SkyTEM Survey Mo i Rana, Area1 - Norway

Data report

December 2007

SkyTEM Aps

Data Report - Mo i Rana

Contents

"Data report, Mo i Rana" covers data acquisition of a time domain electromagnetic survey carried out in Mo i Rana, Area1 - Norway 2007, by SkyTEM ApS.

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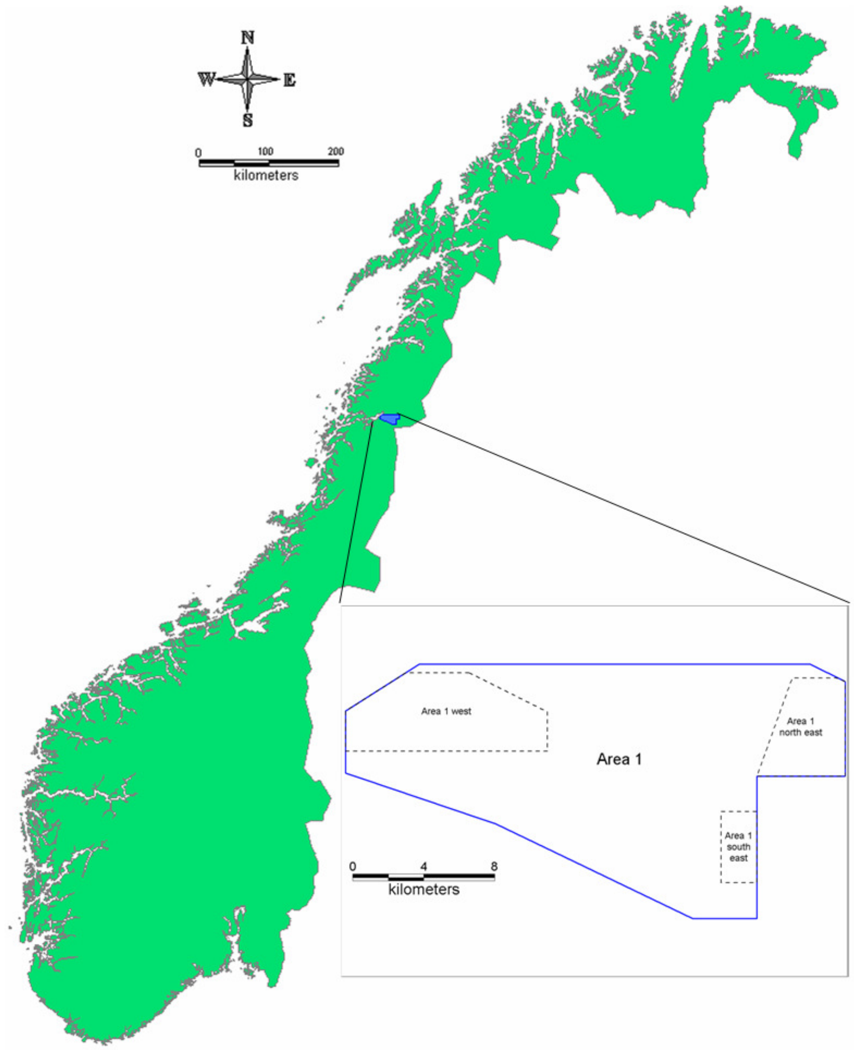

Figure 1. Project overview. The blue box represents the outline of the survey area.

Introduction

From the 23rd of August to the 20th of september 2007 a time domain electromagnetic survey was performed by SkyTEM ApS in Mo i Rana, Area1 - Norway, Figure 1.

The survey requested by MoMin AS was planned to be 2992.4 km of flight lines in total.

SkyTEM has agreed to deliver the electromagnetic raw data measured during the flights together with the standard SkyTEM processing.

The report does not include any geological interpretations of the geophysical dataset.

Client		MoMin AS Postboks 500 8601 Mo I Rana Norway
Field crew		Rasmus Teilmann, Ib Faber Gorm Thøgersen, Max Halkjær Thomas Bojer, Solvej Trautner Per Gisselø
Field work		the 23rd of August to the 20th of september 2007
Actually flown line km		2992
Flight operation	Helicopter type	Eurocopter Astar 350 B2, operated by West Helicopter
	Average flight speed	70 km/h
	Nominal flight height	30 m
Pilots		Jan Veltjens Henrik Morin Tomas Rönkvist
Report	Data processing and presentation	TB RT SPT
Contact Person at SkyTEM		Rasmus Teilmann Email: rasmus.teilmann@skytem.com

Definition of the area

The survey area is defined below by vertex points. The Coordinate system used is UTM (WGS84) Zone 33N.

Area 1 (N-S Flight line orientation)

Vertex	Easting [m]	Northing [m]
1	461000	7354300
2	483000	7354300
3	485000	7353300
4	485000	7348000
5	480000	7348000
6	480000	7340000
7	476400	7340000
8	465300	7345300
9	456835	7348165
10	456835	7351665

Area 1 SouthEast (E-W Flight line orientation)

Vertex	Easting [m]	Northing [m]
1	478000	7346000
2	480000	7346000
3	480000	7342000
4	478000	7342000

Area 1 West (E-W Flight line orientation)

Vertex	Easting [m]	Northing [m]
1	460200	7353800
2	463800	7353800
3	468200	7351600
4	468200	7349400
5	456835	7349400
6	456835	7351665
1	460200	7353800

Area 1 North East (E-W Flight line orientation)

Vertex	Easting [m]	Northing [m]
1	484500	7353500
2	485000	7353300
3	485000	7348000
4	480000	7348000
5	482000	7353500

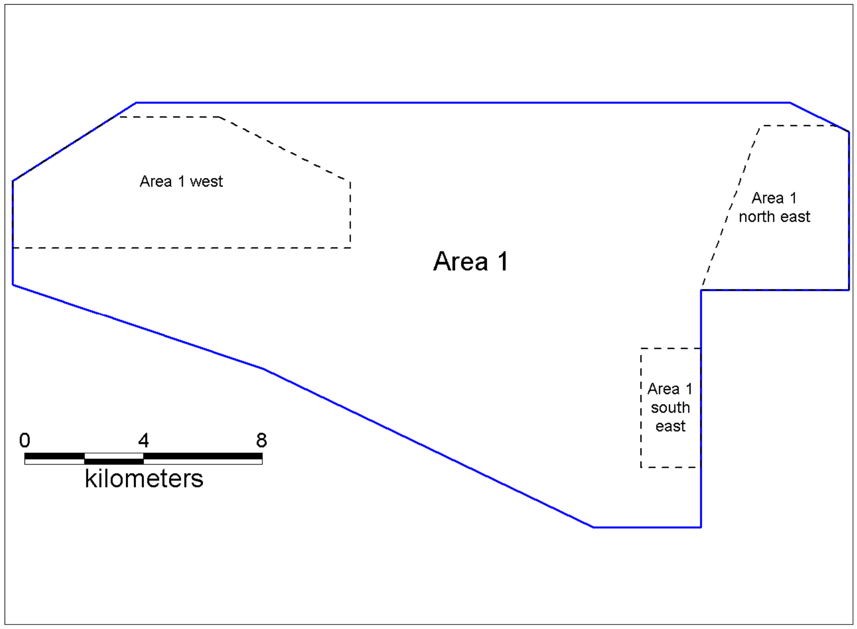

Figure 2. Survey area. Coordinates of the polygon corner points are defined in the table above. UTM (WGS84) Zone 33N.

Instruments and set up parameters

The instrumentation involves a time domain electromagnetic system, inclinometer, altimeters, gps, dgps and a magnetometer.

The measurements were carried out, using a set up as described below.

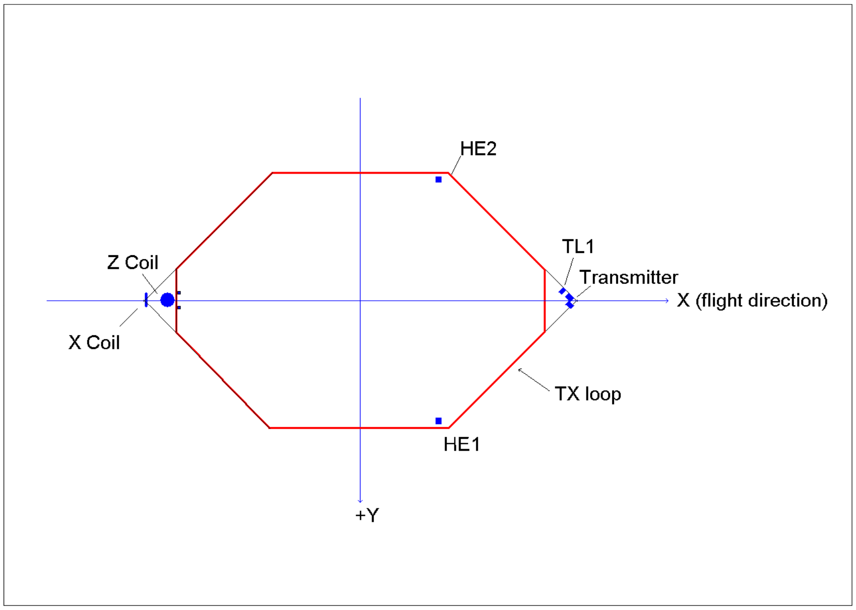

Figure 3. Sketch showing the frame and the position of the basic instruments. The red line defines the transmitter loop. The horizontal plane is defined by (x,y).

The location of instruments in respect to the frame is shown in Figure 3, and is given in (x,y,z) coordinates in the table below.

X and y define the horizontal plane. Z is perpendicular to (x,y). X is positive in the flight direction, y is positive to the right of the flight direction, and z is positive downwards.

The GPS systems are mounted on a box placed 21.3 m above the transmitter together with the two computers used for controlling and collecting data.

The generator used for powering of the transmitter is positioned an additional 2.00 m above the GPS systems.

The DGPS antenna is mounted in the front of the frame.

Device	x	y	z
GP1 (GPS)	12.0	0.0	-21.3
GP2 (GPS)	12.0	0.0	-21.3
DGPS	13.75	0.0	0.00
HE1 (altim.)	5.04	7.77	0.00
HE2 (altim.)	5.04	-7.77	0.00
Inclinometer	13.00	-0.60	0.00
Mag sensor	12.5	0.00	-17.5
RX (Z Coil)	-12.40	0.00	-2.22
RX (X Coil)	-13.75	0.00	0.00
TX (transmit.)	13.47	-0.23	0.00

The location of instruments. See Figure 3.

Transmitter

The time domain transmitter loop can be described as an octagon with the corners listed below:

x	Y
-11.87	-2.03
-5.68	-8.22
5.68	-8.22
11.87	-2.03
11.87	2.02
5.68	8.22
-5.68	8.22
-11.87	2.03

The total area of the transmitter coil defined by the corner points is 314 m² and 65.9 m in circumference.

The key parameters defining the transmitter set up are:

Parameter	Value
Number of transmitter turns	4
Transmitter area	314 m²
Peak current	~ 110 A
Peak moment	140000 Am²
Repetition frequency	25 Hz
On-time	10000 µs
Off-time	10000 µs
Duty cycle	50%
Wave form	Square
Turn on wave form exp. decay constant	360 s^{-1}
Turn off linear ramp	3.13E+06 A/s
Turn off current end avalanche mode	1.71 A at 32.0 µs
Turn off free decay exp. decay constant	1.0E+06 1/s from 32.0 µs

The measured transmitter wave form can be seen in Figure 13 *and* Figure 14.

