Geoforce-SkyTEM
Technical Description

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geophysical solutions

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Introduction

The Geoforce – SKYTEM system is designed to provide a helicopter platform which can produce similar quality electromagnetic sounding data from the air as is possible with high quality ground TEM sounding system (e.g. Geonics PROTEM or equivalent).

This document reviews the technical aspects of the SkyTEM system and illustrates its capability by means of field data examples. A full technical description of the SkyTEM is given by Sorensen and Auken (2004) and Halkjaer et al. (2006). Updates to the system parameters since 2006 are described in this document and in header files supplied with survey data.

Measurement setup and quality control

Technical approach

The Geoforce - SkyTEM system is designed for mapping geological structures for groundwater and environmental investigations, and was developed as a rapid alternative to ground-based TEM surveying. The entire system is carried as an external sling load suspended from the helicopter as shown in the figure below. No operator is required in the helicopter. During acquisition, essential data which confirms correct operation of the system is transmitted to the pilot via wireless link, and to the ground crew by radio modem. The pilot automatically receives notification to return to the ground base should any component of the instrument cease to operate correctly.

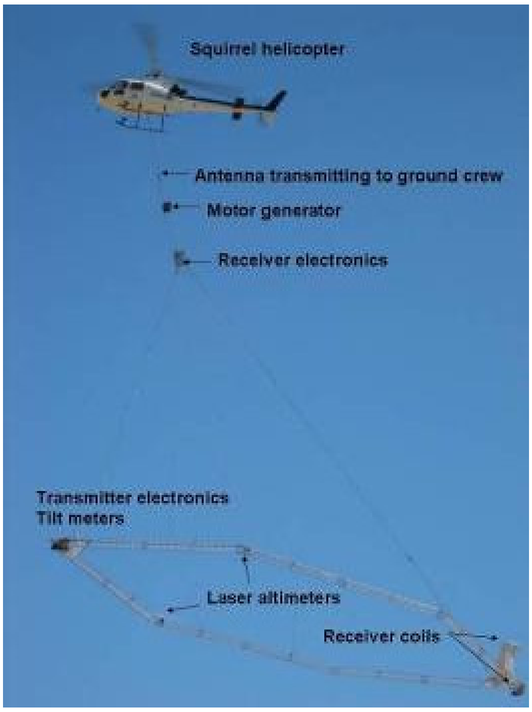

Figure 1 Photo of SkyTEM in operation at Toolibin Lake, Western Australia, October 2006. Transmitter area is 314 m^2.

The measurement configuration is based on a 314 m^2 or 494 m^2 transmitter loop and vertical and horizontal in-line axis receiver coils. Transmitter and receiver geometry is illustrated in Figure 2.

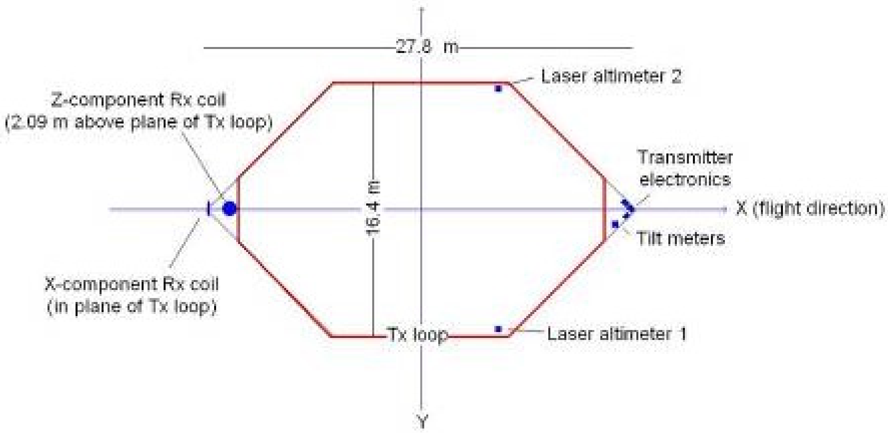

Figure 2 Sketch showing the Tx frame and instrument locations for a configuration with Tx loop area of 314 m^2.

