DATA REPORT

SkyTEM Survey:

Paso Robles Basin SkyTEM312M,
California, USA

Client: San Luis Obispo County Flood Control
and Water Conservation District

Date: October 2020

AIRBORNE SURVEYS WORLDWIDE

SKYTEM SURVEYS APS
DYSSEN 2
8200 AARHUS N, DENMARK

TEL: +45 8620 2050
VAT: 27704379

WWW.SKYTEM.COM
INFO@SKYTEM.COM

Structure of the Digital Data Delivery catalogue

Folder	Sub folder	Sub folder	File format	Content
01_Data	01_GDB		.gdb (Geosoft database)	Data in Geosoft format
	02_ Workbench_ SKB	01_Rawdata	Flight number: .skb .sps	Workbench data in skb format
		02_Mask	.lin	
		03_Geo	skb.gex .sr2	
	03_Workbench_XYZ		.xyz .alc .xyz.gex	Workbench data in SkyTEM-xyz format
02_Grids	01_EM	01_LMZ 02_HMZ	.grd (Geosoft grids)	EM Z channels Corrected for height variations
	02_DEM_Powerline		.grd (Geosoft grids)	DEM & PLNI
	03_MAG		.grd (Geosoft grids)	Magnetic data (TMI and RMF)
03_Maps			.map (Geosoft maps) .pdf	Planned flightlines Flight path DEM Powerline Monitor Magnetic data (TMI and RMF)
04_Report			.pdf	Data report

Contents

Abbreviations Table

μs:	microsecond
A/Amp:	Ampere
Base Station:	ground monitoring station used to correct or verify data
dB/dt:	change in amplitude of magnetic field over the time it takes to make that change
C:	degrees Celsius
DGPS:	Differential Global Positioning System
EM:	Electromagnetic
Gate Time:	A small amount of time over which the amplitude of the decaying magnetic field is measured and output as a data channel.
GDB:	Geosoft database
GMT:	Greenwich Mean Time
HA:	high altitude, a flying height such that the return ground EM signal is greatly reduced or eliminated.
HM:	High Moment EM dB/dt data
Hz:	Hertz
IGRF:	International Geomagnetic Reference Field
l-km:	line kilometer
LM:	Low moment EM dB/dt data
Km	Kilometers
Kph:	Kilometers per hour
LM:	Low Moment
M. a .sl.:	meters above sea level
m	meter
NIA:	strength of generated EM field, i.e. dipole moment. Where *I* is the current in the transmitter, *A* is the area of the transmitter and *N* is the number of turns of wire
nT:	nanotesla
PFC:	primary field Compensation
PLNI:	Power Line Noise Intensity
pV:	pico volts
RX:	EM Receiver
TEM:	Time-domain (transient) Electromagnetic
TX:	EM Transmitter
UTC:	Coordinated Universal Time
UTM:	Universal Transverse Mercator coordinate system
V:	Volts
X data:	measurement of the horizontal component of the secondary magnetic field
Z data:	measurement of the vertical component of the secondary magnetic field
ρ:	Resistivity
Ω:	ohm

Executive Summary

This report covers data acquisition, technical specifications, data processing and presentation of the SkyTEM312M survey flown in the period from November 5th to November 7th, 2019 in the Paso Robles Basin, California. The survey is comprised of 856 km planned flight lines in total.

The SkyTEM312M collects time domain electromagnetic and magnetic data along with supporting navigation measurements.

All material is delivered digitally. The final product includes:

- Data report
- Processed data as Geosoft database file format
- Grids and maps in Geosoft format
- Raw data files and Workbench input files

An overview of the digital data delivery can be seen on the front inside cover of this report.

Introduction

The SkyTEM electromagnetic and magnetic survey described in this report was flown with the SkyTEM312M system. The survey is requested by San Luis Obispo County and performed by SkyTEM Canada Inc.. Basic survey information and key personnel are listed in Table 1.

This report covers data acquisition, instrument descriptions, data processing and presentations. The data delivery includes processed magnetic and electromagnetic data and presentations, spatially constrained inversion results and model presentations. The digital data delivery folder is described in the front inside cover of this report.

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

San Luis Obispo County (Client) Client Contact person	 Catherine Martin Email: cmmartin@co.slo.ca.us
Client Consultant	Max Halkjaer Email: maxh@ramboll.dk
SkyTEM Canada Inc (Contractor) Contact person Project Manager Field Crew	 Bill Brown Email: bb@skytem.com Doug Garrie P.Geo. Email: dga@skytem.com Jennifer Blanchard Raymond Caron
Sinton Helicopters (Helicopter operator) Helicopter type Pilot	 Eurocopter Astar 350 B3 Scott Sinton
Data acquisition period	November 5th to November 7th, 2019
Data processing, presentations and report	Doug Garrie P.Geo.

Table 1: Key personnel and survey information.

Survey outline

The survey area is located near the Paso Robles Basin, California and was flown from November 5th to November 7th, 2019.

Planned and flown line-kilometres (l-km) are listed in Table 2. Line numbering is listed in Table 3.

Flown flight lines are shown on Figure 1. Actual flown lines (red lines) versus planned lines (blue lines) are presented on Figure 2.

Discrepancies between planned and flown lines occur where obstacles on the ground or weather necessitates a diversion.

Traverse line spacing was generally at 500m but several lines of irregular spacing and direction were flown. Tie lines were not flown for this project. A repeat line was flown daily for this project. Four infill lines were added during data acquisition.

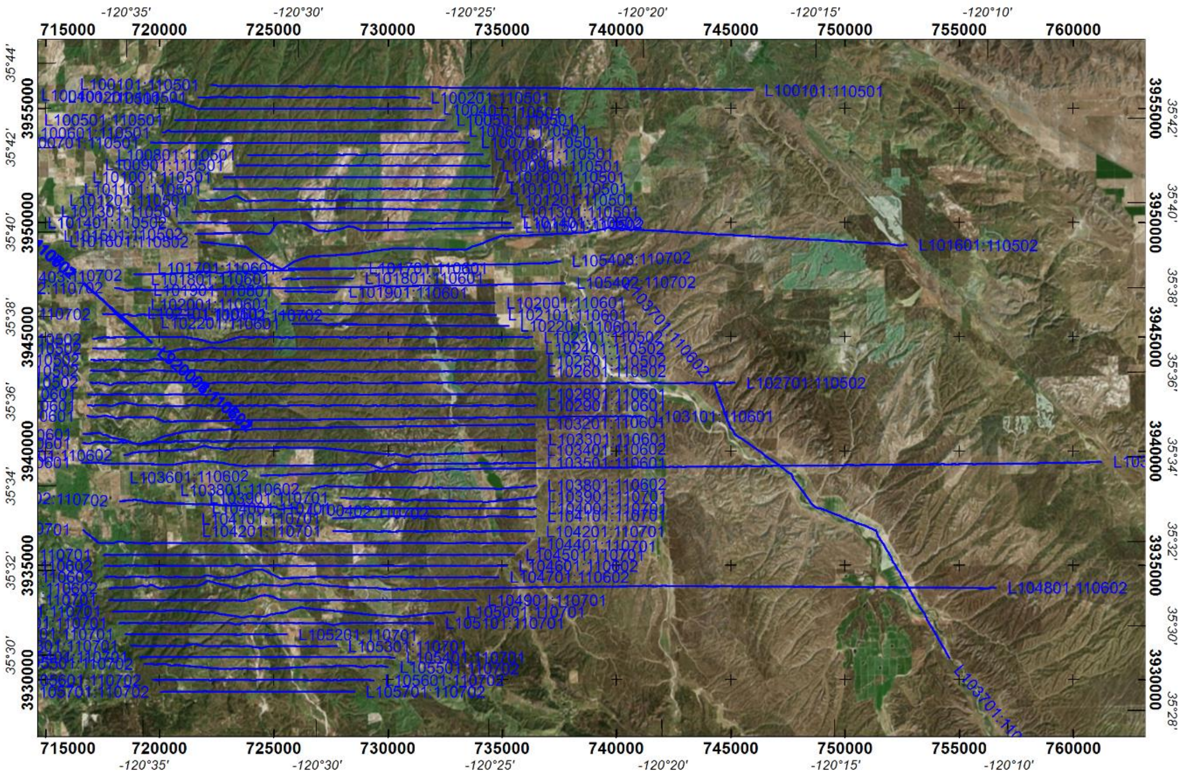
The coordinate system is kept in UTM Zone 10N (WGS84) throughout this report and the digital data delivery.

Area name	General Traverse spacing (m)	General Traverse direction (deg)	Planned Flight lines (km)	Flown Flight lines (km)
Paso Robles Basin	500 m	90°/270°	805.0	811.8
Repeat lines	NA		-	23.5
Infill lines	variable		51.0	50.1
Total Line km			**856 km**	**885.4 km**

Table 2: Planned and actual survey details.

Area	Line numbering
Paso Robles Basin	L1004101 – L105701
Repeat Line	L920001 – L920005
Infill	L100101 L100402 L105402 L105403

Table 3: Line numbering.