Figure 4. The 314 m² frame in production mode.

Receiver system

The decay of the secondary magnetic field is measured using two independent active induction coils. The Z coil is the vertical component, and the X coil is the horizontal in-line component. Each coil has an effective receiver area of 31.4 m^2.

The receiver coils are placed in a null-position:

Z coil (x,y,z) = (-12.40, 0.00, -2.22)
X coil (x,y,z) = (-13.75, 0.00, 0.00)

In the null-position, the primary field is damped with a factor of 0.005.

The Z-component receiver terrain clearance is nominal 32.22 m, and is placed -12.40 m behind the center of the transmitter loop.

The X-component receiver terrain clearance is nominal 30.00 m, and is placed -13.75

m behind the center of the transmitter loop.

Figure 5. Rudder containing the Z coil located approximately 2.22 m above the transmitter coil.

The key parameters defining the receiver set up are:

Receiver parameters	
Sample rate	All decays are measured
Number of output windows	30
Receiver coil low pass filter	450 kHz
Receiver instrument low pass filter	Ch0: 106 kHz, Ch1: 50.5kHz
Repetition frequency	25 Hz
Front gate	46.0 µs

Receiver window times are measured from the start of the transmitter current turn-off. The window times represent the interval from 0.053 ms to 10 ms. A complete list describing open/close and window center times are listed in Appendix 1.

Inclination

Instrument type: Bjerre Technology

The inclination of the frame is measured 2 times per second in two directions. The protractor is placed in the front of the frame.

The angle data are stored as x, y. X is parallel to the flight direction and positive when the front of the frame is above horizontal. Y is perpendicular to the flight direction and positive when the right side of the frame is above horizontal.

The angle is given with one decimal.

The angle is checked and calibrated manually within 0.5 degree by use of a level meter.

GPS

Instrument type: GPS1 and GPS2: Hollux

The geographical coordinates are measured with two independent GPS receivers (GP1 and GP2). The GPS receivers are placed on the top of the box, below the motor generator.

Each GPS delivers one dataset per second. The coordinates are given in Latitude/longitude, WGS84.

The uncertainty in the xy-directions is in the range of ± 10 m.

GPS parameters	
Sample rate	1 Hz
Uncertainty	± 10 m
Coordinate system	Latitude/longitude, WGS84

DGPS

Instrument type:

Chipset: Ublox RCB-LJ 16-channel ANTARIS technology, 4 Hz position update rate.

Antenna: Trimble, Bullet III GPS Antenna

The differential GPS receiver is on top of the cooling unit in front of the frame.

The DGPS delivers one dataset per second. The coordinates are given in latitude/longitude, WGS84.

The uncertainty in the xyz-directions is better than ± 1 m after processing.
The processed DGPS data is combined with the EM data in the xyz-files, giving the precise position.

DGPS parameters	
Sample rate	4 Hz
Uncertainty	± 1 m
Coordinate system	latitude/longitude, WGS84

Altimeter

Instrument type: MDL ILM300R

Two independent laser units mounted on each side of the frame measure the distance from the frame to the ground, see Figure 3.

Each laser delivers 50 measurements per second, and covers the interval from 1.5 m to approximately 130 m.

Dark surfaces including water surfaces will reduce the reflected signal. Consequently, it may occur that some measurements do not result in useful values default value: 9999.99.

The altimeter measurements are given in meters with two decimals. The uncertainty is 10-30 cm. The lasers are checked as a routine against well defined targets.

Laser parameters	
Sample rate	50 Hz
Uncertainty	10-30 cm
Min/ max range	1.5 m / 130 m
Wave length	905 nm

Magnetometer Airborne unit

Instrument type: Geometrics G822A sensor and Kroum KMAG4 counter

The Geometrics G822A sensor and Kroum KMAG4 counter is a high sensitivity cesium magnetometer. The basics of the sensor is a self-oscillating split-beam Cesium Vapor (non-radioactive) princip, which operates on principles similar to other alkali vapor magnetometers.

The sensitivity of the Geometrics G822A sensor and Kroum KMAG4 counter is stated as <0.0005 nT/√Hz rms. Typically 0.002 nT P-P at a 0.1 second sample rate, combined with absolute accuracy of 3 nT over its full operating range.

The magnetometer is synchronized with the TEM system. When the TEM signal is on the counter is closed. In the TEM off-time the magnetometer data is measured from 100 microseconds until the next TEM pulse is transmitted. The data are averaged and sampled as 50 Hz.

Parameter	Value
Sample frequency	50 Hz
Accuracy	3 nT
Sensitivity	< <0.0005 nT/√Hz rms. Typically 0.002 nT P-P at a 0.1 second sample rate
Magnetometer on	9900 µs
Magnetometer off	10100 µs

Magnetometer Base station

Instrument type: GEM Systems, Inc., GSM-19

Figure 6. GSM-19 magnetometer used as base station

The GSM-19 is a portable high-sensitivity Overhauser effect magnetometer/.

The GSM-19 is a secondary standard for measurement of the Earth's magnetic field with 0.01 nT resolutions, and 0.2 nT absolute accuracy over its full temperature range.

The base station data are sampled with a 1 Hz frequency.

Parameter	Value
Sample frequency	1 Hz
Accuracy	0.2 nT
Resolution	0.2 nT

Synchronizing the data

All recorded data are marked with a time stamp used to link the different data types.

The time stamp is UTC/GMT. The time stamp format is either

yyyy-mm-dd hh:mm:ss.sss or

Date time value defined as the number of days since 1900-01-01

The second notation is very useful for data presentation along a time axis.

Calibration of the TEM system

The complete TEM equipment has been tested and calibrated at the Danish National Reference Site, the 29th of June 2006

The calibration includes measurements of the transmitter wave form and measurements in different altitudes. Hereby, it has been documented that the instrumentation can reproduce the reference site with the same set of calibration parameters and independent of the flight altitude.

The calibration results in the following parameters:

Shift factor 1.0 (on the raw dB/dt data)

Time shift -1.0 µs

All processed data are corrected according to the calibration parameters.

The wave form as well as the reproduced soundings in different altitudes is shown in Appendix 2.

High altitude test

A high altitude test was performed on the 25th of September 2007 at 1000 m above the ground. The test was performed with exactly the same equipment and configuration used during the project.

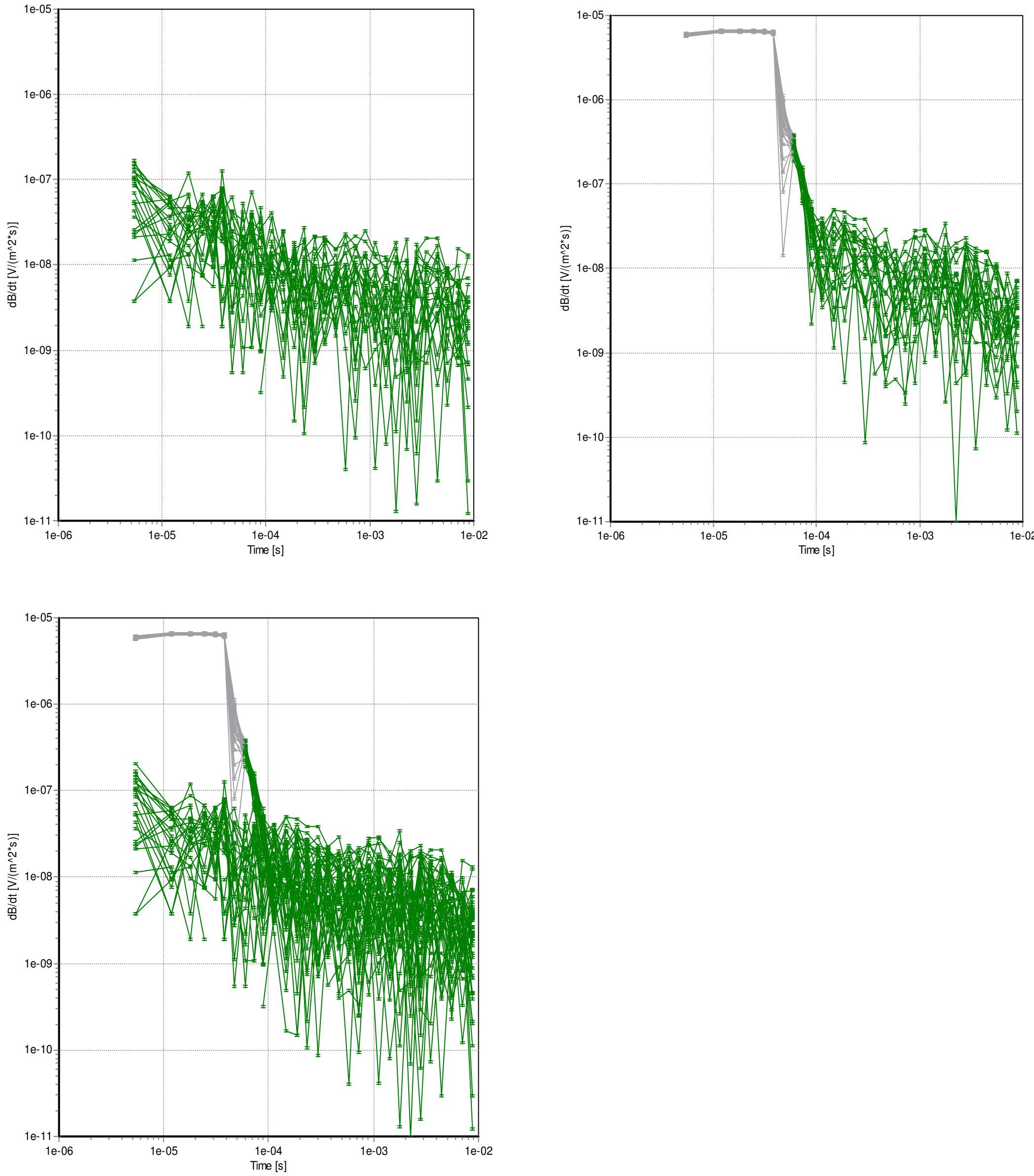

Figure 7. High altitude test performed the 25th of September 2007 1000 m above the ground. A comparison of the back ground noise level (the plot to the left) with the signal when the transmitter is on (the plot to the right). Stack size 96. The figure at the bottom shows the two figures superimposed. The data unit is V/m^2 (data normalized with the receiver coil area only).

The background noise and the signal with the transmitter on is very much alike in the high altitude (Figure 7).

When the transmitter is on, a slightly higher level is seen up to 100 µs. In areas with very low earth signal this may add noise to the early gates

Data Acquisition

The planned flight lines covering the Mo i Rana, Area1 - Norway is shown in Figure 8. The lines are parallel-spaced 100 m apart, with the main area striking N-S and the three subareas striking east-west.

