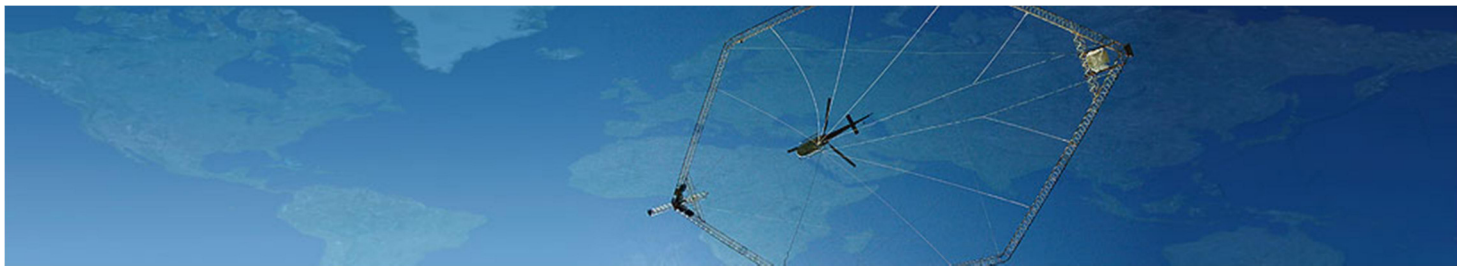
SKYTEM Airborne surveys worldwide



SkyTEM Survey:
Raudvatnet
Data report

Client: Metal Prospecting AS

Date: June 2012

SkyTEM Survey ApS, Tofteledet18, 8330 Beder, Denmark, +45 8620 2050

Contents

Introduction 3
Definition of the area 5
Instruments and parameter setup 6
Synchronizing the data 8
Calibration of the TEM system 8
High altitude test 9
Magnetometer test and calibrations 11
  Magnetometer lag (parallax) test 11
  Magnetic heading effect test 11
  Magnetometer noise test 11
Data acquisition 12
Ground Base Stations 13
  GPS base station 13
  Magnetometer base station 14
Flight reports 14
  Weather 14
  Flight Diary 15
Processed data 16
  Tilt processing 16
  Height processing 16
  DGPS processing 17
  Digital elevation model 17
  EM Processing 18
  Magnetic data 19
  Processing of base station magnetic data and diurnal correction 19
  Filtering of airborne magnetic data 20
  Corrections to the magnetic data 20
  IGRF correction 20
  Tie-line levelling and micro-levelling of magnetic data 21
  TMI recalculation 21
  GDB-file of EM, MAG and AUX 21
  Presentation of GDB-file - EM 23
  Presentation of GDB-file: Gridding of magnetic data 24
Inversion of the TEM data 25
  Initial model and optimization norm 25
  Regularization 27
  Noise model 27
  Inversion results 28
  Presentations - Model sections and grids 28
References 30
Appendix list 31
  Appendix 1: Instruments 31
  Appendix 2: Time gates 31
  Appendix 3: Calibration 31
  Appendix 4: Control parameters 31
  Appendix 5: Modelling and inversion of TEM data 31
  Appendix 6: Inversion results 31
  Appendix 7: Digital data 31

Introduction

This data report covers data acquisition of a time domain electromagnetic and magnetic survey carried out in Raudvatnet, Norway, by SkyTEM Survey ApS.

Contact person at SkyTEM: Solvej Trautner Tel. +45 8620 2050
Email: spt@skytem.com

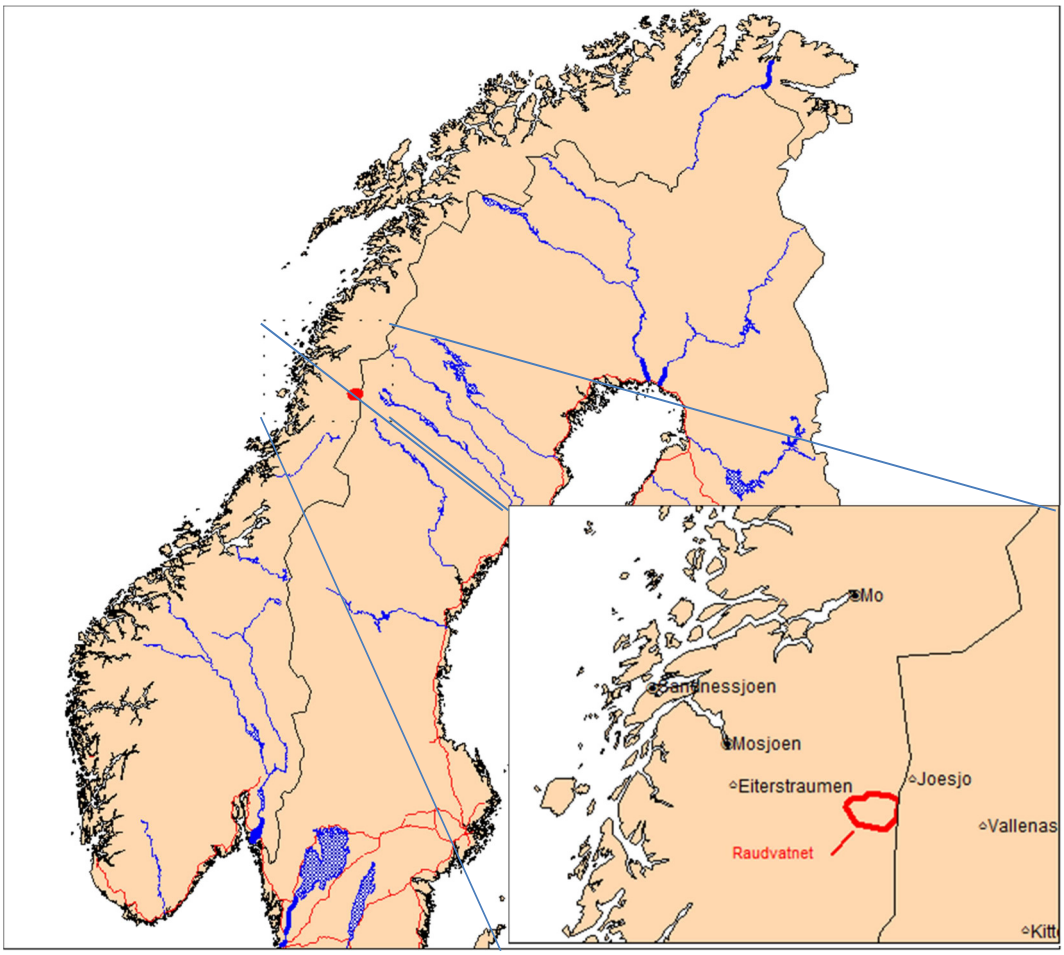


Figure 1 Project overview. Shown are the location and outline (in red) of the survey area.

From November 22nd 2011 to April 25th 2012 a time domain electromagnetic and magnetic survey was performed by SkyTEM Surveys ApS in Raudvatnet, see Figure 1. Due to bad weather conditions the data acquisition was put to a stop two times and data were subsequently acquired in three phases during November 2011, March 2012 and April 2012.