SKYTEM

Scale 1:200000

2500 0 2500 5000

metres

WGS 84 / UTM zone 10N

Airborne Geophysical Survey

In the region of:

Paso Robles Basin (CA)

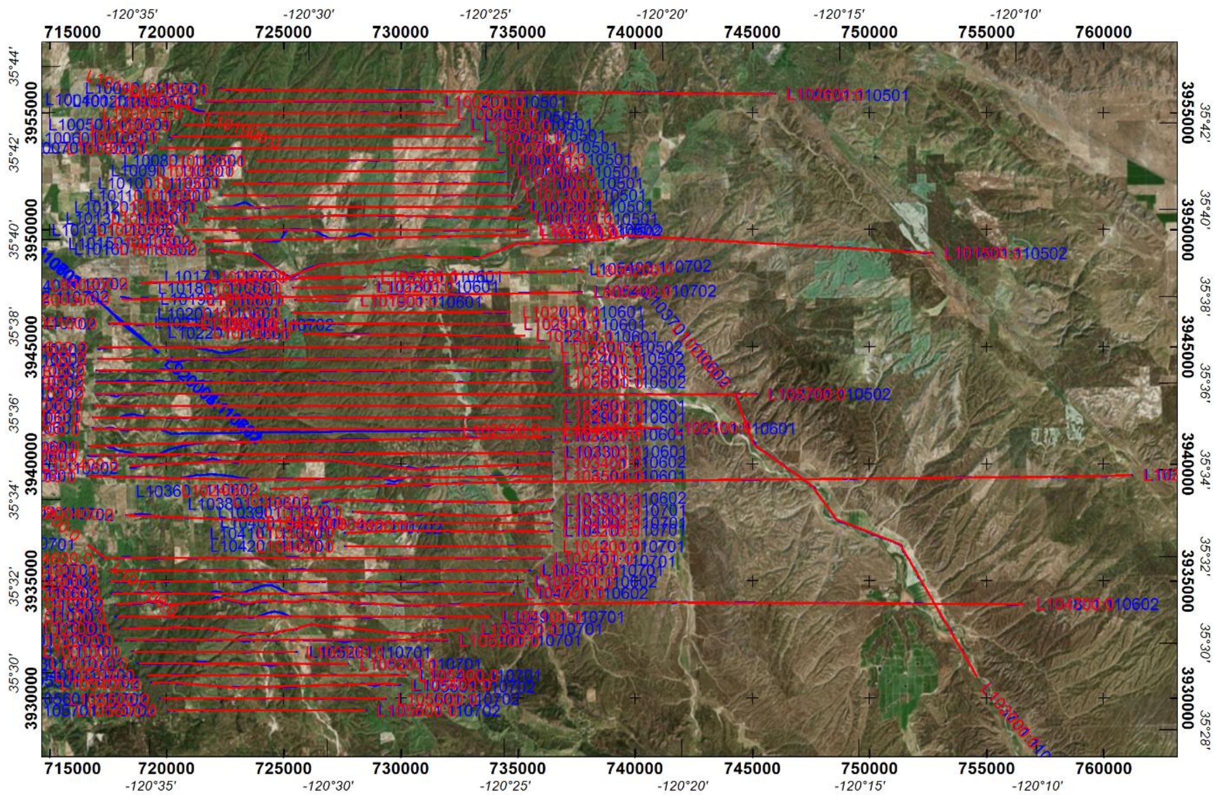
Flight Path

Client: San Luis Obispo County Flood Control and Water Conservation District

Contractor: Skytem Canada Inc.

2019/12/06

Figure 1: Survey outline. Paso Robles Basin, Flown survey lines.



Scale 1:200000

2500 0 2500 5000

metres

WGS 84 / UTM zone 10N

Airborne Geophysical Survey

In the region of:

Paso Robles Basin (CA)

Planned Survey Lines

Client: San Luis Obispo County Flood Control and Water Conservation District

Contractor: Skytem Canada Inc.

2019/12/06

Figure 2: Paso Robles Basin, Flown lines (blue) superimposed on planned lines (red).

Flight Parameters

The average terrain clearance was 73.6 m, with an increase due to steep terrain, power lines, or any other obstacles or hazards on the ground. The safe flying height during the survey is always based on the pilot's assessment of risk and deviations from nominal values are at the discretion of the pilot.

The nominal production airspeed is 70 - 110 kph for a flat topography with no wind. This may vary in areas of rugged terrain and/or windy conditions.

Average values and standard deviations of survey flight parameters are found in Table 4:

Control parameter		Average Value	Standard Deviation
Ground speed*)		85.4 kph	7.1 kph
Processed height		50.3 m	12.3 m
Tilt angle	X	0.3 degrees	2.5 degrees
	Y	0.57 degrees	1 degrees
Tx Voltage	Tx_off	71 V	-
	Tx_on	67 V	-
Low Moment Current		6.6 A	0 A
High Moment Current		112.8 A	2.4 A
Tx temperature		25 °C	-

**) Actual speed varies as a function of day and flight direction due to different wind directions and magnitude.*

Table 4: Flight parameters for the area.

Flight Reports

For each flight, a report with key information regarding the data acquisition is made in the field. Listed in the reports are details on the weather, special data parameters and other events which may influence data. Selected information from the flight reports are shown in Table 5 and Table 6.

Flight	Comments
20191104.03	HA (high altitude) calibration flight
20191105.01	Production
20191105.02	Production
20191106.01	Production
20191106.02	Production
20191107.01	Production
20191107.02	Production + extra flight lines (vineyards)

Table 5: Flight report.

Flight	Temperature (C)	Wind (m/s)	Visibility	Description
20191104.03	25	10	Okay	Sunny, hazy
20191105.01	18	10	Okay	Sunny, hazy
20191105.02	27	10	Okay	Sunny, hazy
20191106.01	10	10	Okay	Sunny, hazy
20191106.02	26	10	Okay	Sunny, hazy
20191107.01	10	10	Okay	Sunny, hazy
20191107.02	25	10	Okay	Sunny, hazy

Table 6: Weather report.

Instruments

This section provides an overview of airborne as well as ground base instruments, thorough technical descriptions are provided in Appendix 1.

Airborne unit

The airborne instrumentation comprising a SkyTEM312M system includes a time domain electromagnetic system, a magnetic data acquisition system and an auxiliary data acquisition system containing two inclinometers, two altimeters and two DGPS’. All instruments are mounted on the frame suspended ~40 m below the helicopter. The generator used to power the transmitter is suspended between the frame and the helicopter about 30 m below the helicopter. A picture of the airborne SkyTEM312M unit is seen on Figure 3, and a sketch of the instrumentation is seen on Figure 4.

Figure 3: SkyTEM312M Airborne unit.

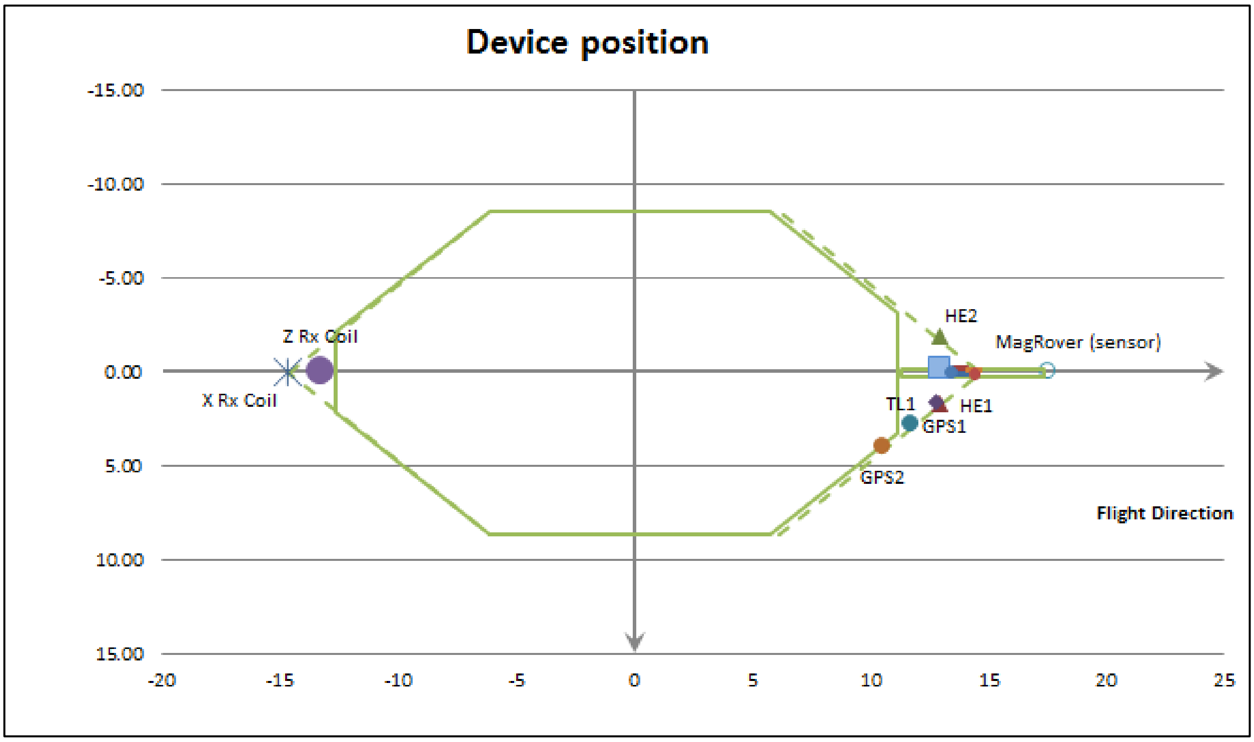


Figure 4: Sketch showing the frame and the position of the basic instruments. The green line defines the transmitter loop. The horizontal plane is defined by (x,y).

Ground base stations

The DGPS and magnetic base stations were positioned in the vicinity of the survey area at Pasco Robles Municipal Airport.

DGPS base station

DGPS base stations were placed at a location of maximum possible view to satellites and away from metallic objects that could influence the GPS antenna.

Table below shows the location of the DGPS base station:

Area	Easting (m)	Northing (m)	Ellipsoidal height (m)
California	713745.17	3949614.86	214.5 m

Magnetometer base station

The base station magnetometer was placed in a location of low magnetic gradient, away from electrical transmission lines and moving metallic objects, such as motor vehicles and aircrafts.

The table below shows the location of the magnetic base station:

Magnetometer Base station	Easting (m)	Northing (m)	Elevation (m)
California	713761.73	3949603.14	213.6 m

Data Acquisition

The SkyTEM312M system setup is a dual moment configuration containing a Low Moment (LM) with a peak moment of ~4,100 NIA and a High Moment (HM) with a peak moment of ~ 450,000 NIA. Where *I* is the current in the transmitter, *A* is the area of the transmitter and *N* is the number of turns of wire.

A dual moment system provides a major advantage over single moment systems in that it is possible to measure a wider range of time gates. In LM mode early time gates can be measured allowing more accurately resolution in the near surface while in the HM mode, deep penetration can be achieved.