Transmitter

The transmitter loop is roughly hexagonal with nominal diameter which can be configured to vary from about 15m – 30m. The 4 turn transmitter loop is mounted on a light weight wooden/PVC lattice frame, and is powered by a motor generator, which is suspended on the tow cable between the helicopter and the loop (Figure 1). Total weight of the system, including electronics, generator and total field magnetic sensor and associated electronics, is ~ 400 kg, depending on the Tx loop size.

A unique feature of SkyTEM is that the system is capable of operating in a dual transmitter mode:

- **Low moment (LM)** mode where low current, high base frequency and fast Tx switch off provide early time data and high spatial sampling for shallow imaging;

- **High moment (HM)** mode, where a higher current and lower base frequency provides high quality late time data for deep imaging.

The system can operate in either the LM or HM mode, or in a combined (dual) mode. In dual mode, LM and HM data are acquired sequentially, (although the LM mode only uses one Tx turn). The exact sequencing of HM and LM measurements is completely programmable, and can be designed to trade off vertical versus horizontal resolution depending on the specific survey objective.

Transmitter waveform specifications in the LM and HM modes are as follows:

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Low moment

- 1 transmitter turn
- Current approx. 40 A
- Peak moment (314 m^2 Tx loop): 12,500 nAI
- Repetition frequency typically 222.22 Hz (programmable)
- On-time: 1 ms
- Off-time: 1.25 ms
- Switch off typically 6 microseconds.

High moment

- 4 transmitter turns
- Current approx. 100A
- Peak moment (314 m^2 Tx loop): 125,600 nAI
- Repetition frequency 25 Hz
- On-time: 10 ms
- Off-time: 10 ms
- Switch off typically 38 microseconds.

The nominal LM and HM Tx current waveforms are shown in Figures 3 and 4. The Tx waveform is measured on the ground once per month to verify correct Tx operation. Unlike some other airborne electromagnetic systems, it is not possible to record the SkyTEM system waveform during flight (e.g., at high altitude) as both receiver coils are null-coupled to the Tx in order to suppress the primary signal in the off-time due to any leaking current in the Tx loop. The waveform shape and timing are temperature-independent, whereas the amplitude (ie peak current) depends on the ambient temperature during survey operations. The peak Tx current is recorded just before the onset of the Tx current ramp for each transient recorded during a survey. During data processing and interpretation, the measured peak current is used to scale the amplitude of the complete waveform.

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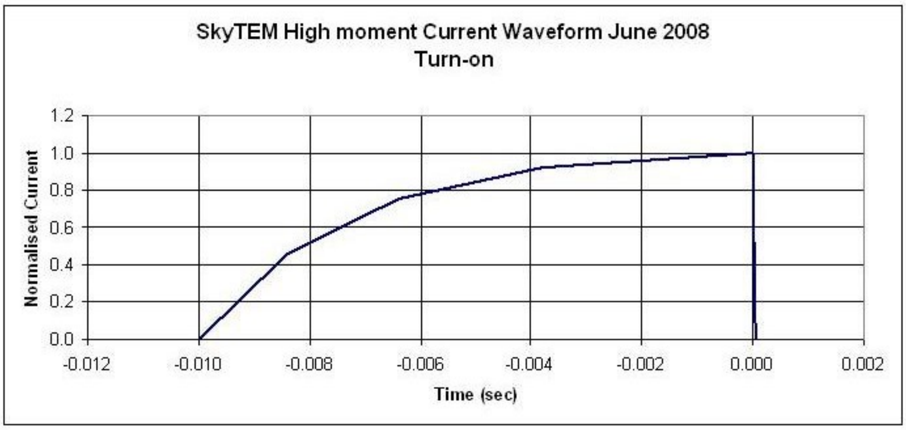
(a)



