Final Report
Zeehan SkyTEM Survey

Geoforce Job Number: SK987MI

Authors: James Reid, Tristan Kemp, Russell Eade

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1 Summary

Geoforce Job Number	SK987MI
Survey Company	Geoforce Pty Ltd
Dates Flown	20th January – 30th January 2009
Client	Zeehan Zinc Ltd.
Terrain Clearance	30 m (nominal)
Total Line km	1572
Datasets acquired:	Time-domain EM
	Total Magnetic Intensity
	Digital Terrain Model
EM System	SkyTEM (Interleaved Low and High Moment)
Helicopter company	HeliWest, Perth, WA
Helicopter type	AS350 Super D2
Helicopter registration	VH-NRW
Traverse Line Spacing	100 m
Traverse Line Direction	090 – 270
Tie Line Spacing:	1000 m
Tie Line Direction	000 - 180
Navigation	DGPS
Coordinate System	AMG55 / AGD66

2 Personnel

The following personnel were employed for this project:

2.1 Field Operations

Crew Chief	Campbell Greenwood
Technical Assistants	Chris Ward-Allen, Samantha Long, Brett Rees
Pilot	Ian Pullan

2.2 Base Operations

Project Manager	James Reid
Data Processing	Russell Eade, Tristan Kemp.

3 Flight plan

The flight plan and line numbers are shown in Figure 3-1.

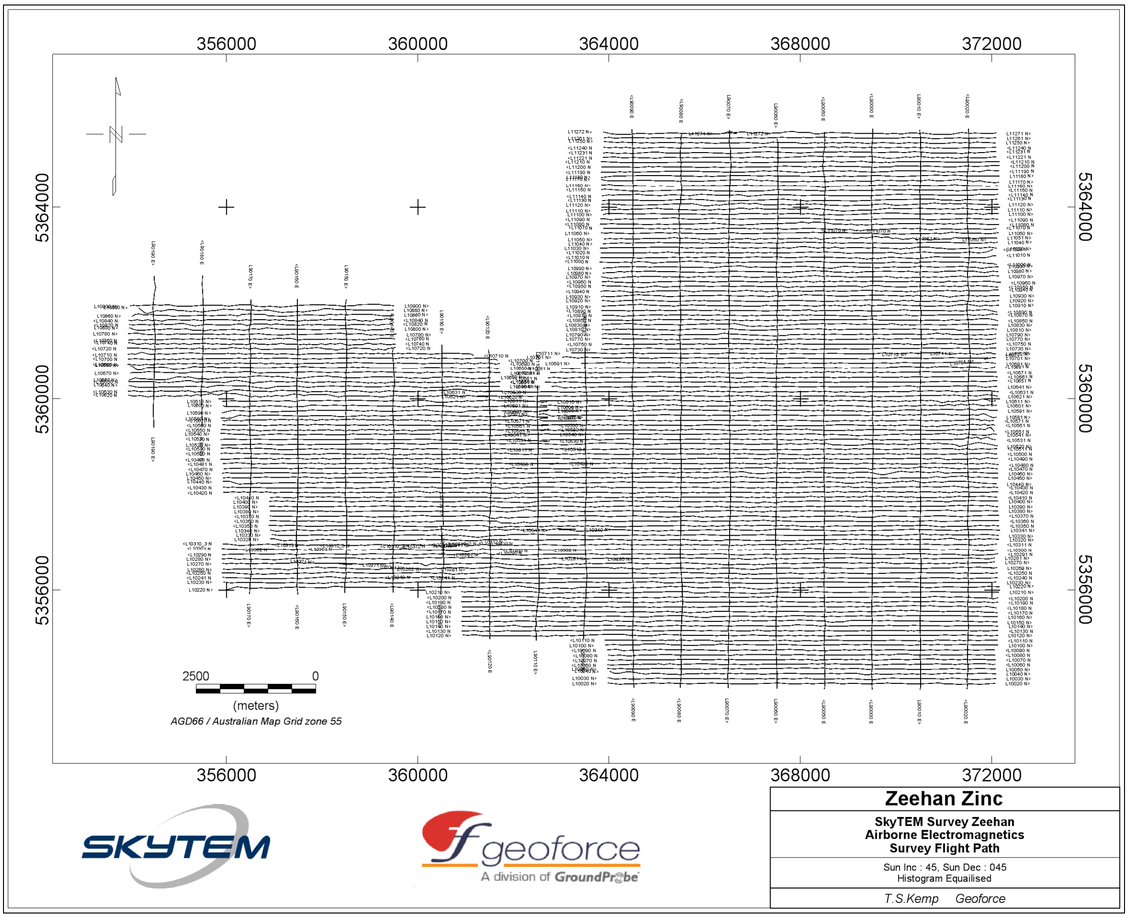

Figure 3-1: Flight path map for Zeehan SkyTEM Survey (AMG55/AGD66 coordinates).

4 Logistics

The survey was flown between 20th January and 30th January, 2009. Rain, high winds and low cloud reduced production rates although the survey was completed without incident in an acceptable timeframe.

A logistics summary report is provided on DVD (SK987MI_logistics Report.pdf).

5 Geometry

Geometry of the system is illustrated below. X, Y and Z coordinates of each sensor are given with respect to the centre of the Tx loop. The Z-coordinate is positive above the Tx loop wire. Positive X and Y-axes are in the flight direction and to the starboard side respectively.

Sensors are as follows:

Z-coil:	EM Z-axis sensor
X-coil:	EM X-axis sensor
Tilt1:	Tiltmeter set 1 (measures tilts from horizontal with respect to both X and Y axes)
Tilt2:	Tiltmeter set 2 (measures tilts from horizontal with respect to both X and Y axes)
Alt1:	Laser Altimeter 1
Alt 2:	Laser Altimeter 2
GP1:	GPS 1 Antenna
GP2:	GPS 2 Antenna (RTK DGPS via Fugro Omnistar HP Service)
Magnetometer:	G-822A caesium magnetometer sensor

5.1 Sign conventions

Vertical (Z) -component electromagnetic data measured over a purely-conductive (non-polarizable) one-dimensional earth is positive. Early-time Z-component negatives are sometimes observed in very resistive areas due to the transmitter bias, if it has not been removed from the measured data. Late time Z-component negatives are occasionally observed due to induced polarization effects.

Horizontal inline (X) -component electromagnetic data is positive in the flight direction: The X-component response measured over a purely-conductive (non-polarisable) one-dimensional earth is typically negative. However, X-component data is strongly affected by frame tilt, which can introduce a large contribution from the much-stronger Z-component response and significantly distort the measured X-component response. The only rigorous way to account for this effect in the data is to explicitly include the transmitter loop tilts in the X and Y directions in the forward/inverse modelling algorithm used to interpret the data.

AngleX (measured by both Tilt1 and Tilt2) **is positive when the nose of the transmitter loop frame is pitched up**, ie over level ground, AngleX is positive when the nose of the frame is further from the ground than the base of the tail rudder.

AngleY (measured by both Tilt1 and Tilt2) **is positive when the starboard side of the transmitter loop frame is tilted down** ie over level ground, AngleY is positive when the starboard side of the frame is closer to the ground than the port side.

