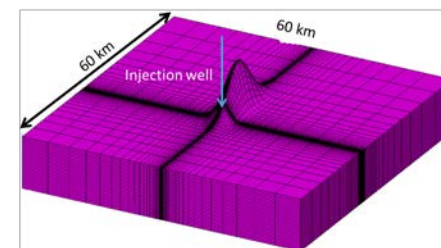
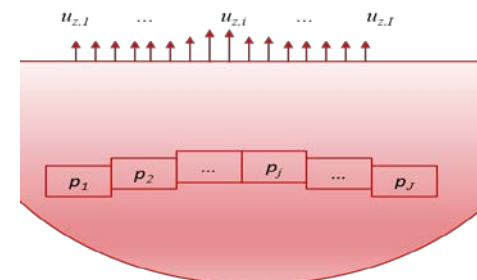
- Safe storage of CO<sub>2</sub> in long term  
(Early warning in case of unexpected events)

# Highlights – project level

- **Automatic InSAR data processing:** a routine for *automatic change detection-BGS* has developed and applies to Hatfield Moors gas storage site → **reduces errors/mistakes & provides timely and inexpensive access to InSAR.**
- **Ocean Bottom Lander development (OBL)-** GEOMAR did the first test in offshore Malta in 2020. Will deploy OBL in Boknis Eck for detecting vertical movement at seafloor → **advantages and competitiveness in the market.**
- **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)

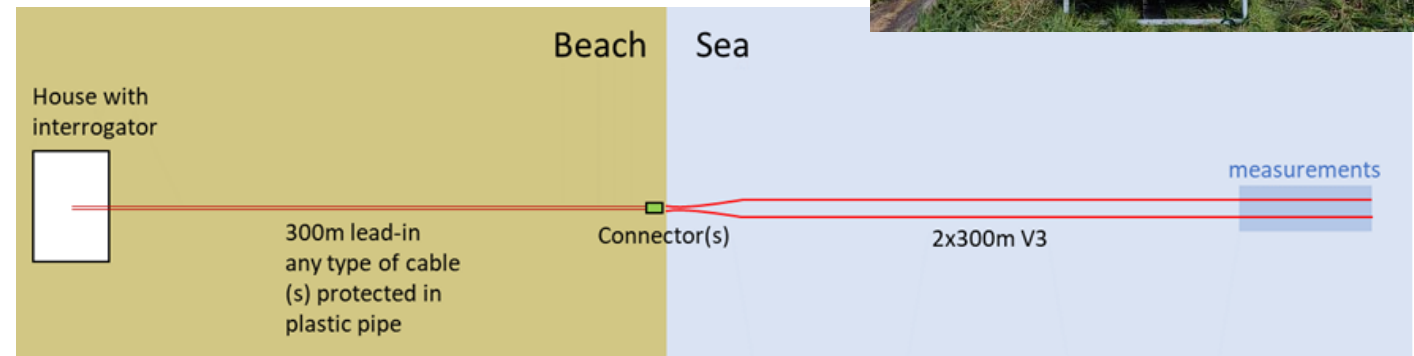


Shallow trench for fiber cable installation



# Deviations from plan

- Geogreen (France) left SENSE Consortium → KIGAM-Korea joined, contributes with 100+ k€ in-kind
- Cancellation of Hontomin → In Salah post injection-work is advancing well.
- Challenge with COVID-19
  - Some delays for InSAR acquisition-Hatfield Moors, now back on track.
  - Offshore campaign, Mecklenburg → replaced by Boknis Eck (shallower water-no injection)





# Expected impact:

## Contribution to the facilitation of the emergence of CCUS

**Onshore: improve confidence in CO<sub>2</sub> storage sites monitoring through:**

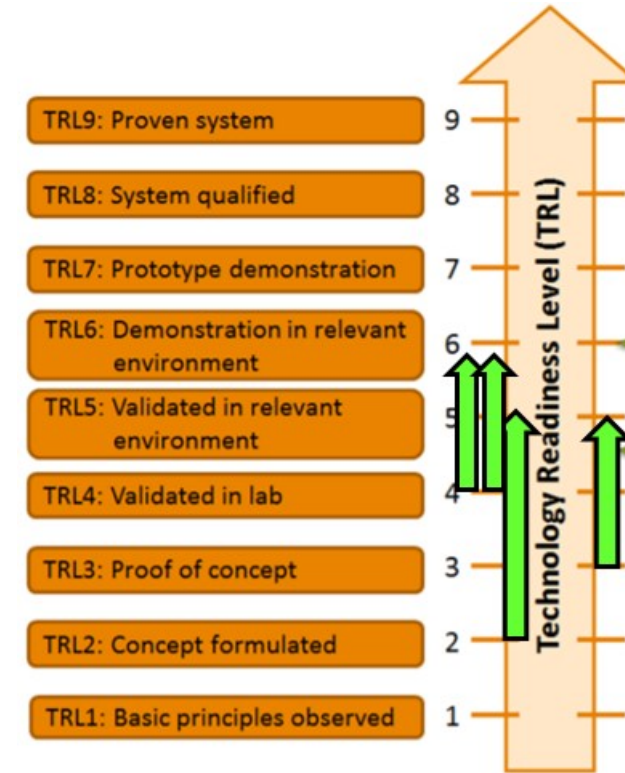
- effective use of InSAR data, improve data quality