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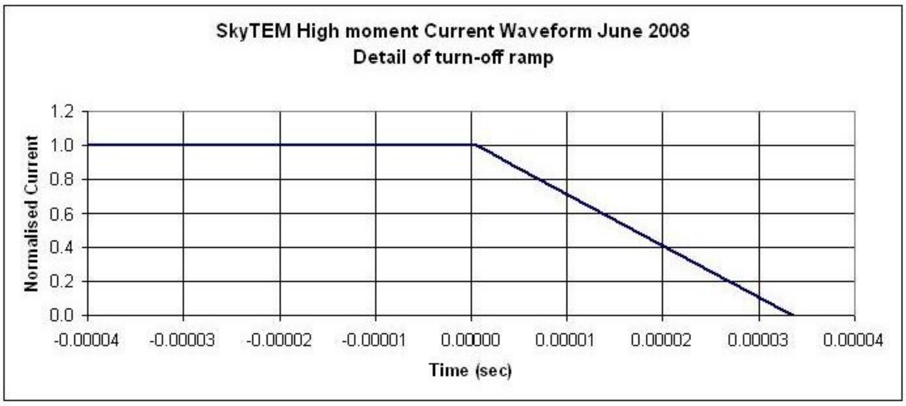

Figure 3 Piecewise linear approximation to the high moment transmitter waveform, plotted as a fraction of peak current (typically 100A). Panel a) shows the on-time of the HM current waveform. b) shows detail of the current turn-off ramp. The total turn-off ramp is typically 38 µs, depending on peak transmitter current.

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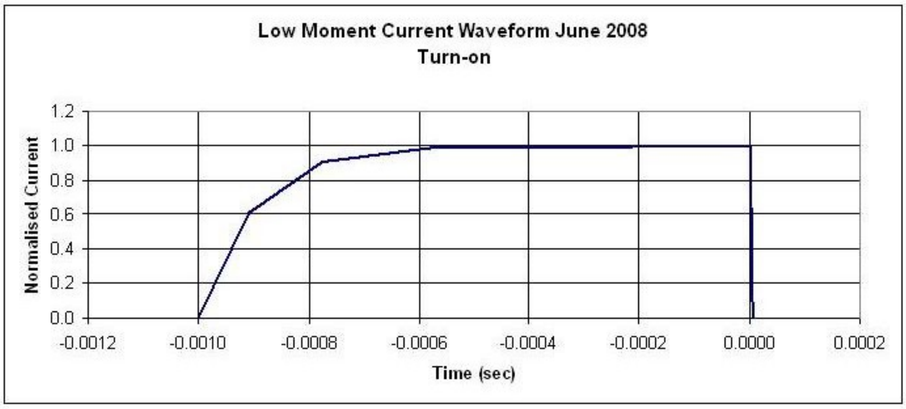
(a)



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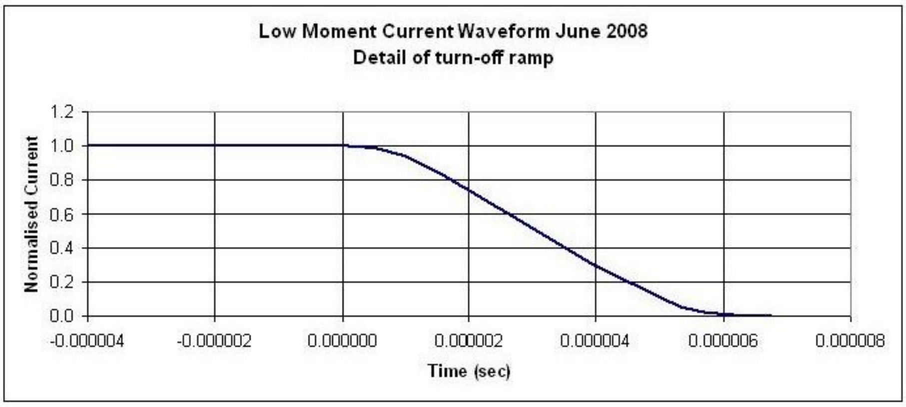

Figure 4 Piecewise linear approximation to the low moment transmitter waveform, plotted as a fraction of peak current (typically 40A). Panel a) shows the on-time of the LM current waveform. b) shows detail of the current turn-off ramp. The total turn-off ramp is approximately 6 µs.

Receiver

The receiver coils are shielded, overdamped, multi-turn loops, with a first-order cut-off frequency of 450 kHz. The effective area of the coils is 31.4 m^2.