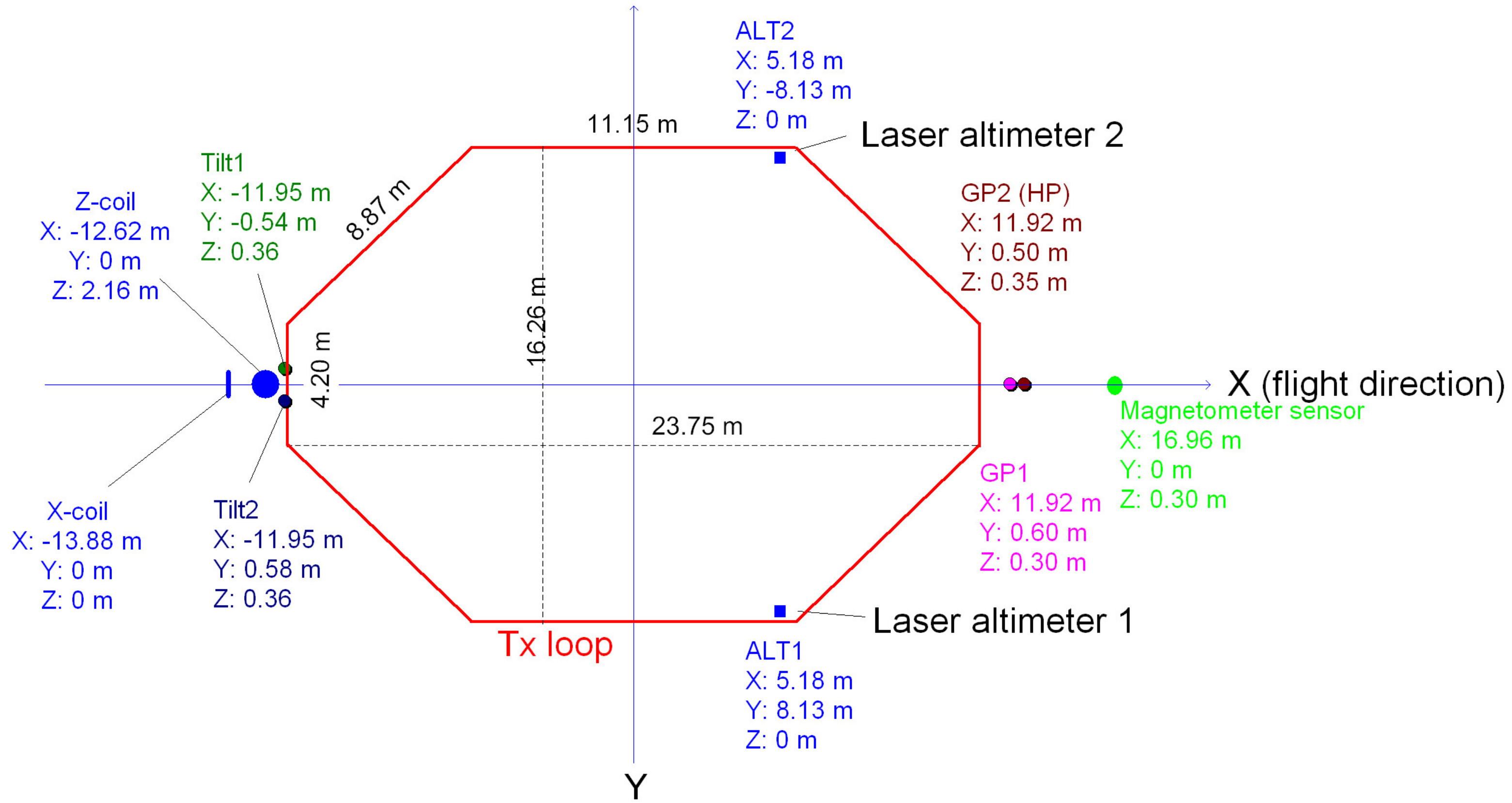

Figure 5-1: Sensor geometry for Zeehan SkyTEM survey. See main text for explanatory notes.

6 SkyTEM System specifications

EM Transmitter – High Moment	
Transmitter loop area	314 m^2
Number of transmitter loop turns	4
Average peak current	96.73 A
Peak moment	121,493 A.turn.m^2
Tx loop height (nominal)	30 m
Tx Waveform – High Moment	
Base frequency	25 Hz
Tx duty cycle	50%
Tx waveform	Bipolar
Tx on-time	10 ms
Tx off time	10 ms
Tx ramp time	44 µs
EM Transmitter – Low Moment	
Transmitter loop area	314 m^2
Number of transmitter loop turns	1
Average peak current	40.63 A
Peak moment	12,758 A.turn.m^2
Tx loop height (nominal)	30 m
Tx Waveform – Low Moment	
Base frequency	222.22 Hz
Tx duty cycle	44.4%
Tx waveform	Bipolar
Tx on-time	1 ms
Tx off time	1.25 ms
Tx ramp time	10.0 µs

Table 6-1: Skytem Tx specifications.

EM Receiver	
EM Sensors	dB/dt coils
Rx coil effective area (Z and X)	31.4 m^2
Low pass cut-off frequency for Rx coils	450 kHz
Low pass cut-off frequency for Rx electronics	300 kHz
Z-component Rx coil position	
Behind Tx loop centre	12.62 m
Above plane of Tx loop	2.16 m
X-component Rx coil position	
Behind Tx loop centre	13.88 m
Above plane of Tx loop	0 m

Table 6-2: Skytem Rx specifications.

7 SkyTEM data processing

Raw (binary) SkyTEM data have been processed using the proprietary software package SkyPro (Build 43) to generate ASCII data files. All positions, altitudes etc in processed data are relative to the centre of the transmitter loop. Altitudes have been corrected for Tx loop attitude, and are averages of data from both altimeters following application of a local maximum filter. Electromagnetic data have been stacked using a moving average filter of width 2 seconds, representing a stack of ~80 transients for high moment data and ~160 transients for LM data.

Stacked data have been output every 0.25 seconds (~6 m on the ground at 80km/h groundspeed).

Units for processed data are V(A.turns.m^4), ie voltage normalized by transmitter area × number of turns × peak current × receiver area).

7.1 Known data issues

Due to the steep terrain and high winds, effects from variations in height can be seen in the magnetic dataset. The effects are minor but must be taken into consideration when performing interpretations based on this dataset.

7.2 EM Signal Bias Removal

A design feature of the SkyTEM system is the low transmitter bias signal, which usually means it is not necessary to subtract the bias from the measured data (see document SKYTEM technical overview January August 2008.pdf included on DVD). However, transmitter bias becomes significant in resistive areas, where the early time signal arising from the earth has very low amplitude. Transmitter bias effects were clearly visible in preliminary processed data for the Zeehan survey (see Figure 7-1). Accordingly, the transmitter bias signal was determined from high-altitude data and subtracted from the processed data prior to generation of CDIs. The bias signal at each channel was determined by averaging the biases measured during high-altitude flights conducted at the start and end of the Zeehan survey. Bias signals for each channel are given in Table 7.1. The effect of subtracting the transmitter bias from the raw data is illustrated in Figure 7-1. All EM xyz files and derived data on the DVD have had the bias removed.

Channel	Gate Centre (microsec)	Mean X LM V/(A.turns.m4)	Mean Z LM V/(A.turns.m4)	Mean X HM V/(A.turns.m4)	Mean Z HM V/(A.turns.m4)
4	14.2	-3.19454E-10	-7.29514E-11		
5	18.2	-2.47053E-10	1.73204E-11		
6	22.7	-1.16823E-10	1.99322E-11		
7	28.7	-5.39914E-11	1.32127E-11		
8	36.2	-2.59867E-11	7.54855E-12		
9	45.2	-1.36867E-11	5.59025E-12		
10	56.7	-8.52815E-12	3.60087E-12	-4.69892E-11	-3.31849E-11
11	71.2	-6.37839E-12	2.10363E-12	-2.40152E-11	-1.61374E-11
12	89.7	-1.38492E-12	1.08742E-12	-1.10195E-11	-7.29252E-12
13	113.2	-1.73614E-12	5.14495E-13	-4.24778E-12	-2.64033E-12
14	142.2	2.91447E-13	3.31492E-13	-1.38853E-12	-6.85274E-13
15	179.2	-4.2763E-13	8.28482E-14	-3.43171E-13	-7.33683E-14
16	225.7	6.69197E-14	1.38172E-14	-7.37083E-14	8.25241E-14
17	283.7	-9.0643E-14	4.67963E-14	7.87737E-16	9.61346E-14
18	357.2	-1.77833E-13	7.9488E-15	-2.09716E-14	4.74422E-14
19	449.7	-3.45686E-14	6.85559E-14	-4.74319E-15	3.96406E-14
20	566.2	-8.14138E-14	3.75994E-14	4.01375E-15	1.63915E-14
21	712.7	-6.18121E-14	-8.65178E-15	-5.28815E-15	1.16644E-14
22	897.2	-3.62992E-14	-1.07022E-14	2.00006E-15	3.69066E-15
23	1129.7			1.17953E-14	7.29733E-15
24	1422.2			4.70945E-15	1.14718E-14
25	1790.2			7.23201E-16	6.04685E-15
26	2253.7			-3.47943E-16	7.13208E-15
27	2837.2			-6.53288E-15	2.44317E-15
28	3571.7			-1.25703E-14	-3.65418E-16
29	4496.7			-1.44031E-14	4.75859E-15
30	5661.2			-1.05575E-14	5.92297E-15
31	7126.7			6.36164E-15	3.21785E-15
32	8843.2			1.84276E-14	4.84841E-15

Table 7-1: Transmitter biases determined by averaging high altitude data recorded at the start and end of the Zeehan survey.