Data from two GPS receivers are recorded by the EM data acquisition system while a third GPS is recorded by the magnetic data acquisition system.
The DGPS system is used for time stamping, positioning, and correlation of the EM and magnetic datasets. All recorded data are marked with a time stamp used to link the different data types.

The time stamp is in UTC/GMT and the formats are either,

- Date and Time defined as; yyyy/mm/dd hh:mm:ss.sss
  or
- Datetime values defined as the number of days since 1900-01-01 and seconds of the day; ddddd.ssssssss

Gate times

Raw and calibrated gate times for low moment and high moment are presented in Table 7 and Table 8, respectively. *All times are referred to start of turnoff of ramp down.*

The earliest gates are not used as those are in the transition zone. HM gate times needs to be shifted 350 µs with respect to the start of turnoff ramp. Furthermore, the calibration time shifts need to be applied.

The "Workbench" inversion software applies these shifts automatically as it is defined in the geometry file, but if third party inversions are undertaken using the processed data as the base dataset, the corrected gate center times should include these time shifts during import.

Gate Open = Gate Center – (Gate center/2)
Gate Close = Gate Center + (Gate center/2)

LM: Calibrated Gate Center = Raw Gate Center -1.99e-6 s

HM: Calibrated Gate Center = Raw Gate Center +350 µs -1.8e-6 s

Gate #	Gate width (µs)	Raw Gate center (µs)	Calibrated LM Gate center (µs)	Comment
1	0.57	0.715	-1.275	Not Used
2	1.57	2.215	0.225	Not Used
3	1.57	4.215	2.225	Not Used
4	1.57	6.215	4.225	Not Used
5	1.57	8.215	6.225	Not Used
6	1.57	10.215	8.225	Not Used
7	1.57	12.215	10.225	Not Used
8	2.57	14.715	12.725	Not Used
9	3.57	18.215	16.225	LM
10	4.57	22.715	20.725	LM
11	5.57	28.215	26.225	LM
12	7.57	35.215	33.225	LM
13	9.57	44.215	42.225	LM
14	12.57	55.715	53.725	LM
15	15.6	70.2	68.210	LM
16	19.6	88.2	86.210	LM
17	24.6	110.7	108.710	LM
18	30.6	138.7	136.710	LM
19	39.6	174.2	172.210	LM
20	50.6	219.7	217.710	LM
21	62.6	276.7	274.710	LM
22	80.6	348.7	346.710	LM
23	100.6	439.7	437.710	LM
24	126.6	553.7	551.710	LM
25	160.6	697.7	695.710	LM
26	201.6	879.2	877.210	LM
27	254.6	1107.7	1105.710	LM
28	321.6	1396.2	1394.210	LM

Table 7: Gate times, Low Moment.

Gate #	Gate width (µs)	Raw Gate center (µs)	Calibrated HM Gate center (µs)	Comment
1	0.57	0.715	349.215	Not Used
2	1.57	2.215	350.715	Not Used
3	1.57	4.215	352.715	Not Used
4	1.57	6.215	354.715	Not Used
5	1.57	8.215	356.715	Not Used
6	1.57	10.215	358.715	Not Used
7	1.57	12.215	360.715	Not Used
8	2.57	14.715	363.215	Not Used
9	3.57	18.215	366.715	Not Used
10	4.57	22.715	371.215	Not Used
11	5.57	28.215	376.715	Not Used
12	7.57	35.215	383.715	Not Used
13	9.57	44.215	392.715	Not Used
14	12.57	55.715	404.215	Not Used
15	15.57	70.2	418.715	Not Used
16	19.57	88.2	436.715	Not Used
17	24.57	110.7	459.215	HM
18	30.57	138.7	487.215	HM
19	39.57	174.2	522.715	HM
20	50.57	219.7	568.215	HM
21	62.57	276.7	625.215	HM
22	80.57	348.7	697.215	HM
23	100.57	439.7	788.215	HM
24	126.57	553.7	902.215	HM
25	160.57	697.7	1046.215	HM
26	201.57	879.2	1227.715	HM
27	254.57	1107.7	1456.215	HM
28	321.57	1396.2	1744.715	HM
29	405.57	1760.2	2108.715	HM
30	510.57	2217.1	2567.215	HM
31	645.57	2797.2	3145.715	HM
32	791.57	3516.2	3864.715	HM
33	967.57	4396.2	4744.715	HM
34	1184.57	5427.1	5821.215	HM
35	1451.57	6791.2	7139.715	HM
36	1775.57	8405.2	8753.715	HM
37	2179.57	10383.2	10731.715	HM

Table 8: Gate times, High Moment.

System Verification

To verify the performance of the SkyTEM312M system calibration and waveform repetition is carried out. The following sections document the results.

Calibration

The SkyTEM312M system has been calibrated at the Danish National Reference site. Calibration includes measurements of the transmitter survey data repeated at a range of altitudes at the reference site. Hereby, it is documented that the instrumentation can reproduce the reference site with the same set of calibration parameters independent of the flight altitude. All processed data are corrected according to the calibration parameters.

The calibration resulted in the following parameters:

Low Moment (LM)
Multiplicative shift factor: 0.94 (on the raw dB/dt data)
Additive time shift: -1.99e-6 s (on gate times)

High Moment (HM)
Multiplicative shift factor: 0.94 (on the raw dB/dt data)
Additive time shift: -1.8e-6 s (on gate times)

The reference data for both LM and HM data are shown as grey curves and the measured data for LM and HM as green and blue curves, respectively, on Figure 5 to Figure 10.

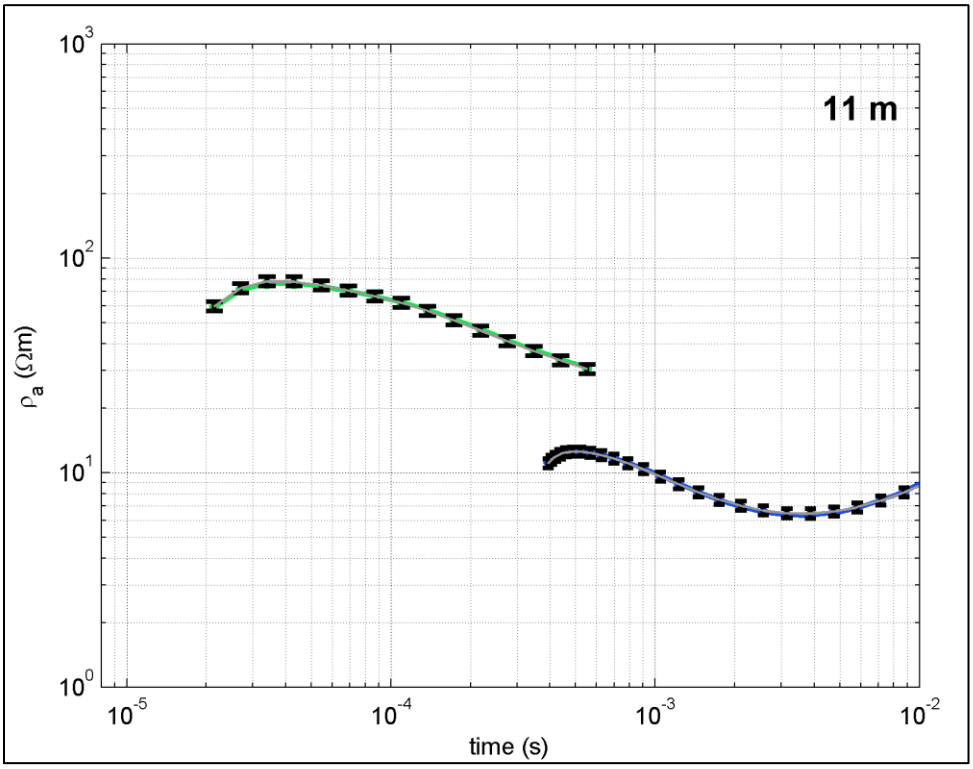


Figure 5: Grey curves with 5% error bars are the expected response, and green curves (LM) and blue curves (HM) are the actual measurements.

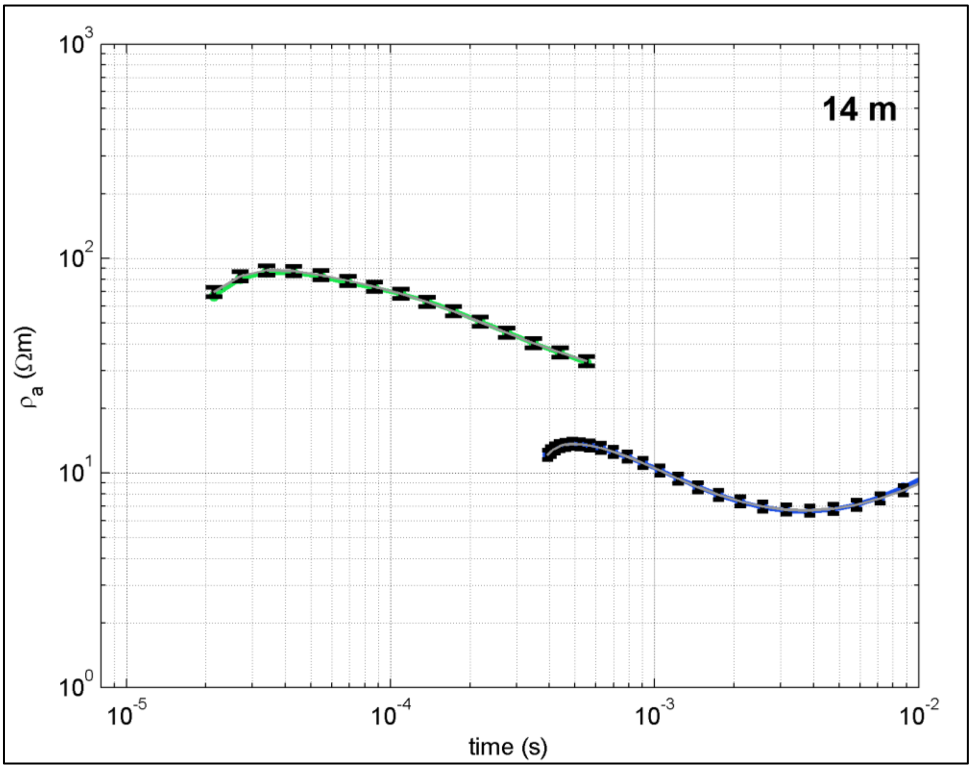


Figure 6: Grey curves with 5% error bars are the expected response, and green curves (LM) and blue curves (HM) are the actual measurements.