**Offshore: Robust monitoring of offshore sites by developing:**

- ocean bottom landers and fiber optics systems.

**In general: improve understanding of subsurface geomechanics for CO<sub>2</sub> storage:**

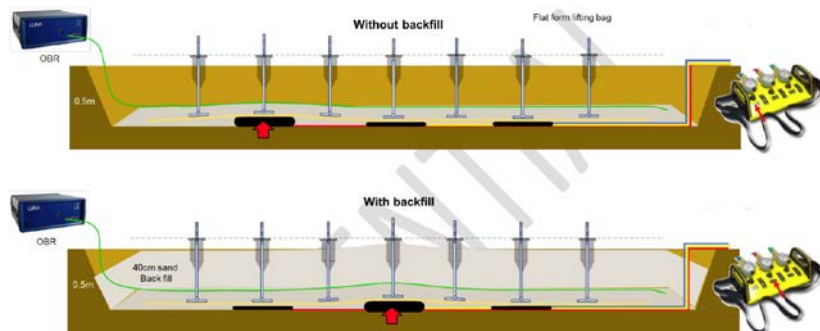
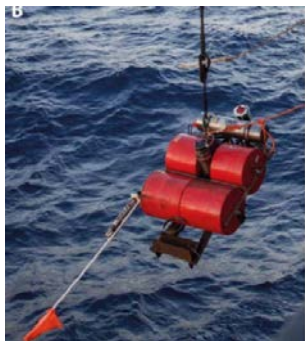
- analytical/mathematical solution for stress-strain and upward propagation
- effective simulation and inversion techniques (software/codes)



From SENSE Kick-off meeting-Oct. 2019

# Chances for commercializing the technology

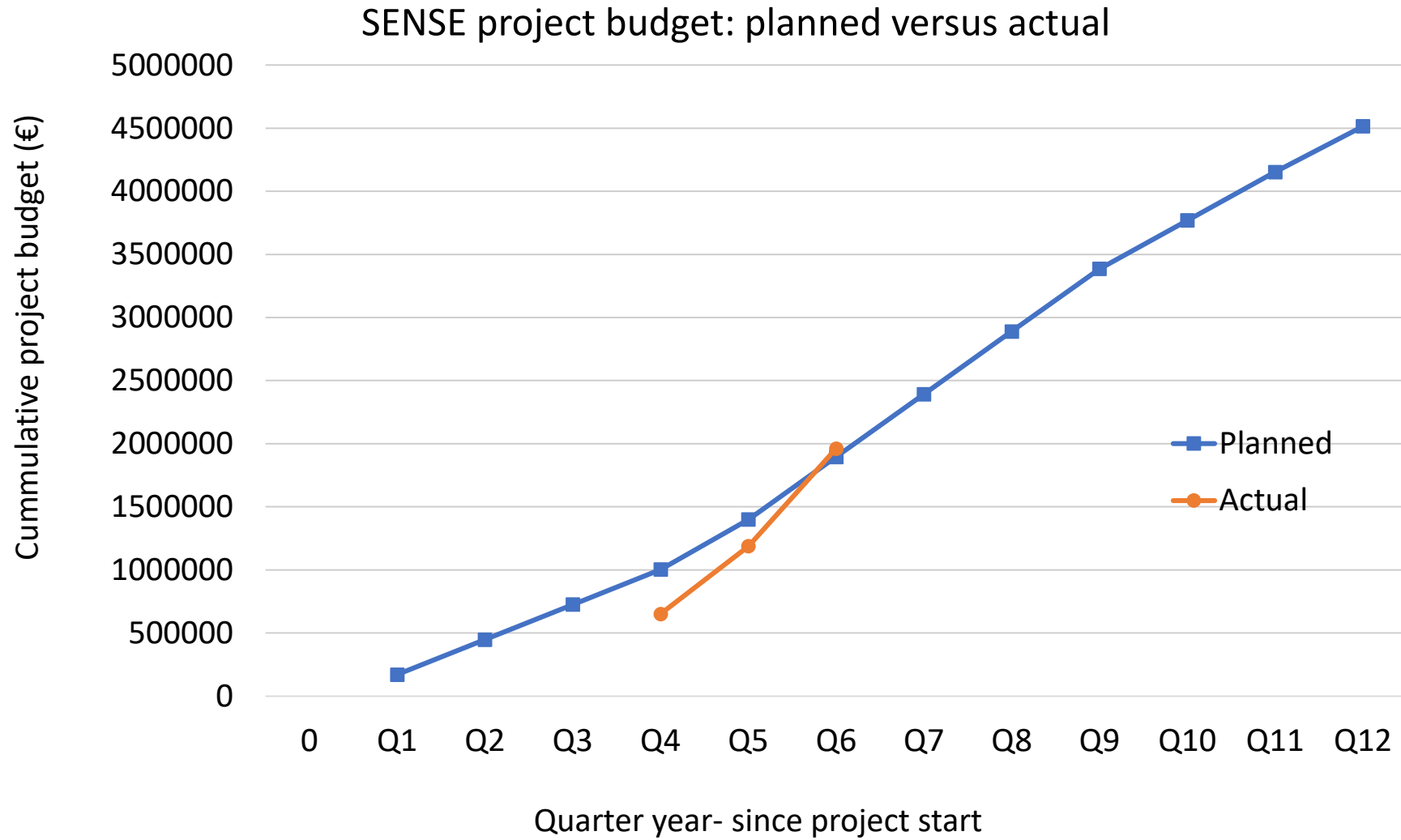
- Potentials for innovations and commercialization:
  - Hardware
    - Ocean Bottom Lander
    - Fiber optics system (cable, interrogator, layout)
  - Software
    - Workflow for automatic processing of InSAR data
    - Software for calculating reliable ground deformation using new Geertsma-type solution
    - Numerical simulation modules & inversion codes.



