Report of Transnational Access Projects

Project ID: C3_TA1-44-1-3

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Project title: *Svelvik Borehole Electromagnetic Monitoring*

Project acronym: *SBEM*

Hosting installation: *Svelvik CO2 Field Lab (TA1-44-1), SINTEF*

Hosting team: *Marcin Duda, SINTEF – Michael Jordan, SINTEF*

Period of access: *26.05.2025 – 08-06.2025*

Report of activities:

During the SBEM project at the Svelvik CO_2 Field Lab, we conducted an integrated electromagnetic (GPR and ERT) and seismic monitoring campaign (Figure 1) to image both the shallow overburden and deeper formations prior to injection and track gas migration and potential leakage pathways.

Field activities included the acquisition of GPR data, on-site validation of processing workflows, and close collaboration with installation staff to integrate GPR results with downhole seismic and Distributed Acoustic Sensing (DAS) system. Initial efforts focused on cross-well and reflection GPR acquisition. However, 100 MHz borehole antennas experienced strong attenuation below the phreatic surface, resulting in insufficient signal-to-noise ratio despite extensive stacking. Consequently, cross-hole GPR was suspended.

Acquisition then focused on the most reliable configurations: 3D surface GPR and Vertical Radar Profiling (VRP). A 3D grid (2 m spacing) was acquired over a 10 m × 35 m area north of well M3, using 100, 250 and 500 MHz antennas (Figure 2), with repeated daily surveys. In parallel, GPR Common Midpoint (CMP) surveys were performed to constrain the velocity model. For VRP, the transmitter was deployed at the surface at 2 m intervals, while the receiver was lowered in the borehole at 0.10 m increments. 3D time-lapse and VRP datasets were acquired to improve sensitivity to changes in the subsurface and to define the geometry and orientation of the shallowest layers that could serve as leakage pathways for CO_2.

In addition, Electrical Resistivity Tomography (ERT) was carried out along a north-south profile (48 electrodes, 2 m spacing) to characterize the near-surface electrical properties prior to monitoring (Figure 3).

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Complementary seismic monitoring included Vertical Seismic Profiling (VSP) and cross-well seismic surveys. For both surveys, the seismic wavefield produced by a P-wave sparker source was recorded with both hydrophones and DAS fibers in well M3 (Figure 4). For the cross-well surveys the source was deployed in well M4, while at the surface for the VSP surveys. Two different configurations of DAS fibers were interrogated, linear (LIN) and helical-wound cable (HWC). These datasets enabled the detection of time-lapse changes within the seismic data related to the CO_2 injection. Repeated cross-well surveys revealed changes in the reflected wavefield and disruptions of the P-wave first arrivals after injection (Figure 5), which are consistent with the accumulation of CO_2 within the monitored volume. Moreover, these datasets allowed the construction of tomographic P-wave velocity models and supported the validation of the injection regime.

All deployed methods showed good signal-to-noise ratio and repeatability after calibration and quality control. The 3D GPR data revealed laterally continuous, dipping reflectors in the shallow overburden. These structures are interpreted as potential preferential flow pathways that could influence the migration of injected CO_2 and represent possible leakage routes within the shallow subsurface. The multi-frequency GPR acquisition highlights different levels of detail within the shallow near-surface. Lower frequencies provide greater penetration and emphasize deeper, laterally continuous reflectors, whereas higher frequencies improve the resolution of shallow features and finer stratigraphic details. The use of surface 3D GPR proved operationally efficient for near-surface characterization and demonstrated promising potential for monitoring shallow CO_2 migration through repeated time-lapse surveys. Current work focuses on amplitude analysis of VRP and 3D GPR data to isolate injection-related signals from environmental effects. The ERT profile provides complementary information on the electrical structure of the shallow subsurface, clearly imaging the freshwater layer and the transition from freshwater to saltwater. These resistivity contrasts help constrain the hydrogeological setting and support the interpretation of the GPR results. The seismic datasets acquired with hydrophones, linear DAS, and helically wound DAS provide complementary sensitivities to the same subsurface volume. This allows us to develop a monitoring protocol in which hydrophone data are used as a high-quality benchmark, while DAS measurements can be exploited for more extensive and scalable spatial coverage. In parallel, inversion workflows are under development: permittivity inversion from GPR data, seismic first-arrival tomography for velocity models to detect changes associated with CO_2. The integration of multiple geophysical methods provides a robust multi-physics monitoring framework, enabling cross-validation of anomalies and reducing interpretation uncertainty. Continuous collaboration with SINTEF staff through daily technical briefings ensured consistency in acquisition and processing. The developed workflow is transferable to other shallow CO_2 storage sites and represents a scalable approach for integrated subsurface monitoring.

Part of the results obtained within the SBEM project have already been presented at scientific conferences, while additional contributions are planned for upcoming conferences. The ongoing analyses will also form the basis of future journal publications, aimed at disseminating the developed methodologies and the scientific findings of the monitoring campaign.