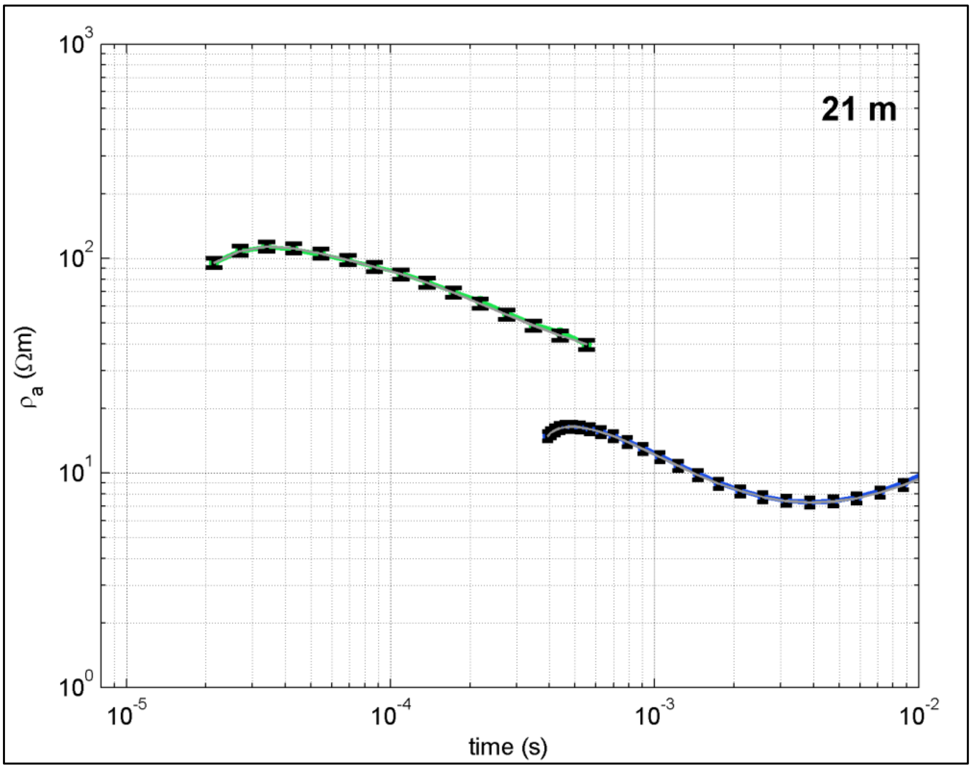


Figure 7: Grey curves with 5% error bars are the expected response, and green curves (LM) and blue curves (HM) are the actual measurements.

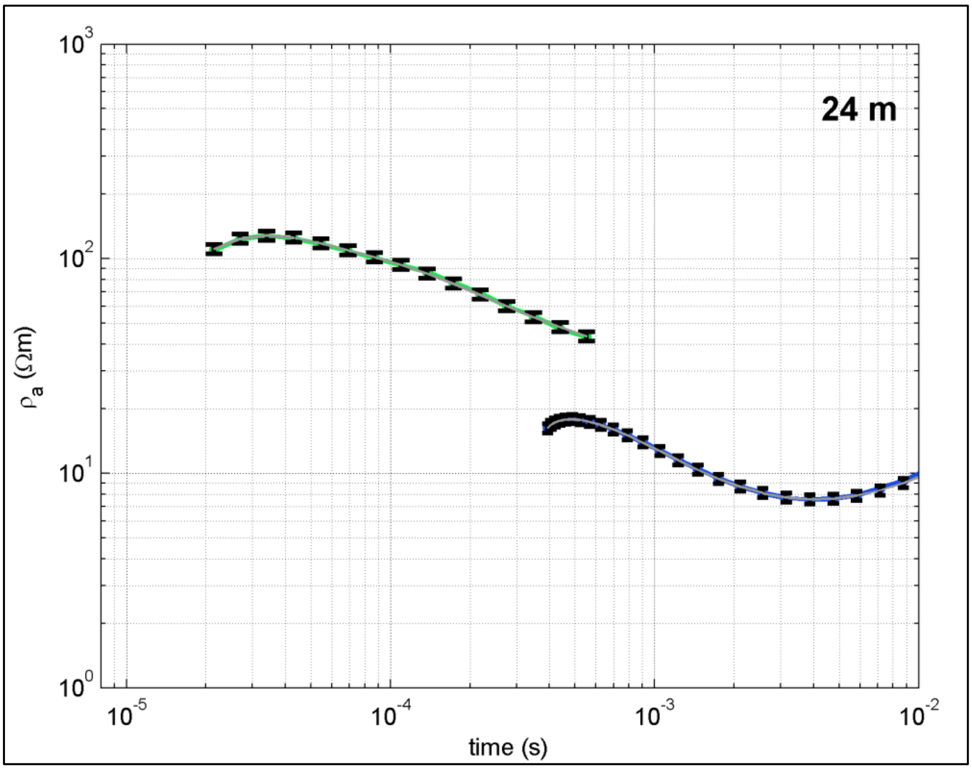


Figure 8: Grey curves with 5% error bars are the expected response, and green curves (LM) and blue curves (HM) are the actual measurements.

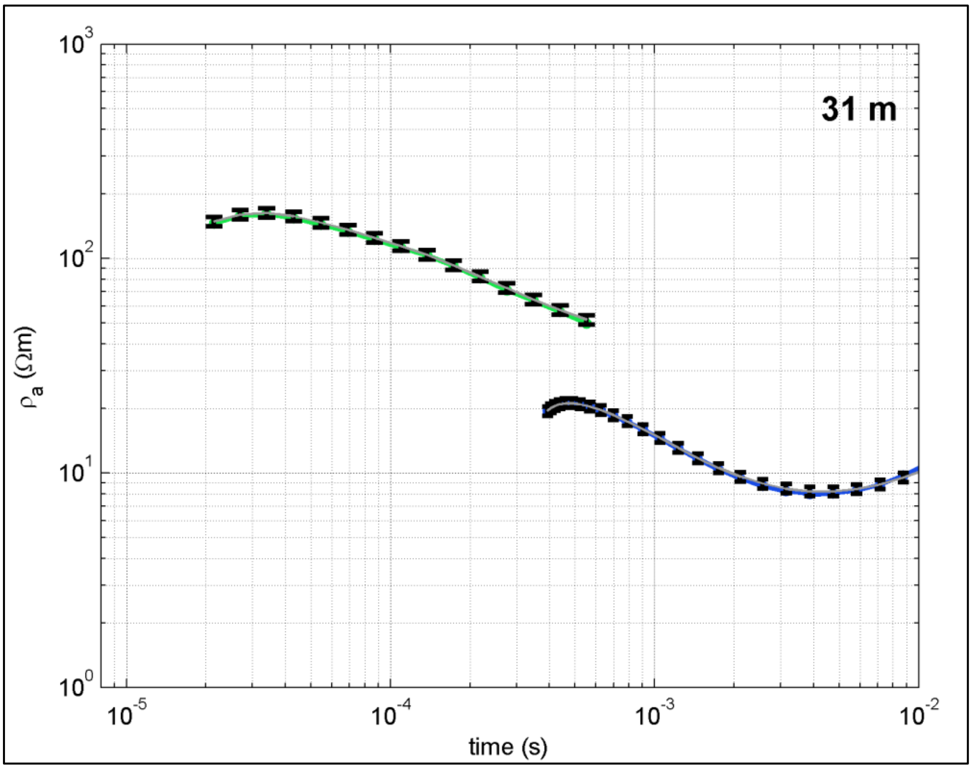


Figure 9: Grey curves with 5% error bars are the expected response, and green curves (LM) and blue curves (HM) are the actual measurements.

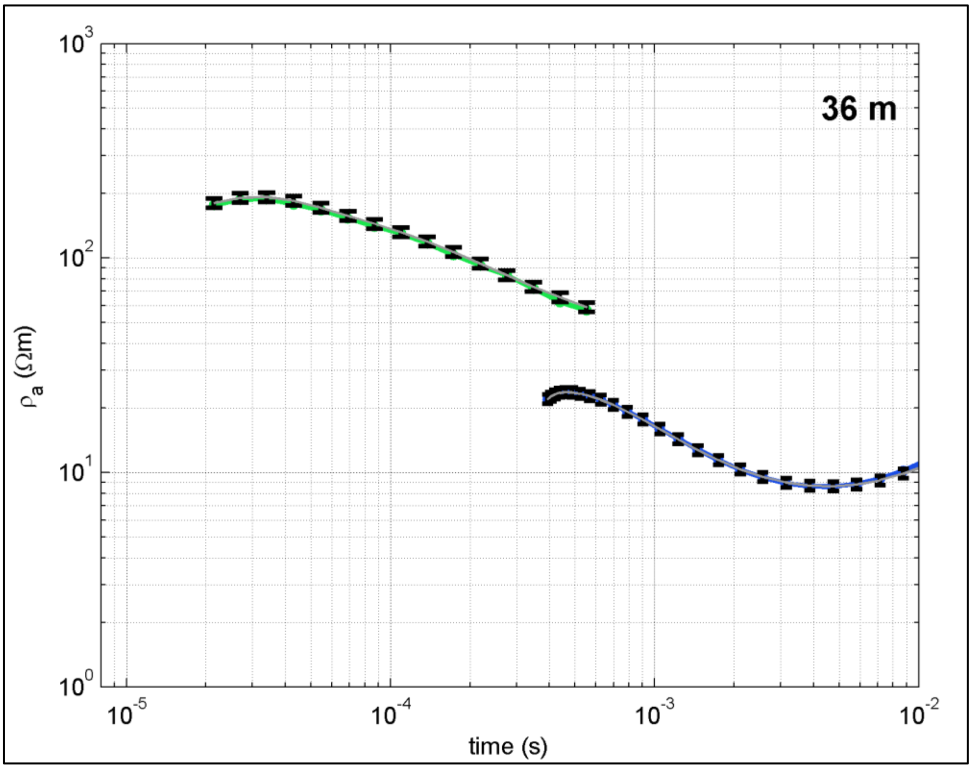


Figure 10: Grey curves with 5% error bars are the expected response, and green curves (LM) and blue curves (HM) are the actual measurements.

