Reservoir Monitoring using Controlled Source Electromagnetics

A case study from a producing oil field in NW Germany

Cedric Patzer[1,2], Kristina Tietze[1], Oliver Ritter[1,2], Paul Veeken[3]

[1] German Research Centre for Geoscience (GFZ), Section 2.7 Near Surface Geophysics, Potsdam
[2] Freie Universität, Berlin
[3] Wintershall Holding GmbH, Kassel

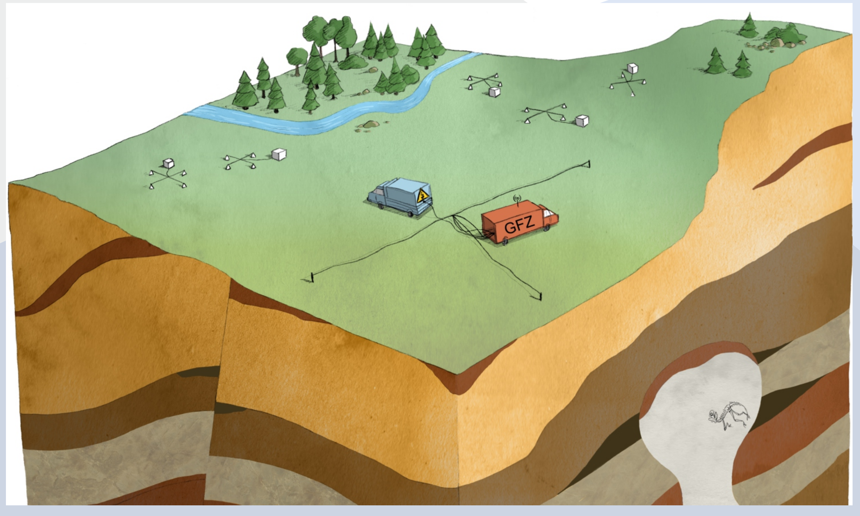


Fig: 2 Above: Artistic illustration of the CSEM method (Grayver, 2013). Below: Impressions from field surveys in the area of the Bockstedt oil field, Germany, with the installed CSEM transmitters and receivers.

Aim is to reconstruct the electrical resistivity distribution in the subsurface from measured EM fields.

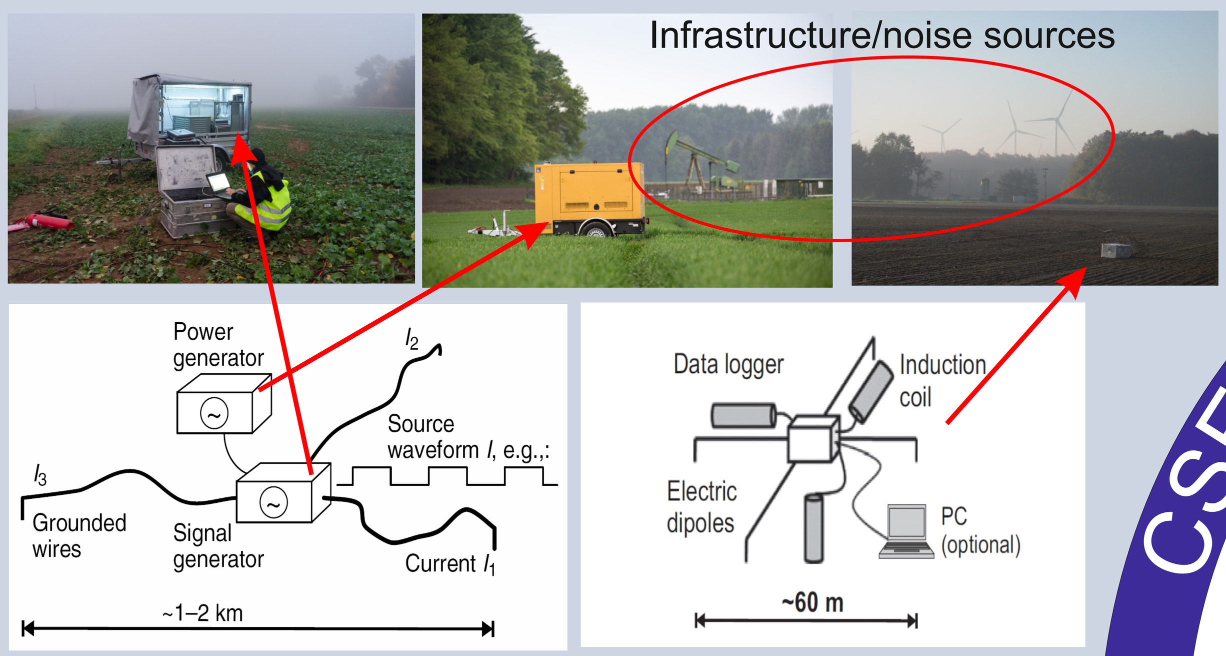
Time varying electric current is injected into the ground using three-phase transmitter.