The survey requested by Metal Prospecting AS was planned to consist of 932.80 km of flight lines.

SkyTEM has agreed to deliver the electromagnetic and magnetic 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		Metal Prospecting AS Postboks 17 N-8138 Inndyr Norway
Field crew		Mads Kristensen John Blyth
Field work		November 22nd 2011 to April 25th 2012
Planned line km		932.80 km
Flown line km		929.07 km
Flight operation	Helicopter type Target flight speed Nominal flight height	Eurocopter Astar 350 B3, operated by Heliscan AS 30 - 60 km/t 30 - 40 m
Pilot		Tomas Ronnkvist Sven Magnus Lie
Report	Data processing and presentation QC by	Solvej Trautner Per Gissel Gisslø
Contact Person at SkyTEM		Solvej Trautner Email: spt@skytem.com

Definition of the area

The Raudvatnet survey area consists of one block. The project area surveyed is defined by vertex points in the table below. The Coordinate system used is UTM Zone 33N (WGS84).

Vertex	Easting [m]	Northing [m]
Raudvatnet		
1	460205.80	7281619.70
2	461829.17	7283706.88
3	465940.30	7283580.39
4	468238.32	7285983.82
5	475828.10	7284908.60
7	478505.61	7283116.57
8	477767.71	7276981.49
9	473972.82	7273017.94
10	463410.37	7274936.47
11	460058.22	7280649.87

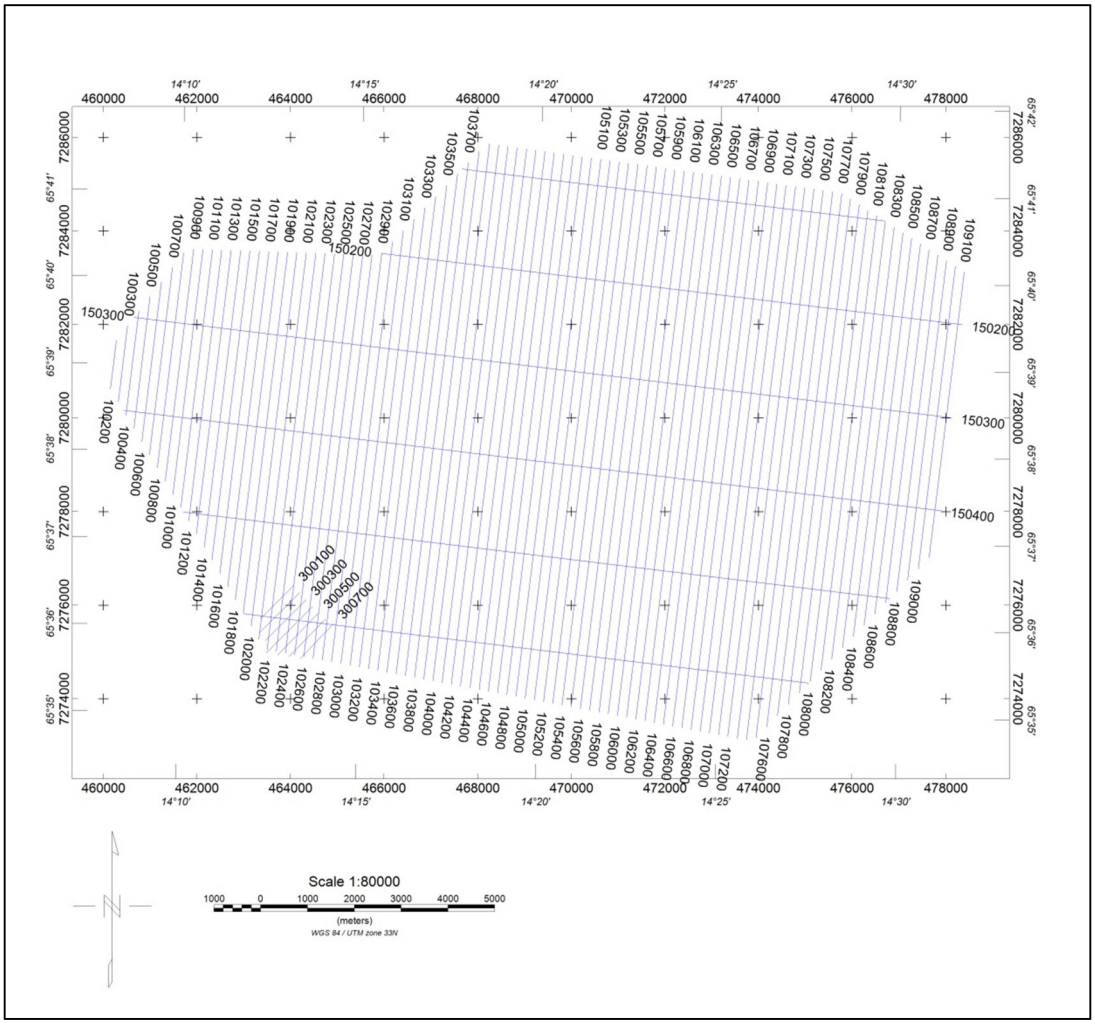


Figure 2 Map of the Raudvatnet survey area illustrating the numbering of the blue flight lines. Coordinates of the polygon corner points are defined in the table above. UTM Zone 33N (WGS84).

Instruments and parameter setup

The instrumentation involves a time domain electromagnetic system including a data acquisition system, two inclinometers, two altimeters, three DGPS', magnetometer and a magnetic data acquisition system.

The equipment setup has been chosen as a dual moment configuration with a Low moment (LM) with a peak moment of ~5400 NIA and a High Moment (HM) with a peak moment of ~474500 NIA.

The main benefit of the dual moment system is the possibility to measure the early time gates when transmitting in LM mode while still having the deep penetration obtained with the HM mode.

A simplified illustration of the SkyTEM system can be seen in Figure 3 which displays the approximate location of instruments that are rigidly attached to the frame. A similar configuration was used for this survey.

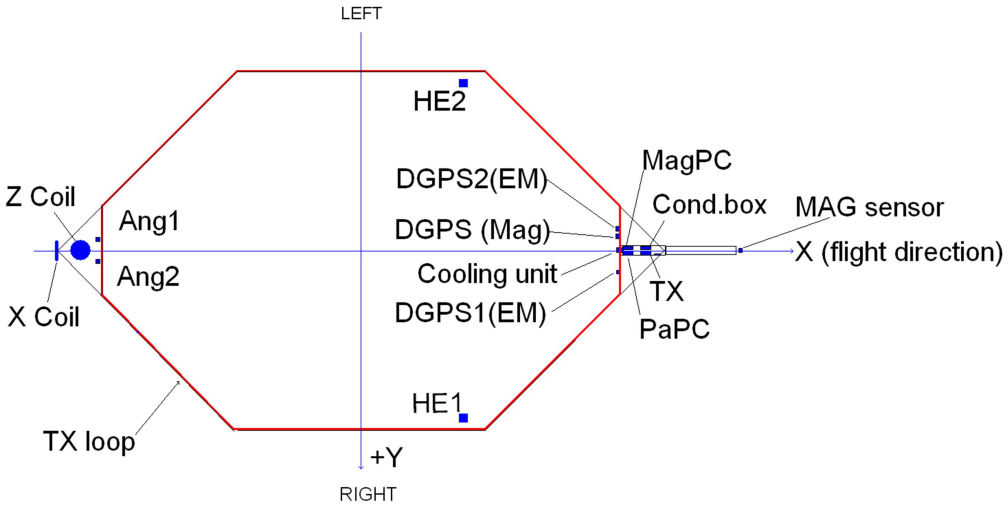


Figure 3 Sketch showing the frame and the position of the basic instruments. The red line defines the transmitter loop. The horizontal plane is defined by (x,y).