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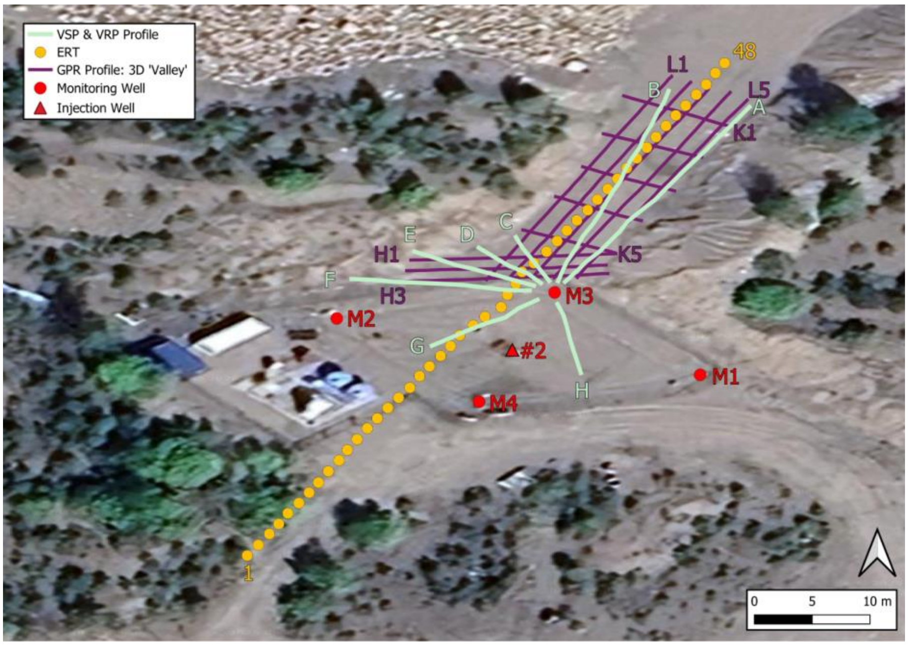

Figure.1 - Overview of the geophysical acquisitions carried out at the Svelvik CO_2 Field Lab.

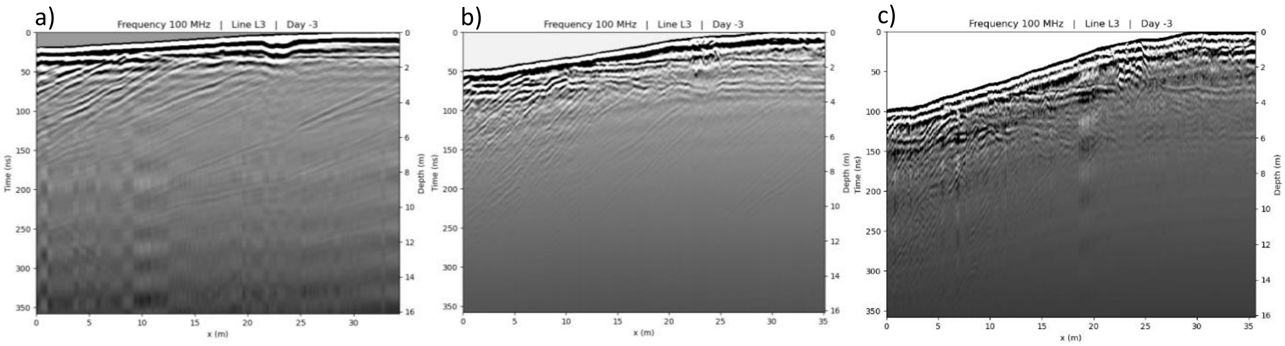

Figure 2 – Pre-injection baseline of section L3 after static correction recorded with different GPR antennas; a) 100 MHz, b) 250 Hz, c) 500 Hz.

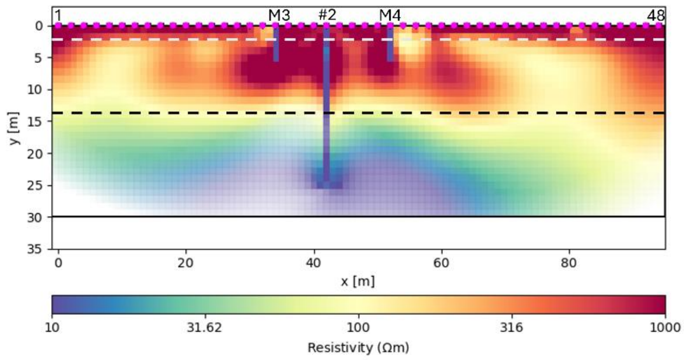

Figure 3 – ERT profile showing inverted resistivity. The grey-dotted line indicate the upper freshwater interface, while the black-dotted line highlights the transition from freshwater to saltwater.