EM fields propagate diffusively through the underground.

At receivers, the electric field is recorded using non polarisable electrodes.

Collected 3 data-sets across the Bockstedt oil field in 2014,2015 and 2016.

Data are collected in high noise environment (power lines, windmills, pipelines etc...).



Simulation of 2 reservoir states

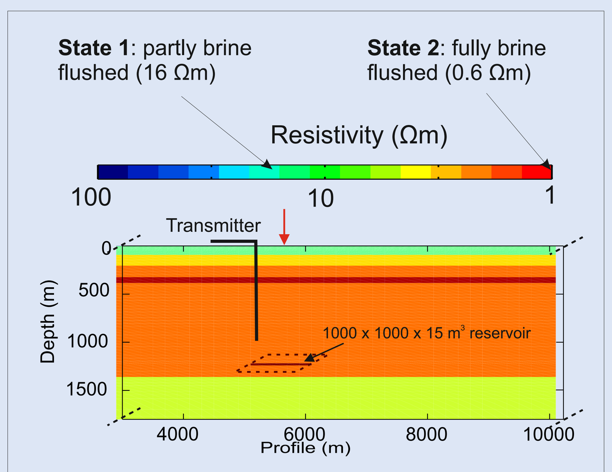
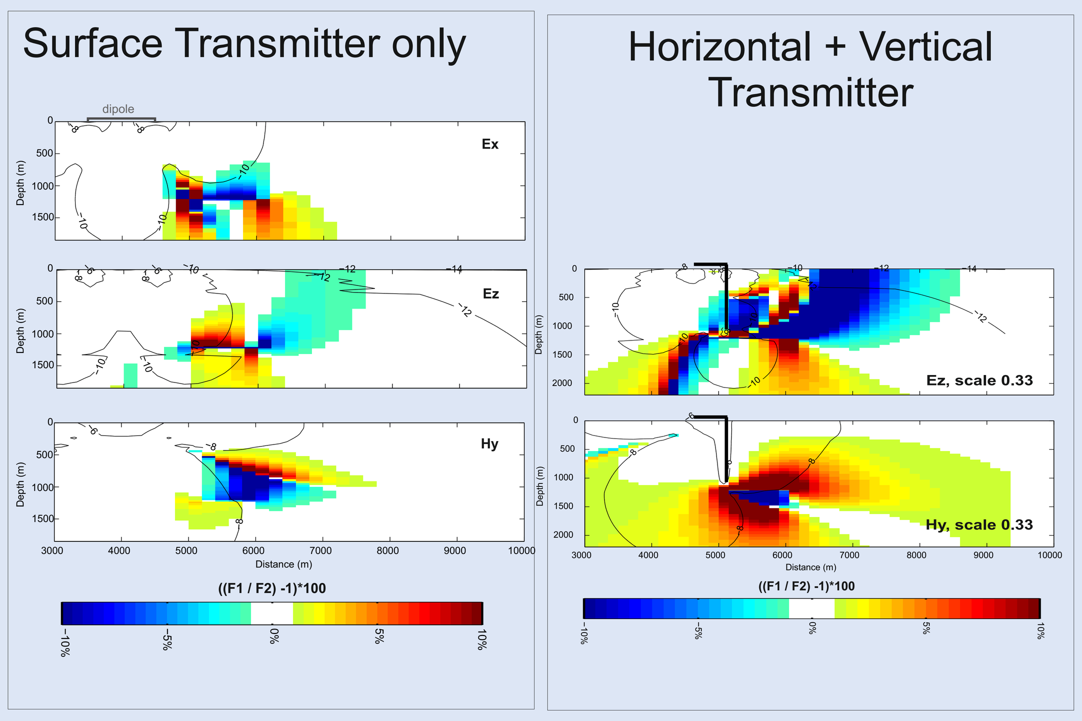


Fig: 3 A simulation study was carried out to obtain the source receiver configuration most sensitive to changes inside a reservoir. Difference in EM field distribution for two distinct reservoir states was analysed to find optimal setup (Tietze 2015).