The x and y axis define the horizontal plane. The z axis 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.

Three DGPS systems are mounted on a boom located towards the front of the frame. Data from two DGPS receivers are recorded by the EM data acquisition system while a third DGPS is recorded by the magnetic data acquisition system. The DGPS systems are used for time stamping, positioning, and correlation of the EM and magnetic datasets

The generator used to power the transmitter is suspended 10 m below the helicopter.

A more thorough description of the individual instruments can be found in Appendix 1.

Synchronizing the data

All recorded data are marked with a time stamp used to link the different data types. The time stamp is in UTC/GMT.

The time stamp 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.sssssssss

Calibration of the TEM system

The complete TEM equipment has been tested and calibrated at the Danish National Reference Site on August 2011.

The calibration includes measurements of the transmitter wave form and survey data collected at a range of altitudes at the Danish National Reference Site. 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:

Low moment
Shift factor: 1.05(on the raw dB/dt data)
Time shift: 0

High Moment
Shift factor: 1.05(on the raw dB/dt data)
Time shift: -2.5e-6

All processed data has been corrected according to the calibration parameters including time gates in Appendix 2, and the scale factor on dB/dt data.

Skytem inversion software (iTEM) and the Aarhus Workbench (i.e. the geometry file) include the calibration parameter information during the import and processing of raw data. If third party processing or inversions are undertaken using the processed data as the base dataset (i.e. .gdb EM data) the calibrated gate center times in Appendix 2 should be used.

The waveform, as well as the reproduced soundings in different altitudes is shown in Appendix 3.

High altitude test

A high altitude test, in which the system was raised above 1000 masl was performed on the 11th November 2011 for the Raudvatnet survey and again on the 5th March 2012 after start phase two. The same equipment and configuration tested is used for the duration of the project.

The test was performed in order to establish that system signal to noise level was below an acceptable level on all used gates and that no drift was present in the system.

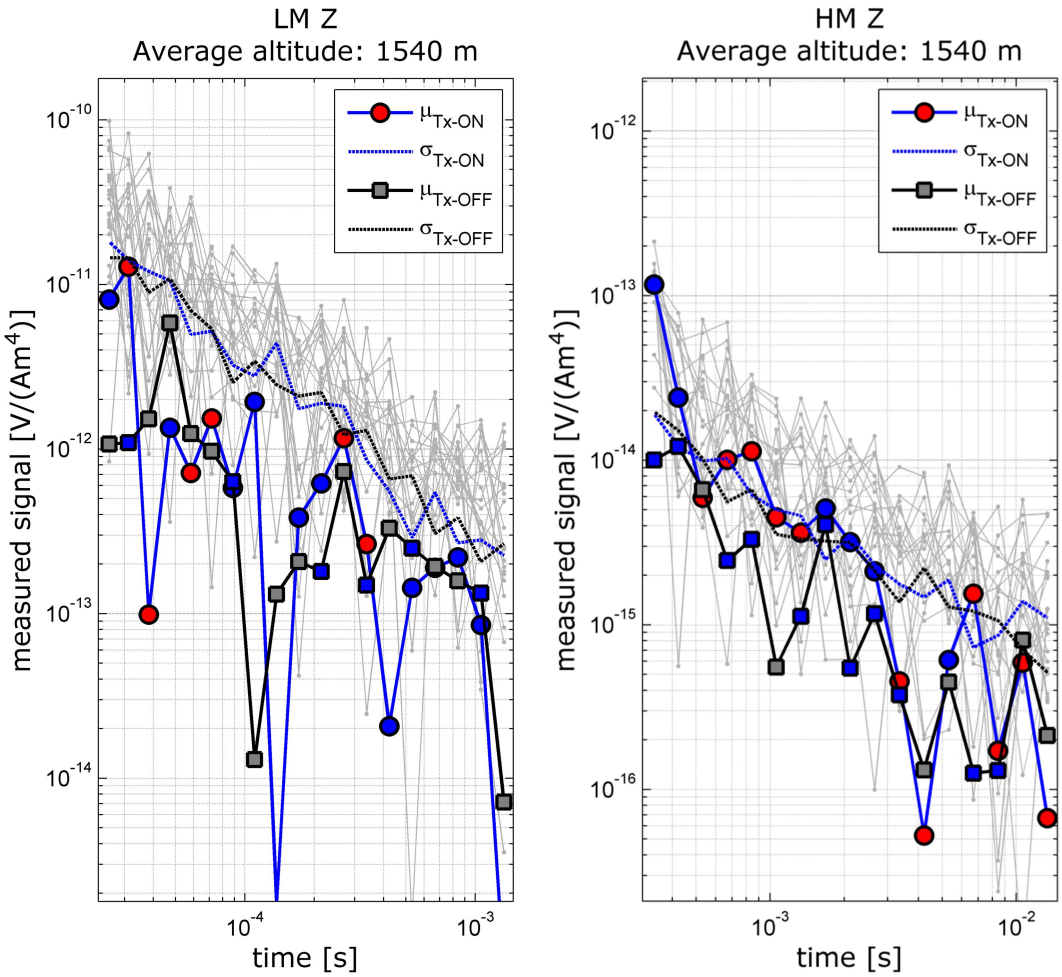


Figure 4 High altitude test flown on the 13th of November, 2011. Right plot is high moment and left plot is low moment. Grey curves are un-stacked responses with the transmitter turned on. The circles are the stacked response of all the grey curves. Squares represent the background noise (i.e. the transmitter turned off). Dotted lines represent the standard deviation of the noise and Tx-on measurements.