Waveform

The waveforms applied in the forward modelling are presented below.

The LM waveform is modelled based on the primary field compensation (PFC) analysis. Approximations to those waveforms are applied in modelling of the EM data. Figure 11 and Figure 12 show the approximated up and down ramps. Waveform details are presented in Table 9 to Table 12.

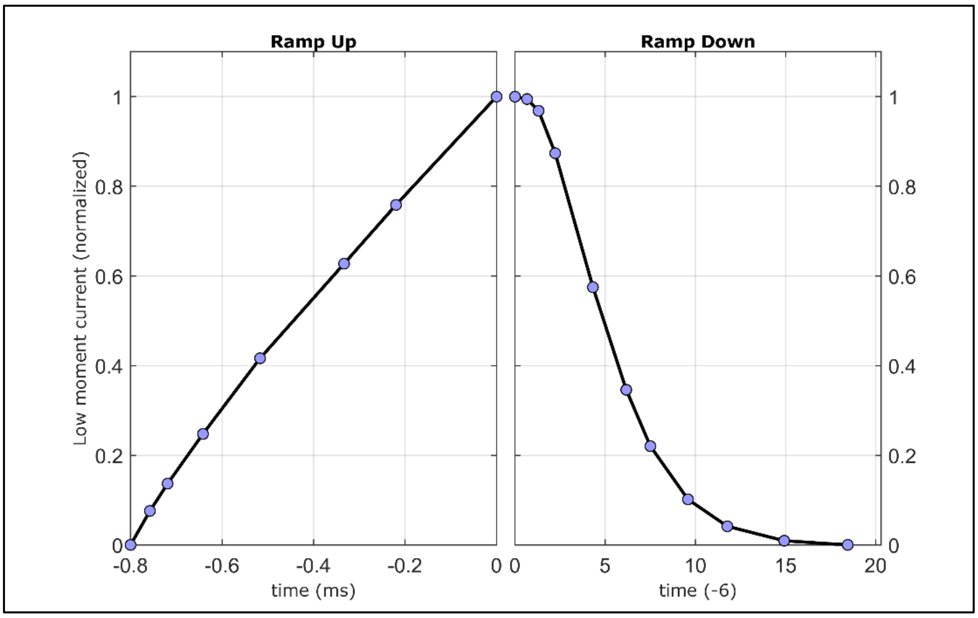


Figure 11: Ramp up and down at 210 Hz (LM). The current is normalised.

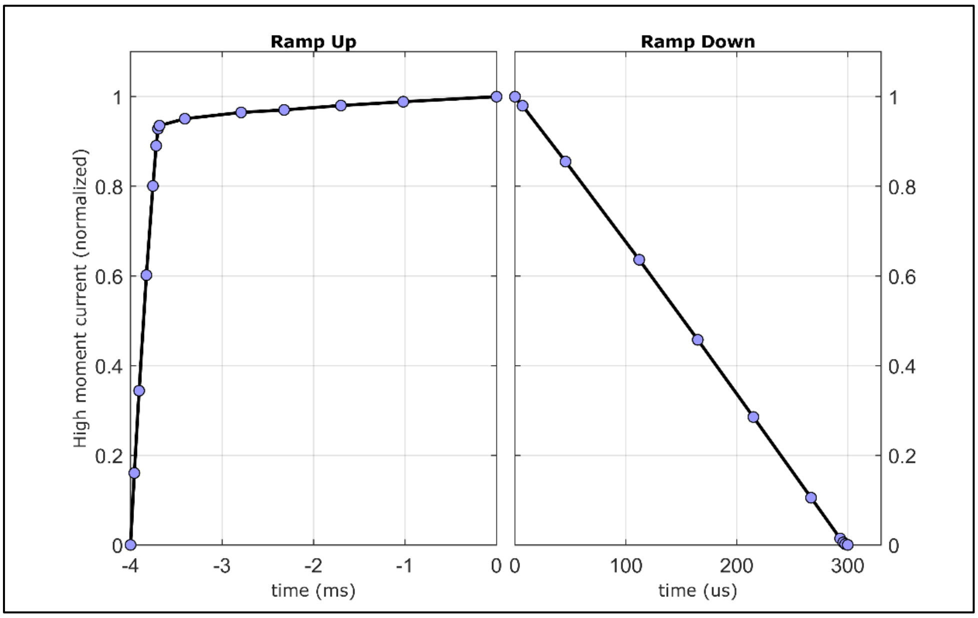


Figure 12: Ramp up and down at 30 Hz (HM). The current is normalised.

LM

Parameter	Value
Base frequency	210 Hz
Current range	6.6 Amp

Table 9: Waveform parameters for LM.

Time [s]	Normalized current
-8.00000E-04	0.00000E+00
-7.57594E-04	7.57813E-02
-7.18942E-04	1.36719E-01
-6.41639E-04	2.47656E-01
-5.16827E-04	4.16406E-01
-3.33232E-04	6.27344E-01
-2.19693E-04	7.58594E-01
0.00000E+00	1.00000E+00
6.69291E-07	9.94638E-01
1.30795E-06	9.68501E-01
2.23047E-06	8.73757E-01
4.32386E-06	5.74822E-01
6.16889E-06	3.46129E-01
7.50741E-06	2.20287E-01
9.59251E-06	1.01624E-01
1.17769E-05	4.15605E-02
1.49294E-05	9.33121E-03
1.84542E-05	0.00000E+00

Table 10: Normalized current for LM.

HM

Parameter	Value
Base frequency	30 Hz
Current range	110 Amp

Table 11: Waveform parameters for HM.

Time [s]	Normalized current
-4.00000E-03	0.00000E+00
-3.95821E-03	1.60446E-01
-3.90603E-03	3.44013E-01
-3.82639E-03	6.01847E-01
-3.75498E-03	8.00828E-01
-3.71928E-03	8.90510E-01
-3.70006E-03	9.28344E-01
-3.68358E-03	9.35350E-01
-3.40620E-03	9.50764E-01
-2.79103E-03	9.64777E-01
-2.32141E-03	9.70382E-01
-1.70075E-03	9.80191E-01
-1.01967E-03	9.88599E-01
0.00000E+00	1.00000E+00
6.82410E-06	9.79671E-01
4.55516E-05	8.55120E-01
1.11996E-04	6.36159E-01
1.64771E-04	4.57587E-01
2.14889E-04	2.85374E-01
2.66906E-04	1.05282E-01
2.93104E-04	1.44090E-02
2.95921E-04	5.56108E-03
2.97705E-04	1.88210E-03
2.99970E-04	0.00000E+00

Table 12: Normalized current for HM.

Digital Data

The complete dataset of the SkyTEM survey is delivered as a Geosoft database (GDB) which can be used as input for further processing and gridding and as input to inversion and interpretation software. The channels of the GDB are described in Table 13 - Channel description, Survey Data

Parameter	Explanation	Unit
Fid	Unique Fiducial number	seconds
Line	Line number	LLLLLL
Flight	Name of flight	yyyymmdd.ff
DateTime	DateTime format	Decimal days
Date	Date	yyyymmdd
Time	Time	hhmmss.zzz
AngleX	Angle in flight direction	Degrees
AngleY	Angle perpendicular to flight direction	Degrees
Height	Filtered height measurement	Meters
Lon	Latitude/Longitude, WGS84	Decimal degrees
Lat	Latitude/Longitude, WGS84	Decimal degrees
E*	UTM Zone 10N (WGS84)	Meter
N*	UTM Zone 10N (WGS84)	Meter
DEM	Digital Elevation Model	M. a. sl.
Alt	DGPS Altitude	M. a. sl.
GdSpeed	Ground Speed	[km/h]
Curr_LM	Current, low moment	Amps
Curr_HM	Current, high moment	Amps
LM_Z [xx]**	Geosoft array channels. Normalized LM Z-coil value.	pV/(m4*A)
HM_Z [xx]**	Geosoft array channels Normalized HM Z-coil value.	pV/(m4*A)
HM_X [xx]**	Geosoft array channels Normalized HM X-coil value.	pV/(m4*A)
60Hz_Intensity	Amplitude spectral density of the power line noise 60 Hz	-
Bmag_raw	Total Magnetic Intensity Magnetic base station data levelled to Base station Location Filtered	nT
Mag_Raw	Total Magnetic Intensity Raw magnetic data	nT
Diurnal	Diurnal variation Magnetic base station data	nT

TMI	Final Total Magnetic Intensity Corrected for diurnal variations	nT
IGRF	IGRF value 2015 mode;	nT
Inc	IGRF Inclination	degrees
Dec	IGRF Declination	degrees
RMF	Residual magnetic Field IGRF corrected based on 2015 model Microlevelled Final corrected data	nT

Table 13 Channel description, survey data

**) Data positions refer to the center of the frame.*

***) The first valid gates are: 9 (LM Z), 17 (HM Z).*

The applied gridding methods, cell size, blanking distance and filtering are listed in Table 14.

Gridding method and parameters

Area	Gridding algorithm	Gridding filter	Cell size	Blanking distance
California	Minimum curvature	-NA	100 m	1000 m

Table 14: Geosoft gridding.

Data processing and presentation

This section covers processing of auxiliary data and processing and inversion of EM data and presentations.

All devices (DGPS, Laser altimeters, inclinometers) are moved to the centre of the frame and corrected for the tilt of the frame hence all data positions refer to the center of the frame. Data is split at the beginning and end of each planned flight line.

After the initial filtering all data are resampled to 10Hz.