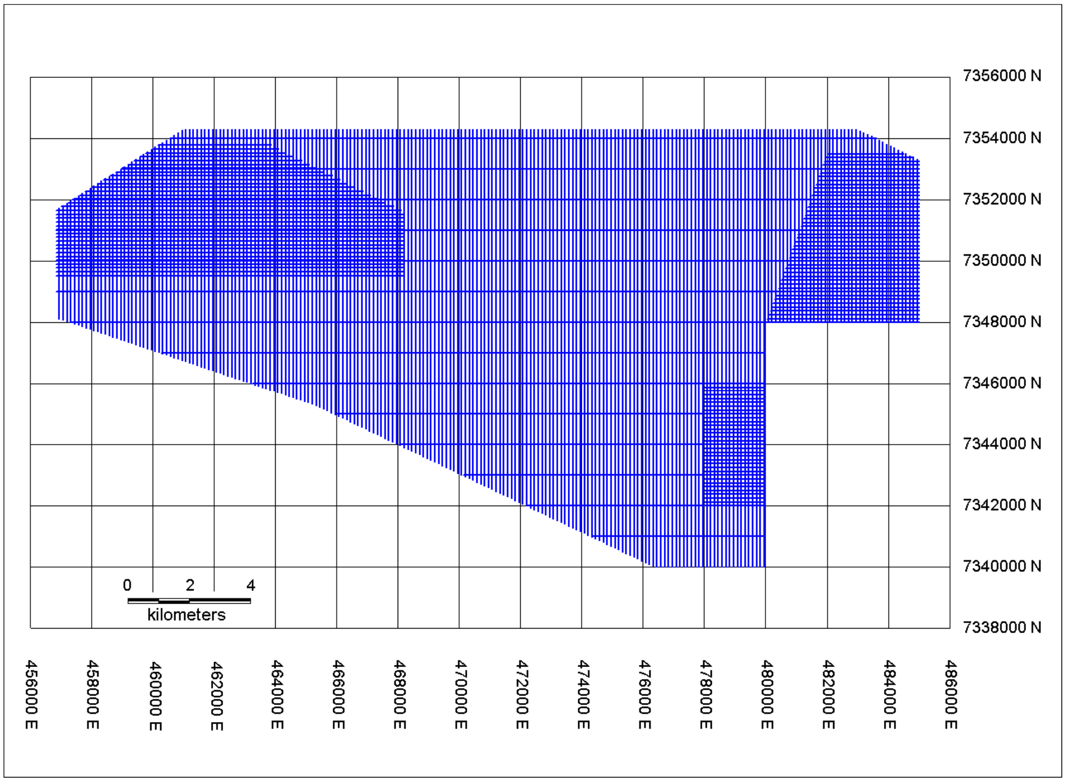

Figure 8. Planned survey lines in the Mo i Rana, Area1 - Norway. Coordinate system UTM (WGS84) Zone 33N.

The flight lines are numbered from 100101 to 200821. A complete list including coordinates and time for begin and end of line can be found in Appendix 3.

The intended terrain clearance is 30.00 m, with an increase over forests, power lines etc. It is always the pilot who desides the safety height for the operation.
The helicopter airspeed was planned to be approximately 70 km/h (19 m/s) above a flat topography, but this may vary in areas of rugged terrain.

Actually flown lines can be seen in Figure 9. Discrepancies from the planned lines occur when possible noise sources are present, or the nature of the ground like roads, buildings and antennas has called for it.

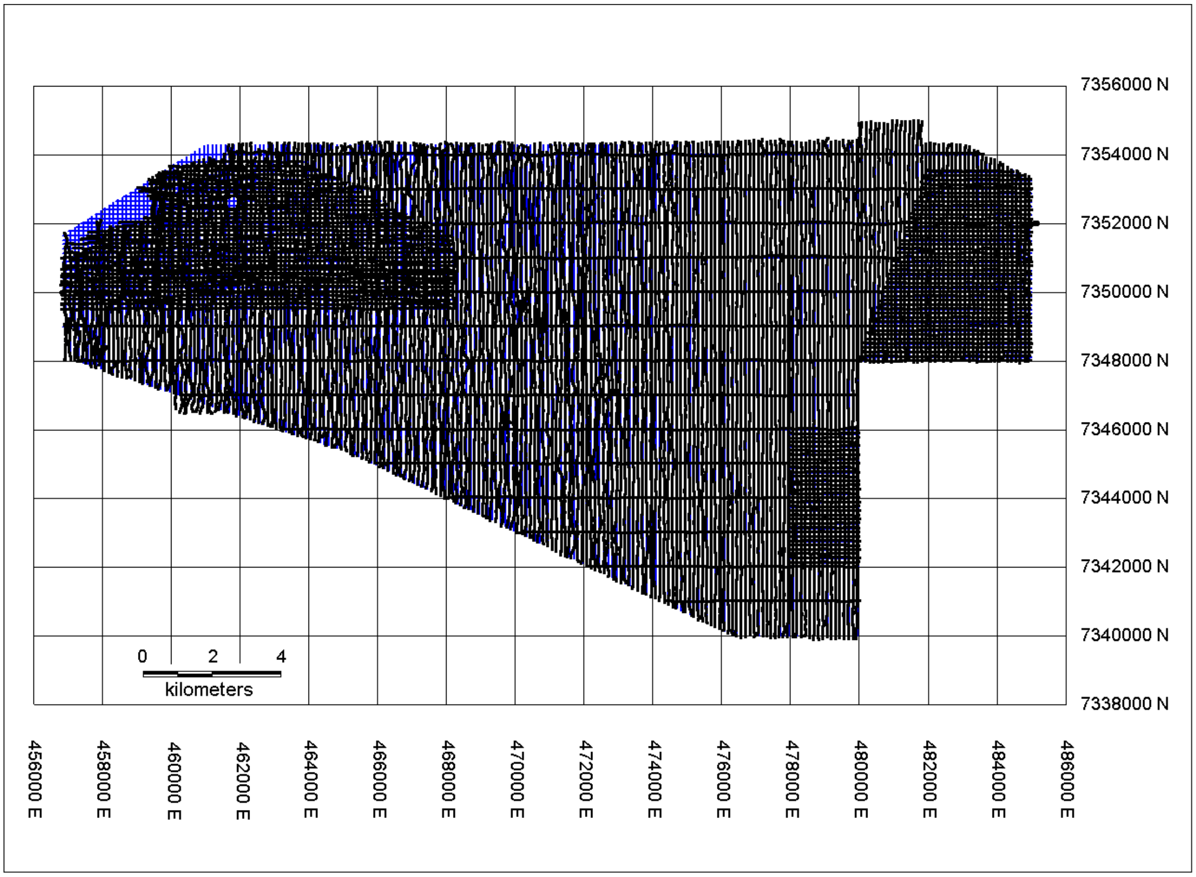

Figure 9. Area A1, black dots represent actually flown lines in respect to planned flight lines (blue lines). Coordinate system UTM (WGS84) Zone 33N.

Flight reports

For each flight, a report with key information regarding the data gathering is made. Listed in the reports are details on the weather, specials data parameters and other events which may influence the data. Selected information from the flight reports are shown in the table below:

Date	#Flights	Comments	Weather
20070823	1	Very steep topography in the western part of area1. Steepest part flown on another flight	Light showers, 5m/s W, 10℃
20070824	-	-	Rain
20070825	-	No helicopter on this day	Heavy Rain
20070826	2	Additional PC with background maps installed in the helicopter on request from the pilot	Showers, 5-8m/s SW, 10℃
20070827	3	Few restarts on PaPC (Flight01). Flight continued.	Some low clouds, 5m/s W, Showers
20070828	2	-	Fair, 5m/s W, 15℃
20070829	1	Short return after 3 min. of flight. No problem with the equipment	Overcast, 5-8 m/s W
20070830	-		Bad weather
20070831	2	Some lines flown twice on flight 1 and 2 (No charge)	Showers, 5 m/s W, 2-5℃
20070901	2	PaPC changed. Few drops in Voltage. Data ok.	Showers, 5 m/s, 5-10℃
20070902	1	Flight #2 aborted due to heavy rain	Showers, 5 m/s, 5-10℃
20070903	1	Few drops in Voltage. Data ok.	Showers, 5-8 m/s, 5-10℃
20070904	-	Instrument maintenance, crew change	Heavy Rain
20070905	-	-	Heavy Rain
20070906	1	-	Showers, 10-15 m/s, 5-10℃
20070907	2	Flights in Area 3, Area4	Cloudy, 2-5m/s W, 10-12℃
20070908	2	Flights in Area 1, Area 3	Cloudy, Strong wind ENE
20070909	1	Flights in Area 1	Cloudy, 2-5m/s E, 10℃
20070910	-	Helicopter at service	-
20070911	-	Helicopter at service	-
20070912	-	Helicopter at service	-
20070913	-	Helicopter at service	-
20070914	-	Helicopter at service	-
20070915	-	Helicopter used for other jobs at MoMin	Too strong wind for production
20070916	2	Area 3	2-6 m/s SW, Clouds at 800m
20070917	2	Area 3, Crew change	High Clouds 0-4 m/s NW
20070918	-	-	-
20070919	2	Magnetometer board broke during Take off. System landed and problem fixed before production flight	High Clouds 0-4 m/s
20070920	2	Area 2, NRK Filming SkyTEM	High Clouds 2-4 m/s
20070921	1	Area 2	High Clouds 2-4 m/s, 5℃
20070922	2	Area 2	Clouds at 1200m, 3-5 m/s S.
20070923	2	Area 2, Radio cable snapped during take off.	High Clouds 2-4 m/s S, 5℃

20070924	-	No Production	-
20070925	1	High Altitude test, No Production due to heavy wind	8-12 m/s, No clouds
20070926	-	No Production	-
20070927	3	Area 2	No clouds 0-3 m/s NW, 4℃
20070928	1	Area 2	Few clouds, 1-3 m/s NW, 6℃

Processed data

Selected control parameters are plotted in Appendix 4. The plot contains information about the flight altitude, speed, angle of the frame, transmitted current, transmitter voltage and transmitter temperature.

Average value of control parameters are found in the table below

Control parameter		Value
Ground speed*)		35-80 km/h
Measured height		20-60 m
Processed height		30-60 m
Tilt angle	X	± 10º
	Y	± 5º
Tx Voltage**)	Tx_off	66-67 V
	Tx_on	62-54 V
Current**)		80-110 A
Tx temperature**)		20-40ºC

**) Actual speed varies as a function of day and flight direction due to different wind directions and magnitude.*
***) Few spikes are seen in the temperature, current and voltage data. These are not caused by errors in the instruments but a matter of digital drop outs.*

XYZ-files

The xyz files are the main results of the SkyTEM survey, containing all the collected EM data and information for the interpretation and inversion.

Based on the positions of all devices a xyz ASCII file is produced. All parameters in the xyz-file hence refer to the Origo of the frame.

The raw EM data are filtered based on the signal level, i.e. high level means a low number of transients in the stack and vice versa.

The xyz file is used as input to the inversion and interpretation software.
The parameter plots are based on the xyz-file.

The projection of the xyz-files is UTM (WGS84) Zone 33N.

Each filtered data set at a given position is numbered with a unique fiducial number.