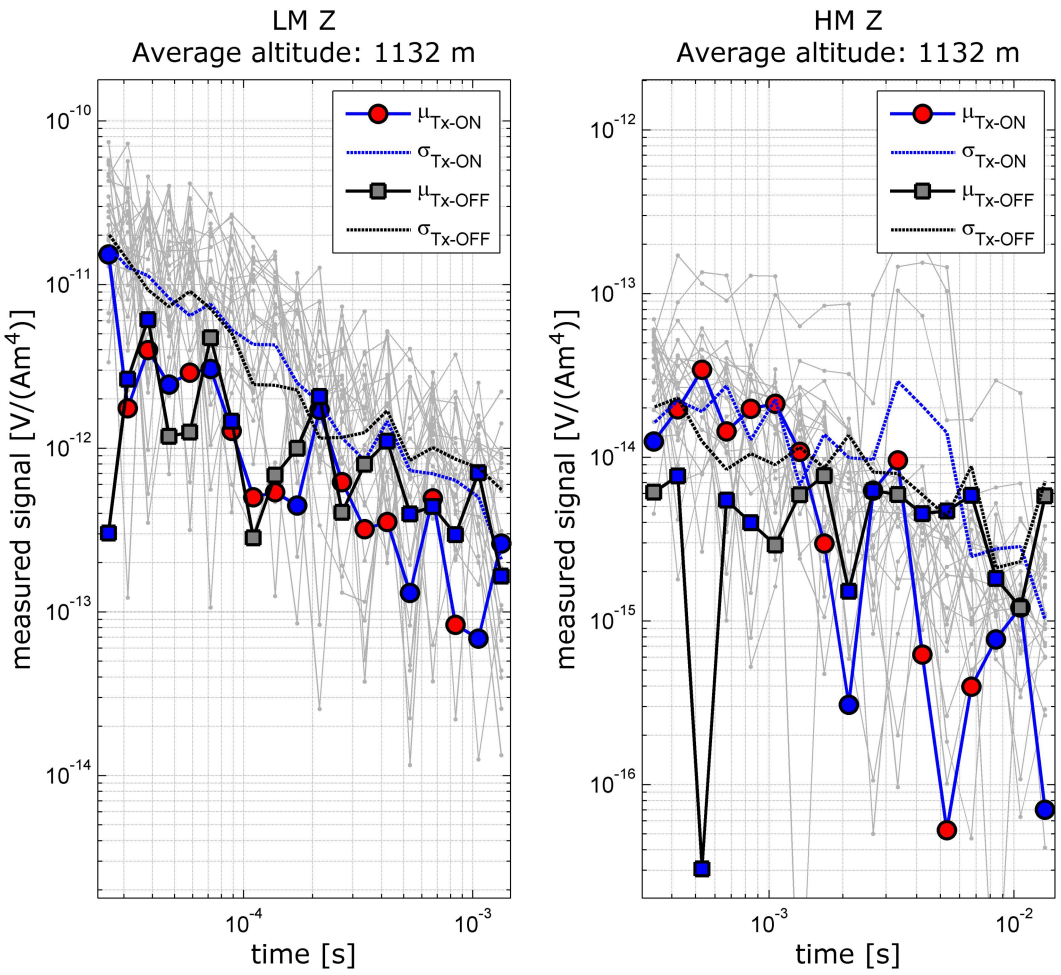


Figure 5 High altitude test flown on the 5th of March, 2012. Right plot is high moment and left plot is low moment. Grey curves are un-stacked responses with the transmitter turned on. The circles are the stacked response of all the grey curves. Squares represent the background noise (i.e. the transmitter turned off). Dotted lines represent the standard deviation of the noise and Tx-on measurements.

At high altitude the background noise and the signal with the transmitter on are very much alike after the front gate opens (Figure 4 and Figure 5). Because of the high altitude no signal from the ground is present. Therefore it can be concluded that there was no noise of significance in the system.

Magnetometer test and calibrations

Magnetometer lag (parallax) test

The lag in the magnetometer system was determined by flying a test line. The test involves flying in opposite directions over a magnetic cultural feature and measuring the apparent positional shift of the associated sharp magnetic anomaly. The shift in the location of the raw data reflects the time taken for the magnetic field measured by the airborne magnetometer to be recorded on the acquisition computer, and the physical offset between the sensor and the GPS antenna. The test showed that there was no lag in the magnetometer system.

Magnetic heading effect test

The magnetic heading effect is checked by flying a cloverleaf pattern in high altitude. Two passes in each four cardinal direction are flown to estimate the heading error. The heading effect for the Raudvatnet area (if existing) is then removed by levelling in Geosoft. The following parameters were found and are used for the heading correction:

Direction	Heading Correction
75 deg	0.798
165 deg	-0.316
255 deg	-0.244
345 deg	-0.239

Magnetometer noise test

The nominal aerodynamic noise of the magnetometer system is determined during a test flight. In-flight a down the line frequency noise envelope (estimate based on fourth order difference) has not exceed +/- 0.2 with a mean of 0.1 nT. Results are provided on Figure 6.

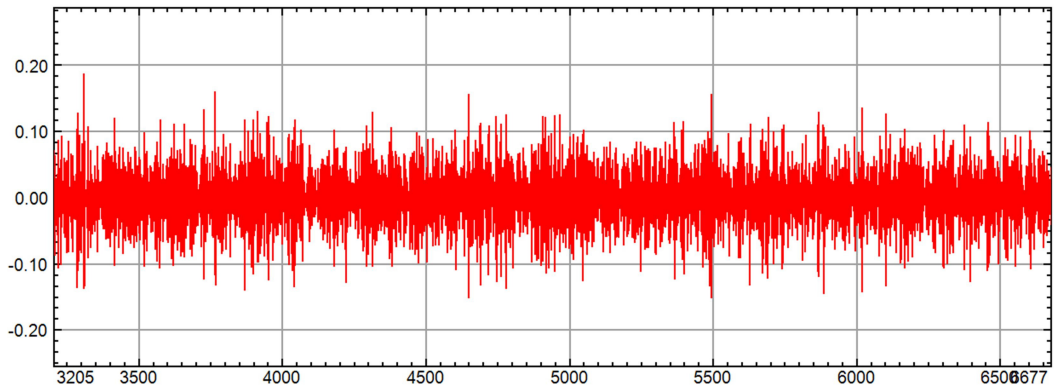


Figure 6 Airborne magnetometer test – noise envelope

Data acquisition

The planned Raudvatnet flight lines are displayed in Figure 2. The spacing and orientation of these survey lines is defined in the table below.

Block	Flight Line Spacing	Tie-Line Spacing
Raudvatnet	200 m - Approximately NS	2000 m – Approximately EW

The numbering of the flight lines is explained by the table below.

Block	In-line	Tie-Line
Raudvatnet	100201 – 109102 300101 – 300701	150101 – 150601

The nominal terrain clearance is 30 m above any obstacles or hazards, with an increase over forests, power lines, etc. The safe flying height during survey is always based on the pilot's assessment of risk and deviations from nominal values are at the discretion of the pilot.

The helicopter airspeed was planned to be approximately 50-80 km/h for a flat topography with no wind. This may vary in areas of rugged terrain and/or windy conditions.

The surveyed flight path (what was actually flown) can be seen as red lines in Figure 7 for the Raudvatnet area. Discrepancies from the planned lines occur when possible noise sources are present or cultural features such as roads, buildings, and antennas necessitate a diversion. This can also result in the survey lines being broken into pieces and flown in multiple passes or flights.
In the NorthEastern corner around location 469 000 E , 7 284 5000 N steep terrain and wind conditions caused the helicopter to hover at a few lines in the attempt to ascend up the hill (L103701, 103801, 104001 and 300501).