Auxiliary data

Tilt processing

The X and Y angle processing involves manual and automated routines using a combination of the SkyTEM in-house software SkyLab and Geosoft.

The processing involves the following steps:

1. 3 sec box filter (SkyLab)
2. Low pass filtering of 3.0 sec. (Geosoft)

Height processing

The height processing involves manual and automated routines using a combination of the SkyTEM in-house software SkyLab and Geosoft.

The processing involves the following steps:

1. Keeping the 5 highest values pr. second and discarding the rest to correct for the canopy effect (treetop filter) (SkyLab)
2. 3 sec running box filter (SkyLab)
3. Tilt correction (SkyLab)
4. Averaging of the two laser values (SkyLab)
5. Additional filters:
    a. Low pass filter of 3.0 sec (Geosoft)

DGPS processing

The DGPS has been processed using the Waypoint GrafNav Lite Differential GPS processing tool. The standard airborne settings have been used.

1. Import of base station (Master)
2. Import of airborne files (Rover)
3. Calculation of forward and reverse DGPS solution
4. Export as .txt file

The DGPS.txt files are used as input to the SkyLab software assuring DGPS corrected data in the processed files.

The ground speed, altitude, latitude and longitude from the processed DGPS' are imported into Geosoft and merged into the final database, where the coordinates are converted into UTM Zone 10N (WGS84) and a low pass filter of 3.0 sec is applied.

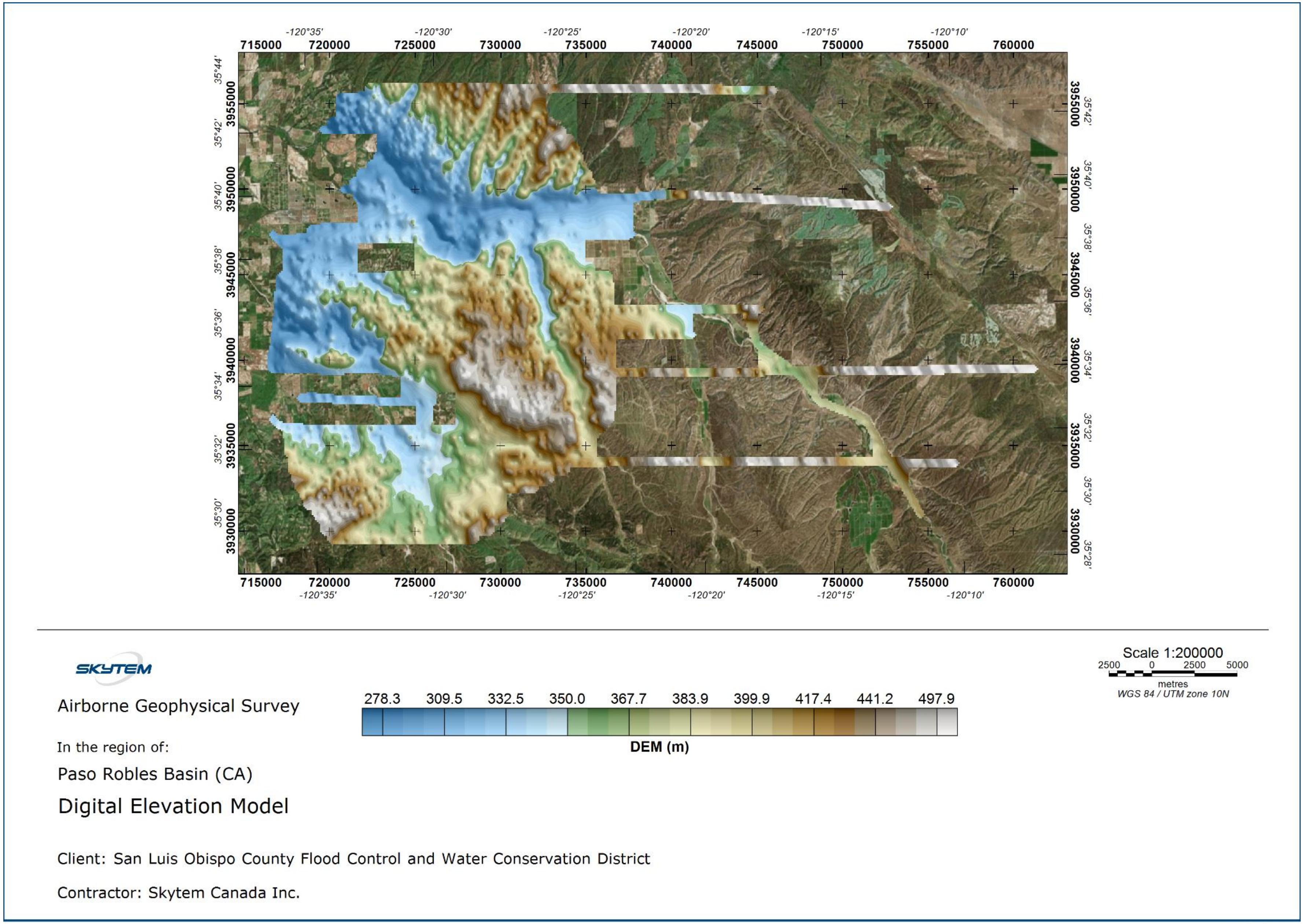
Digital elevation model

A digital elevation model (DEM) has been calculated by subtracting the filtered laser altimeter data from the DGPS elevation. All steps related to the DEM are carried out in Geosoft.

The processing of the final DEM involves the following steps:

1. Filtering and processing of the laser altimeter height as described above
2. DEM data received by subtraction of final filtered laser data from final processed DGPS altitude data

Figure 13 shows the DEM for the survey areas.



2019/12/06

Figure 13: Digital Elevation Model (DEM) in meter above sea level Block 1.

Magnetic data

Final processing of the magnetic data involves the application of traditional corrections to compensate for diurnal variation and heading effects prior to gridding.
Geosoft magnetic data processing tools are applied as follows:

- Processing of static magnetic data acquired on magnetic base station
- Pre-processing of airborne magnetic data
    - Stacking of data to 10 Hz in SkyLab.
    - Moving positions to the center of the system in SkyLab.
- Processing and filtering of airborne magnetic data
- Standard corrections to compensate the diurnal variation
- IGRF correction
- Gridding
- No heading correction applied.

Processing of base station magnetic data

The base station magnetometer data was merged into the base station Geosoft database on a daily basis for further processing.

The following filtering was applied:

- Manual despiking to remove spikes
- Interpolation (Geosoft Akima)
- Fraser Low-pass filter (width 60 sec)
- Diurnal variations are calculated by subtracting 56303.0 nT.

Processed residual magnetic data from the magnetic base station representing short term variations was merged together with airborne magnetic data.

Processing and Filtering of airborne magnetic data

Airborne magnetic data is filtered and interpolated as follows:

- Adjustment of the data for the time lag between the GPS position and the position of the magnetic sensor.
- Data resampling to 10 Hz (stacking)
- Manual despiking to remove spikes and spurious data
- Geosoft processing:
    - Akima interpolation
    - Fraser Low-pass filter (width 3 sec)

Corrections to the magnetic data

The following corrections are applied to the airborne magnetic data:

- Correction for diurnal variation using the digitally recorded ground base station magnetic values as described above
- Tie line levelled where required
- Lag was negligible and no lag correction was applied
- Heading was negligible and no heading correction was applied
- IGRF correction
- Micro-levelling

The result is the Residual Magnetic Field data (RMF)

IGRF correction

The International Geomagnetic Reference Field (IGRF) is a long-wavelength regional magnetic field calculated from permanent observatory data collected around the world. The IGRF is updated and determined by an international committee of geophysicists every 5 years. Secular variations in the Earth's magnetic field are incorporated into the determination of the IGRF.

The IGRF model is calculated before levelling using the following parameters:

IGRF model year: 2015, IGRF 15th generation
Date: variable according to date channel in database
Position: variable according to GPS WGS84 longitude and latitude
Elevation: variable according to magnetic sensor altitude derived from DGPS data

TMI

Total magnetic intensity (TMI) data was created by diurnally correcting the magnetic data.

Figure 14 shows the total residual magnetic field of survey areas.