The TEM receiver instrument is suspended on the tow cable between the helicopter and the Tx loop (Figure 1). The receiver samples the transient decay at 19 delay times in LM mode (designated channels 4 – 22), and 23 times in HM mode (designated channels 10 – 32). Receiver channel delay times are measured from the top of the current turn-off ramp (0 s in Figures 3 and 4).

In LM mode, the channel centre times range from 14.2 microseconds up to about 1.13 milliseconds, and in HM mode from 50 microseconds to 8.8 ms. Channel delay times and widths are listed in Table 1.

The receiver electronics have a user-selectable first-order cut-off frequency of 300 kHz, 100 kHz, 30 kHz or 10 kHz. A cutoff of 100 kHz is used as standard (X and Z-components).

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Gate No.	Transmitter moment	Gate Width [usec]	Gate Open [usec]	Gate Close [usec]	Gate Center Time [usec]
1	*	3.6	0.4	4	2.2
2	*	3.6	4.4	8	6.2
3	*	3.6	8.4	12	10.2
4	LM	3.6	12.4	16	14.2
5	LM	3.6	16.4	20	18.2
6	LM	4.6	20.4	25	22.7
7	LM	6.6	25.4	32	28.7
8	LM	7.6	32.4	40	36.2
9	LM	9.6	40.4	50	45.2
10	LM + HM	12.6	50.4	63	56.7
11	LM + HM	15.6	63.4	79	71.2
12	LM + HM	20.6	79.4	100	89.7
13	LM + HM	25.6	100.4	126	113.2
14	LM + HM	31.6	126.4	158	142.2
15	LM + HM	41.6	158.4	200	179.2
16	LM + HM	50.6	200.4	251	225.7
17	LM + HM	64.6	251.4	316	283.7
18	LM + HM	81.6	316.4	398	357.2
19	LM + HM	102.6	398.4	501	449.7
20	LM + HM	129.6	501.4	631	566.2
21	LM + HM	162.6	631.4	794	712.7
22	LM + HM	205.6	794.4	1000	897.2
23	LM + HM	258.6	1000.4	1259	1129.7
24	HM	325.6	1259.4	1585	1422.2
25	HM	409.6	1585.4	1995	1790.2
26	HM	516.6	1995.4	2512	2253.7
27	HM	649.6	2512.4	3162	2837.2
28	HM	818.6	3162.4	3981	3571.7
29	HM	1030.6	3981.4	5012	4496.7
30	HM	1297.6	5012.4	6310	5661.2
31	HM	1632.6	6310.4	7943	7126.7
32	HM	1799.6	7943.4	9743	8843.2

Table 1. Time Gates for high moment (HM) and low moment (LM) modes in seconds.

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Quality control

The quality of SkyTEM data is comparable to that measured with similar ground-based TEM system (e.g., Geonics PROTEM). The measured data are not significantly distorted by drift or bias and are ready to be interpreted without further data processing, such as levelling.

High-altitude measurements are used to demonstrate that there is minimal bias in the system (Figure 5). Data are acquired with the system at >1000 m above the ground in normal survey mode and with the transmitter off as shown in Figure 5 below.