Change in EM field distribution between 2 reservoir states



CSEM is sensitive to resistivity changes for 3D reservoir structures, but the effect is close to the resolution threshold for standard CSEM measurements at surface and practical field conditions.

Sources with vertical components and/or location of receivers at depth closer to the reservoir are essential to increase sensitivity to deep targets. In particular, measurements of the vertical electric field in observation boreholes are most promising.

Resolution for resistivity changes within the reservoir with CSEM methods depends significantly on resistivities of the surrounding formations.

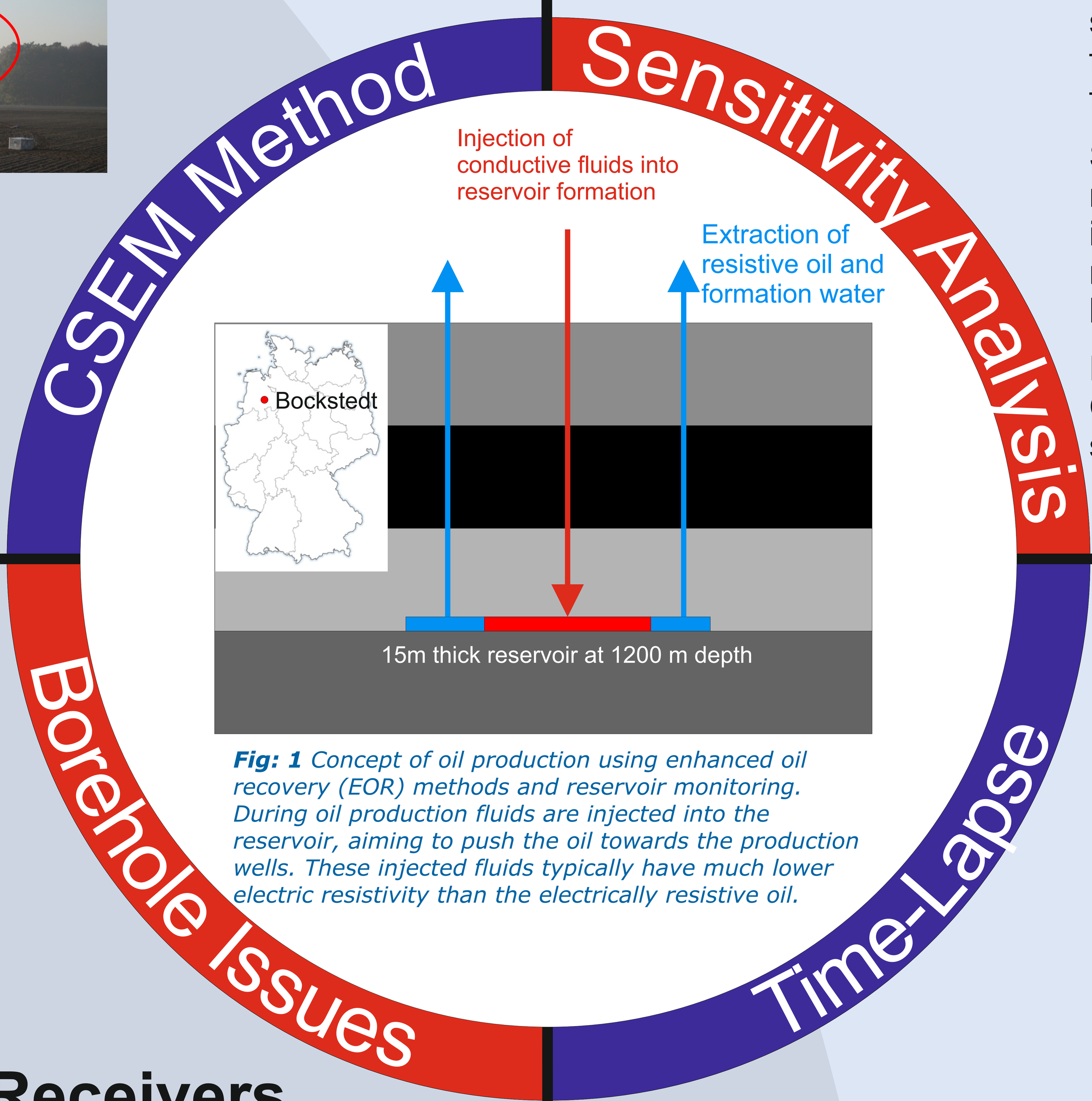


Fig: 1 Concept of oil production using enhanced oil recovery (EOR) methods and reservoir monitoring. During oil production fluids are injected into the reservoir, aiming to push the oil towards the production wells. These injected fluids typically have much lower electric resistivity than the electrically resistive oil.