The header of the xyz-file gives the following information:

Parameter	Typical value	Explanation
Fid	1-178411	Unique Fiducial number
Line	200501	Flight line number
Flight	20070920_Flight01	Name of flight

DateTime	39345.3230111921	DateTime format
Date	2007/09/20	Date yyyy/mm/dd
Time	07:45:08.167	Time hh:mm:ss:zzz
AngleX	2.890	Angle in flight direction [deg]
AngleY	-2.363	Angle perpendicular to AngleX [deg]
Height	36.5	Filtered Height measurement [m]
DTM	576.8	Digital Terrain Model [m.a.sl]
Current	109.95	Current [A]
Mag	0.0	Mag reading –Not active. See separate Magnetometer data file
N	7345887.838	UTM (WGS84) Zone 33N [m]
E	478298.961	UTM (WGS84) Zone 33N [m]
Alt	613.3	DGPS/GPS Altitude [m]
GdSpeed	69.2	Ground Speed [km/t]
2_Z2_8 - 2_Z2_30	7.4402E-013	Normalized Z-coil value: gate 8-30
4_X2_8 – 4X2_30	-2.9481E-012	Normalized X-coil value: gate 8-30

Inversion of the TEM data

In this section, the particulars of modeling and inversion of SkyTEM data from Mo i Rana, Area1 - Norway will be described with reference to the more general material found in Appendix 5.

The inversion code is named SELMA, ref /2/.

The model used for inversion of SkyTEM data is a multi-layer model (MLM) with 30 layers. Thicknesses and layer depths are stated in the table below.

Layer #	Layer Thickness [m]	Layer depth [m]
1	10.00	0.0
2	10.04	10.00
3	10.11	20.04
4	10.22	30.15
5	10.38	40.37
6	10.6	50.8
7	10.8	61.3
8	11.1	72.1
9	11.4	83.2
10	11.7	94.6
11	12.1	106.3
12	12.6	118.5
13	13.1	131.1
14	13.6	144.1
15	14.2	157.8
16	14.9	172.0
17	15.6	186.8
18	16.3	202.4
19	17.2	218.7
20	18.0	235.9
21	19.0	253.9
22	20.0	272.9
23	21.1	293
24	22.3	314.1
25	23.6	336.4
26	24.9	360.0
27	26.4	384.9
28	27.9	411.3
29	29.6	439.2
30	N/A	468.8

The inversion is performed on individual soundings along the profiles. The model is one dimensional.

The input data is the xyz file described in the chapter "Processed data".

As initial model the resistivity of each layer is set to 200 Ωm, i.e. the initial model is essentially a homogeneous half space. The maximum resistivity is set to 10000 Ωm and the minimum resistivity is 0.01 Ωm.

The only prior information involved is thickness of each layer and a vertical smoothness constraint from layer resistivity to layer resistivity. By using a L_1-norm inversion approach, the final model is characterized by sharp layer boundaries, even though there is a constraint between the resistivities.

Noise model
For the survey, the noise parameters have pragmatically been determined as 0.1ms and 2.5E-13 in field units normalized with Tx moment.

The noise model V is expressed as a sum of two contributions:

$$V = \frac{V_0}{\sqrt{2}} \frac{t_0}{t} \sqrt{1+\frac{t}{t_0}}$$

Where $t_0 =$ 0.1 ms and $V_0 =$ 2.5E-13 in field units, normalized with Tx moment.
See Appendix 5 for more details.

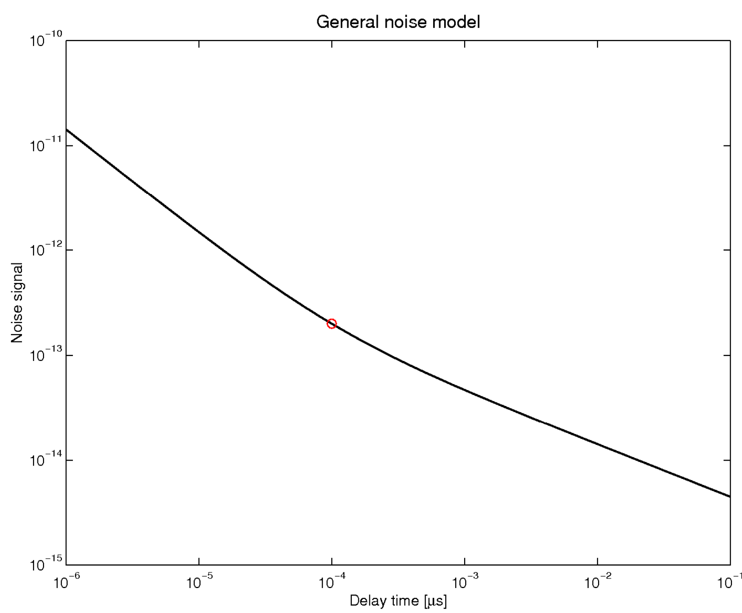

Figure 10. The noise model. The red circle denotes the actual parameters of 0.1ms and 2.5E-13.

The data used for the inversion has not been reviewed to avoid data affected by man made conductors such as power lines, rail roads etc.

Presentations

The models resulting from inversion of the individual sounding data are displayed in model sections/profiles, and interval elevation maps of conductivity and resistivity.

With the conductivity sections the color scale represents variations of the good conductor where as the resistivity presentations result in a more detailed picture of the more poor conductors.

The conductivity and resistivity model sections are enclosed in digital form. A brief description is given in appendix 6

The quality of the inversion results can be evaluated by inspecting the residuals.

The data residual is calculated by comparing the measured data with the signal, which the resulting model would produce. If the residual is in the range of 1, the data are well fitted. If the residual is high, it can be due to two or three dimensionally effects. Another possibility is if the resistivities are high, the signal to noise level will be reduced resulting in more noisy data and a higher residual. In this case it is reliable that the inverted resistivities are high. The last source to a higher residual could be coupling effects to power lines and other man made conductors.

The residual of vertical constraints shows where the model has to diverge from a homogeneous half space in order to fit data. A high residual is an indication of deviation from a 1-D model e.g. in case of a conductive structure.

The total residual is a weighted average of the individual residuals.

Maps of data residual, vertical constraints and total residuals are enclosed in digital form.

The interval elevation maps of conductivity and resistivity are enclosed in digital form. A brief description is given appendix 6

For every 20 m depth an average conductivity and resistivity is calculated, based on the obtained inverted model. The result is depth slices, showing variations in specific depth-intervals.

Similar for every 20 m a horizontal slice is extracted. When looking at the horizontal slice, the map will not show any colors in areas where the topographical terrain is below the actual horizontal slice.

In Area1 the elevation slices covers -400m to 1080 meter above sea level in 20 m intervals.

Digital terrain model

The digital terrain model (DTM) is a digitized topographic map of the survey region.

The DTM is generated from measurements of the height and measurements of the DGPS altitude giving the topography as:

DTM = (DGPS_altitude) – (HEIGHT).

The DTM is located in the data delivery catalogue as .tab files.

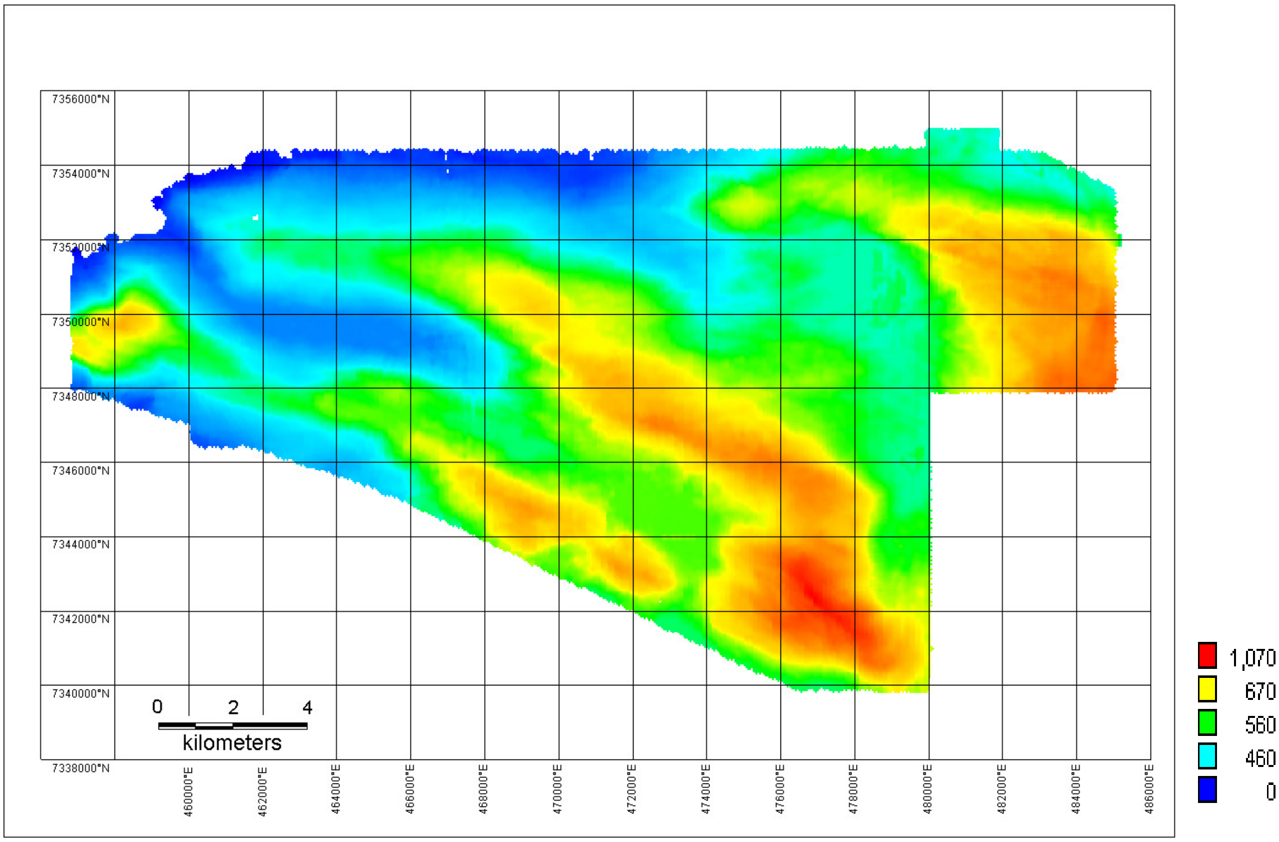

Figure 11. DTM of the Mo i Rana, Area1 - Norway. Meter above sea level. Coordinate system UTM (WGS84) Zone 33N.

Magnetic data

The magnetic data is located in the Datadelivery Catalogue.

Processing of the magnetometer data involves the following steps:

1. Spike removal (non-spike filtering and spline interpolation)
2. Editing and checking of the raw data
3. Base station corrections
4. Since the heading error is very low – <0.15 nT over entire 360 polar and equatorial spin, no heading error correction has been used
5. Gridding and contouring

Figure 12 shows a contoured map after processing data from the magnetometer.

