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Recent Developments for Land-based Controlled-source Electromagnetic Surveying

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SUMMARY

Controlled-source electromagnetic (CSEM) surveying has been in use for more than ten years and has become a well-established tool for hydrocarbon exploration in marine environments. On land, however, CSEM methods are rarely applied in a similar manner, since challenges are greater for a range of technical, logistical, and numerical aspects.

Over the last five years, the Geo-Electromagnetics working group at the German Research Centre for Geosciences Potsdam (GFZ) has been developing the CSEM method for land-based applications, including a three-phase current transmitter allowing for arbitrary source polarizations, new robust data processing concepts, and 1D to 3D modelling and inversion software. The CSEM hardware and software has been successfully applied in a series of surveys on different targets. We show examples from case studies, including 3D inversion results from the Ketzin CO2 injection test site in Northern Germany.

Introduction

Whereas controlled-source electromagnetic (CSEM) methods have become well-established in industrial marine hydrocarbon exploration over the last decade, they are rarely applied for such purposes on land. Possible reasons include limited source strengths, poor data quality in populated areas, difficult accessibility/logistics, and the presence of air weakening target responses compared to marine environments (Streich et al. 2011).

Over the last five years, the Geo-Electromagnetics working group at the German Research Centre for Geosciences Potsdam (GFZ) has been developing the CSEM method for land-based applications in terms of both hard- and software. Major components are a three-phase current transmitter, data processing tools suitable for noisy data, and 1D to 3D modelling and inversion software. The CSEM equipment and software has been successfully applied in a series of surveys for different targets within Northern Germany.

Instrument and software developments for land-based CSEM application

For current injection, a three-phase transmitter was developed at GFZ in collaboration with Metronix GmbH (Fig. 1a). Power is supplied by a standard three-phase AC current generator (400 V @ 50 Hz). The output is fed into a programmable signal generator, which transforms the input signal to the desired current waveform (e.g. square waves, sine waves, pseudorandom binary sequences) at a voltage of 560 V and a maximum current strength of 40 A. The source current is injected into the subsurface simultaneously via three grounded electrodes (distance ~1 km); the tripole transmitter layout allows for arbitrary source polarizations largely independent of the surface accessibility (Fig. 1b). By using multiple polarizations, we can ensure that fields of measurable amplitude can be retrieved.

Streich et al. (2013) introduced a new concept for CSEM data processing, which adopts the concept of transfer functions used for passive magnetotelluric measurements. The processing scheme estimates frequency-dependent response functions between the three-phase transmitter signal and the observed electric and magnetic field components at the receiver point, which allows combining data from different polarizations and waveforms. Applying time- and frequency domain stacking and robust statistical methods improves the quality of subsurface responses significantly, particularly if data are affected by strong EM noise. Consequently, CSEM surveys become feasible in areas with abundant infrastructure which are typical for Central Europe.

Furthermore, a series of 1D to 3D modelling and inversion tools have been developed at GFZ. The modelling tools are based on finite difference discretization of the subsurface (Streich 2009) and allow for modelling of real-world source geometries, i.e. finite wire sources (Streich & Becken 2011). Recently, Grayver et al. (2013) implemented a parallel and distributed 3D inversion scheme for interpreting CSEM data in the frequency domain. At GFZ, this algorithm is run on a modern high performance cluster rendering 3D inversion of real-world CSEM data sets practical (Grayver et al. 2013, 2014).

Application example– CSEM survey across the Ketzin CO2 injection test site

In November 2010, a land CSEM survey comprising 39 receivers (two electric and three magnetic field components) and eight tripole transmitter locations was carried out across the CO2 injection test site in Ketzin, Germany, in order to obtain a 3D electrical conductivity model for a wider region around the injection site (Streich et al. 2011). Although the measurements were severely contaminated by cultural noise originating from gas pipelines, high-voltage power lines, and a large array of wind turbines, stable response functions could be obtained (Streich et al. 2011, 2013). 3D inversion of this CSEM data set resulted in excellent data fit and the electrical conductivity model (Fig. 1c) agrees very well with the regional geology (Grayver 2013, Grayver et al. 2014).

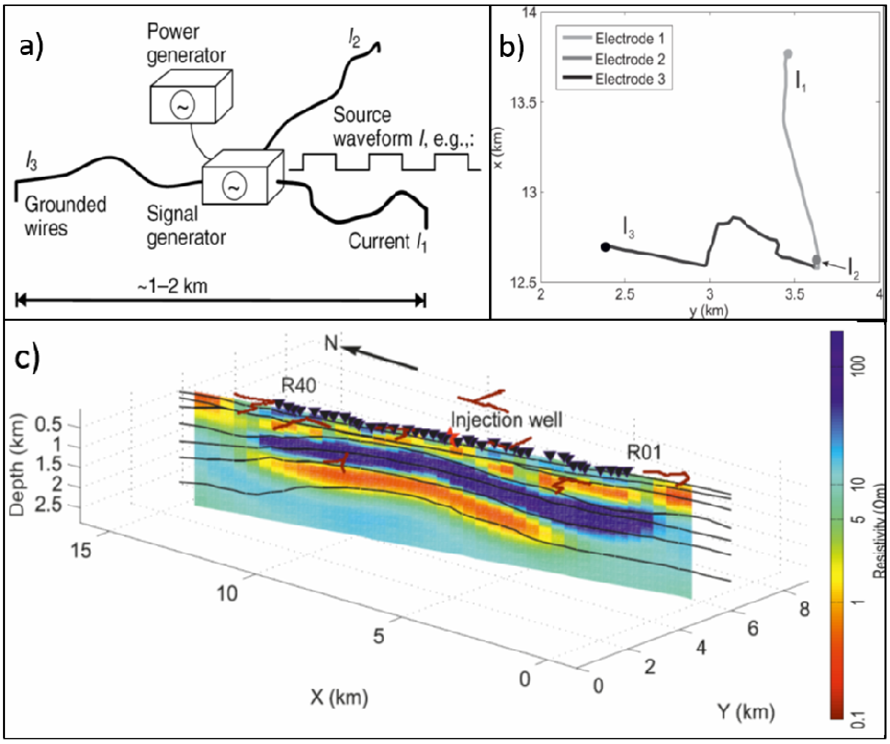

Figure 1 *(a) A three-electrode transmitter (modified from Streich et al. (2013)); (b) exemplary field layout of transmitter. (c) Section from the CSEM 3D inversion model for the Ketzin CO2 injection test site. Triangles indicate receiver locations, red lines show CSEM transmitter layouts, black lines show geological horizons (Klapperer et al. 2011); modified from Grayver (2013).*

Conclusions

CSEM surveys are feasible on land using modern instrumentation and software tools: (i) Tripole transmitters are practical in the field and allow for arbitrary source current polarizations, (ii) a new CSEM processing concept using response functions and robust statistics allows us to obtain satisfying data quality even in high-noise areas, and (iii) 3D modelling and inversion tools allow interpretation of real-world CSEM surveys. These recent developments suggest considerable potential for future use of land CSEM.

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