Steel Casings

Conventional ~10 m long steel rods for current injection

Fig: 4 Realisation of vertical electric sources in the field by galvanic attachment of the CSEM transmitter to existing abandoned well.

Current injection via steel casing of 1.3 km long abandoned well

Current injection through steel casing of abandoned oil well with maximum current of transmitter (40 A).

Galvanically connected steel casing requires adequate description of current distribution along casing during modelling and inversion.

Even if steel casings are only nearby they significantly influence the measurements (see Fig. 5).

Our modelling code considers now galvanically as well as inductively coupled wells.

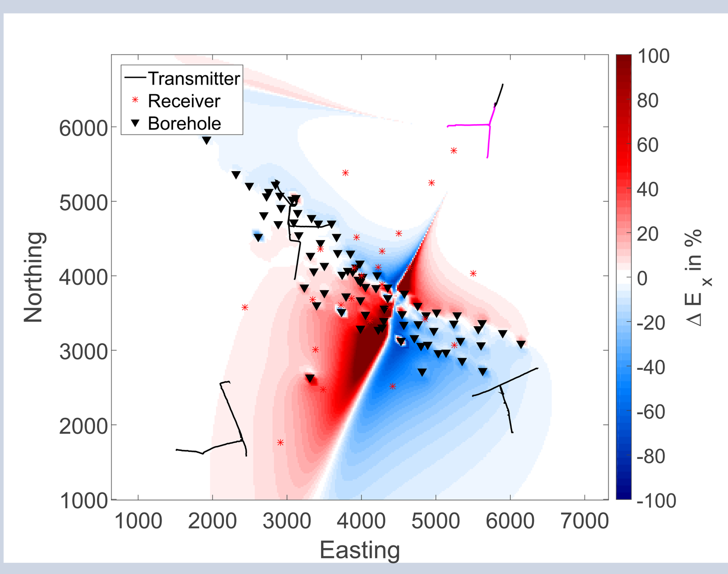
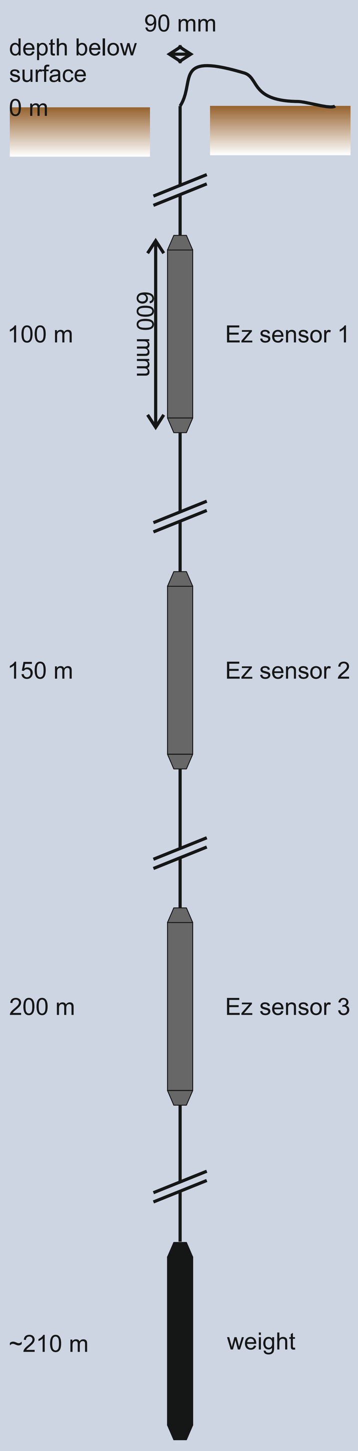