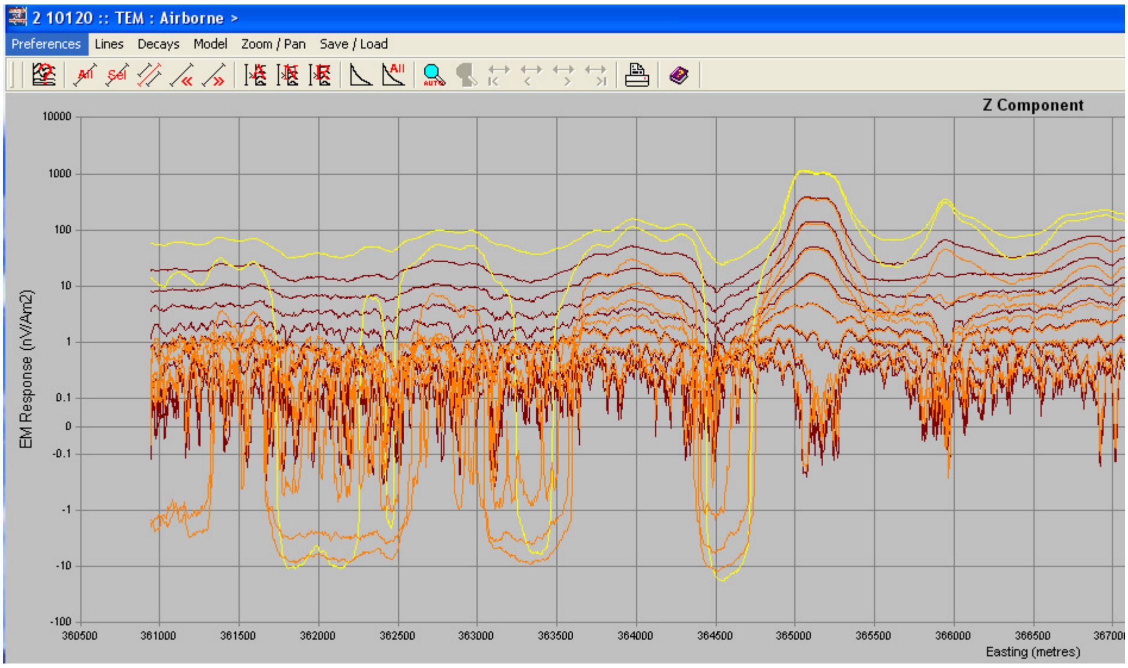

Figure 7-1: Comparison of raw Z channel biased EM signal to raw Z channel EM signal with bias removed displayed in *Maxwell* software. Bias affected EM signal coloured orange, bias removed signal coloured red. Note that the early time response is negative in the bias affected data due to the bias signal being greater than the earth response.

7.3 EMaxAir processing

Z-component XYZ data have been converted to apparent conductivity vs. depth using EMax_air v2.24a (Fullagar and Reid, 2001). The apparent conductivity data have been 'sharpened' in order to yield improved depth resolution of conductive layers. The sharpening process treats the apparent conductivity (σ_a) generated by the initial transformation as a depth average, ie

$$\sigma_a(z) = \frac{1}{z - z_0} \int_{z_0}^{z} \sigma(u)\,du$$

The above equation can be inverted for the 'sharpened' conductivity, which provides improved depth resolution of conductive layers.

$$\sigma(z) = \sigma_a(z) + (z - z_0)\frac{d\sigma_a}{dz}(z)$$

Figure 7-2 compares original and sharpened apparent conductivity curves for a synthetic three-layered model.

Conductivity-depth data files have extension *.CDI. A complete description of the CDI file format can be found in Appendix G.

Images of CDI sections for each flight line are also provided on DVD.

Average conductivities in a number of 'depth slices' below surface have also been computed and are provided both as ASCII data. The ASCII file format for the conductivity depth slices is given in Appendix H.

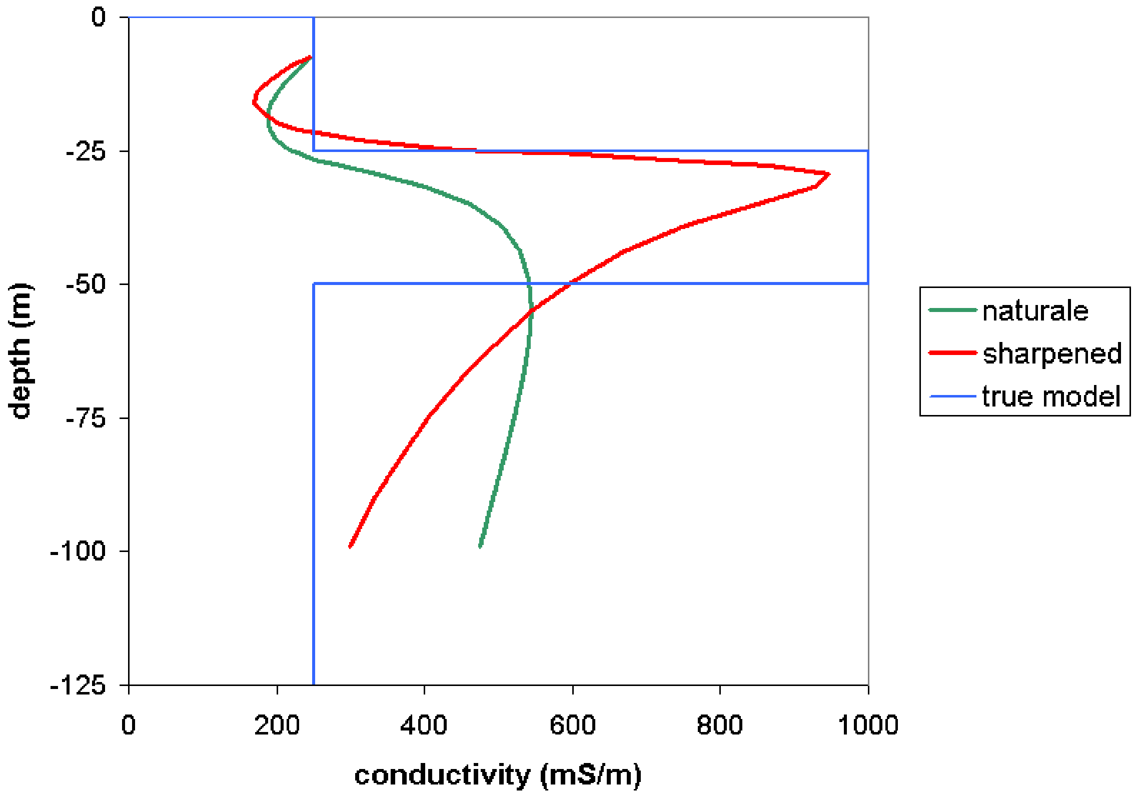

Figure 7-2: Comparison of original (green) and sharpened (red) conductivity-depth curves for a synthetic three-layer model (blue) (Fullagar et al., 2008)

8 Magnetometers

Raw and processed magnetic data are provided with this report. Raw magnetic data is given in the 'raw' column in the located magnetics data. Raw data has undergone pre processing only (spike removal, short gaps interpolated, low pass filtering, but not corrected for heading, diurnal, IGRF, or levelled).

The airborne magnetometer samples only during the off time of the high moment EM measurements – not during either low-moment or noise measurements.

Airborne Sensor	Geometrics G-822A Caesium Magnetometer
Sample Rate	0.1 sec / 2 - 4 m
Magnetometer Counter	KroumVS Instruments KMAG4
Base Magnetometer:	Geometrics G-856
Sample Rate:	5 sec

The base magnetometer was located at: 362,941 E, 5,361,092 N (AMG55/AGD66).

9 Magnetics Processing

Final Easting, Northing (X, Y) positions were derived from RTK DGPS (Fugro Omnistar HP real-time correction).

The diurnal base station data was analyzed for spikes and spurious sections which were manually removed from the dataset. A 10 point low pass filter was then applied to the diurnal data. A base value of 61866.44nT was established by averaging all readings acquired at the base over the survey duration and this value was subtracted from the base values to determine a diurnal correction.

Magnetic survey data was inspected for spikes and spurious segments which were removed manually. Short gaps (less than 50m) were linearly interpolated. Gaps larger than 50m were not interpolated.

The diurnal correction was removed from the magnetic survey data by synchronizing the diurnal data time and the roving magnetics system time. The diurnally corrected magnetics survey data was then low pass filtered using a filter width of 25m.

System lag was analyzed from series of test and survey lines flown in opposite directions. The system lag is negligible at +0.1 sec, nevertheless a lag correction was applied.

Heading error was analyzed from test data. The Skytem system has no compensation system so a heading correction is necessary. A heading correction of ±7.8 nT was applied for traverse lines and ±10 nT for tie lines, with the sign of the correction dependent on the flight direction.

The updated IGRF 2005 correction was calculated at each data point and applied to the data.

Tie line leveling was applied to the data by least squares minimization, using a DC shift only option. Micro-levelling was selectively applied to areas of the data where levelling problems persisted to remove the minor variations in profile intensity. Selective micro-levelling of the data maintains the integrity of data that does not need harder levelling techniques.

The final data sets consisted of a RMF, (Residual Magnetic Field – filtered, corrected for, lag, heading, diurnal, IGRF, levelled, microlevelled), and a TMI (Total Magnetic Field = RMF + IGRF).