$$\begin{aligned}
 U_1 &= \frac{c_m P}{k} + az(Ae^{kz} - Be^{-kz}) + Ce^{kz} + De^{-kz} \\
 U_3 &= \left(\frac{\alpha+1}{k} - az\right) Ae^{kz} - \left(\frac{\alpha+1}{k} + az\right) Be^{-kz} - Ce^{kz} + De^{-kz} \\
 S_{rz} &= 2G \left[ \left(akz - \frac{1}{2}\right) Ae^{kz} + \left(akz + \frac{1}{2}\right) Be^{-kz} + kCe^{kz} - kDe^{-kz} \right] \\
 S_{zz} &= 2G \left[ \left(1 - akz + \frac{\nu}{1-2\nu}\right) Ae^{kz} + \left(1 + akz + \frac{\nu}{1-2\nu}\right) Be^{-kz} - kDe^{-kz} - c_m P \right] \\
 \text{where } a &= 1/2(1 - 2\nu); c_m = \alpha(1 - 2\nu)/2G\nu; P=R/kJ_1(kR)
 \end{aligned}$$



# Financial status – project level



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Partner	WP1	WP2	WP3	WP4	WP5	Total at Month 19 (€)	% of total grant
NGI (€)	156459	23265	165176		108065	452965	52 %
QUAD GEO (€)	17000	1500			4000	22500	28 %
GEOMAR (€)	187200					187200	30 %
BGS (€)	178298					178298	35 %
IFPEN (€)		332230	182698			514928	66 %
UiO (€)	55978					55978	93 %
IGME (€)	15241					15241	13 %
CIUDEN (€)	9190					9190	9 %
LLNL (\$)		150000		57000		207000	72%
UT Austin (\$)		4985				4985	3%
RITE (€)	300000					300000	60 %
KIGAM (€)		18300				18300	18 %
<b>TOTAL</b>	919366	530280	347874	57000	112065	1961600	44%

# Dissemination and deliverable status

- Conference and events (5<sup>th</sup> ACT Knowledge sharing Workshop, CLIMIT Digit 2021, GHGT-15, TCCS-11, Sustainability in Geotechnical Engineering, Society of Exploration Geophysicists)
- Scientific and popular science publications
- LLNL gave a presentation on SENSE at the Society of Petroleum Engineers (SPE) Workshop on Offshore CCUS, 6-13 April, 2021 <https://www.spe.org/events/en/2021/workshop/21aho2/about.html>
- IFPEN communication to students from Centrale Marseille University, will be published in “Centrale Marseille” alumni journal (SENSE and CCS in general)
- NGI presented SENSE and CCS in general in for SPE Geomechanics Forum, Feb. 2021
- Project website: <http://sense-act.eu/>
- Twitter Channel: @SenseAct
- [ResearchGate](#) channel
- Teams Channel to share data and information between partners (by invitation only)
- **A series of SENSE webinars:**
  - Webinar 1: September 2021 **Overview + Park’s analytical solution**
  - Webinar 2: September 2021 **Machine learning and inversion**
  - Webinar 3: October 2021 **InSAR monitoring**
  - Webinar 4: October 2021 **Fiber optics experiments**
  - Webinars 5-8 in 2022.