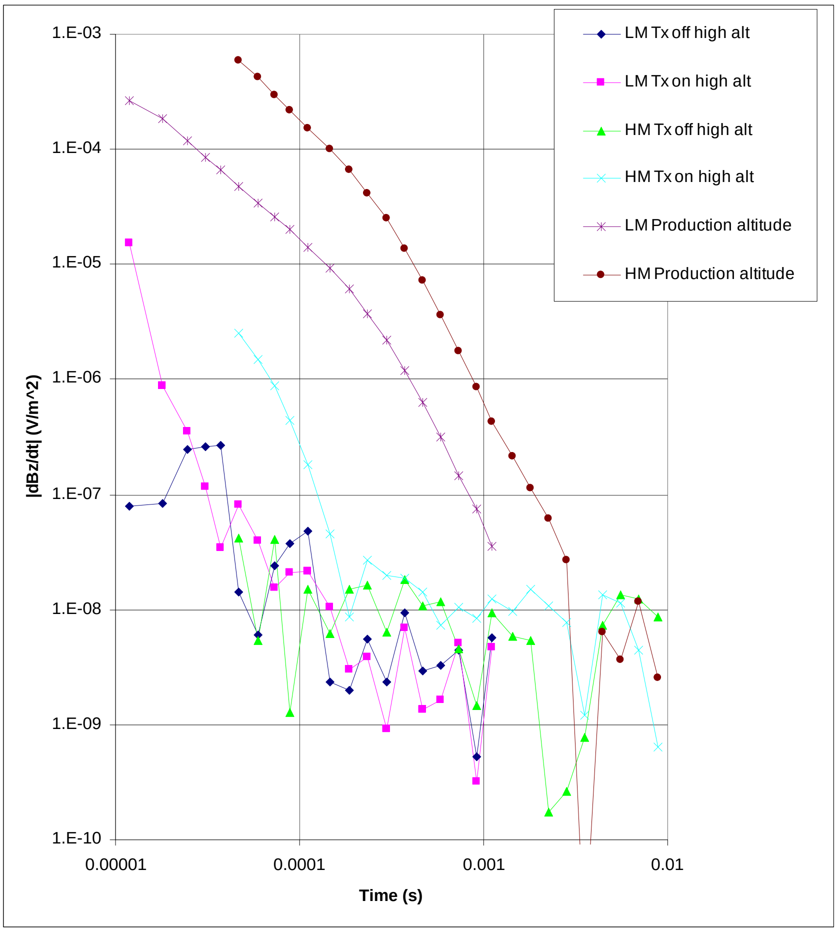

Figure 5. LM and HM noise response based on low (30 m) and high (1300 m) altitude measurements at Toolibin Lake, Western Australia in October 2006. High altitude measurements where there is no signal from the ground show that the response with the transmitter on lies largely within the natural noise envelope of the system measured with the transmitter off. A small bias signal is evident in the high altitude data measured with the transmitter on [first two channels of LM data (pink curve) and first five channels of HM data (light blue curve)]. However the bias signal is at least 1 – 2 orders of magnitude smaller than the amplitude of data measured at production altitude, and hence does not significantly distort the measured secondary response.

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Calibration

The equipment is calibrated in the laboratory, and the calibration is verified at the Danish National Reference site. Figure 6 shows a comparison of SkyTEM data with the average response measured at the same site using ten different Geonics PROTEM ground TEM instruments. The ground TEM data have been upward continued to the same altitude as the SkyTEM measurement (15 m). The SkyTEM response reproduces the ground based soundings to within 2-3%.