Located and gridded data were generated from the final processed magnetic data.

10 GPS Positioning

Two GPS receivers were employed for the Zeehan survey (see Section 5 above). GP1 is a standard GPS unit for which differentially-corrected positions are obtained via post-processing in conjunction with data from a ground base station recorded at 1 second intervals. GP2 is a real-time kinematic (RTK) unit for which differential corrections are received in real time from the Fugro Omnistar HP service.

All processed data delivered with this report uses elevations and positions from GP2. Elevation data are relative to the GRS80 ellipsoid corrected to AHD in the DTM channel only.

11 Navigation

Navigation was done through the proprietary software SkyMap version 19 using flight lines created by Geoforce and approved for use by Kate Godber of Mitre Geophysics. Accurate frame location was obtained from the RTK Omnistar HP GPS2 unit via a radio modem feed. Height above ground of the frame was obtained from the two laser altimeters mounted on the frame via the radio modem. There was also a backup radar altimeter used in the helicopter. Through SkyMap the pilot could also monitor the frame tilt and groundspeed to ensure the best possible data was obtained.

12 Altimeters

Laser Altimeter:	LaserAce IMHR 300
Reflectorless Range:	2 – 150 m
Accuracy:	0.2 m
Resolution:	0.1 m

13 References

Fullagar, P.K., and Reid, J.E., 2001, EMax conductivity-depth transformation of airborne TEM data: Expanded Abstracts, Australian Society of Exploration Geophysicists 15th Conference, Brisbane.

Fullagar, P. K., Reid, J. E., and Pears, G., 2008, Advances in EMaxAir conductivity-depth imaging of airborne TEM data: Conference presentation, 5th international conference on airborne electromagnetics, Haikko Manor, Finland, 28-30 May 2008.

Appendix A Survey Specifications

A.1 Groundspeed

The mean survey groundspeed for the survey was 65.1km/h. Average values have been calculated for each line: these range from 38.1km/h to 85km/h.

A.2 Terrain clearance

The mean terrain clearance for the survey was 37.6m. Average altitudes for each survey line ranged from 26.7m to 102m.

A full report of line statistics is included on DVD (SK987MI_Line_Statistics.xlsx).

Appendix B Transmitter current waveform measurements

Transmitter current waveforms were measured on the ground on 20th January 2009.

The current turnon was measured using a Fluke 80i-100s current clamp and PicoScope ADC212 digital oscilloscope.

The turnoff was measured using a custom-built pickup coil (serial number Pickup 01) and a PicoScope ADC212 digital oscilloscope. The pickup coil measures the time rate of change of current.

Current turnon and (dI/dt) turnoff data have been processed using WaveFormInv, an inversion code written by Niels Christensen of the University of Aarhus. WaveFormInv reconstructs the waveform from the I (turnon) and dI/dt (turnoff) measurements, and generates a piecewise linear approximation to the waveform.

The piecewise linear waveforms are given below and are supplied with this report in ASCII format files (*.wfn). The waveforms are normalized by peak current such that a normalized current of 1 corresponds to the peak transmitter current.

The *.wfn files contain two header lines, followed by the waveform data (two columns). The first column of the waveform data is time in seconds (time zero = start of current switch off), and the second column is normalized current.

Figures B1 and B2 show examples of the high and low-moment waveforms measured using the Fluke current clamp.

Figures B3 and B5 show examples of measured turn on waveforms for high and low-moment respectively.

Figures B4 and B6 show examples of measured turn-off ramps for high- and low-moment respectively.

B.1 Piecewise approximation to high moment current waveform

Time zero is the start of current turnoff. Normalised current is actual current normalized by peak current.

20th January 2009

Time (sec)	*Normalised current*
-1.000e-002	0.000e+000
-8.394e-003	4.588e-001
-6.394e-003	7.548e-001
-3.799e-003	9.217e-001
0.000e+000	1.000e+000
4.099e-007	9.984e-001
8.055e-007	9.917e-001
1.254e-006	9.805e-001
3.560e-006	9.201e-001
2.109e-005	4.600e-001
3.863e-005	1.011e-002
3.926e-005	4.047e-003
4.005e-005	1.096e-003
4.115e-005	1.568e-004
4.395e-005	0.000e+000

B.2 Piecewise approximation to low moment current waveform

Time zero is the start of current turnoff. Normalised current is actual current normalized by peak current.

20th January 2009

Time (sec)	*Normalised current*
-1.000e-003	0.000e+000
-9.199e-004	6.371e-001
-7.994e-004	9.209e-001
-6.165e-004	9.922e-001
0.000e+000	1.000e+000
4.794e-007	9.903e-001
8.999e-007	9.487e-001
1.386e-006	8.683e-001
2.440e-006	6.648e-001
4.142e-006	3.340e-001
5.844e-006	5.867e-002
6.338e-006	2.348e-002
6.949e-006	6.359e-003
7.806e-006	9.099e-004
9.995e-006	0.000e+000

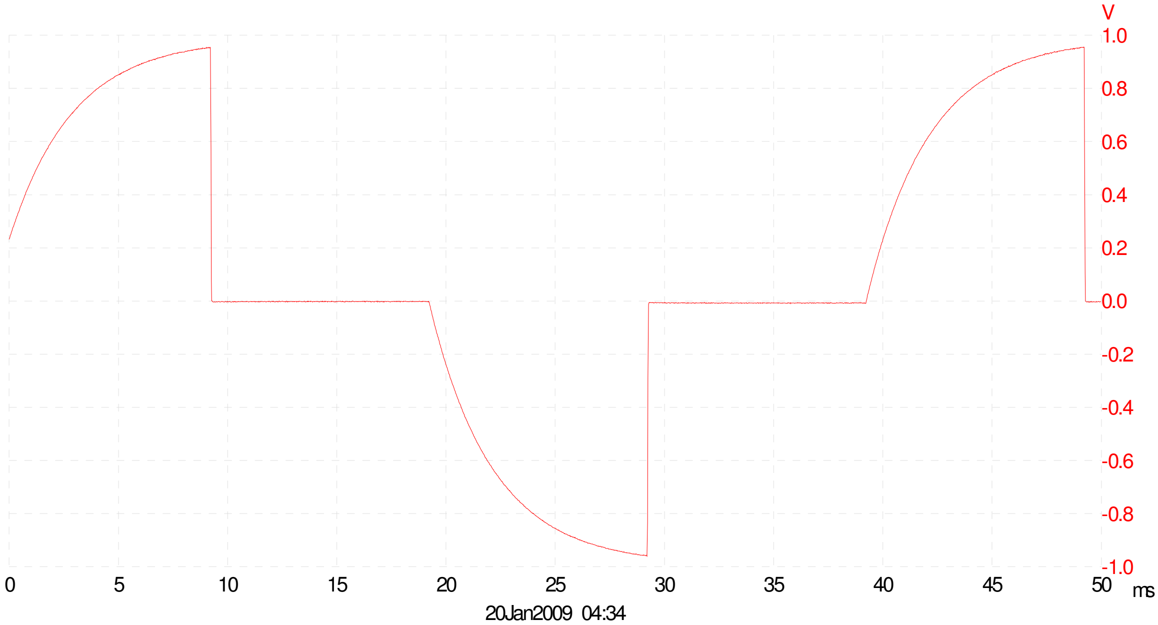

Figure B-1: High moment current waveform measured on 20th January 2009. Horizontal axis is time in ms. Vertical axis shows voltage measured using a current clamp (1 V = 100 A).