# Dissemination- published material

## Journal papers

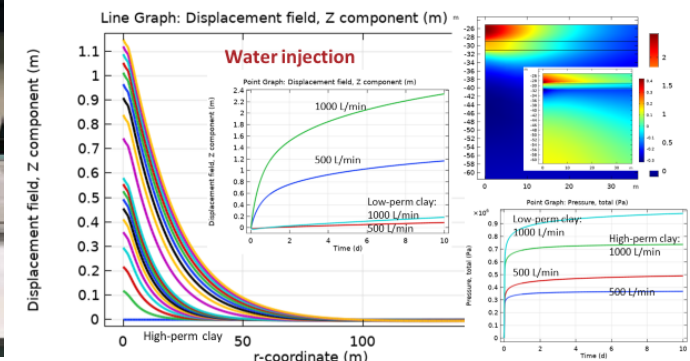
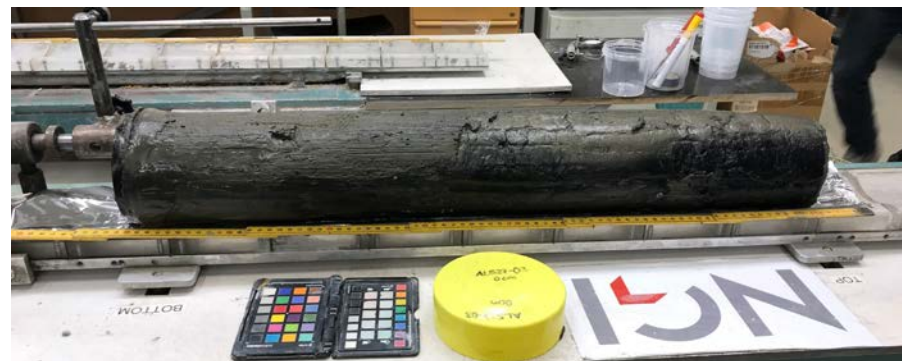
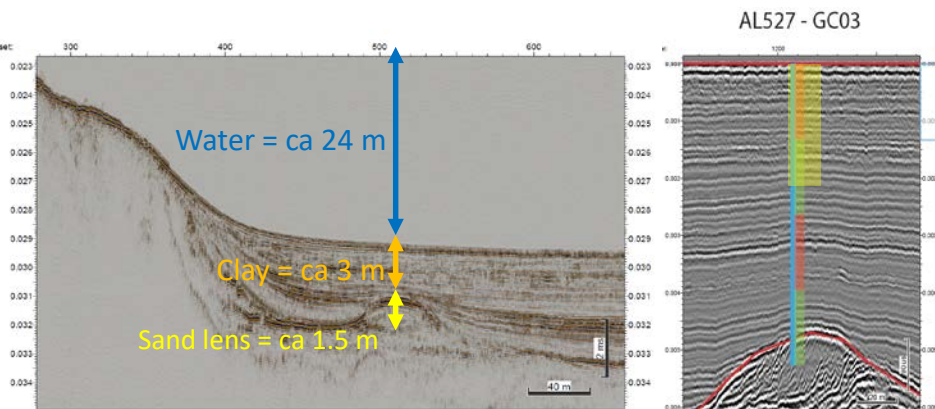
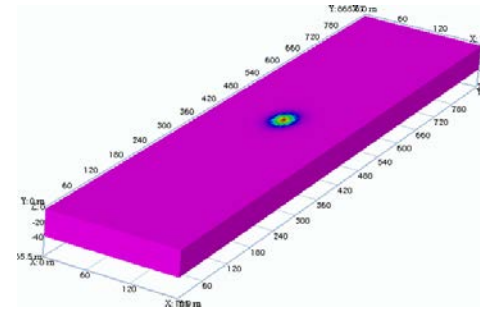
1. Hussain E., Novellino A., Jordan C., Bateson L., 2021. Offline-Online change detection for Sentinel-1 InSAR time series. Remote Sens. 2021, 13, 1656, DOI: 10.3390/rs13091656. (Ref.: Task 1.2)
2. Park J, Bjørnarå TI, Bohloli B., 2021. An Analytical Solution for Pressure-Induced Deformation of Anisotropic Multilayered Subsurface. Geosciences 11(4):180, <https://doi.org/10.3390/geosciences11040180>
3. Ramos A., Mediato J.F., Pérez-López R., and Rodríguez-Pascua M. A., 2021. Miocene to present-day tectonic control on the relief of the Duero and Ebro basins confluence (North Iberia), Journal of Maps, 17:2, 290-300, DOI: 10.1080/17445647.2020.1869111