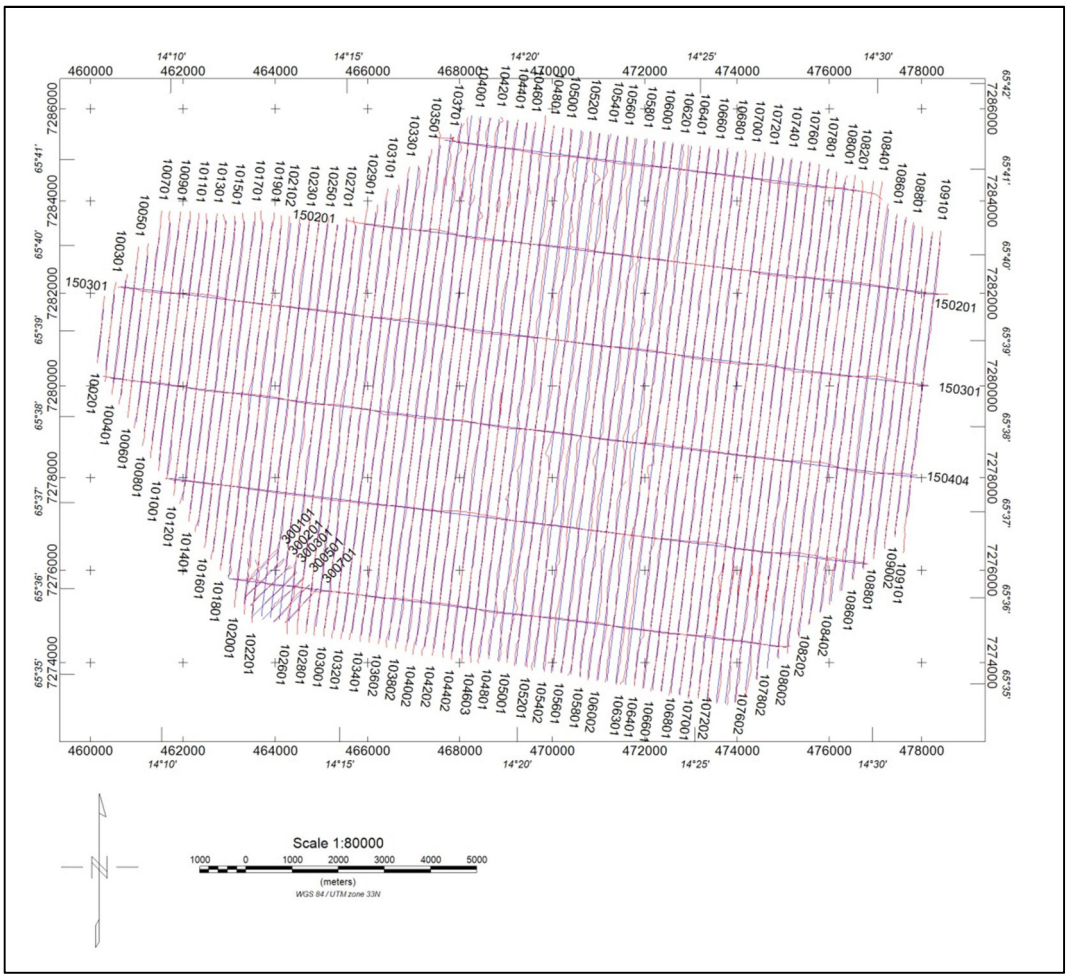


Figure 7 Red lines represent the GPS recorded flight path of the survey instrument while blue lines indicate the planned flight lines. Coordinate system: UTM Zone 33N (WGS84).

Ground Base Stations

The GPS and magnetic base stations were positioned at the closest accessible place to the survey areas.

GPS base station

Great effort was made to ensure that the DGPS base station was placed at a suitable location. Criteria for these locations are a clear view of the sky with maximum exposure to potential satellites and areas which are free of any metallic objects that could influence the GPS antenna.

Magnetometer base station

Great effort was made to ensure that 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 aircraft.

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 tables below:

Weather

Flight	Temp. (C)	Wind (m/s)	Visibility	Description
Phase 1				
20111113.02	-5	4 - 6	Good	Clear
20111122.01	5	0 - 1	Good	Overcast
20111122.02	3	0 - 1	Good	Clear
20111123.01	2	Strong	Good	Clear
20111124-20111128	-	Strong	Very low	-
20111129.02	2	Strong	Low	Cloudy
Phase 2				
20120305.03	-6	8 m/s E	Clear	-
20120305.04	-6	8 m/s E	Clear	-
20120306.01	-6	-	Good	Clear
20120306.02	-6	-	Good	Clear
Phase 3				
20120420.01	-1	5-10 m/s	Good	Some clouds
20120420.02	-1	5-10 m/s	Good	Clear
20120420.03	-1	8-14 m/s	Good	Clear
20120421	-	-	Bad	Snow
20120422	-	-	Bad	Snow
20120423.01	-	-	-	-
20120424	-	-	-	-
20120425.01	-	-	-	-
20120425.02	-	-	-	-

Flight Diary

Flight	Comments
Phase 1	
20111113.02	High Altitude Test
20111122.01	Production
20111122.02	Production
20111123.01	Production
20111124-20111128	Stand-by
20111129.02	Production
Phase 2	
20120305.03	High Altitude Test
20120305.04	Production
20120306.01	Production
20120306.02	Production
Phase 3	
20120420.01	Production
20120420.02	Production
20120420.03	Production
20120421	Stand-by
20120422	Stand-by
20120423.01	Production
20120424	Stand-by
20120425.01	Production
20120425.02	Production

Processed data

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

Mean values and standard deviations of control parameters are found in the table below.

Control parameter		Value	Standard Deviation
Ground speed*)		45 km/h	7.1 km/h
Processed height		42 m	15.3 m
Tilt angle	X	-4.6 deg.	4.9 deg.
	Y	-0.6 deg.	2.9 deg.
Tx Voltage	Tx_off	77 V	-
	Tx_on	72 V	-
Low moment Current		11.4 A	0.02 A
High Moment Current		126 A	0.3 A
Tx temperature		20-40°C	-

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

Tilt processing

The X and Y angle processing involves manual and automated routines using a combination of the SkyTEM in-house software SkyPRO and Oasis Montaj Geosoft.
The processing involves the following steps:

1. 3.7 sec box filter (SkyPRO)
2. Manual editing for spikes (Geosoft)
3. Akima interpolation of edited gaps (Geosoft)
4. Low pass filtering of 3.0 sec. (Geosoft)

Height processing

The height processing involves manual and automated routines using a combination of Skytem in house software (SkyPro) and Geosoft.
The processing involves the following steps:

1. Keeping the highest values and discarding the remainder to correct for the canopy effect (treetop filter).
2. 2 sec running box filter (smoothing filter).
3. Tilt correction
4. Averaging of the two laser values

5. Manually checked and edited for remaining spikes and artefacts in Geosoft.
6. Additional filters in Geosoft involving:
    a. Editing of spurious data (i.e. missing data over lakes etc.)
    b. Small data gaps interpolated (Akima interpolation).
    c. Low pass filter of 2.0 sec.

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 basestation (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 SkyPRO software assuring DGPS corrected data in the processed files.