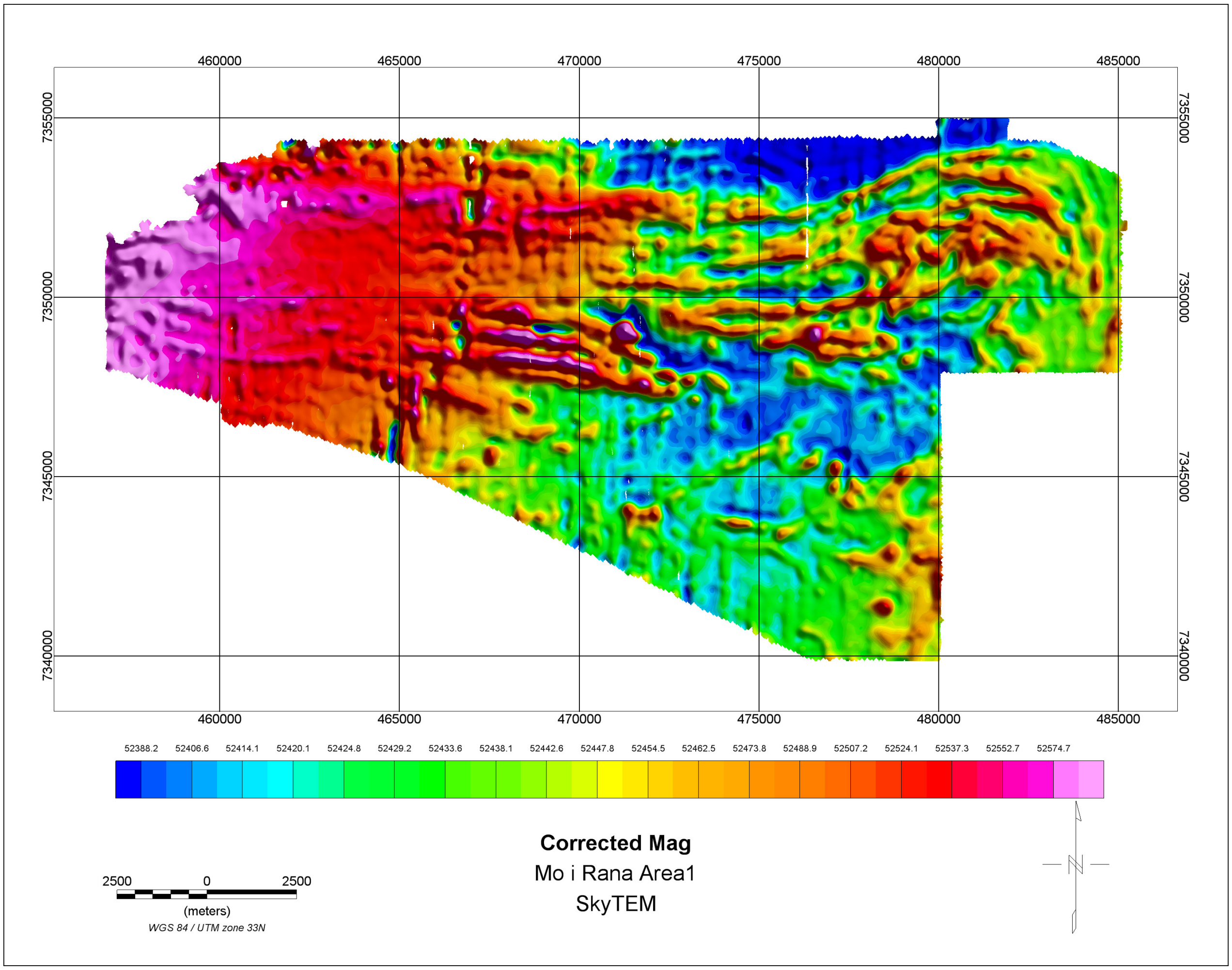

Figure 12. Total magnetic field after correction [nT]. Coordinate system UTM (WGS84) Zone 33N.

References

/1/ Sorensen, K. I. and Auken, E., 2004, SkyTEM - A new high-resolution helicopter transient electromagnetic system: Exploration Geophysics, 35, 191-199.

/2/ Christensen, N. B., 2002. A generic 1-D imaging method for transient electromagnetic data. Geophysics, 67, 438-447.

Appendix

Appendix 1: Time gates

Window	GateOpen	GateCenter	Gatewidth	GateClose	Comment
1	2.66E-06	4.47E-06	3.63E-06	6.29E-06	Not used
2	9.10E-06	1.08E-05	3.63E-06	1.27E-05	Not used
3	1.55E-05	1.72E-05	3.63E-06	1.91E-05	Not used
4	2.19E-05	2.36E-05	3.63E-06	2.55E-05	Not used
5	2.83E-05	3.00E-05	3.63E-06	3.19E-05	Not used
6	3.47E-05	3.64E-05	3.63E-06	3.83E-05	Not used
7	4.09E-05	4.60E-05	1.01E-05	5.10E-05	Not used
8	5.37E-05	5.88E-05	1.01E-05	6.38E-05	
9	6.65E-05	7.16E-05	1.01E-05	7.66E-05	
10	7.93E-05	8.76E-05	1.65E-05	9.58E-05	
11	1.00E-04	1.11E-04	2.12E-05	1.21E-04	
12	1.29E-04	1.45E-04	3.06E-05	1.60E-04	
13	1.65E-04	1.82E-04	3.34E-05	1.98E-04	
14	2.09E-04	2.32E-04	4.70E-05	2.56E-04	
15	2.63E-04	2.92E-04	5.66E-05	3.20E-04	
16	3.30E-04	3.70E-04	7.90E-05	4.09E-04	
17	4.14E-04	4.63E-04	9.78E-05	5.12E-04	
18	5.18E-04	5.79E-04	1.22E-04	6.40E-04	
19	6.48E-04	7.27E-04	1.58E-04	8.06E-04	
20	8.11E-04	9.08E-04	1.94E-04	1.01E-03	
21	1.02E-03	1.14E-03	2.46E-04	1.27E-03	
22	1.27E-03	1.43E-03	3.10E-04	1.58E-03	
23	1.59E-03	1.79E-03	3.93E-04	1.98E-03	
24	2.00E-03	2.25E-03	5.02E-04	2.50E-03	
25	2.50E-03	2.82E-03	6.29E-04	3.13E-03	
26	3.14E-03	3.53E-03	7.92E-04	3.93E-03	
27	3.94E-03	4.44E-03	9.97E-04	4.94E-03	
28	4.94E-03	5.57E-03	1.26E-03	6.20E-03	
29	6.21E-03	7.00E-03	1.59E-03	7.80E-03	
30	7.80E-03	8.80E-03	2.00E-03	9.80E-03	

The given time windows are adjusted due to the calibration time value (-1.0 µs).

Note: The gates numbered 1 to 7 are not used in the present survey.

Appendix 2: Calibration

On the 15th of october 2007 the wave form was measured for the following repetition frequencies 25 Hz. The plots below show the up and down ramp, respectively.

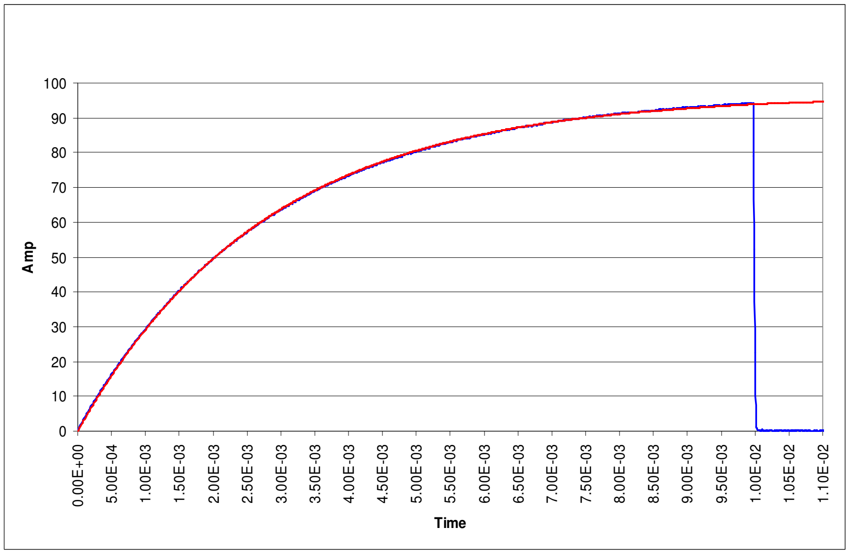

Figure 13 Ramp up at 25 Hz. Blue curve is the measured wave form. Red curve is the exponential function that fits the data. The current is 96.5 A and the decay constant τ = 360 s⁻¹.

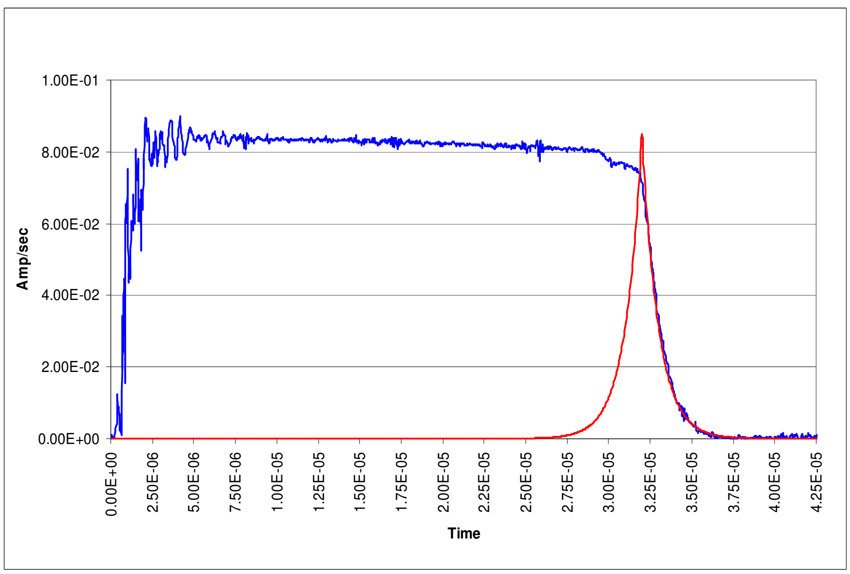

Figure 14 Ramp down at 25 Hz. Blue curve is the measured wave form. Red curve is the exponential function that fits the data. Avalanche mode 32.0 µs. Exponential mode 32.0 µs to 40.0 µs. Decay constant 1.0 E6 s⁻¹. The spikes are due to background noise, and noise in the oscilloscope while using a pickup coil for measuring the turn off.

	Parameter	Value
Ramp up	Repetition frequency	25 Hz
	Decay constant, τ	360 s^{-1}
Ramp Down	Avalanche mode	32.0 µs
	Linear ramp dI/dt	3.13 E+06 A/s
	End avalanche mode	32.0 µs
	Decay const exp mode, τ	1.0 E6 s^{-1}

The complete SkyTEM equipment has been calibrated at the National Danish Reference Site on the the 29th of June 2006. The following plots show the measured data as well as the expected response in altitudes from 0 to 30 m.

The reference data are shown as blue curves and the measured data as red curves.