## Conference papers and reports

1. Bohloli B., Sparrevik P.M., Vöge M., Frauenfelder R., Park J., Berndt C., Bateson L., Karstens J., Hussain E., Novellino A., 2020. [Quantification of ground movement – State-of-the-art](#). SENSE report.
2. Bohloli B., Bateson L., Berndt C., Bjørnarå T.B., Eiken O., Estublier A., Frauenfelder R., Karstens J., Orio R.M., Meckel T., Mondol N.M., Park J., Soroush A., Soulat A., Sparrevik P., Vincent C., Vöge M., Waarum I.K., White J., Xue Z., Zarifi Z., Gutiérrez I. A., Vidal J.A.M., 2021a. Assuring integrity of CO<sub>2</sub> storage sites through ground surface monitoring (SENSE). 15th International Conference on Greenhouse Gas Control Technologies, GHGT-15, 15th - 18th March 2021 Abu Dhabi, UAE.
3. Bohloli B., Park J., Bjørnarå T.I., Frauenfelder R., Vöge M., Berndt C., Karstens J., Bouquet S., Estublier A., Soulat A., Xue Z., 2021b. Measurement and inversion techniques for onshore and offshore monitoring. CLIMIT Digit21. 10 Feb. 2021. Virtual.
4. Bohloli B., Park J., Bjørnarå T.I., Sparrevik P., Frauenfelder R., Vöge M., Ritter S., Mondol N.H., Berndt C., Karstens K., 2021c. Monitoring ground surface and seafloor deformation caused by subsurface fluid injection. 1st Int. Conference on Sustainability in Geotechnical Engineering, Lisbon, Portugal.
5. Bouquet S. et al., 2021. Analysis of surface movement through conceptual and coupled flow-geomechanics models. An example of surface monitoring assessment for ccs project. TCCS-11 - Trondheim Conference on CO<sub>2</sub> Capture, Transport and Storage Trondheim, Norway - June 21-23, 2021.
6. Camargo J.T., White J.A., 2020. Deformation monitoring feasibility at an offshore carbon storage site, Interim progress report LLNL, December 2020.
7. Dombrowski, E.; Mondol, N.H.; Bohloli, B.; Gaina, C. and Torabi, A. 2021. Applying machine learning on InSAR data for carbon sequestration site monitoring. NGF Winter Conference, 6-8 January, Trondheim, Norway.
8. Kizatbay, A., Shahid, A.A., and Mondol N.H. 2020. Grain size analysis of sediment cores from Bay of Mecklenburg, offshore Germany, Lab report, Department of Geosciences, University of Oslo.
9. Park J., Eiken O., Bjørnarå T.O., Bohloli B., 2021. Generalized Geertsma solution for isotropic layered medium. TCCS-11 - Trondheim Conference on CO<sub>2</sub> Capture, Transport and Storage Trondheim, Norway - June 21-23, 2021. Accepted for Oral presentation.
10. Rogstad A., Bohloli B., Quinteros S., 2020. SENSE Case Study: Geotechnical testing of clay and sand, Bay of Mecklenburg, offshore Germany. NGI report 20190570-02-R, 58 p.
11. Skomedal E., 2021. CO<sub>2</sub> storage is taking off. SPE (Society of Petroleum Engineers) Technical Sections- Geomechanics. SPE Connect website with focus on Petroleum Engineering professionals.

# Outlook including impact of COVID-19 and corrective actions incl. project extension

- SENSE project relies on **case studies to demonstrate technologies** for ground monitoring, has had some challenges (COVID-19) but is almost on track with the mitigations adopted.
- We would suggest an extension of the project by ca 6 months- will deliver the planned and adopted deliverables within that time frame.
- **Bay of Mecklenburg, COVID-19 stopped the campaign**
  - Extensive work done,
  - High potential for development of monitoring tools/techniques,
  - High interest for a spin-off project.





# Acknowledgement



SENSE (Assuring integrity of CO<sub>2</sub> 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.