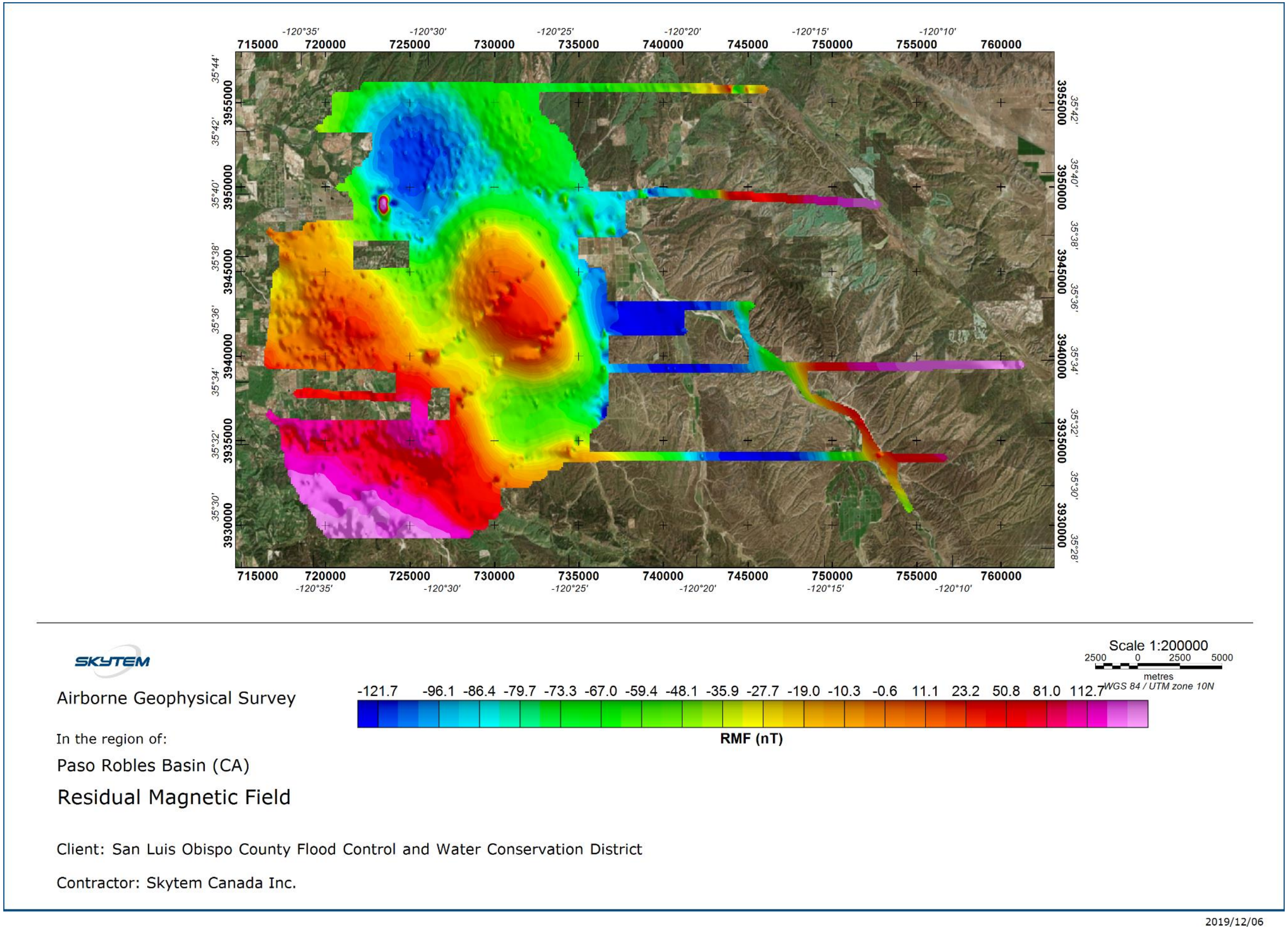


Figure 14: Residual Magnetic Field.

Power Line Noise Intensity (PLNI)

The PLNI is a powerful tool for identifying power line noise effect on EM and magnetic data. The PLNI monitor values are derived from a frequency analysis of the raw Z-component EM data. For every low moment EM data block a PLNI value is obtained by Fourier transformation of the measured values for the latest low moment gate. The Fourier transformation is evaluated at the local power transmission frequency yielding the amplitude spectral density of the power line noise.

CAUTION - When evaluating the PLNI values one should be aware of the following factors that may give rise to anomalous PLNI patterns unrelated to the actual power line noise level:

- The low moment EM data are measured at a rate lower than the Nyquist criterion for the applied system bandwidth which means that some of the frequency components contained may represent aliased frequencies. However, the considerable integration time of the latest low moment gate reduces this problem significantly.
- Other noise sources than power line noise may contribute to the total noise spectral density in the data at the power transmission frequency. When power line noise is present it tends to dominate all such other noise sources.
- The presented PLNI values are not corrected for fly height or frame angles, which means that adjacent lines crossing the same power line may not exhibit the same values of PLNI.

EM data

This section covers processing of EM data, including primary field correction (PFC) and filtering of EM data.

Primary Field Compensation (PFC)

The magnetic field coupling between the receiver coils and the transmitter loop is continuously hardware-monitored, providing a separate value for the magnetic field coupling during each transient sounding. These data are used for raw data correction in a separate post-processing step. The primary field compensation technique has proven stable and has routinely yielded a reduction of the primary field influence in very early time gates by a factor exceeding 50.

EM Filtering

The PFC data is the input for further processing. The data are normalized in respect to effective Rx coil area, Tx coil area, number of turns and current giving the unit [pV/(m^4*A)].

The EM data is filtered adaptively based on the signal-to-noise ratio. The applied EM filtering method is based on iterative weighted spline fitting routines, which operate in positive/negative symmetric transform spaces. The data weighting scheme relies on an extensive noise evaluation performed on the individual gate values of the raw data decays. Optimised sets of averaging filters are used for each measured moment and type of receiver coil in a stepwise averaging process. This allows for optimal suppression of motion induced noise as well as cultural noise components, while keeping track of the resulting data uncertainty.

Height correction

The provided EM grids are corrected for variations in flying height. The data has been adjusted as if it was flown at a constant 50 m EM sensor height.

No height correction has been applied to the raw EM data channels in the delivered Geosoft database and data file.

Stripping due to line to line flying height are still present in these grids. This is due to the extreme line to line difference due to the presence of numerous man-made obstacles.

Figure 15 and Figure 16 show an example of the LM Z and HM Z data (Height corrected) of the block. Geosoft grids of EM Z channels are included in the digital data delivery.

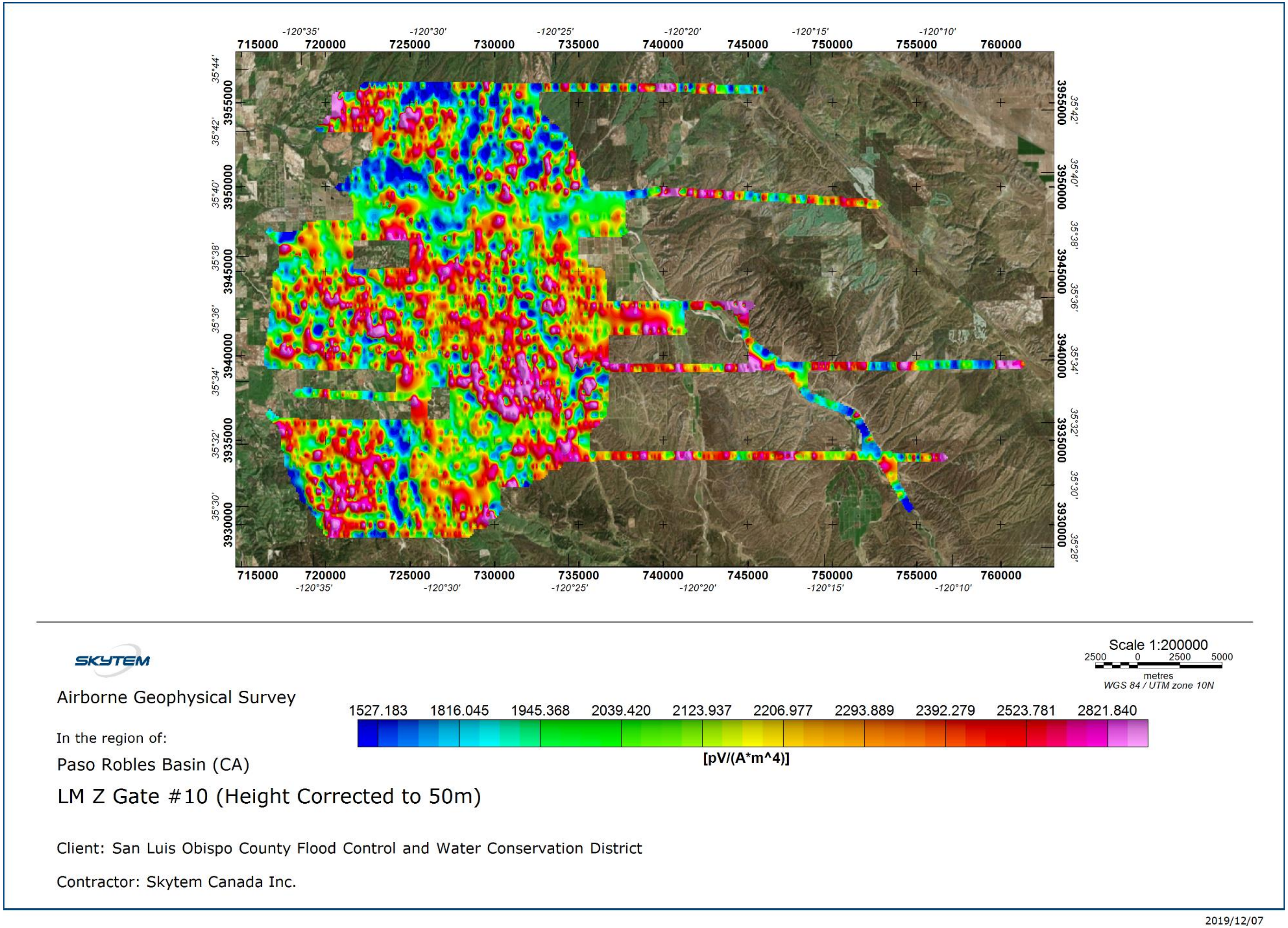


Figure 15: Low Moment Z coil (gate 10). Warm colors (red) represent high intensity.