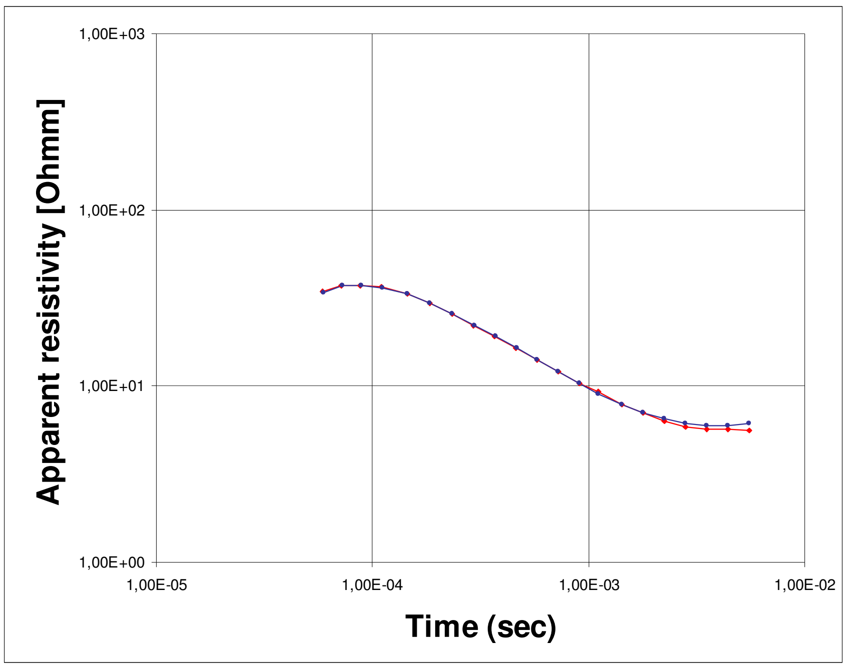

Figure 15. the 29th of June 2006. The frame is in 5 m altitude. Blue curve is the expected response, and the red curves are the actual measurements.

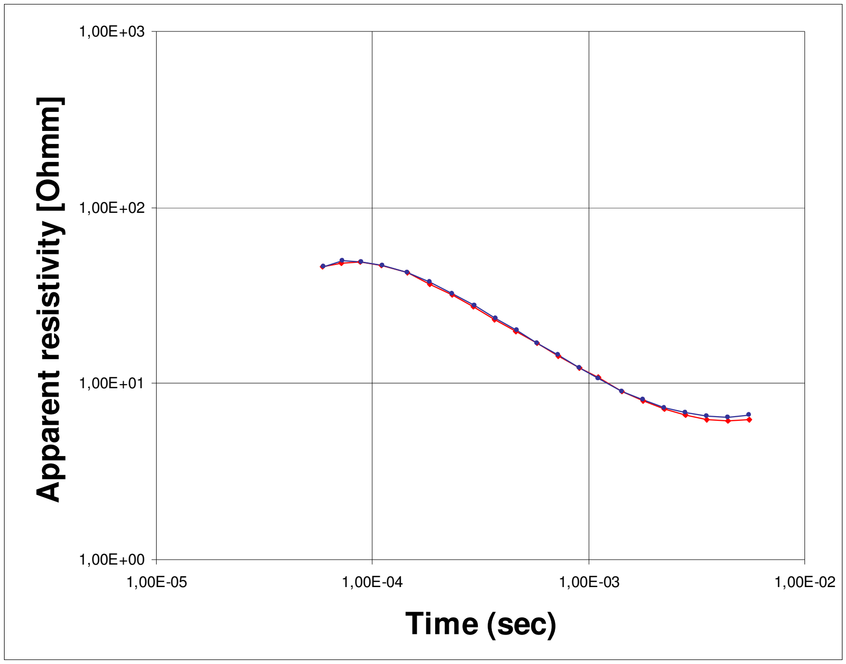

Figure 16. the 29th of June 2006. The frame is in 12.5 m altitude. Blue curve is the expected response, and the curves are the actual measurements.

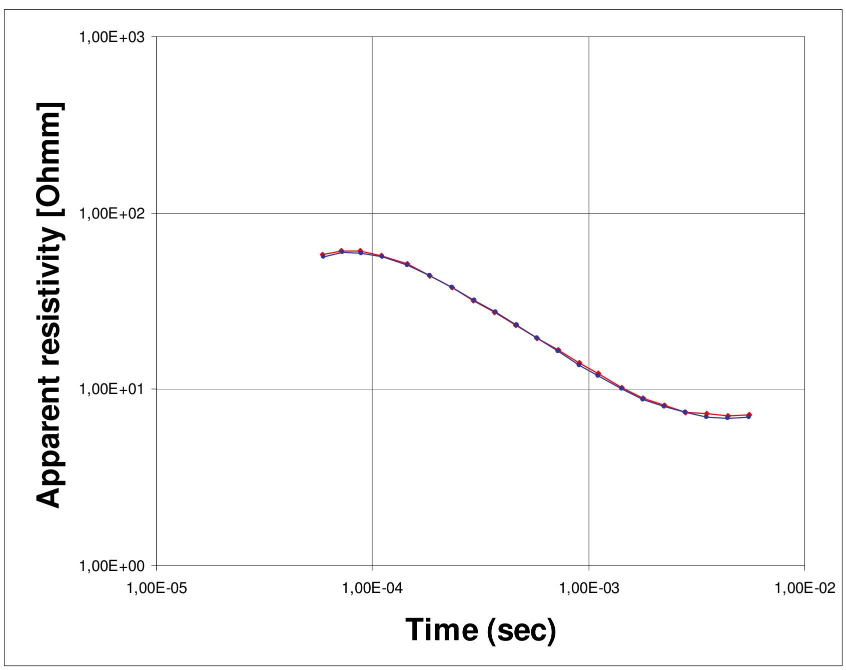

Figure 17. the 29th of June 2006. The frame is in 18 m altitude. Blue curve is the expected response, and the red curves are the actual measurements.

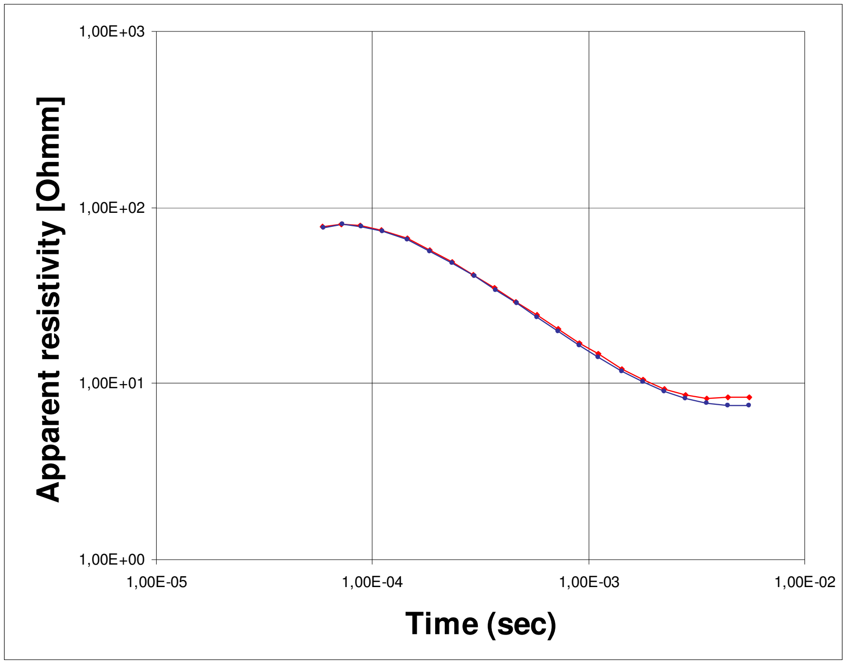

Figure 18 the 29th of June 2006. The frame is in 27 m altitude. Blue curve is the expected response and the red curves are the actual measurements.

Appendix 3: Line numbers

The line numbers are listed below together with information about the position and time for begin and end of line. The list is sorted by date and time.

Line #	Date	Time	Northing, Easting
100101	2007/08/23	13:30:16.534	188142.38,7368750.6
100101	2007/08/23	13:34:12.534	187908.28,7365750.66
100102	2007/08/31	14:48:22.310	187789.52,7365051.88
100102	2007/08/31	14:50:38.310	187922.42,7366060.03
100111	2007/08/23	13:34:42.534	188053.81,7365987.52
100111	2007/08/23	13:36:58.534	188228.26,7368336.19
100112	2007/08/31	14:52:38.310	187973.67,7365043.55
100112	2007/08/31	14:51:26.310	188039.75,7366265.22
100121	2007/08/23	13:26:24.534	188143.78,7365932.68
100121	2007/08/23	13:28:38.534	188373.59,7368131.42
100122	2007/08/31	14:56:04.310	188189.89,7365875.76
100122	2007/08/31	14:53:48.310	188065.86,7365054.93
100131	2007/08/23	13:40:32.534	188235.83,7365555.76
100131	2007/08/23	13:43:12.534	188496.58,7368165.75
100132	2007/08/31	14:56:16.310	188302.88,7365845.07
100132	2007/08/31	14:57:06.310	188185.76,7364979.46
100141	2007/08/23	13:43:22.534	188620.9,7368231.72
100141	2007/08/23	13:47:14.534	188414.37,7365540.35
100142	2007/08/31	14:58:38.310	188276.81,7364984.8
100142	2007/08/31	15:00:16.310	188434.32,7365714.75
100151	2007/08/23	13:54:26.534	188552.47,7365652.73
100151	2007/08/23	13:50:56.534	188732.15,7368166.42
100152	2007/08/31	15:01:22.310	188386.96,7364906.37
100152	2007/08/31	15:00:28.310	188571.64,7365723.59
100161	2007/08/23	13:47:30.534	188602.89,7365488.23
100161	2007/08/23	13:50:22.534	188845,7368251.75
100162	2007/08/31	15:01:44.310	188548.99,7364788.04
100162	2007/08/31	15:03:14.310	188644.1,7365618.38
100171	2007/08/23	13:58:52.534	189106.21,7368995.31
100171	2007/08/23	13:54:50.534	188735.72,7365312.85
100172	2007/08/31	15:03:24.310	188755.23,7365601.39
100172	2007/08/31	15:04:16.310	188665.99,7364741.21
100181	2007/08/23	13:59:04.534	189222.85,7369012.41
100181	2007/08/23	14:03:40.534	188802.44,7365106.22
100182	2007/08/31	15:05:06.310	188764.75,7364835.65
100182	2007/08/31	15:06:02.310	188897.6,7365372.64
100191	2007/08/23	14:03:50.534	188926.28,7365141.84
100191	2007/08/23	14:07:42.534	189326.67,7368612.56