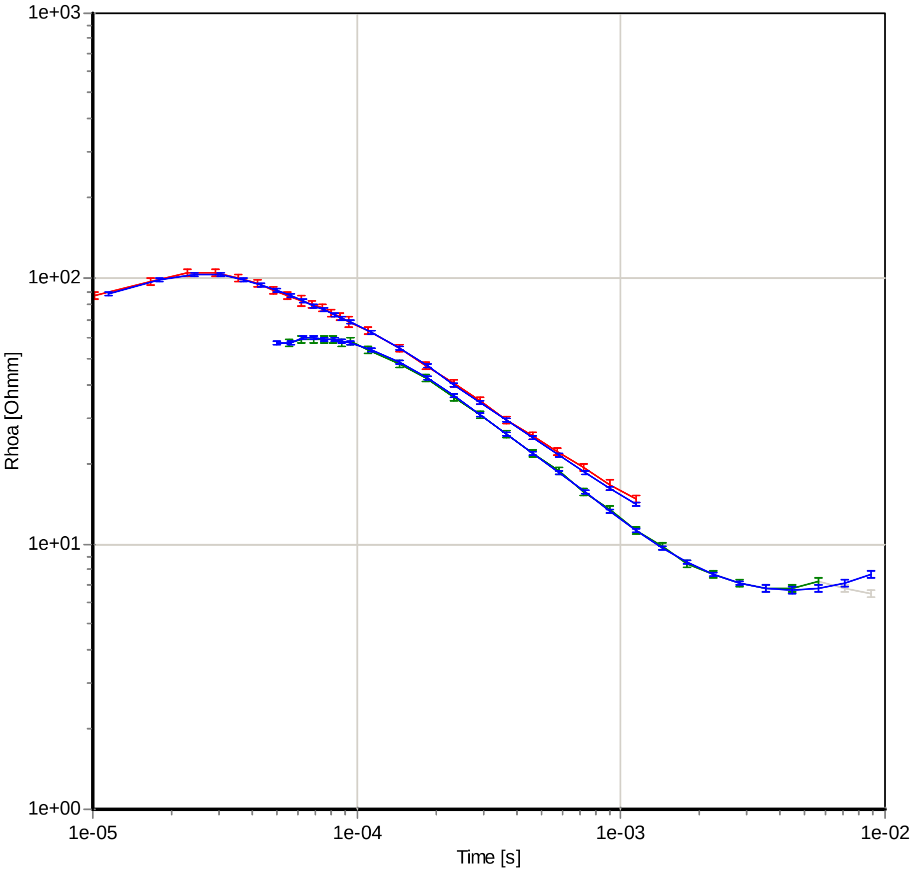

Figure 6. Calibration Data from 15 m altitude at the National Danish Reference site, presented as apparent resistivity vs delay time. The blue curves are the response related to the ground based systems and the green and the red curves are the measured data with the SkyTEM system. The error bars are 2%.

Magnetometer

The magnetometer specifications are as follows:

Sensor: Geometrics G-822A
Noise level: 0.1 – 0.2 nT
Sample rate: 10 Hz

The magnetometer is mounted on a stinger at the nose of the transmitter loop frame, ie at a nominal height above ground of 30 m.

Processing and Inversion

Geoforce offers several processing and inversion options, including

- EMax_Air conductivity-depth images (vertical-component data only)
- SELMA rapid layered-earth inversion (vertical-component data only)
- Layered-earth inversion (LEI - vertical-component data)
- Laterally-constrained inversion (LCI - vertical-component data)

EMax_Air conductivity-depth images (Fullagar and Reid, 2001) are useful for rapid, first-pass appraisal of SkyTEM data. LEI and LCI are more computer intensive, but provide a more reliable geoelectric model in areas of quasi-layered geology. For high quality imaging, we offer the Laterally Constrained Inversion (LCI) scheme developed by Auken et. al. (2005). The LCI simultaneously inverts both high and low moment data (if both are present). This approach has been demonstrated to provide high quality inversions of geometrically complex features with subtle resistivity variations. A relevant example is shown in Figure 7, where the LCI performance in imaging a fresh water bearing palaeochannel is demonstrated on three-dimensional model data and contrasted with a more conventional LEI approach (Jacobsen, 2004).

Toolibin Lake Study, Western Australia

We have undertaken an orientation survey over the saline environs of Lake Toolibin in Western Australia in late October 2006. The survey was flown over the same lines flown using a fixed-wing airborne electromagnetic system (TEMPEST) in 1998. Some survey results are shown in Figures 8 and 9. More comprehensive results and data from the Toolibin survey can be provided by Geoforce on request .The results demonstrated:

- That the SkyTEM data is highly repeatable.
- That the SkyTEM system could successfully map features conjectured to be associated with hydrogeological changes.
- That the SkyTEM system could map to a depth in excess of 100m under challenging conditions where ground resistivities of 1 – 10 ohm.m were typical.

