CO_2 ReMoVe – 4 years in

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The FP6 project CO_2ReMoVe aims at creating a scientifically based reference for the monitoring and verification of CO_2 geological storage. Through extensive R&D into monitoring, measurements and verification on multiple storage sites, CO_2ReMoVE wants to prove the long term reliability and safety of geological CO_2 storage and provide the R&D necessary for monitoring and verification leading to guidelines and standards for policy makers, regulators and industry. This is useful for CO_2 storage to qualify in emission trading schemes. The four main sites used to test the methodologies and tools are In Salah, Sleipner, Snøhvit, and Ketzin as well as additional sites K12-B and Kaniow.

2009 at the *In Salah* site saw several successful field monitoring operations, where working in an arid environment presents its own challenges. A mobile open path laser system was deployed in March 2009 (Figure 1); the results highlighted the potential of such systems as well as some of the technical difficulties of carrying out such measurements in such a dusty environment. The repeat soil gas flux measurements (Figure 2) gave similarly low values to those in 2004, which were confirmed by preliminary laboratory analysis at the University of Rome. Both the soil gas and the mobile laser measurements were repeated in November 2009 and no significant anomalies were found. Given the very low gas concentrations this provided baseline data and was a feasibility study for carrying out work in a desert environment. In late 2009 the first studies of the soil microbiology and plant species over the site were conducted. The botanical and soil microbiology work particularly focuses on the area around the three CO_2 injection wells.

The value of using tiltmeter/GPS and satellite imagery data at In Salah has been shown. The satellite data shows subtle (less than 5mm/year) but highly interpretable subsidence and uplift respectively related to the production and injection operations (Figure 3). Integration of the permeability pattern inverted from the surface uplift data into the reservoir simulation has lead to an improved prediction of the CO_2 plume migration around one of the wells. This is consistent with the surface monitoring data, as well as reservoir-based observations. The results show that the CO_2 plume migration extent and direction in the storage complex appears to be consistent with expectations.

Also being tested at In Salah is a microseismic survey before full deployment of ongoing measurements while additional three-dimensional seismic data was acquired in June 2009.