100192	2007/08/31	15:06:14.310	189021.29,7365347.97
100192	2007/08/31	15:06:58.310	188899.18,7364631.03
100201	2007/08/23	14:13:34.534	189038.99,7364569.88
100201	2007/08/23	14:08:02.534	189466.43,7368805.97
100211	2007/08/23	14:14:10.534	189142.98,7364510.71
100211	2007/08/23	14:18:56.534	189544.96,7368754
100221	2007/08/23	14:25:08.534	189270.6,7364440.83
100221	2007/08/23	14:19:10.534	189699.78,7368775.63
100231	2007/08/23	14:25:24.534	189399.39,7364400.58
100231	2007/08/23	14:30:04.534	189883.22,7368783.98
100241	2007/08/23	14:30:40.534	189927.63,7368738.95
100241	2007/08/23	14:36:24.534	189518.91,7364367.76
100251	2007/08/23	14:37:14.534	189620.28,7364382.33
100251	2007/08/23	14:42:08.534	190082.15,7368766.59
100261	2007/08/23	14:47:28.534	189775.19,7364281.6
100261	2007/08/23	14:42:32.534	190218.35,7368782.69
100271	2007/08/23	14:52:48.534	190366.28,7368809.27
100271	2007/08/23	14:47:52.534	189891.01,7364220.35
100281	2007/08/23	15:02:12.534	189961.05,7364148.25
100281	2007/08/23	14:57:18.534	190429.11,7368780.63
100291	2007/08/23	15:07:56.534	190595.51,7368866.6
100291	2007/08/23	15:03:10.534	190101.54,7364213.86
100301	2007/08/31	15:14:48.310	190849.2,7370126.22
100301	2007/08/31	15:08:46.310	190179.36,7364080.14
100311	2007/08/31	15:15:08.310	191026.61,7370172.02
100311	2007/08/31	15:22:10.310	190323.9,7364010.58
100321	2007/08/31	15:22:44.310	190414.89,7363964.46
100321	2007/08/31	15:29:10.310	191145.69,7370263.25
100329	2007/08/26	09:51:30.390	191052.89,7370230.98
100329	2007/08/26	09:56:48.390	190577.95,7365471.49
100331	2007/08/31	15:36:44.310	190650.47,7363901.22
100331	2007/08/31	15:29:36.310	191266.69,7370240.42
100341	2007/08/31	15:43:46.310	191430.22,7370374.91
100341	2007/08/31	15:37:34.310	190691.64,7363930.8
100351	2007/08/31	15:44:08.310	191525.17,7370248.98
100351	2007/08/31	15:51:06.310	190869.95,7363781.96
100361	2007/08/26	09:59:56.390	190878.84,7363357.59
100361	2007/08/26	10:07:38.390	191635.54,7370366.11
100371	2007/08/26	10:17:12.390	190972.27,7363225.11
100371	2007/08/26	10:07:54.390	191781.97,7370360.48
100381	2007/08/26	10:25:52.390	191872.98,7370372.09
100381	2007/08/26	10:17:26.390	191114.43,7363177.86
100391	2007/08/26	10:34:28.390	191153.02,7363206.04
100391	2007/08/26	10:26:06.390	192016.18,7370399.05
100401	2007/08/26	10:34:48.390	191344.21,7363230.86

100401	2007/08/26	10:43:02.390	192110.33,7370435.92
100411	2007/08/26	10:51:50.390	191425.94,7363182.99
100411	2007/08/26	10:43:12.390	192231.4,7370469.82
100421	2007/08/26	11:00:18.390	192368.63,7370492.29
100421	2007/08/26	10:52:18.390	191560.65,7363157.24
100431	2007/08/26	11:00:32.390	192549.42,7370515.68
100431	2007/08/26	11:09:20.390	191758.52,7363133.75
100441	2007/08/26	11:17:44.390	192672.83,7370478.84
100441	2007/08/26	11:09:58.390	191901.88,7363107.51
100451	2007/08/26	11:27:30.390	191996.11,7363127.11
100451	2007/08/26	11:18:34.390	192709.65,7370373.06
100461	2007/08/26	11:29:14.390	192119.25,7363185.07
100461	2007/08/26	11:37:12.390	192917.79,7370437.71
100471	2007/08/26	14:53:37.457	193001.94,7370593.59
100471	2007/08/26	15:02:29.457	192462.78,7364776.51
100472	2007/08/26	15:08:43.457	192264.61,7363081.95
100472	2007/08/26	15:05:51.457	192518.82,7365598.44
100481	2007/08/26	15:09:43.457	192373.66,7363083.09
100481	2007/08/26	15:18:51.457	193154.66,7370842.3
100491	2007/08/26	15:18:59.457	193252.98,7370829.57
100491	2007/08/26	15:30:59.457	192517.99,7363032.76
100501	2007/08/26	15:40:59.457	193442.97,7370867.16
100501	2007/08/26	15:32:03.457	192600.67,7362974.49
100511	2007/08/26	15:52:53.457	192781.87,7362896.88
100511	2007/08/26	15:41:29.457	193552.85,7370825.22
100521	2007/08/26	16:07:39.457	193464.86,7369103.28
100521	2007/08/26	16:04:25.457	193651.4,7370821.57
100522	2007/08/26	15:54:05.457	192849.68,7362894.03
100522	2007/08/26	16:00:27.457	193501.72,7369127.86
100531	2007/08/26	16:29:21.457	193781,7370822.6
100531	2007/08/26	16:32:57.457	193575.35,7368765.01
100532	2007/08/26	16:15:41.457	192987.7,7362831.06
100532	2007/08/26	16:08:27.457	193579.59,7368728.39
100541	2007/08/26	16:24:31.457	193896.74,7370416.85
100541	2007/08/26	16:16:45.457	193087.62,7362749.03
100551	2007/08/26	16:36:07.457	193996.98,7370621.51
100551	2007/08/26	16:47:01.457	193234.39,7362693.87
100561	2007/08/26	16:55:05.457	194175.31,7370361.47
100561	2007/08/26	16:47:51.457	193335.46,7362660.11
100571	2007/08/27	08:36:24.261	194314.41,7370791.68
100571	2007/08/27	08:45:06.261	193501.39,7362595.45
100581	2007/08/27	08:54:42.261	194402.5,7370774.61
100581	2007/08/27	08:46:02.261	193570.18,7362575.45
100582	2007/08/27	10:56:30.383	193613.29,7362549.4
100582	2007/08/27	10:51:26.383	194112.23,7368051.71

100591	2007/08/27	09:00:50.261	193952.41,7365081.37
100591	2007/08/27	08:54:56.261	194559.6,7370754.36
100592	2007/08/27	10:49:30.383	194172.47,7367246.37
100592	2007/08/27	10:44:32.383	193713.95,7362496.17
100601	2007/08/27	10:35:20.383	194557.11,7370478.92
100601	2007/08/27	10:43:26.383	193841.26,7362416.11
100611	2007/08/27	11:07:18.383	194755.34,7370745.84
100611	2007/08/27	10:57:48.383	193899.47,7362411.2
100621	2007/08/27	11:07:52.383	194889.56,7370735.53
100621	2007/08/27	11:16:48.383	194084.58,7362331.58
100631	2007/08/27	11:27:02.383	195051.42,7370726.12
100631	2007/08/27	11:17:50.383	194181.77,7362287.16
100641	2007/08/27	11:36:40.383	194316,7362212.66
100641	2007/08/27	11:27:54.383	195157.33,7370692.77
100651	2007/08/27	11:37:24.383	194484.73,7362169.19
100651	2007/08/27	11:46:32.383	195277.08,7370667.43
100661	2007/08/27	11:50:52.383	195123.69,7368178.6
100661	2007/08/27	11:47:24.383	195409.4,7370664.54
100662	2007/08/27	12:03:46.383	194550.77,7362103.17
100662	2007/08/27	11:54:56.383	195373.27,7370633.13
100671	2007/08/27	12:04:40.383	194687.66,7362074.53
100671	2007/08/27	12:14:08.383	195485.18,7370652.56
100681	2007/08/27	12:24:28.383	194803.95,7362030.64
100681	2007/08/27	12:15:14.383	195621.73,7370643.82
100691	2007/08/27	12:35:06.383	195740.25,7370624.6
100691	2007/08/27	12:25:24.383	194893.29,7361969.26
100701	2007/08/27	12:35:30.383	195896.14,7370625.89
100701	2007/08/27	12:44:08.383	195010.07,7362098.53
100711	2007/08/27	12:45:12.383	195117.71,7361852.98
100711	2007/08/27	12:55:36.383	195995.37,7370616.52
100721	2007/08/27	13:04:36.383	195289.16,7361770.88
100721	2007/08/27	12:55:58.383	196129.18,7370587.23
100731	2007/08/27	13:15:46.383	196290.06,7370482.6
100731	2007/08/27	13:05:28.383	195352.13,7361763.46
100741	2007/08/27	13:24:46.383	195547.97,7361688.61
100741	2007/08/27	13:15:56.383	196407.12,7370489.72
100751	2007/08/27	13:25:28.383	195701.51,7361635.43
100751	2007/08/27	13:36:20.383	196493.19,7370560.6
100761	2007/08/27	15:46:08.232	195788.91,7361518.95
100761	2007/08/27	15:37:28.232	196618.61,7370456.59
100771	2007/08/27	15:59:20.232	196824.63,7370489.19
100771	2007/08/27	15:46:44.232	195871.42,7361480.69
100781	2007/08/27	16:08:30.232	195982.65,7361449.98
100781	2007/08/27	15:59:28.232	196927.09,7370520.7
100791	2007/08/27	16:22:42.232	197013.39,7370566.44

100791	2007/08/27	16:09:22.232	196122.86,7361384.91
100801	2007/08/27	16:32:38.232	196250.15,7361310.93
100801	2007/08/27	16:23:18.232	197152.83,7370540.74
100811	2007/08/27	16:33:40.232	196324.78,7361247.61
100811	2007/08/27	16:48:06.232	197234,7370496.57
100821	2007/08/27	16:58:10.232	196479.06,7361187.21
100821	2007/08/27	16:48:28.232	197384.79,7370512.86
100831	2007/08/27	17:12:08.232	197518.79,7370530.65
100831	2007/08/27	16:59:14.232	196616.58,7361090.03
100841	2007/08/27	17:22:10.232	196691.63,7361031.27
100841	2007/08/27	17:12:34.232	197688.24,7370495.21
100851	2007/08/27	17:36:54.232	197779.85,7370486.85
100851	2007/08/27	17:22:54.232	196834.92,7360939.99
100861	2007/08/28	08:40:06.872	196990.6,7360839.17
100861	2007/08/28	08:29:44.872	197883.58,7370472.35
100871	2007/08/28	08:51:14.872	198084,7370431
100871	2007/08/28	08:41:06.872	197066.15,7360798.34
100881	2007/08/28	09:02:14.872	197189.52,7360736.61
100881	2007/08/28	08:51:26.872	198236.62,7370411.33
100891	2007/08/28	09:03:06.872	197287.11,7360671.63
100891	2007/08/28	09:13:02.872	198252.24,7370401
100901	2007/08/28	09:24:18.872	197436.55,7360585.32
100901	2007/08/28	09:13:24.872	198506.21,7370380.04
100911	2007/08/28	09:35:06.872	198677.55,7370352.77
100911	2007/08/28	09:25:02.872	197541.19,7360549.1
100921	2007/08/28	09:46:34.872	197646.11,7360447.3
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200411	2007/09/19	08:54:41.120	215867.95,7363105.5
200421	2007/09/19	08:50:11.120	211071.22,7363444.15
200421	2007/09/19	08:46:03.120	215848.48,7362973.6
200431	2007/09/19	08:45:33.120	215832.44,7362859.69
200431	2007/09/19	08:41:30.120	211000.82,7363338.31
200441	2007/09/19	08:36:43.120	215812.41,7362732.19
200441	2007/09/19	08:41:01.120	210940.66,7363201.23
200451	2007/09/19	08:36:09.120	215807.67,7362605.49
200451	2007/09/19	08:31:58.120	210879.62,7363086.85
200461	2007/09/19	08:27:00.120	215762.51,7362504.11
200461	2007/09/19	08:31:27.120	210819.85,7362955.27
200471	2007/09/19	13:01:56.157	188160.36,7365000.34
200471	2007/09/19	12:43:06.157	210897.79,7362842.14
200472	2007/09/19	08:22:29.120	210854.62,7362868.65
200472	2007/09/19	08:26:26.120	215772.07,7362353.47
200481	2007/09/19	13:22:10.157	210664.44,7361836.18
200481	2007/09/19	13:04:53.157	191025.52,7363749.48