Digital elevation model

A digital elevation model (DEM) channel has been calculated by subtracting the filtered laser altimeter data from the DGPS elevation, defined as ellipsoidal WGS84 height.
The Processing to 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
3. Grids produced using the minimum curvature method – grid cell size 60 m

The DEM channel was produced and gridded as described above (see Figure 8) and is included in the data delivery catalogue in Geosoft format as well as GeoTIFF.

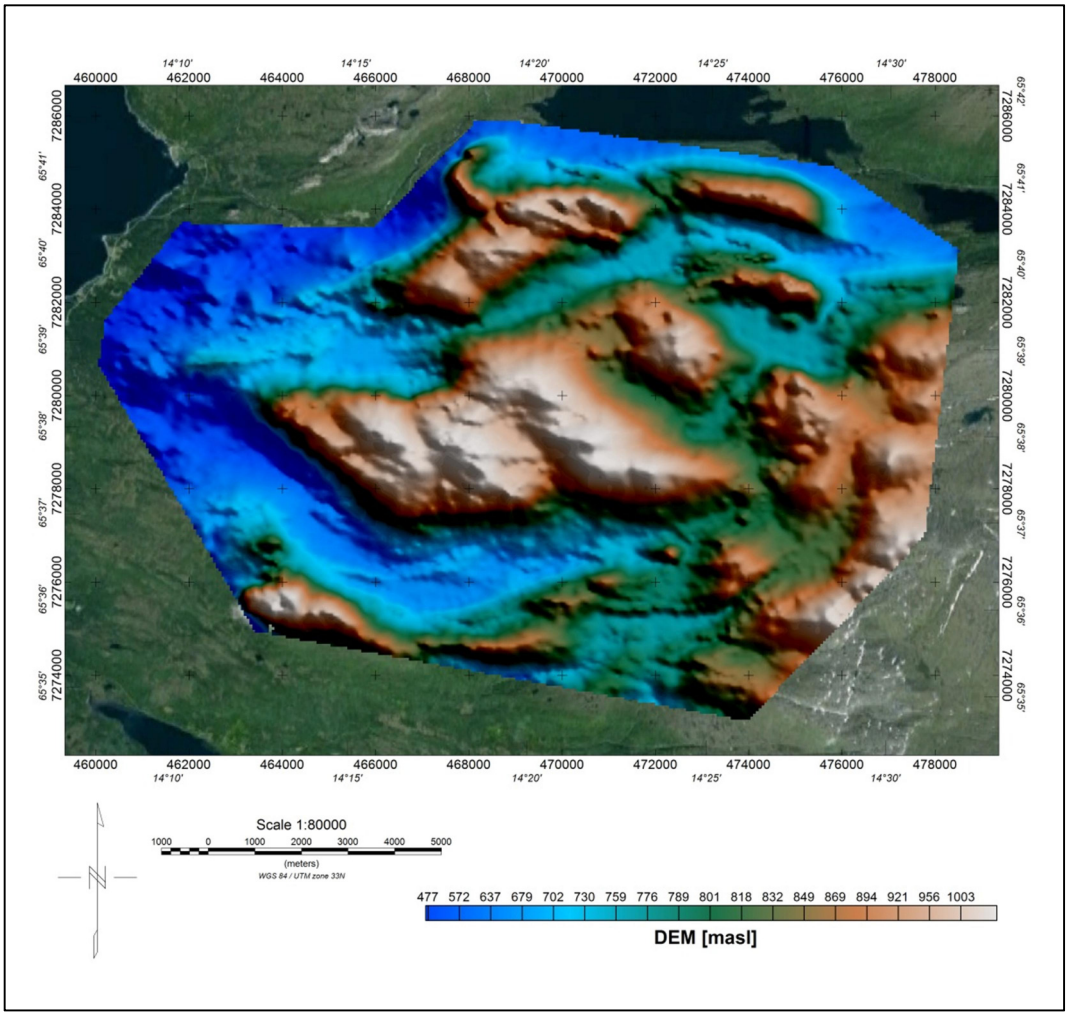


Figure 8 Digital Elevation Model from the Raudvatnet dataset in meters above sea level. UTM Zone 33N (WGS84).

EM Processing

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

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

After merging auxiliary data together with EM data in SkyPRO data channels was transferred into Geosoft Array channels.

Magnetic data

Final processing of the magnetic data involved the application of traditional corrections to compensate for diurnal variation, lag, heading effects and levelling prior to gridding. Processes applied to improve the gridding include micro-levelling and application of higher order filter operators.

Advanced full processing of magnetic data was implemented in Geosoft's Oasis Montaj software as follows:

- Processing of static magnetic data acquired on magnetic base station
- Standard corrections to compensate the diurnal variation, lag and heading effect
- IGRF correction
- Statistical levelling of tie lines and advanced levelling (careful levelling and micro levelling)
- Gridding

Processing of base station magnetic data and diurnal correction

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

The following filter parameters were used:

- Manual despiking to remove spikes
- Low-pass filter to smooth the diurnal channel (35 sec)
- IRGF correction
    - IRGF: coefficients derived by IGRF 11th generation
    - Date: variable according to date of acquired data
    - Position: fixed GPS WGS84 longitude, latitude and elevation of magnetic base station

Processed residual magnetic data form magnetic base stations representing short term variations was merged together with airborne magnetic data using the date and UTC time as reference channels.

Airborne magnetometer data was corrected for diurnal variations by subtracting the residual base station magnetic data and adding back the average RMF base station value.

Filtering of airborne magnetic data

A low-pass filter was applied to smooth the airborne magnetic data.
Following filter parameters were used:

- Manual despiking to remove spikes and spurious data
- Non-linear filter – width 3 sec and lower amp limit 0.5 nT
- Bi-cubic spline (tension of 0.1 and smoothness of 0.6) – this filter also interpolates the gaps in magnetic data not acquired during LM TEM data acquisition (0.3 sec gaps)

Corrections to the magnetic data

The processing of the airborne magnetic data involved the application of the following corrections:

- Correction for diurnal variation using the digitally recorded ground base station magnetic values as described above
- Adjustment of the data for the time lag between the GPS position and the position of the magnetic sensor (no lag applied as lag test flown 20th of November shows no lag in system).
- Heading correction determined from heading test on November 13th 2011 was applied. The heading correction parameters in the table in the magnetic test and calibration section were used.

IGRF correction

Network adjustment using the flight line and tie line information was applied to level the data set.

Geosoft Oasis Montaj Levelling Toolkit was used for applying corrections and levelling on magnetic data.

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 was calculated before levelling using the following parameters for the survey area:

- IGRF model year: IGRF 11th 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

Tie-line levelling and micro-levelling of magnetic data

After applying the above corrections to the profile data, statistical levelling of control lines followed by full levelling of traverse lines and micro-levelling was applied as a standard procedure.

As a part of this levelling procedure, intersections between control and traverse lines were determined. DEM, altitude, x, and y values were extracted for each intersection. Spurious values (high magnetic gradient areas, obvious differences in flight altitude etc) at intersections were deleted, prior to application of the tie-line levelling process.