Figure 1 Open path mobile laser fitted to the front of the vehicle

Figure 2 Soil gas and flux methods used at In Salah

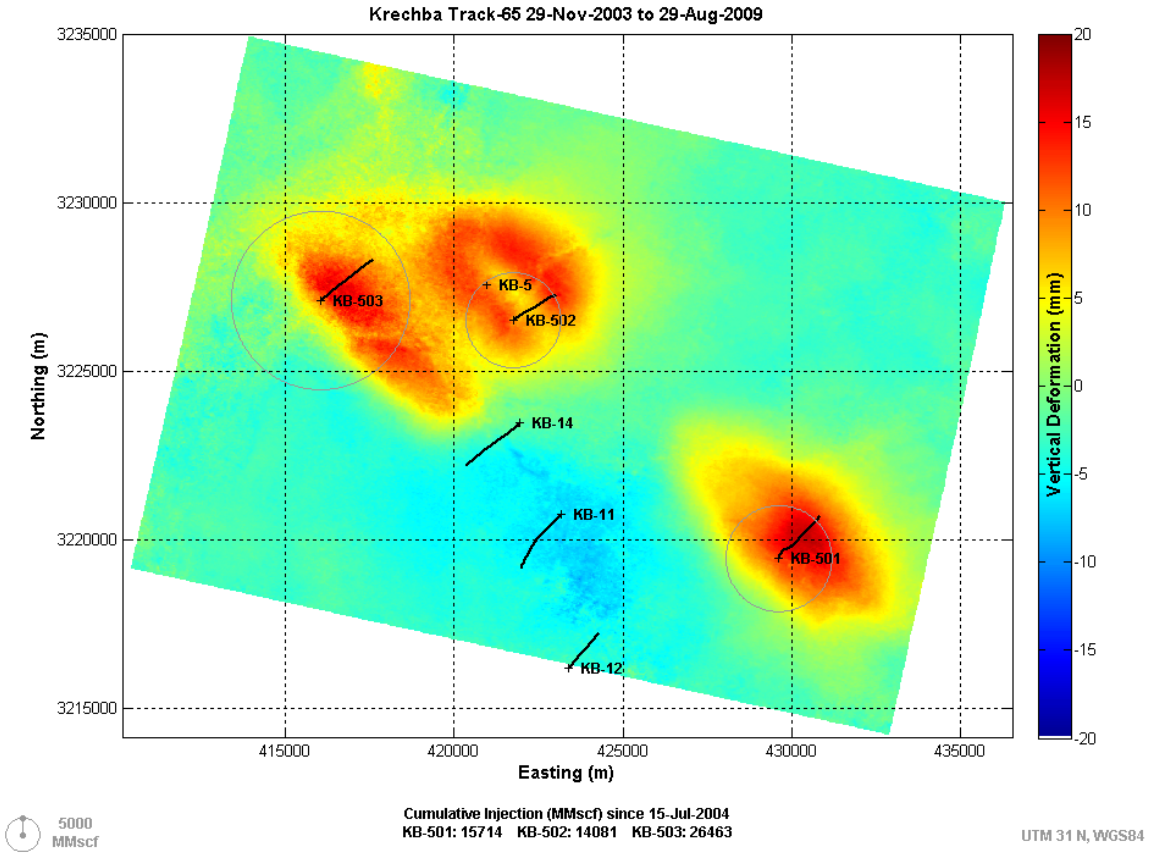

Figure 3 Ground deformation (courtesy of MDA/Pinnacle ISG JIP)

At *Sleipner* time-lapse seismic and gravity surveys are the main geophysical monitoring tools. A baseline Electromagnetic (EM) survey was conducted in 2008 and a repeat seabed gravity survey in 2009. In the scope of validating methods for monitoring CO_2 migration, a pre-stack stratigraphic inversion method has been applied on the 2006 3D repeated seismic to map the CO_2 plume (Figure 4). Such results help updating the reservoir model improving reliability for long term simulations. Geological models have been generated in Petrel and populated with porosity and permeability using statistical methods. Several simulation models representing the Utsira Sandstone Formation (large and small scale) have been constructed. Work on the common and unified Earth model has been finalized.

The biomarkers laboratory is underway for which organisms in the intertidal zone and deep-water shrimp have been collected. Experiments have been completed exposing organisms to different concentrations of dissolved CO_2 (0.5, 1, 2 and 3 % CO_2). Animals exposed to 1 % (10000 ppm) CO_2 were subjected to acute (in 1-48 hours) and chronic (4-28 days) exposures in order to examine the changes, while animals exposed to the other levels of CO_2 were exposed for 14 days. The objective of the laboratory is to find biomarkers of possible/potential seepage of carbon dioxide from the seabed.