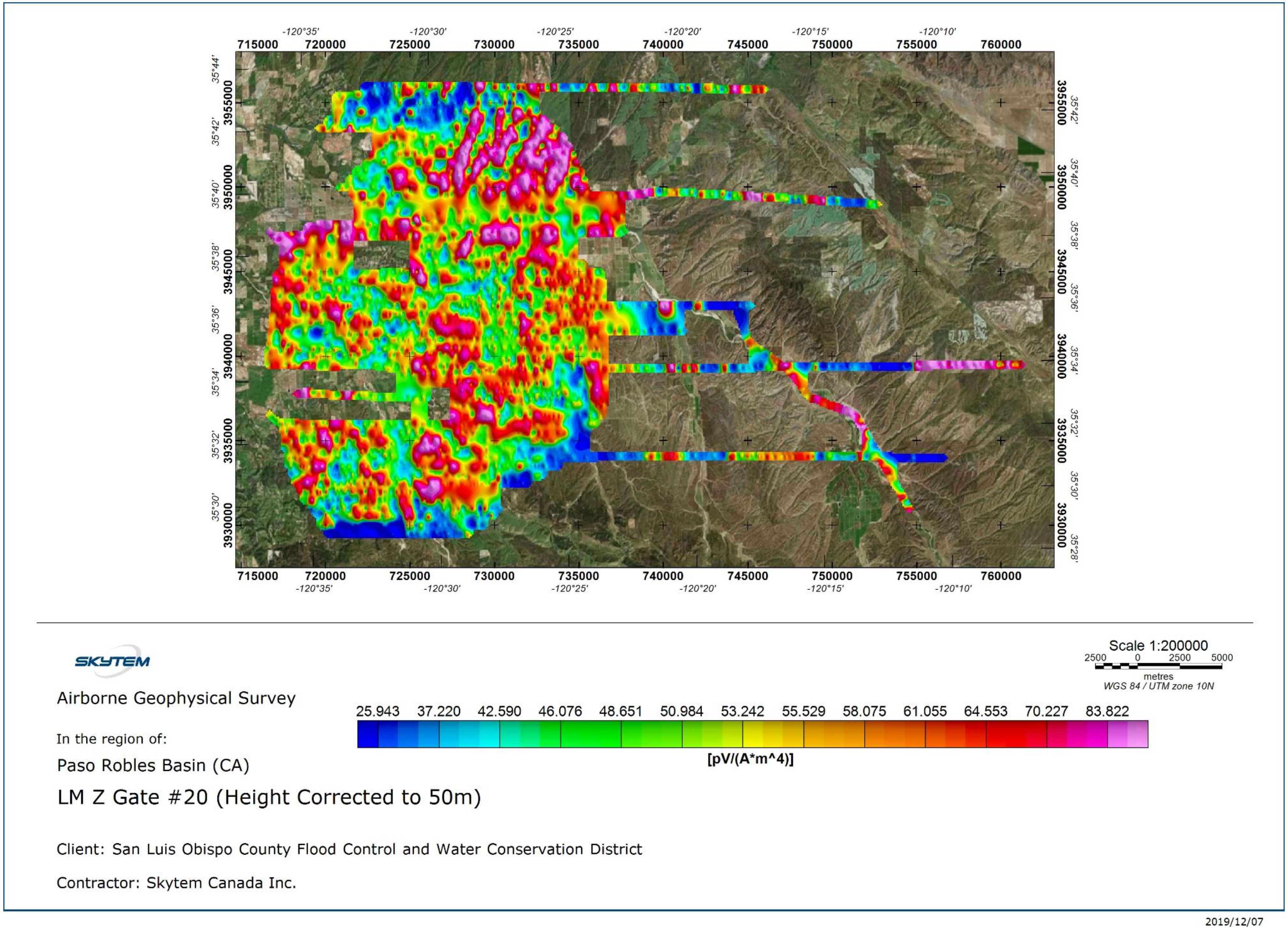


Figure 16: High Moment Z coil (gate 10). Warm colors (red) represent high intensity.

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Appendix list

Appendix 1: Instruments

Instrument positions

The instrumentation involves a time domain electromagnetic system, two inclinometers, two altimeters and two DGPS'.

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

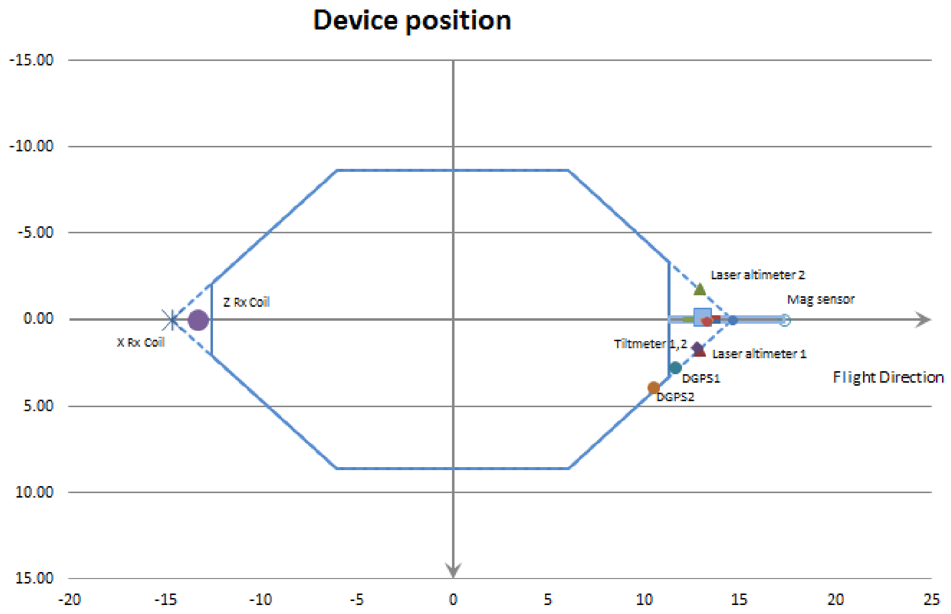

Figure 17: Sketch showing the frame and the position of the basic instruments. The blue line defines the transmitter loop. The horizontal plane is defined by (x, y).

The location of instruments in respect to the frame is shown in *Figure 17* and is given in (x, y, z) coordinates in *Table 15 Instrument locations.*.

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 generator used to power the transmitter is suspended ~30 m below the helicopter and above the frame.

Device	X	Y	Z
DGPS1 (EM)	11.68	2.79	-0.16
DGPS2 (EM)	10.51	3.95	-0.16
HE1 (altim.)	12.94	1.79	-0.12
HE2 (altim.)	12.94	-1.79	-0.12
Inclinometer 1	12.79	1.64	-0.12
Inclinometer 2	12.79	1.64	-0.12
RX (Z Coil)	-13.25	0.00	-2.00
RX (X Coil)	-14.65	0.00	0.00
Mag sensor	20.50	0.00	-0.56

Table 15: Instrument locations.

Transmitter

The time domain transmitter loop can be described as an octagon with the corners listed in *Table 16*.

X	Y
-12.64	-2.10
-6.14	-8.58
6.14	-8.58
11.41	-3.31
11.41	3.31
6.14	8.58
-6.14	8.58
-12.64	2.10

Table 16: Corners of the transmitting loop.

The total area of the transmitter coil defined by the corner points is 342 m^2 and 68.3 m in circumference.

The key parameters defining the transmitter are listed in *Table 17* and *Table 18*.

Low Moment

Parameter	Value
Number of transmitter turns	2
Transmitter area	342 m^2
Peak current	6.66.6 Amp
Peak moment	~4,100 NIA
Repetition frequency	210 Hz
On-time	800 µs
Off-time	1581 µs
Duty cycle	33 %
Wave form	Triangular

Table 17: LM transmitter key parameters.

High Moment

Parameter	Value
Number of transmitter turns	12
Transmitter area	342 m^2
Peak current	110 Amp
Peak moment	~ 450,000 NIA
Repetition frequency	30 Hz
On-time	4000 µs
Off-time	12667 µs
Duty cycle	24 %
Wave form	Square

Table 18: HM transmitter key parameters.

Figure 18: The 342 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 175 m² (Z), 115 m² (x).

The receiver coils are placed in a null-position:

Z coil (x, y, z) = (-13.25 M, 0.0 m, -2.0 m)
X coil (x, y, z) = (-14.65 m, 0.0 m, 0.0 m)

In the null-position, the primary field is damped with a factor of 0.01 on HM and due to PFC correction it can be neglected on LM.

Figure 19: Rudder containing the Z coil located in the top part of the tower.

The key parameters defining the receiver set up are found in *Table 19*.

Receiver parameters		
Sample rate		All decays are measured
Number of output gates		37 (HM) and 28 (LM)
Receiver coil low pass filter		210 kHz (Z-coil) and 250 kHz (X-coil)
Receiver instrument low pass filter		300 kHz
Repetition frequency	LM HM	210 Hz 30 Hz
Front gate	LM HM	0.0 µs 370 µs

Table 19: Receiver key parameters.

Receiver gate times are measured from the start of the transmitter current turn-off. A complete list describing gate open, close and centre times are listed in Appendix 2.

Inclination

Instrument type: Bjerre Technology

The inclination of the frame is measured with 2 independent inclinometers. The x and y angles are measured 2 times per second in both directions. The inclinometers are placed in the rear of the frame as close to the z coil as possible, see Figure 17.

The angle data are stored as x, y readings. 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 negative when the right side of the frame is above horizontal.

The angle is checked and calibrated manually within 1.0 degree by use of a level meter.

DGPS airborne unit and base stations

Chipset: OEMV1-L1 14-channel rate.
Antenna: Trimble, Bullet III GPS Antenna

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

The DGPS delivers one dataset per second. The raw coordinates are given in Latitude/Longitude, WGS84.

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

Key parameters of the DGPS instruments are found in *Table 20*.

DGPS parameters	
Sample rate	1 Hz
Uncertainty	± 1 m

Table 20: DGPS key parameters.

Altimeter

Instrument type: MDL ILM300R

Two independent laser units mounted on the frame measuring the distance from the frame to the ground, see Figure 17 and Figure 3.

Each laser delivers 30 measurements per second, and covers the interval from 0.2 m to approximately 200 m.

Key parameters of the laser instruments are found in *Table 21*.

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

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

Laser parameters	
Sample rate	30 Hz
Uncertainty	10 - 30 cm
Min/ max range	0.2 m / 200 m

Table 21: Laser key parameters.

Magnetometer airborne unit

Instrument type: Geometrics G822A sensor.

The Geometrics G822A sensor is a high sensitivity Cesium magnetometer. The basic of the sensor is a self-oscillating split-beam Cesium vapor (non-radioactive) Principe, which operates on principles similar to other alkali vapor magnetometers.

The sensitivity of the Geometrics G822A sensor is stated as <0.0005 nT/√Hz rm, combined with absolute accuracy of 3 nT over its full operating range.

Key parameters of the magnetometer airborne unit are found in *Table 22*.

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 60 Hz.

Parameter	Value
Sample frequency	60 Hz (in between each HM EM pulse)
Magnetometer on	HM
Magnetometer off	LM

Table 22: Magnetometer Airborne unit key parameters.

Magnetometer base station

Instrument type: GEM Proton.

The GEM Proton is a portable high-sensitivity precession magnetometer.

The GEM Proton is a secondary standard for measurement of the Earth's magnetic field with 0.01 nT resolutions, and absolute accuracy of 1 nT over its full temperature range.

The base station data are sampled with 1 Hz frequency.