Fig: 5 Modelling study showing the effect of 78 steel-cased wells present in the Bockstedt oil field on measured data (Patzer, 2017a).

Vertical Receivers



Development of novel vertical electric field sensor.

Installation in September 2015 in 200 m deep plastic cased observation borehole.

CSEM signals of all transmitters were clearly identified.

Fig: 6 Above: Details of the Ez receiver installed in a observation well in the Bockstedt oil field. Right: The newly developed electric field sensors.

Repeatability

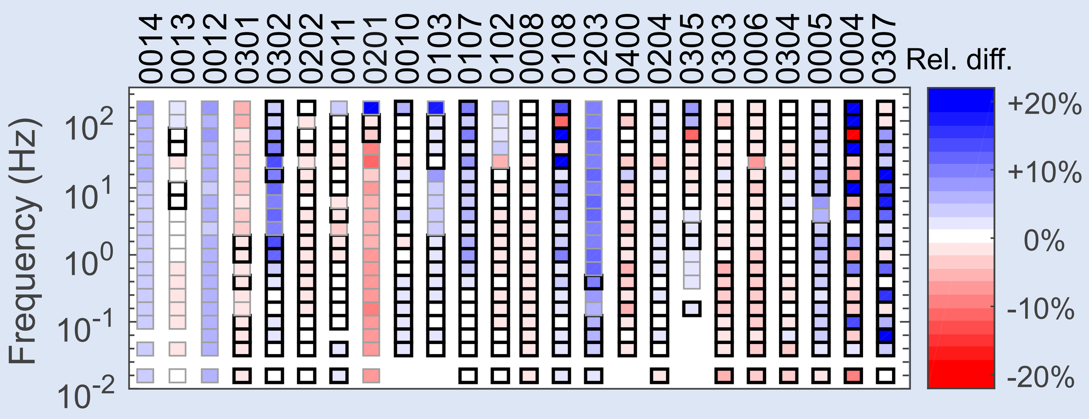


Fig: 7 Relative difference between measured electric fields in north direction in two consecutive years (2015-2016) for one transmitter per receiver station and frequency. Sources and receivers have been removed and reinstalled between surveys. Stations are sorted over distance to the transmitter. For markers with highlighted outlines differences exceed 3 times their uncertainties.

Since oil has been produced since 1950 and there was no sizable increase in production during the time of monitoring, we do not expect significant differences in the subsurface resistivity structure and therefore between the 3 datasets.

Repeatability of CSEM measurements is high, for the majority of data points within ±5%.

If instruments can only be deployed in a time-lapse manner, relocation of sources and receivers within ~10 m is essential.

Although Ez signals have small amplitudes, recordings using the novel receiver chain are stable. Ez response functions of the 2015 and 2016 data sets show excellent quality and repeatability.

Time-Lapse Inversion

Cascaded inversion scheme is used as basis for time-lapse inversion.

To increase resolution at reservoir depth various focussing techniques and a-priori information had to be implemented. (Non-smoothing regularisation, model weighting, conductivity constraints, etc...)

Cascaded time-lapse inversion works with synthetic data (proof of concept).