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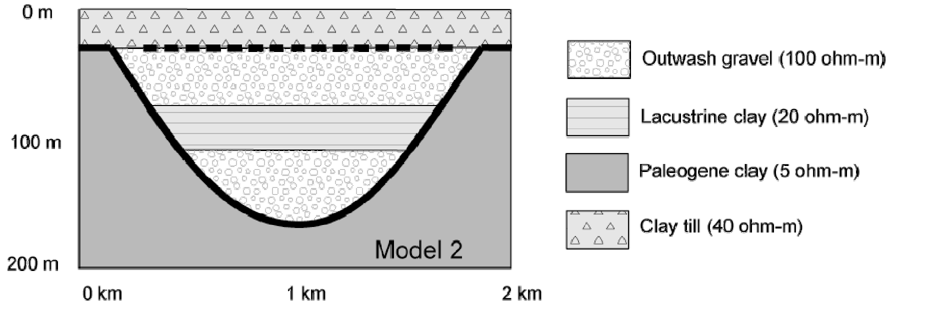
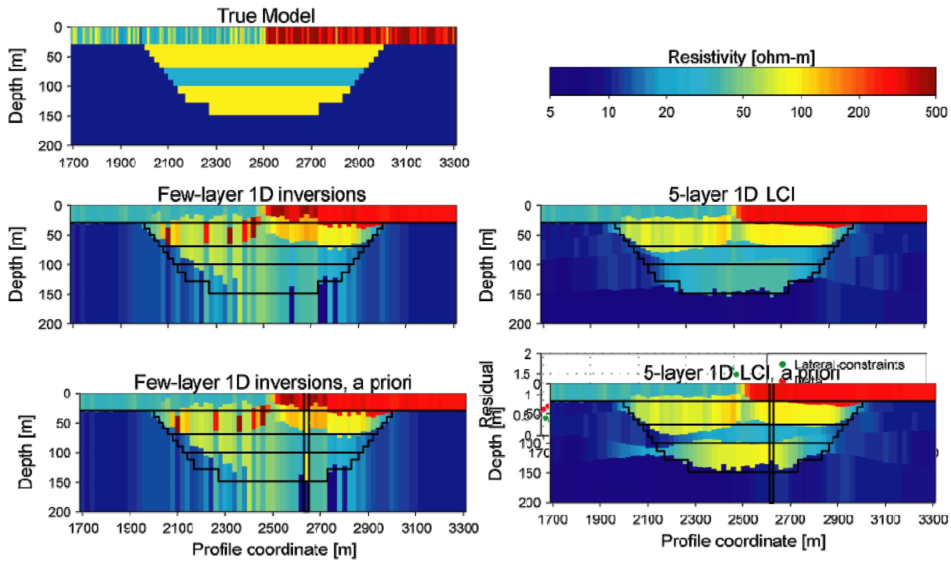


a)



b)

Figure 7 a) Conceptual geological and geoelectrical model, typical of a fresh water bearing palaeochannel in Denmark. b) Inversion results. A representative cross-section through the three-dimensional geoelectrical model of the palaeochannel is shown at upper right. The centre left panel shows the results of conventional LEI using a model with a few layers, and the bottom left panel shows the LEI inversion result when a priori information from a single borehole is included in the inversion. The right-hand panels show LCI results with and without inclusion of a priori information. The LCI improves the performance in mapping the geometry and internal resistivity structure of the paleo channel, particularly when a-priori information is added.This study indicates the advantage of LCI inversion when imaging geometrically complex features with relatively subtle resistivity variations.