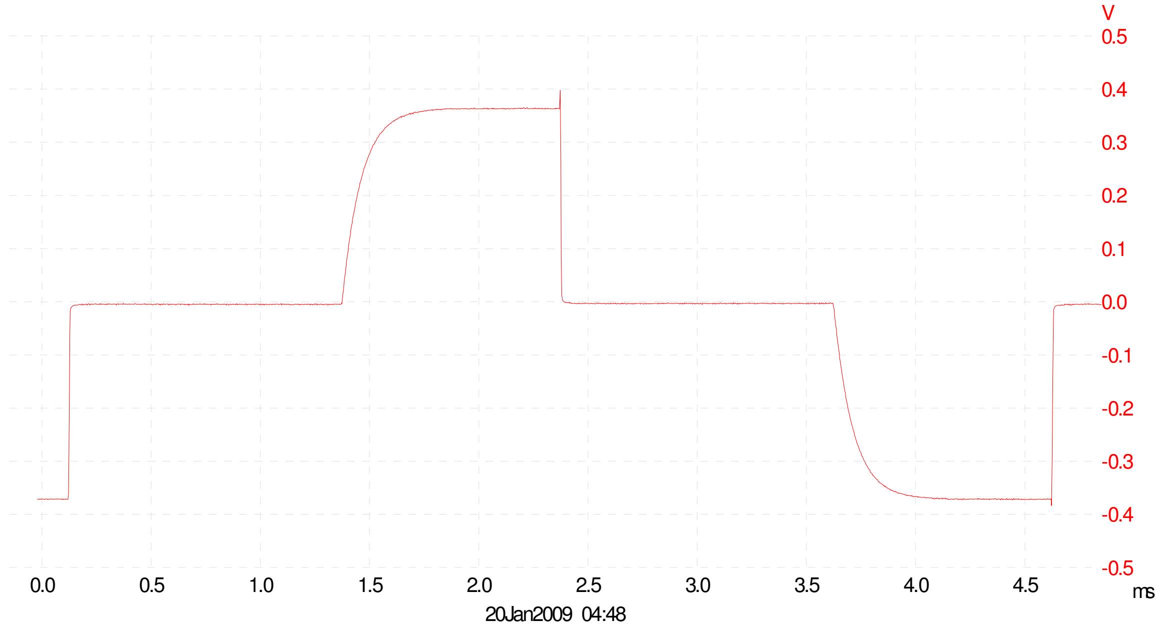

Figure B-2: Low moment current waveform measured on 20th January 2009. Horizontal axis is time in ms. Vertical axis shows voltage measured using a current clamp (1 V = 100 A).

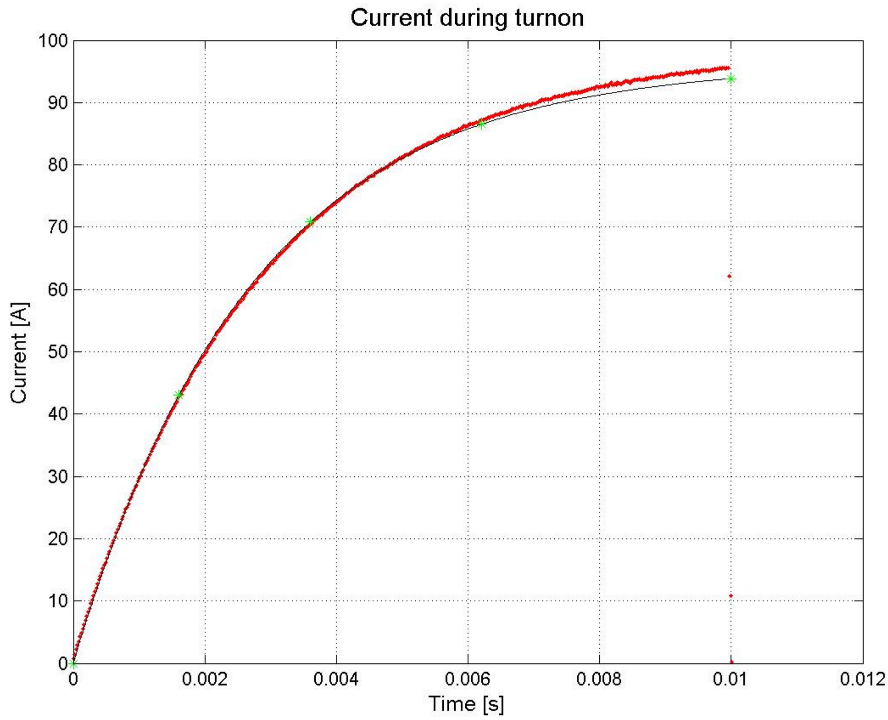

Figure B-3: High moment current turn-on measured on 20th January 2009.

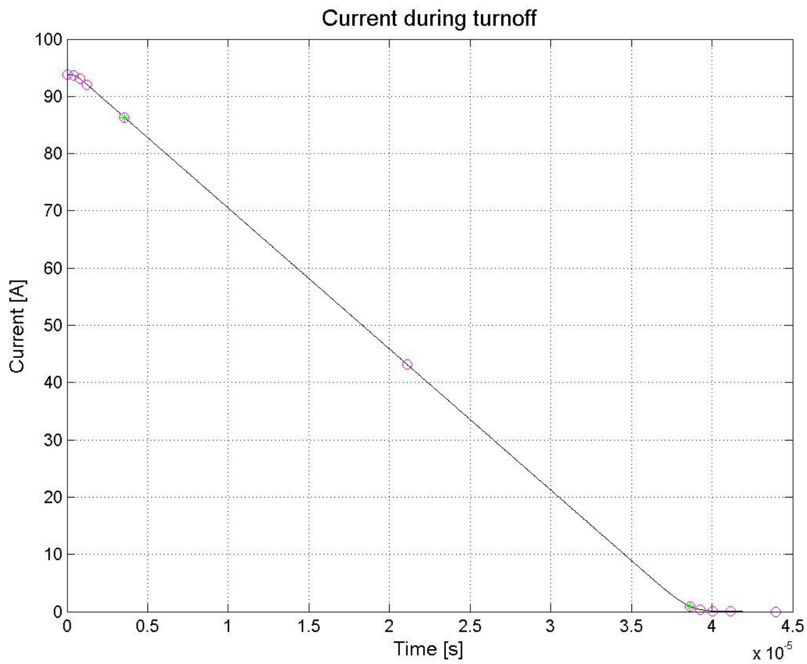

Figure B-4: High moment current turn-off measured on 20th January 2009.

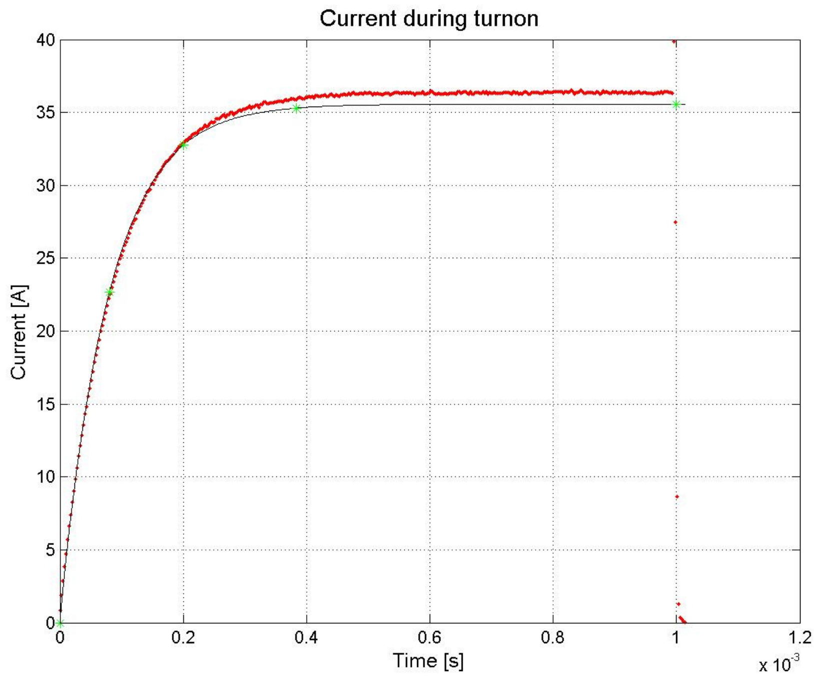

Figure B-5: Low moment current turn-on measured on 20th January 2009.

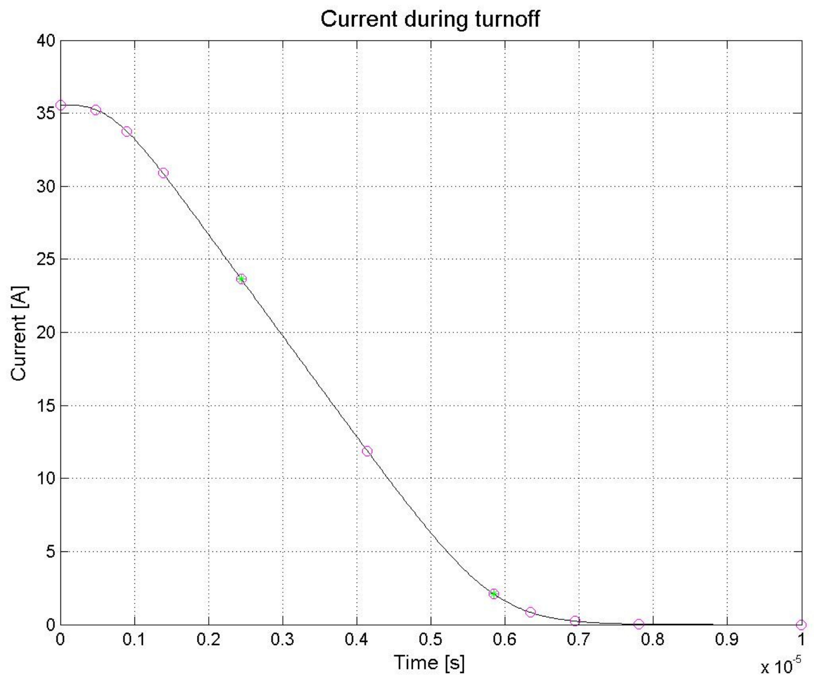

Figure B-6: Low moment current turn-off measured on 20th January 2009.