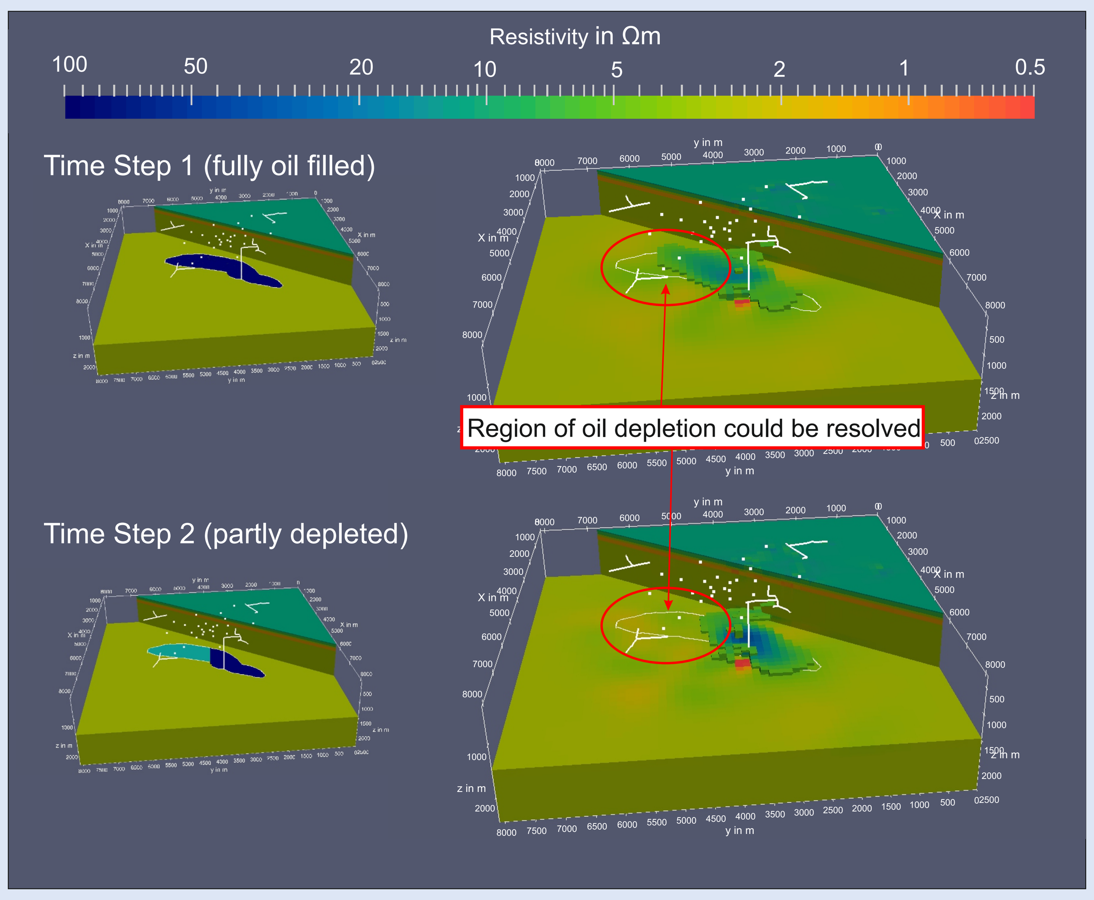


Fig: 8 Time-lapse inversion of synthetic data for two distinct reservoir states (Time step 1 & 2). Reservoir outline of the Bockstedt oil field as provided by Wintershall. Source-Receiver setup is taken from the field surveys in 2014. The galvanic connected steel cased well is included in the simulation. (Patzer,2017b)

References:
Grayver, A. V.; Streich, R. & Ritter, O. (2013), Three-dimensional parallel distributed inversion of CSEM data using a direct forward solver. Geophysical Journal International, 193, 1432-1446
Patzer, C.; Tietze, K. & Ritter, O. (2017), Steel-cased wells in 3-D controlled source EM modelling Geophysical Journal International, 209, 813-826
Patzer, C., Ritter, O., & Tietze, K. (2017). Time-lapse CSEM inversion using focussing regularization techniques for reservoir monitoring. Society of Exploration Geophysicists.
Tietze, K.; Ritter, O. & Veeken, P. (2015), Controlled-source electromagnetic monitoring of reservoir oil saturation using a novel borehole-to-surface configuration Geophysical Prospecting, 63, 1468–1490

Acknowledgements:
This project is funded by Wintershall Holding GmbH, Kassel (Germany). The authors would like to thank P. Veeken and M. Dillen and the MT component of the Geophysical instrument pool (GIPP) for providing the instruments during the field campaigns.