After tie-line levelling the residual line-direction-related noise was removed through application of micro-levelling. This technique consists of applying directional and high pass filters to produce a grid containing noise-only in the line direction. In order to differentiate between the signal and noise, the noise grid is extracted from the profile database. An optimum amplitude limit and a filter length are determined, so that the final error channel reflects only the noise present on the grid, without removing or changing the geological signal content. This error channel is then subtracted from the initial data channel to obtain the final micro-levelled channel. The corrected data were then used to generate the final grids free of line directional noise.

TMI recalculation

The outcome of processed magnetic data after all corrections and levelling is the Residual magnetic field (RMF).

Total magnetic intensity (TMI) was recalculated to mean sea ellipsoidal level altitude by adding the IGRF regional field back to RMF.

For TMI recalculation IGRF 11th generation was used with date and position as flown.

GDB-file of EM, MAG and AUX

The GDB file is the foremost results of the SkyTEM survey, containing all the collected and processed EM data and information for the interpretation and inversion.

Data in the files are clipped at the beginning and end of each planned flight line. The raw EM data, magnetic data and auxiliary data are filtered and processed as described above. All parameters in the GDB-file hence refer to the origin of the frame.

The GDB-file can be used as input for further processing and gridding and as input to inversion and interpretation software.

The projection of the GDB-file is given in Latitude/longitude, WGS84 and UTM Zone 33N (WGS84).

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

Parameter	Explanation	Unit
Fid	Unique Fiducial number. Fid with the value of 0.0 is equal to midnight on the date of 2011/11/22	-
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 33N (WGS84)	Meter
N	UTM Zone 33N (WGS84)	Meter
DEM	Digital Elevation Model	Meters above mean sea level
Alt	DGPS Altitude	Meters above mean sea level
GdSpeed	Ground Speed	km/h
Curr_2	Current, low moment	Amps
Curr_1	Current, high moment	Amps
LM_Z_G4	Normalized LM Z-coil value - a Geosoft array channel	pV/(m4*A)
HM_Z_G16	Normalized HM Z-coil value - a Geosoft array channel	pV/(m4*A)
LM_X_G5	Normalized LM X-coil value - a Geosoft array channel	pV/(m4*A)
HM_X_G16	Normalized HM X-coil value - a Geosoft array channel	pV/(m4*A)
IGRF	Calculated IGRF-11 - Total magnetic	nT

	intensity	
Inc	Calculated IGRF-11 - Magnetic Inclination	Degrees
Dec	Calculated IGRF-11 - Magnetic Declination	Degrees
Bmag	Raw TMI for ground magnetic base	nT
Diurnal	Diurnal variation – magnetic base station data	nT
Mag_raw	Raw edited magnetic data – total magnetic intensity - despiked	nT
Mag_fil	Filtered raw magnetic data - TMI	nT
Mag_Cor	Residual magnetic field – corrected for diurnal, lag, heading and IGRF-11	nT
RMF	Residual magnetic field – IGRF removed - final corrected and levelled magnetic data	nT
TMI	Total magnetic intensity – final corrected and levelled magnetic data; IGRF recalculated	nT

Presentation of GDB-file - EM

Selected gates from the GDB-file have been exported as Geosoft Montaj .grd files. The files are included in the data delivery. Figure 9 shows an example of the HM data. Please note that no height correction has been applied on the raw EM data. This can cause striations in the data set when looking at the grids. This is due to the fact that variations in height will change the magnitude of the EM signal.

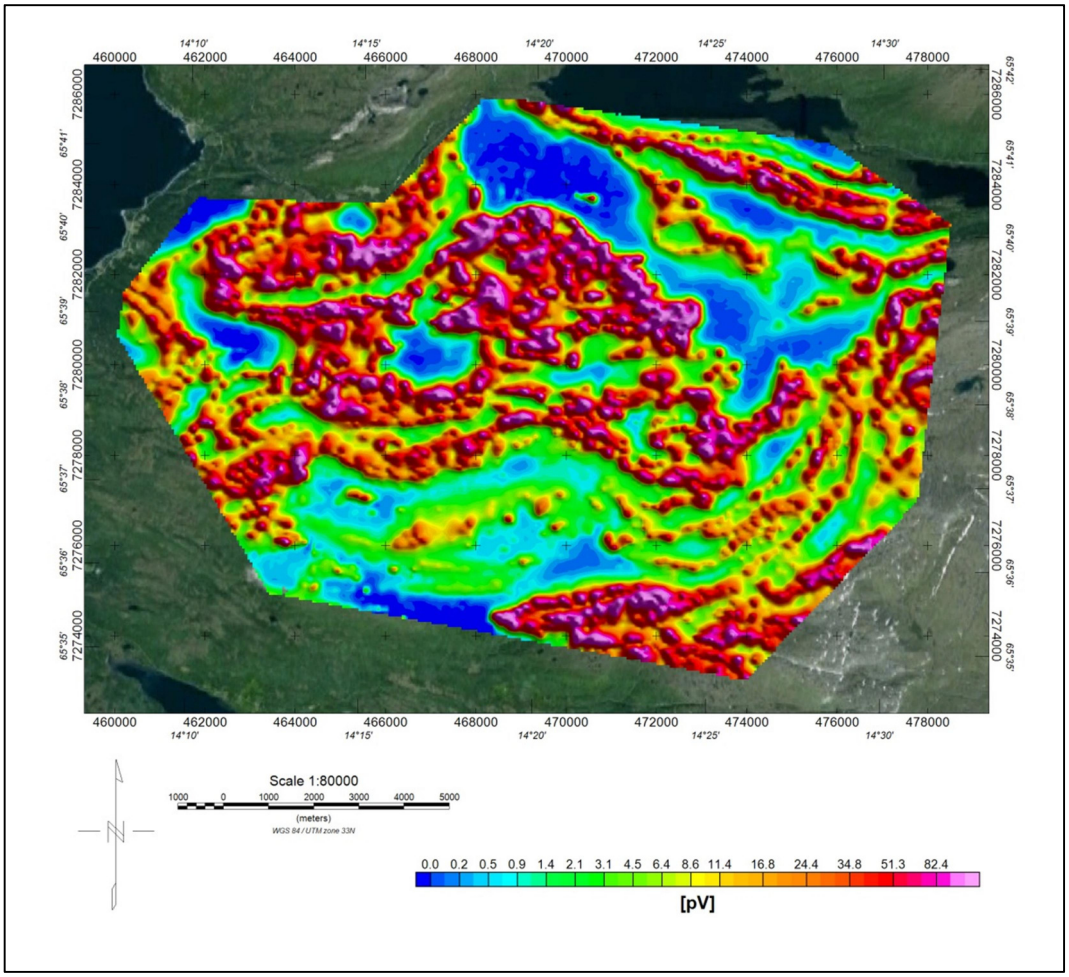


Figure 9 Plot of raw HM Z coil data of gate 16 of the dataset. Gate plots can be found as Geosoft Montaj .grd files in the data delivery folder (warm colors (red) represent high signal and cold colors (blue) represent low signal.