Appendix C High altitude tests

High altitude tests were conducted at the start and end of the survey.

Plots of the mean and standard deviation of the response at each channel are provided in Excel spreadsheets supplied with this report. All flights conducted met Geoforce quality control standards.

Plots of the mean channel amplitudes in the Excel spreadsheets show a nominal noise level for the high and low-moment data as an orange dashed line. This nominal noise corresponds to 10 nV/m^2 (voltage normalized by receiver area) at a delay time of 1 ms, which is a typical expected noise level for the SkyTEM system. When converted to survey EM units of $V/(A.turns.m^4)$ this noise level becomes 7.96e-13 $V/(A.turns.m^4)$ for low-moment data and 8.38e-14 $V/(A.turns.m^4)$ for high-moment data.

Note that laser altimeter data is null for all high altitude tests as the maximum range of the altimeters employed was 150 m. Magnetic (TMI) data has not been processed or supplied for the high altitude flights as these tests were performed for the purposes of EM quality control.

Appendix D Header for high moment SkyTEM data

Column	Field	Format	Null value	Description	Units
Column 1	Fid	I7	999999	Geoforce Fiducial	n/a
Column 2	Line	I8	99999	Line Number	n/a
Column 3	Flight	F11.1	99999999.9	Flight number	n/a
Column 4	DateTime	F17.10	99999.9999999999	Decimal days since midnight, December 31st, 1899	days
Column 5	Date	I10	99999999	Date (yyyymmdd) - GMT	n/a
Column 6	Time	F12.3	999999.999	Time (hhmmss.000) - GMT	n/a
Column 7	AngleX	F8.3	999.999	Tilt of frame from horizontal in flight direction	degrees
Column 8	AngleY	F8.3	999.999	Tilt of frame from horizontal perpendicular to flight direction	degrees
Column 9	LasAlt	F8.1	99999.9	Laser altitude of Tx loop centre (average of lasers 1 and 2)	metres
Column 10	DTM_AHD	F8.1	99999.9	Digital terrain model: corrected to AHD	metres
Column 11	Current	F8.2	999.99	Peak transmitter current	Amperes
Column 12	North_AGD	F10.1	9999999.9	Northing (AMG55/AGD66)	metres
Column 13	East_AGD	F10.1	999999.9	Easting (AMG55/AGD66)	metres
Column 14	GpsAlt	F9.1	9999.9	GPS Elevation of Tx loop centre: (GRS80)	metres
Column 15	Gdspeed	F8.1	999.9	Ground speed	km/hr
Column 16	_2_Z2_1	E13.5	1.00000E+33	Normalised voltage Z-component Channel 1	V/(A.turns.m^4)
Column 17	_2_Z2_2	E13.5	1.00000E+33	Normalised voltage Z-component Channel 2	V/(A.turns.m^4)
Column 18	_2_Z2_3	E13.5	1.00000E+33	Normalised voltage Z-component Channel 3	V/(A.turns.m^4)
Column 19	_2_Z2_4	E13.5	1.00000E+33	Normalised voltage Z-component Channel 4	V/(A.turns.m^4)
Column 20	_2_Z2_5	E13.5	1.00000E+33	Normalised voltage Z-component Channel 5	V/(A.turns.m^4)
Column 21	_2_Z2_6	E13.5	1.00000E+33	Normalised voltage Z-component Channel 6	V/(A.turns.m^4)
Column 22	_2_Z2_7	E13.5	1.00000E+33	Normalised voltage Z-component Channel 7	V/(A.turns.m^4)
Column 23	_2_Z2_8	E13.5	1.00000E+33	Normalised voltage Z-component Channel 8	V/(A.turns.m^4)
Column 24	_2_Z2_9	E13.5	1.00000E+33	Normalised voltage Z-component Channel 9	V/(A.turns.m^4)
Column 25	_2_Z2_10	E13.5	1.00000E+33	Normalised voltage Z-component Channel 10	V/(A.turns.m^4)
Column 26	_2_Z2_11	E13.5	1.00000E+33	Normalised voltage Z-component Channel 11	V/(A.turns.m^4)

Column 27	_2_Z2_12	E13.5	1.00000E+33	Normalised voltage Z-component Channel 12	V/(A.turns.m^4)
Column 28	_2_Z2_13	E13.5	1.00000E+33	Normalised voltage Z-component Channel 13	V/(A.turns.m^4)
Column 29	_2_Z2_14	E13.5	1.00000E+33	Normalised voltage Z-component Channel 14	V/(A.turns.m^4)
Column 30	_2_Z2_15	E13.5	1.00000E+33	Normalised voltage Z-component Channel 15	V/(A.turns.m^4)
Column 31	_2_Z2_16	E13.5	1.00000E+33	Normalised voltage Z-component Channel 16	V/(A.turns.m^4)
Column 32	_2_Z2_17	E13.5	1.00000E+33	Normalised voltage Z-component Channel 17	V/(A.turns.m^4)
Column 33	_2_Z2_18	E13.5	1.00000E+33	Normalised voltage Z-component Channel 18	V/(A.turns.m^4)
Column 34	_2_Z2_19	E13.5	1.00000E+33	Normalised voltage Z-component Channel 19	V/(A.turns.m^4)
Column 35	_2_Z2_20	E13.5	1.00000E+33	Normalised voltage Z-component Channel 20	V/(A.turns.m^4)
Column 36	_2_Z2_21	E13.5	1.00000E+33	Normalised voltage Z-component Channel 21	V/(A.turns.m^4)
Column 37	_2_Z2_22	E13.5	1.00000E+33	Normalised voltage Z-component Channel 22	V/(A.turns.m^4)
Column 38	_2_Z2_23	E13.5	1.00000E+33	Normalised voltage Z-component Channel 23	V/(A.turns.m^4)
Column 39	_2_Z2_24	E13.5	1.00000E+33	Normalised voltage Z-component Channel 24	V/(A.turns.m^4)
Column 40	_2_Z2_25	E13.5	1.00000E+33	Normalised voltage Z-component Channel 25	V/(A.turns.m^4)
Column 41	_2_Z2_26	E13.5	1.00000E+33	Normalised voltage Z-component Channel 26	V/(A.turns.m^4)
Column 42	_2_Z2_27	E13.5	1.00000E+33	Normalised voltage Z-component Channel 27	V/(A.turns.m^4)
Column 43	_2_Z2_28	E13.5	1.00000E+33	Normalised voltage Z-component Channel 28	V/(A.turns.m^4)
Column 44	_2_Z2_29	E13.5	1.00000E+33	Normalised voltage Z-component Channel 29	V/(A.turns.m^4)
Column 45	_2_Z2_30	E13.5	1.00000E+33	Normalised voltage Z-component Channel 30	V/(A.turns.m^4)
Column 46	_2_Z2_31	E13.5	1.00000E+33	Normalised voltage Z-component Channel 31	V/(A.turns.m^4)
Column 47	_2_Z2_32	E13.5	1.00000E+33	Normalised voltage Z-component Channel 32	V/(A.turns.m^4)
Column 48	_4_X2_1	E13.5	1.00000E+33	Normalised voltage X-component Channel 1	V/(A.turns.m^4)
Column 49	_4_X2_2	E13.5	1.00000E+33	Normalised voltage X-component Channel 2	V/(A.turns.m^4)
Column 50	_4_X2_3	E13.5	1.00000E+33	Normalised voltage X-component Channel 3	V/(A.turns.m^4)
Column 51	_4_X2_4	E13.5	1.00000E+33	Normalised voltage X-component Channel 4	V/(A.turns.m^4)
Column 52	_4_X2_5	E13.5	1.00000E+33	Normalised voltage X-component Channel 5	V/(A.turns.m^4)
Column 53	_4_X2_6	E13.5	1.00000E+33	Normalised voltage X-component Channel 6	V/(A.turns.m^4)
Column 54	_4_X2_7	E13.5	1.00000E+33	Normalised voltage X-component Channel 7	V/(A.turns.m^4)
Column 55	_4_X2_8	E13.5	1.00000E+33	Normalised voltage X-component Channel 8	V/(A.turns.m^4)
Column 56	_4_X2_9	E13.5	1.00000E+33	Normalised voltage X-component Channel 9	V/(A.turns.m^4)

