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Exploration and monitoring of CO2 storage sites using controlled-source electromagnetics: results of a feasibility study at Ketzin, Germany.

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Electrical and electromagnetic geophysical methods are sensitive to the electrical conductivity of pore fluids. Where CO2 substitutes a fraction of saline pore fluid within a storage aquifer, bulk electrical resistivity increases significantly. Imaging the migration of an electrically resistive plume is therefore a key geophysical technology to trace CO2 in the subsurface. For instance, borehole electrical resistivity tomography (ERT) has been successfully applied to monitor the migration of CO2 between injection and observation wells within a ∼635 m deep storage aquifer at the in situ laboratory at Ketzin, Germany. However, the resolution power of cross-hole tomography is generally limited to regions in-between the boreholes; beyond the boreholes, techniques with a wider spatial footprint are required.
Controlled source electromagnetic (CSEM) techniques are powerful in detecting thin resistive layers and may provide a tool to explore and monitor a wider region around the injection site. Here, we present the results of a CSEM feasibility study at the Ketzin site. We utilized the existing ERT borehole electrodes to inject a square-wave electrical current with fundamental periods between 32 s and 0.125 s, and recorded the induced electric and magnetic fields at three surface sites, located at 800 m to 1.8 km distance from the borehole array. We tested two source dipole configurations. A vertical dipole combined electrodes at the top and bottom of the ERT spread, yielding an effective vertical dipole length of ∼120 m centered at ∼665 m depth. This dipole cuts through the CO2 bearing reservoir. A second source dipole combined electrodes within two separate boreholes at approximately the same depth, yielding a 100-m long near-horizontal source dipole at ∼655 m depth, i.e. just below the reservoir formation. A current of 6 Amperes was injected in both cases, limited by the cable diameters in the boreholes. Nevertheless, the resulting dipole moments of both source configurations were sufficient to generate measurable signals at the surface, in spite of unfavourable noise conditions at the site.
Tomographic inversion of the measured data was not applied due to the limited amount of data. Instead, we evaluate the consistency of the measured data with the results of synthetic modelling results based on geological and other geophysical models and borehole resistivity measurements. In view of the results of this feasibility study and of further modelling studies of the injection scenario, we discuss promising field geometries for an expanded CSEM survey at Ketzin.