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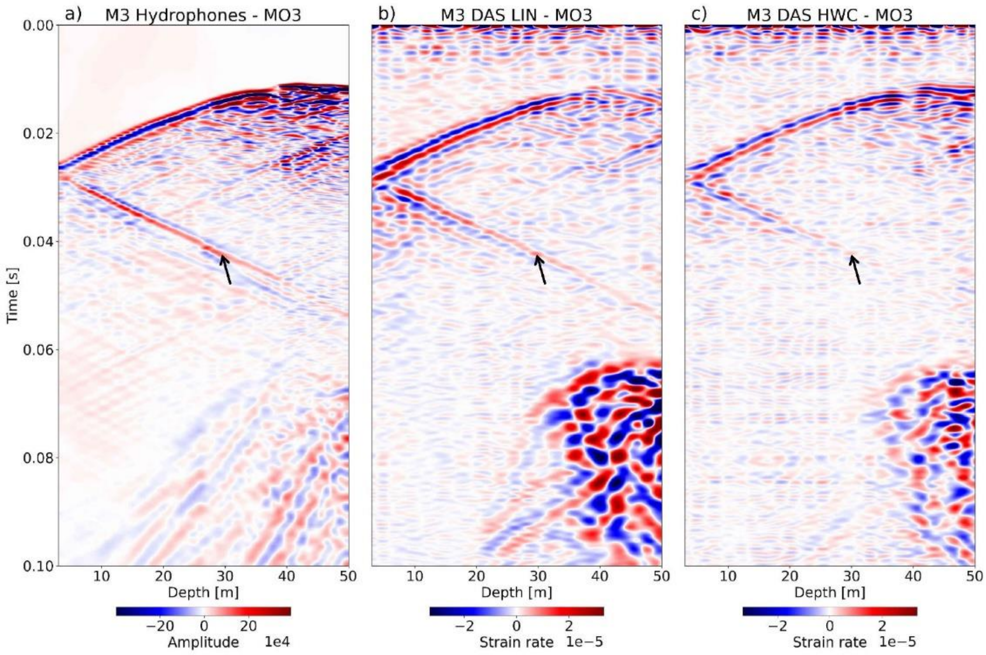

Figure 4 - Comparison between hydrophone (a) and DAS recordings (b-c) collected during the cross-well survey with source at 45 m depth in well M4 and receivers in well M3. The DAS data are shown for the Linear (a) and Helically-Wound-Cable (c) configurations.

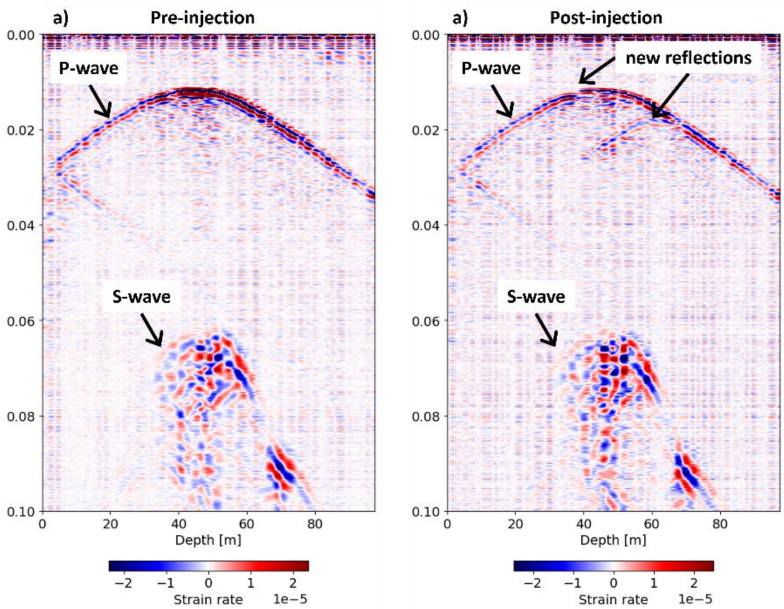

Figure 5 – An example of time-lapse shot gathers with time-lapse changes related to the accumulation of CO_2, collected during the cross-well survey with source at 45 m depth in well M4 and HWC DAS in well M3. In (a) the baseline pre-injection, while in (b) the monitor post-injection data. As indicated in the figure, changes as new reflections and local perturbation of the P-wave first-arrival can be detected.

Project outcomes:

G. Pantaleo, E. Ligas, G. Roncoroni, E. Forte, M. Pipan - Time-lapse monitoring at the Svelvik CO_2 Field Lab: survey design. 44th GNGTS, Udine, Italy, 10-13 February 2026. https://gngts.ogs.it/wp-content/uploads/2026/Abstract/3.1_Abstracts_0102.pdf

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E. Ligas, G. Pantaleo, G. Roncoroni, E. Forte, M. Pipan - Time Time-lapse monitoring at the Svelvik CO_2 Field Lab: QC and preliminary results. 44th GNGTS, Udine, Italy, 10-13 February 2026. https://gngts.ogs.it/wp-content/uploads/2026/Abstract/3.1_Abstracts_0102.pdf

E. Ligas, G. Pantaleo, E. Forte, M. Pipan - GPR time-lapse challenges and optimization strategies. 21st International Conference on Ground Penetrating Radar (GPR2026), Newcastle, UK, 23-26 June 2026.

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