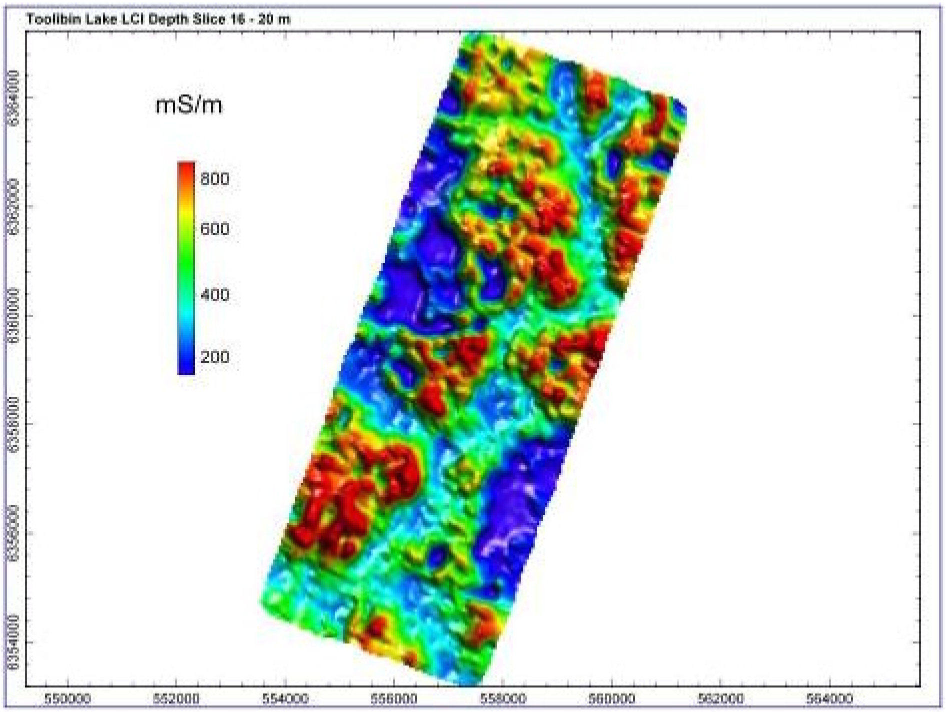


Figure 8. Orientation survey of about 340 line km flown over Lake Toolibin in Western Australia. The image shows an average conductivity slice for the depth interval 16-20 m produced via LCI inversion. The survey area was approximately 12 km × 4 km, and line spacing was 150m. Survey speed was typically 75 km/h and survey height was nominally 32m.

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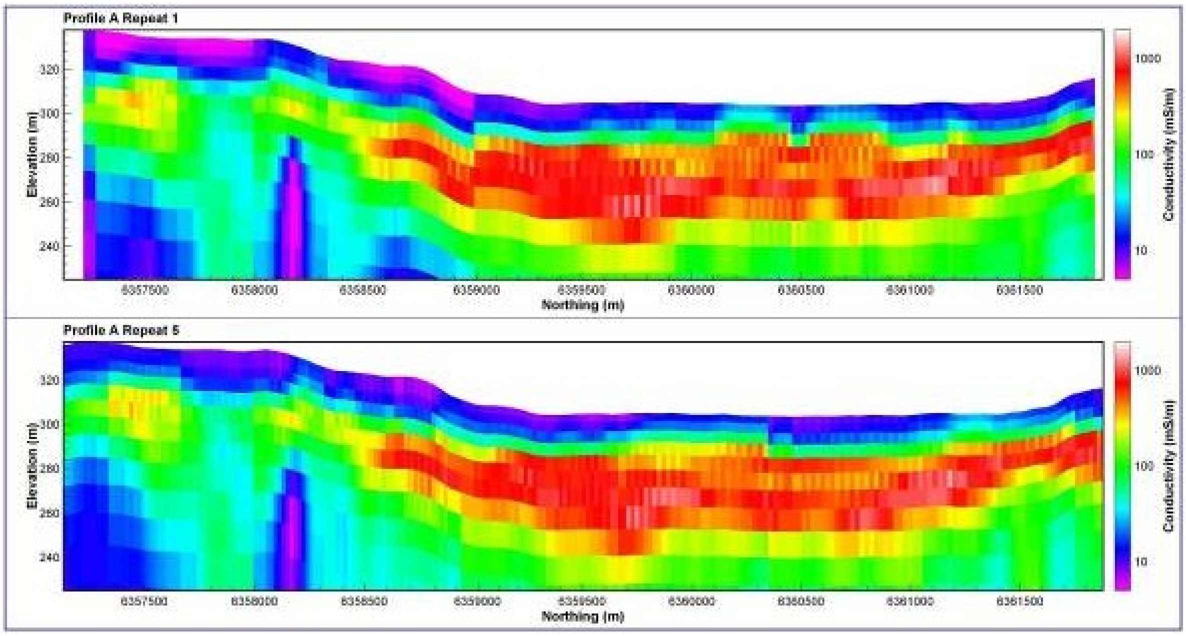

Figure 9. Two repeat calibration lines flown at Toolibin Lake. Lines are 5 km long. These cross sections are produced using 15-layer smooth model LCI inversions. The images are temperature coded with warm colours indicating high conductivity and cold colours indicating high resistivity. The line is dominated by a highly conductive layer at depths from about 20m – 60m. The key observation is that the inverted sections are repeatable.

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