200491	2007/09/19	13:37:02.157	193860.81,7362460.39
200491	2007/09/19	13:23:24.157	210603.72,7360842.95
200501	2007/09/20	07:43:35.167	210590.63,7360738.02
200501	2007/09/20	07:45:25.167	208569.25,7360927.03
200511	2007/09/20	07:41:25.167	208545.81,7360795.06
200511	2007/09/20	07:43:08.167	210584.32,7360601.59
200521	2007/09/20	07:40:55.167	208543.13,7360670.7
200521	2007/09/20	07:39:09.167	210557.77,7360476.62
200531	2007/09/20	07:36:54.167	208536.43,7360571.54
200531	2007/09/20	07:38:37.167	210561.85,7360362.71
200541	2007/09/20	07:36:25.167	208533.67,7360419.16
200541	2007/09/20	07:34:39.167	210528.26,7360238.3
200551	2007/09/20	07:34:15.167	210535.09,7360096.44
200551	2007/09/20	07:32:31.167	208514.47,7360312.35
200561	2007/09/20	07:30:02.167	210494.52,7360009.12
200561	2007/09/20	07:32:00.167	208500.04,7360161.68
200571	2007/09/19	13:51:54.157	210509.67,7359847.89
200571	2007/09/19	13:39:54.157	196456.15,7361213.12
200581	2007/09/19	15:17:00.157	210481.51,7359681.6
200581	2007/09/19	15:19:09.157	208455.49,7359937.39
200591	2007/09/19	15:14:56.157	208467.87,7359773.48
200591	2007/09/19	15:16:39.157	210478.5,7359590.67
200601	2007/09/19	15:12:37.157	210461.98,7359457.5
200601	2007/09/19	15:14:42.157	208442.74,7359672.22
200611	2007/09/19	15:12:20.157	210452.94,7359346.63
200611	2007/09/19	15:10:40.157	208461.88,7359554.91
200621	2007/09/19	15:08:20.157	210441.92,7359225.58
200621	2007/09/19	15:10:11.157	208423.68,7359428.61
200631	2007/09/19	15:07:55.157	210448.79,7359100.88
200631	2007/09/19	15:06:18.157	208438.89,7359312.4
200641	2007/09/19	15:05:55.157	208395.43,7359184.52
200641	2007/09/19	15:03:54.157	210404.85,7358950.01
200651	2007/09/19	14:04:18.157	198413.9,7360012.84
200651	2007/09/19	13:53:28.157	210414.03,7358865.14
200661	2007/09/19	15:01:38.157	208388.32,7358934.35
200661	2007/09/19	15:03:22.157	210416.22,7358721.61
200671	2007/09/19	15:01:18.157	208362.5,7358804.14
200671	2007/09/19	14:59:18.157	210389.11,7358611.23
200681	2007/09/19	14:57:12.157	208340.28,7358679.06
200681	2007/09/19	14:58:57.157	210392.8,7358484.65
200691	2007/09/19	14:54:47.157	210366.47,7358337.4
200691	2007/09/19	14:56:53.157	208337.3,7358549.09
200701	2007/09/19	14:52:39.157	208338.36,7358437.26
200701	2007/09/19	14:54:25.157	210367.18,7358236.6
200711	2007/09/19	14:52:19.157	208313.25,7358311.52

200711	2007/09/19	14:50:17.157	210344.13,7358125.1
200721	2007/09/19	14:49:59.157	210325.72,7357977.54
200721	2007/09/19	14:48:10.157	208345.24,7358190.61
200731	2007/09/19	14:15:10.157	210322.06,7357858.8
200731	2007/09/19	14:06:47.157	200391.33,7358789.04
200741	2007/09/19	14:45:42.157	210303.63,7357727.94
200741	2007/09/19	14:47:33.157	208273.41,7357932.88
200751	2007/09/19	14:45:22.157	210302.07,7357604.02
200751	2007/09/19	14:43:39.157	208270.21,7357796.89
200761	2007/09/19	14:41:23.157	210289.43,7357460.22
200761	2007/09/19	14:43:20.157	208246.94,7357678.99
200771	2007/09/19	14:41:05.157	210277.23,7357342.12
200771	2007/09/19	14:39:17.157	208210.45,7357544.79
200781	2007/09/19	14:36:55.157	210255.79,7357249.3
200781	2007/09/19	14:38:51.157	208227.44,7357421.97
200791	2007/09/19	14:36:33.157	210262.31,7357104.2
200791	2007/09/19	14:34:46.157	208232.21,7357335.1
200801	2007/09/19	14:34:16.157	208203.2,7357171.09
200801	2007/09/19	14:32:20.157	210247.45,7356988.93
200811	2007/09/19	14:16:30.157	210184.99,7356814.16
200811	2007/09/19	14:23:47.157	202421.65,7357619.92
200821	2007/09/19	14:25:56.157	204470.52,7356410.91
200821	2007/09/19	14:31:14.157	210148.08,7355864.32

Appendix 4: Control parameters

The following plots show the speed, altitude and the angle of the frame for every flight. Variations in the current, voltage on the transmitter and transmitter temperature are also shown.

The green line, depicting processed frame height, shows the input from HE1 and HE2 after the frame has been corrected from deviations, away from the horizontal plane and any obstacles on the ground e.g. trees. The processed frame height is the one used in the inversion routine.

Note the time scaling at the x-axis differs between the plots.

Turns at the end of flight lines and transport are shown as gaps in the bottom of the display

Appendix 5: Modeling and Inversion of the TEM Data

In this section, the particulars of modeling and inversion of TEM data will be described.

The model

The model used for inversion of the TEM data is a multi-layer model (MLM) with 30 layers. The layer thicknesses increase downwards as a hyperbolic sine. I.e. the depth to the layer boundaries increases linearly for small depths, thus the top layers are all of approximately the same thickness, and the depth to the layer boundaries increases exponentially with depth for large depths, so that the thickness of a layer is a factor times the previous one. The top layer is 10 m thick, and the asymptotic exponential factor is 1.25, corresponding to 10 layers per decade. The layer thicknesses and layer boundary depths are seen in the table below. The vertical smoothness constraint on the MLM imposing identity between neighboring layers has a relative uncertainty of 0.5.

Inversion - The initial model

The initial model for all inversions is the previously mentioned 30-layer MLM with a resistivity of 200 Ωm in all layers, i.e. the initial model is essentially a homogeneous half space. Throughout, we have used the L_1-norm in the optimization to produce as blocky models as possible.

Data and noise model

The inaccuracy of TEM data is caused by ambient noise. This noise is reduced by stacking delay time series, and by applying appropriate filters in the receiver system.

For TEM data recorded at middle latitudes on the northern hemisphere, experience shows that the noise consists of two types of contributions: one source comes from single frequency radio transmitters, and the other is an ambient wideband noise. The width of the time gates of the SkyTEM system increase approximately exponentially with delay time which helps reduce the effective noise. The single frequency noise is dominated by transmitters with frequencies above 10 kHz, and as such dominating at delay times earlier than 100 μs. The effect of exponential gating is to make this noise decrease with time, t, as $1/t$. For the wideband noise, the exponential gating makes the effective noise decrease as $1/\sqrt{t}$, and this noise dominates at times later than 100 μs. Our noise model is expressed as a sum of the two contributions, and it can be characterized by two parameters: the time, t_0, when the two contributions are of equal size and the amplitude at that time, $V_0 = V(t_0)$.

The noise is assumed to be partly a $1/t$ noise from radio transmitters, and partly

$1/\sqrt{t}$ noise from log gated ambient sources. The two contributions are assumed to be independent, so we have:

$$V = \sqrt{\left(\frac{a}{t}\right)^2 + \left(\frac{b}{\sqrt{t}}\right)^2} \qquad (1)$$

If we assume the two terms to be of equal (squared) weight at the transition point t_0, we find

$$\left(\frac{a}{t}\right)^2 = \left(\frac{b}{\sqrt{t_0}}\right)^2 \Rightarrow \left(\frac{b}{a}\right)^2 = \left(\frac{\sqrt{t_0}}{t_0}\right)^2 = \frac{1}{t_0} \Rightarrow b = \frac{a}{\sqrt{t_0}} \qquad (2)$$

With these assumptions, the noise function is uniquely given by its value at the transition point, V_0.

$$\begin{aligned} V &= \sqrt{\left(\frac{a}{t}\right)^2 + \left(\frac{b}{\sqrt{t}}\right)^2} = \frac{a}{t}\sqrt{1 + \left(\frac{a}{\sqrt{t_0}\sqrt{t}} \cdot \frac{t}{a}\right)^2} \\ V &= \frac{a}{t}\sqrt{1 + \frac{t}{t_0}} = V_0 \quad for \quad t = t_0 \Rightarrow a = \frac{V_0 t_0}{\sqrt{2}} \Rightarrow \\ V &= \frac{V_0}{\sqrt{2}} \frac{t_0}{t} \sqrt{1 + \frac{t}{t_0}} \end{aligned} \qquad (3)$$

The parameters V_0 and t_0 can be pragmatically determined for a given data set.

Data insufficiency

For SkyTEM data, the insufficiency lies primarily in the limited delay time range that can be obtained. The earliest obtainable time gate is determined by the turn-off of the Tx current, and the latest useful time gate is determined by the signal to noise ratio. Increasing the Tx moment will give better measurements at late times, and thus improve the depth penetration, but an increased Tx moment will increase the turn-off time and thus remove early-time gates, thereby making the near-surface resolution poorer. This trade-off is often solved by alternating transmitting a low moment that can be turned off quickly to give good near-surface resolution, and a high moment that will improve the signal-to-noise ratio at late times, thus improving depth penetration.

Appendix 6: Model sections and conductivity and resistivity intervals

Model sections, conductivity and resistivity interval maps for Area 1 can be found in digital form as pdf files.

Model Sections

The top plot in the model sections shows the inverted models with topography where the conductivity and resistivity of the individual layers are color coded according to the color bar. The actual flight elevation is shown with a black dotted line above the model section.

The flight lines have been superimposed to straight lines running from begin to end of a flight line. The profile coordinate gives the distance along the line in meters.

The conductive features of the model sections are emphasized by using color coding that shows conductivity on a linear scale. The resistivity (the inverse of conductivity) is shown on a logarithmic scale, thus conductive and resistive feature appear with the same weight.

Below the model section is a plot of the relative uncertainty of the model. Red indicates where data has contributed perceptibly to the determination of the conductivity. Blue indicate where conductivity or resistivity is more determined by the smoothness constraint (i.e. the vertical constraint) than the data

Below the plot of relative uncertainties is a plot of the residuals of the inversions: blue indicates the data residual and green the total residual.

The gate plot at the bottom shows the forward response compared to the actual values of chosen gate numbers.

Average conductivity and resistivity intervals

For the complete survey area - or parts thereof - so-called interval conductivity/ resistivity maps are produced by contouring the average conductivity and resistivity in a certain depth or elevation interval.

Appendix 7: Digital data

The digital data are:

- *Report*

  The report and appendices (PDF-format)

- *Line File*

  Ascii line file (line number, time, coordinate (Latitude/longitude, WGS84))

- *XYZ TEM data file*

  XYZ ascii files containing the “raw” TEM data

- *XYZ TEM Model result*

  XYZ ascii files containing the TEM model result

- *XYZ Magnetometer data*

  XYZ ascii files containing the magnetometer data

- *MapInfo TAB files*
  - Planned flight lines
  - Interval conductivity and resistivity maps
  - Contoured magnetometer data
  - Contoured DTM
  - Contoured Raw Channel plots of selected channels