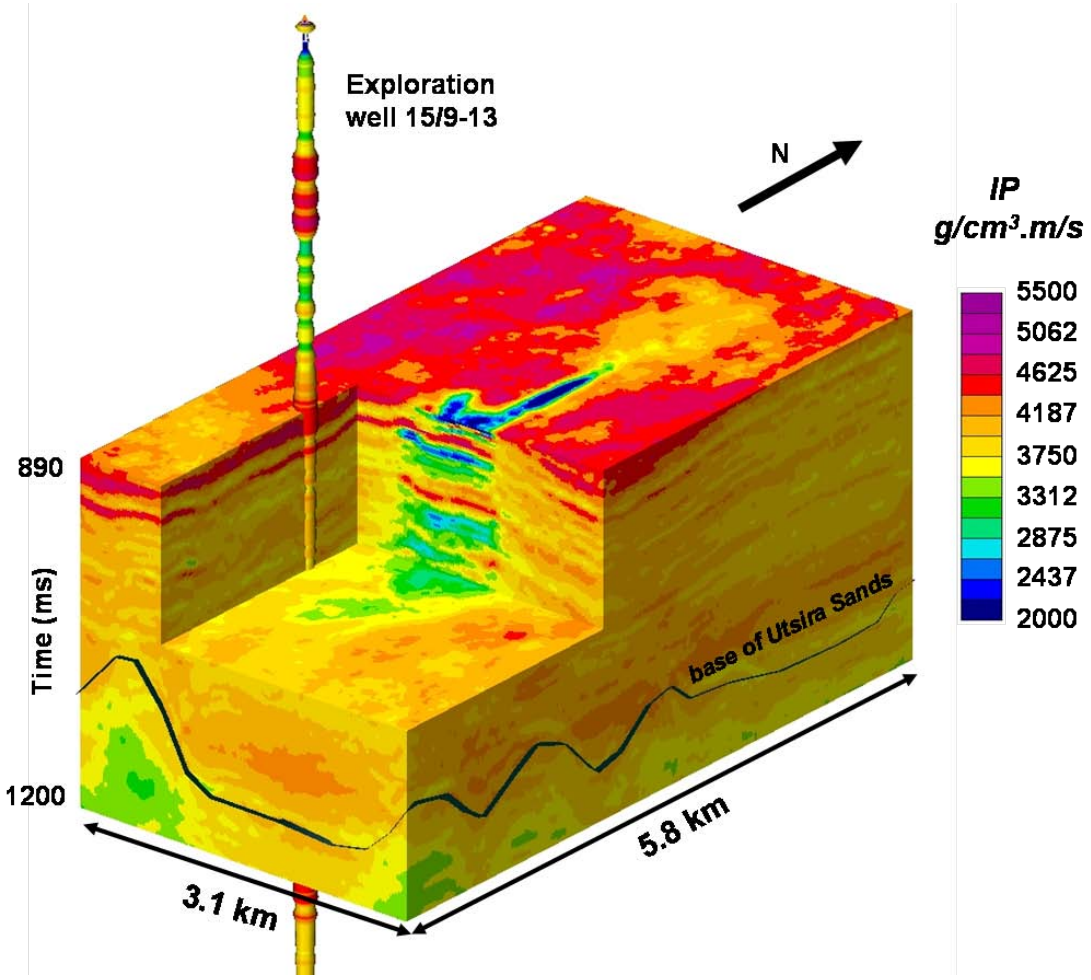

Figure 4 Cut-away view of the 3D P-wave impedance data cube computed by pre-stack stratigraphic inversion of the 2006 vintage. The figure also shows the exploration well used for the calibration step and the intersection between the base of the Utsira Sand formation with the boundaries of the cube. The CO_2 plume is identified by low impedance values displayed in dark blue, blue and green colours (Clochard et al. 2010).

At the *Snøhvit field* – Statoil is reinjecting CO_2 into the ground beneath the gas-bearing formation of the field. The operators have encountered initial challenges with the LNG plant, giving lower injection rates than originally planned for the two first years. The reservoir injection well pressure has risen to levels higher than predicted by the pre-injection reservoir simulation model.

Statoil is in the process of revising/updating the existing reservoir simulation model based on the results of the new interpreted seismic data acquired in 2009.

At *Ketzin* carbon dioxide injection into the aquifer commenced in 2008, and the intention is to monitor the behaviour of this injected gas for many years to research the long term reaction and safety of CO_2 storage in saline aquifer conditions. Monitoring techniques include seismic acquisition, geochemical analyses, temperature and geo-electrical measurements at the surface and within the wells.

The seismic work-flow was rearranged in order to optimise the deployment of the available seismic campaigns for detection of the CO_2 plume propagation direction (in collaboration with CO_2SINK).

Furthermore, the seismic campaigns have to be multiplexed to share the expensive lubricator equipment. The planned VSP/MSP survey was implemented in autumn 2009; a 3D-MSP survey was carried out to record the shot points of the 3D-reflection survey with a 3-component receiver in one well. This technique provides high underground coverage and allows for the areal monitoring of CO_2 migration around the three Ketzin wells.

The evaluation of datasets from Distributed Temperature Sensor (DTS) system has been extended for as long as possible. The DTS plays an important role for safety monitoring of the injection string in well Ktzi201, providing information on the behaviour of CO_2 (supercritical phase). It is planned to evaluate the stability over long injection periods as well as the shut-in and re-start phases of the injection process.

Figure 5 Source (VIBSIST-3000, Vibrometric) used for 2D-MSP and passive seismic check shots, in front of observation well Ktzi202 with lubricator on top

At the *K12-B field* a performance assessment has demonstrated, that should migration of CO_2 to shallower strata or even to the surface occur, the most likely migration pathways to be considered are along the wellbores penetrating the reservoir. Therefore monitoring of the CO_2 injected into K12-B is mainly focussed on the integrity of the wells.

Unable to cover for or insure any possible lost-in-hole charges for the pH logging tool the pH measurements are being carried out by analysing downhole fluid samples from the injection well in a laboratory rather than continuous downhole analysis.

Acquisition of PMIT (platform multi-finger imaging tool) caliper data and EMIT (electro-magnetic tubing and casing integrity tool) data was carried out in summer 2009. Gas composition and tracer analyses are also being conducted on regular intervals.

On the new project website you can find more information about the project and the storage sites that CO_2ReMoVe is using to gain monitoring and verification experience for several different storage scenarios. Details of scientific publications, news and worldwide upcoming CCS events can also be found at: http://www.co2remove.eu/.

CO2ReMoVe is funded by the EC 6th Framework Programme and by industry partners Statoil, BP, Schlumberger, ConocoPhillips, ExxonMobil, Total, DNV, Vector, Vattenfall and Wintershall. R&D partners are BGR, BGS, BRGM, CMI, DNV, ECN, GFZ, GEUS, IEA-GHG, IFP, Imperial College, MEERIPAS, OGS, TNO, URS, Quintessa, Schlumberger SINTEF, Total and Vattenfall R&D. Three R&D institutes outside Europe participate in CO2ReMoVe: CSIR from South Africa, UNDLP from Argentine and ISM from India. For more information please go to the website or contact the project coordinator Ton Wildenborg (e-mail ton.wildenborg@tno.nl tel. + 31 30 256 4636).