Column 57	_4_X2_10	E13.5	1.00000E+33	Normalised voltage X-component Channel 10	V/(A.turns.m^4)
Column 58	_4_X2_11	E13.5	1.00000E+33	Normalised voltage X-component Channel 11	V/(A.turns.m^4)
Column 59	_4_X2_12	E13.5	1.00000E+33	Normalised voltage X-component Channel 12	V/(A.turns.m^4)
Column 60	_4_X2_13	E13.5	1.00000E+33	Normalised voltage X-component Channel 13	V/(A.turns.m^4)
Column 61	_4_X2_14	E13.5	1.00000E+33	Normalised voltage X-component Channel 14	V/(A.turns.m^4)
Column 62	_4_X2_15	E13.5	1.00000E+33	Normalised voltage X-component Channel 15	V/(A.turns.m^4)
Column 63	_4_X2_16	E13.5	1.00000E+33	Normalised voltage X-component Channel 16	V/(A.turns.m^4)
Column 64	_4_X2_17	E13.5	1.00000E+33	Normalised voltage X-component Channel 17	V/(A.turns.m^4)
Column 65	_4_X2_18	E13.5	1.00000E+33	Normalised voltage X-component Channel 18	V/(A.turns.m^4)
Column 66	_4_X2_19	E13.5	1.00000E+33	Normalised voltage X-component Channel 19	V/(A.turns.m^4)
Column 67	_4_X2_20	E13.5	1.00000E+33	Normalised voltage X-component Channel 20	V/(A.turns.m^4)
Column 68	_4_X2_21	E13.5	1.00000E+33	Normalised voltage X-component Channel 21	V/(A.turns.m^4)
Column 69	_4_X2_22	E13.5	1.00000E+33	Normalised voltage X-component Channel 22	V/(A.turns.m^4)
Column 70	_4_X2_23	E13.5	1.00000E+33	Normalised voltage X-component Channel 23	V/(A.turns.m^4)
Column 71	_4_X2_24	E13.5	1.00000E+33	Normalised voltage X-component Channel 24	V/(A.turns.m^4)
Column 72	_4_X2_25	E13.5	1.00000E+33	Normalised voltage X-component Channel 25	V/(A.turns.m^4)
Column 73	_4_X2_26	E13.5	1.00000E+33	Normalised voltage X-component Channel 26	V/(A.turns.m^4)
Column 74	_4_X2_27	E13.5	1.00000E+33	Normalised voltage X-component Channel 27	V/(A.turns.m^4)
Column 75	_4_X2_28	E13.5	1.00000E+33	Normalised voltage X-component Channel 28	V/(A.turns.m^4)
Column 76	_4_X2_29	E13.5	1.00000E+33	Normalised voltage X-component Channel 29	V/(A.turns.m^4)
Column 77	_4_X2_30	E13.5	1.00000E+33	Normalised voltage X-component Channel 30	V/(A.turns.m^4)
Column 78	_4_X2_31	E13.5	1.00000E+33	Normalised voltage X-component Channel 31	V/(A.turns.m^4)
Column 79	_4_X2_32	E13.5	1.00000E+33	Normalised voltage X-component Channel 32	V/(A.turns.m^4)
Column 80	N	F10.1	9999999.9	Northing (MGA55/GDA94)	metres
Column 81	E	F10.1	999999.9	Easting (MGA55/GDA94)	metres

Appendix E Header for low moment SkyTEM data

Column	Field	Format	Null value	Description	Units
Column 1	Fid	I7	999999	Geoforce Fiducial	n/a
Column 2	Line	I8	99999	Line Number	n/a
Column 3	Flight	F11.1	99999999.9	Flight number	n/a
Column 4	DateTime	F17.10	99999.9999999999	Decimal days since midnight, December 31st, 1899	days
Column 5	Date	I10	99999999	Date (yyyymmdd) - GMT	n/a
Column 6	Time	F12.3	999999.999	Time (hhmmss.000) - GMT	n/a
Column 7	AngleX	F8.3	999.999	Tilt of frame from horizontal in flight direction	degrees
Column 8	AngleY	F8.3	999.999	Tilt of frame from horizontal perpendicular to flight direction	degrees
Column 9	LasAlt	F8.1	99999.9	Laser altitude of Tx loop centre (average of lasers 1 and 2)	metres
Column 10	DTM_AHD	F8.1	99999.9	Digital terrain model: corrected to AHD	metres
Column 11	Current	F8.2	999.99	Peak transmitter current	Amperes
Column 12	North_AGD	F10.1	9999999.9	Northing (AMG55/AGD66)	metres
Column 13	East_AGD	F10.1	999999.9	Easting (AMG55/AGD66)	metres
Column 14	GpsAlt	F9.1	9999.9	GPS Elevation of Tx loop centre: (GRS80)	metres
Column 15	Gdspeed	F8.1	999.9	Ground speed	km/hr
Column 16	_1_Z2_1	E13.5	1.00000E+33	Normalised voltage Z-component Channel 1	V/(A.turns.m^4)
Column 17	_1_Z2_2	E13.5	1.00000E+33	Normalised voltage Z-component Channel 2	V/(A.turns.m^4)
Column 18	_1_Z2_3	E13.5	1.00000E+33	Normalised voltage Z-component Channel 3	V/(A.turns.m^4)
Column 19	_1_Z2_4	E13.5	1.00000E+33	Normalised voltage Z-component Channel 4	V/(A.turns.m^4)
Column 20	_1_Z2_5	E13.5	1.00000E+33	Normalised voltage Z-component Channel 5	V/(A.turns.m^4)
Column 21	_1_Z2_6	E13.5	1.00000E+33	Normalised voltage Z-component Channel 6	V/(A.turns.m^4)
Column 22	_1_Z2_7	E13.5	1.00000E+33	Normalised voltage Z-component Channel 7	V/(A.turns.m^4)
Column 23	_1_Z2_8	E13.5	1.00000E+33	Normalised voltage Z-component Channel 8	V/(A.turns.m^4)
Column 24	_1_Z2_9	E13.5	1.00000E+33	Normalised voltage Z-component Channel 9	V/(A.turns.m^4)
Column 25	_1_Z2_10	E13.5	1.00000E+33	Normalised voltage Z-component Channel 10	V/(A.turns.m^4)
Column 26	_1_Z2_11	E13.5	1.00000E+33	Normalised voltage Z-component Channel 11	V/(A.turns.m^4)
Column 27	_1_Z2_12	E13.5	1.00000E+33	Normalised voltage Z-component Channel 12	V/(A.turns.m^4)

Column 28	_1_Z2_13	E13.5	1.00000E+33	Normalised voltage Z-component Channel 13	V/(A.turns.m^4)
Column 29	_1_Z2_14	E13.5	1.00000E+33	Normalised voltage Z-component Channel 14	V/(A.turns.m^4)
Column 30	_1_Z2_15	E13.5	1.00000E+33	Normalised voltage Z-component Channel 15	V/(A.turns.m^4)
Column 31	_1_Z2_16	E13.5	1.00000E+33	Normalised voltage Z-component Channel 16	V/(A.turns.m^4)
Column 32	_1_Z2_17	E13.5	1.00000E+33	Normalised voltage Z-component Channel 17	V/(A.turns.m^4)
Column 33	_1_Z2_18	E13.5	1.00000E+33	Normalised voltage Z-component Channel 18	V/(A.turns.m^4)
Column 34	_1_Z2_19	E13.5	1.00000E+33	Normalised voltage Z-component Channel 19	V/(A.turns.m^4)
Column 35	_1_Z2_20	E13.5	1.00000E+33	Normalised voltage Z-component Channel 20	V/(A.turns.m^4)
Column 36	_1_Z2_21	E13.5	1.00000E+33	Normalised voltage Z-component Channel 21	V/(A.turns.m^4)
Column 37	_1_Z2_22	E13.5	1.00000E+33	Normalised voltage Z-component Channel 22	V/(A.turns.m^4)
Column 38	_3_X2_1	E13.5	1.00000E+33	Normalised voltage X-component Channel 1	V/(A.turns.m^4)
Column 39	_3_X2_2	E13.5	1.00000E+33	Normalised voltage X-component Channel 2	V/(A.turns.m^4)
Column 40	_3_X2_3	E13.5	1.00000E+33	Normalised voltage X-component Channel 3	V/(A.turns.m^4)
Column 41	_3_X2_4	E13.5	1.00000E+33	Normalised voltage X-component Channel 4	V/(A.turns.m^4)
Column 42	_3_X2_5	E13.5	1.00000E+33	Normalised voltage X-component Channel 5	V/(A.turns.m^4)
Column 43	_3_X2_6	E13.5	1.00000E+33	Normalised voltage X-component Channel 6	V/(A.turns.m^4)
Column 44	_3_X2_7	E13.5	1.00000E+33	Normalised voltage X-component Channel 7	V/(A.turns.m^4)
Column 45	_3_X2_8	E13.5	1.00000E+33	Normalised voltage X-component Channel 8	V/(A.turns.m^4)
Column 46	_3_X2_9	E13.5	1.00000E+33	Normalised voltage X-component Channel 9	V/(A.turns.m^4)
Column 47	_3_X2_10	E13.5	1.00000E+33	Normalised voltage X-component Channel 10	V/(A.turns.m^4)
Column 48	_3_X2_11	E13.5	1.00000E+33	Normalised voltage X-component Channel 11	V/(A.turns.m^4)
Column 49	_3_X2_12	E13.5	1.00000E+33	Normalised voltage X-component Channel 12	V/(A.turns.m^4)
Column 50	_3_X2_13	E13.5	1.00000E+33	Normalised voltage X-component Channel 13	V/(A.turns.m^4)
Column 51	_3_X2_14	E13.5	1.00000E+33	Normalised voltage X-component Channel 14	V/(A.turns.m^4)
Column 52	_3_X2_15	E13.5	1.00000E+33	Normalised voltage X-component Channel 15	V/(A.turns.m^4)
Column 53	_3_X2_16	E13.5	1.00000E+33	Normalised voltage X-component Channel 16	V/(A.turns.m^4)
Column 54	_3_X2_17	E13.5	1.00000E+33	Normalised voltage X-component Channel 17	V/(A.turns.m^4)
Column 55	_3_X2_18	E13.5	1.00000E+33	Normalised voltage X-component Channel 18	V/(A.turns.m^4)
Column 56	_3_X2_19	E13.5	1.00000E+33	Normalised voltage X-component Channel 19	V/(A.turns.m^4)
Column 57	_3_X2_20	E13.5	1.00000E+33	Normalised voltage X-component Channel 20	V/(A.turns.m^4)

Column 58	_3_X2_21	E13.5	1.00000E+33	Normalised voltage X-component Channel 21	V/(A.turns.m^4)
Column 59	_3_X2_22	E13.5	1.00000E+33	Normalised voltage X-component Channel 22	V/(A.turns.m^4)
Column 60	N	F10.1	9999999.9	Northing (MGA55/GDA94)	metres
Column 61	E	F10.1	999999.9	Easting (MGA55/GDA94)	metres

Appendix F Header for TMI data

Column	Field	Format	Null value	Description	Units	Sign convention
Column 1	Fid	I7	999999	Geoforce Fiducial	n/a	
Column 2	Line	I8	99999	Line Number	n/a	
Column 3	Flight	F11.1	99999999.9	Flight number	n/a	
Column 4	DateTime	F17.10	99999.99999 99999	Decimal days since midnight, December 31st, 1899	days	Greenwich mean time
Column 5	Date	I10	99999999	Date (yyyymmdd) - GMT	n/a	Greenwich mean time
Column 6	Time	F12.3	999999.999	Time (hhmmss.000) - GMT	n/a	Greenwich mean time
Column 7	NORTH_AGD	F10.1	9999999.9	Northing (AGD66/AMG55)	metres	
Column 8	EAST_AGD	F10.1	999999.9	Easting (AGD66/AMG55)	metres	
Column 9	GPSALT	F9.1	999.9	GPS Elevation of Tx loop centre: (GRS80 Ellipsoid)	metres	
Column 10	GDSPEED	F8.1	999.9	Ground speed	km/hr	
Column 11	MAG_RAW	F9.2	999999.9	Raw total magnetic field strength	nT	
Column 12	MAG_BASE	F9.2	999999.99	Diurnal magnetic field strength	nT	
Column 13	MAG_DIURNAL	F9.2	999999.99	Diurnal corrected magnetic field	nT	
Column 14	MAG_DI_IGRF	F9.2	999999.99	IGRF and Diurnal corrected magnetic field	nT	
Column 15	IGRF	F9.2	999999.99	IGRF field strength	nT	
Column 16	MAG_TLEV	F9.2	999999.99	Tie line levelled magnetic field strength	nT	
Column 17	MAG_MLEV	F9.2	999999.99	Micro levelled magnetic field strength	nT	
Column 18	TMI	F9.2	999999.99	TMI (MAG_MLEV + IGRF)	nT	

Column 19	N	F10.1	9999999.9	Northing (GDA94/MGA55)	metres
Column 20	E	F10.1	999999.9	Easting (GDA94/MGA55)	metres

Appendix G Header for CDI data

Column	Field	Start column	End column	Format	Null value	Description	Units	Sign convention
Column 1	Line	4	10	I7	9999999	Line Number	n/a	
Column 2	Easting	12	20	F9.2	999999.99	Easting (AGD66/AMG55)	metres	
Column 3	Northing	22	31	F10.2	9999999.99	Northing (AGD66/AMG55)	metres	
Column 4	Dist	34	41	F8.2	99999.99	Distance along line	metres	
Column 5	Depth	45	51	F7.2	9999.99	Depth	n/a	-ve below surface
Column 6	Cond	54	62	F9.4	9999.9999	Conductivity	mS/m	
Column 7	Elev	66	72	F7.2	9999.99	Elevation corresponding to depth in Column 5	metres	
Column 8	Time	76	82	F7.2	9999.99	Delay time	µs	Start of ramp
Column 9	Alt	87	92	F6.2	999.99	Laser Altimeter	metres	
Column 10	TxElev	96	102	F7.2	9999.99	GPS Elevation of Tx loop centre: (GRS80 Ellipsoid)	metres	
Column 11	DEM	106	112	F7.2	9999.99	Digital elevation model (AHD)	metres	

Appendix H Header for conductivity-depth slice data

Column	Field	Start column	End column	Format	Null value	Description	Units
Column 1	Line	3	9	I7	9999999	Line Number	n/a
Column 2	Easting	12	19	F8.1	999999.9	Easting (AGD66/AMG55)	metres
Column 3	Northing	23	31	F9.1	9999999.9	Northing (AGD66/AMG55)	metres
Column 4	Av0_5	34	45	E12.6	0.999990e+05	Average conductivity in depth slice 0 to 5 m below surface	mS/m
Column 5	Av5_10	48	59	E12.6	0.999990e+05	Average conductivity in depth slice 5 to 10 m below surface	mS/m
Column 6	Av10_15	62	73	E12.6	0.999990e+05	Average conductivity in depth slice 10 to 15 m below surface	mS/m
Column 7	Av15_20	76	87	E12.6	0.999990e+05	Average conductivity in depth slice 15 to 20 m below surface	mS/m
Column 8	Av20_30	90	101	E12.6	0.999990e+05	Average conductivity in depth slice 20 to 30 m below surface	mS/m
Column 9	Av30_40	104	115	E12.6	0.999990e+05	Average conductivity in depth slice 30 to 40 m below surface	mS/m
Column 10	Av40_60	118	129	E12.6	0.999990e+05	Average conductivity in depth slice 40 to 60 m below surface	mS/m
Column 11	Av60_100	132	143	E12.6	0.999990e+05	Average conductivity in depth slice 60 to 100 m below surface	mS/m
Column 12	Av100_150	146	157	E12.6	0.999990e+05	Average conductivity in depth slice 100 to 150 m below surface	mS/m

Column 13	Av150_200	160	171	E12.6	0.999990e+05	Average conductivity in depth slice 150 to 200 m below surface	mS/m
Column 14	Av200plus	174	185	E12.6	0.999990e+05	Average conductivity in depth slice > 200m below surface	mS/m

Appendix I Deliverables on DVD

The following folders of data are included with this report on DVD. Each directory has a text file description explaining the data format of the raw files inside.

Folder	Description	File Type
AEM_Binary	Raw (binary) data from SkyTEM EM system	ASCII & Binary
AEM_Grids	Grids of EM data	.ers
AEM_Images	Images of EM grids	.jpg
AEM_Located	Header explanation and ASCII data file for processed EM data	ASCII & .pdf
AHD Value	Text file of 'N' value added to bring DEM data up to AHD values	ASCII
ASEG_GDF	Header, data and description files in ASEG GDF format	ASCII
CDI_Depth_Slices	ASCII data file of average conductivity within specified depth intervals below surface	ASCII
CDI_Images	Section Images of CDI data	.jpg
CDI_Located	Header explanation and ASCII data file for processed CDI data	ASCII & .pdf
CurrentWaveform	Transmitter loop current waveform check raw data and images	ASCII & .jpg
High_Alt_Tests	Excel spreadsheets of high altitude EM data	.xlsx
Line Statistics	Clearance and speed statistics	.xlsx
Linefile	Line start and end co ordinates and times	ASCII
Logistics Report	Summary of field crew activity for survey	.pdf
Mag_Base	Base Magnetometer location	ASCII
Mag_Binary	Raw (binary) data from SkyTEM magnetics system	ASCII & Binary
Mag_Located	Header explanation and ASCII data file for processed magnetic data	ASCII & .pdf