Presentation of GDB-file: Gridding of magnetic data

The corrected data was used to generate the Residual Magnetic Field (RMF) and Total Magnetic Intensity (TMI) grid. Corrected magnetic line data was interpolated between survey lines using a random point minimum curvature gridding algorithm to yield x-y grid values for a standard grid cell size of approximately 1/3rd of the nominal flight line spacing (a 60 m grid cell size). Low-pass filtering (Butterworth filter, cut-off wavelength 200, filter order 8, low-pass) is applied on final grids.

Figure 10 shows the RMF map.

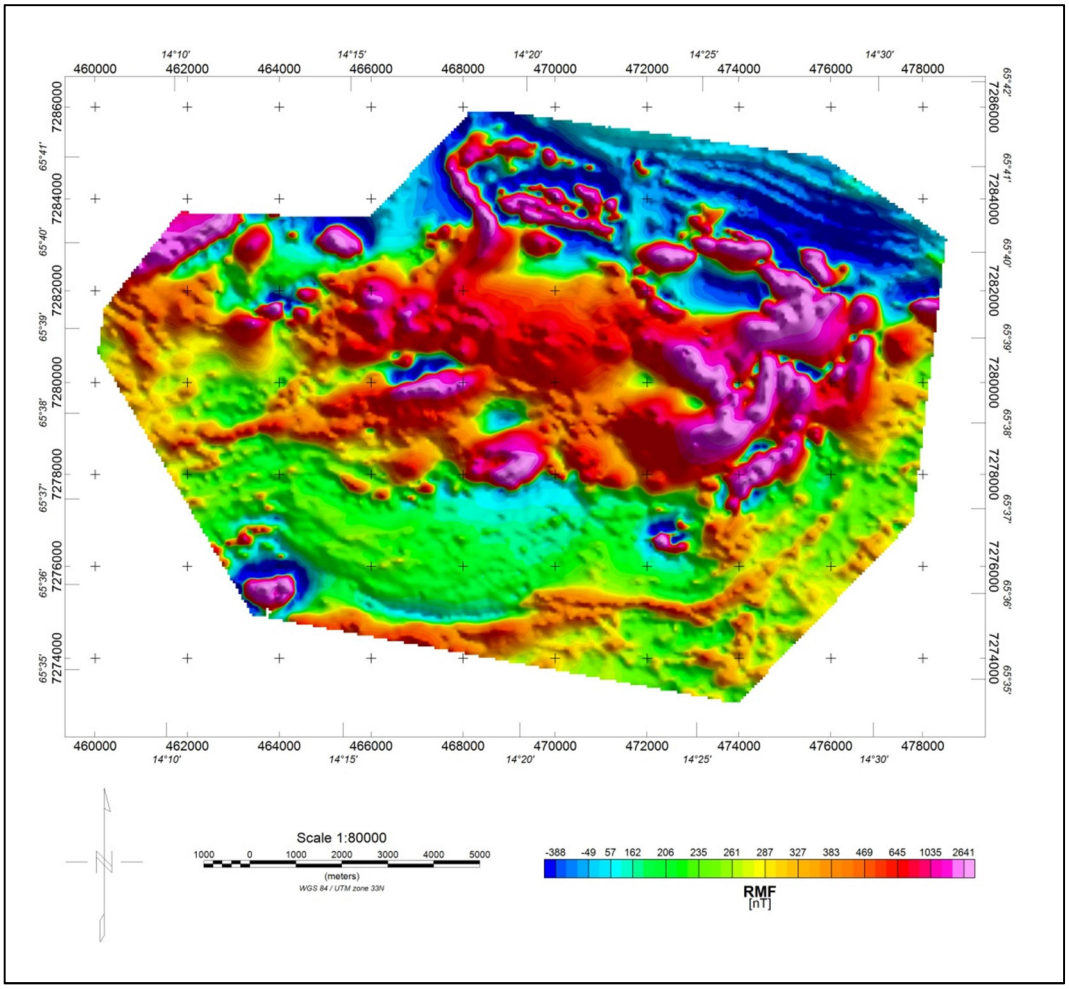


Figure 10 Residual magnetic field after correction [nT]. Coordinate system UTM Zone 33N (WGS84).

Inversion of the TEM data

In this section, the particulars of modelling and inversion of SkyTEM data from Raudvatnet will be described with reference to the more general material found in Appendix 5: Modelling and inversion of TEM data.

The inversion code is named SELMA, ref /2/ and /3/.

Initial model and optimization norm

The inversion is performed on individual soundings along the profiles with a one-dimensional (1D), multi-layer model (MLM) with 30 layers. In the inversion, the thickness of the layers is kept constant and only the layer resistivities are allowed to vary in order to let the model fit the measured data.

The thickness of the first layer is 5 m and the bottom to the deepest layer boundary is 500 m. Thicknesses and depths to top of layers are stated in the table below.

The input data to the inversion is the z-component of the xyz file described in the chapter "Processed data".

In the Raudvatnet survey, the resistivity of the initial model is set to 500, and resistivities are allowed to vary within the interval 0.1 to 10000. Optimization is performed using the L2-norm.

In the Raudvatnet area the inversions are based on a 5 Hz input file giving a model for approximately every 4 m.

Layers used in the inversion:

Layer #	Layer Thickness [m]	Layer depth [m]
1	5.00	0.00
2	5.06	5.00
3	5.17	10.06
4	5.34	15.22
5	5.56	20.56
6	5.85	26.12
7	6.21	31.97
8	6.63	38.18
9	7.13	44.81
10	7.70	51.93
11	8.36	59.63
12	9.11	67.99
13	9.97	77.11
14	10.93	87.08
15	12.02	98.01
16	13.24	110.03
17	14.60	123.26
18	16.13	137.86
19	17.83	153.99
20	19.74	171.82
21	21.86	191.56
22	24.22	213.41
23	26.85	237.64
24	29.78	264.49
25	33.04	294.27
26	36.66	327.31
27	40.70	363.97
28	45.18	404.67

29	50.16	449.84
30	5.00	500.00

Regularization

A statistical broadband approach is used in the regularization of the multi-layer model. Nine different correlation lengths with a maximum of 10 000 km and a standard deviation of 1 were used to define the correlation matrix.

Noise model

In the Raudvatnet survey, the noise parameters were chosen as:

Low moment
V_0 = 3.7e-13 in field units normalized with Tx moment
t_0 = 1 ms
slope = -1.0.

High Moment
V_0 = 6.0e-15 in field units normalized with Tx moment
t_0 = 1 ms
slope = -0.6.

Negative data values caused by e.g. capacitive coupling were excluded in the inversion.

See Appendix 5 for more details.

Inversion results

The results of the inversions are presented in a Geosoft GDB as well as an ascii-XYZ file included in the data delivery catalogue. The file contains the resistivities for each layer in the model. The header of the GDB file is described in the table below.

Parameter	Explanation	Unit
Fid	Unique Fiducial number	-
Line	Line number	LLLLLL
E	UTM Zone 33N (WGS84)	Meter
N	UTM Zone 33N (WGS84)	Meter
DEM	Digital Elevation Model	Meters above mean sea level
TMI	Total magnetic intensity – final corrected and levelled magnetic data; IGRF: 11th generation	nT
ResI1	Data residual	-
ResI2	Residual of prior information of thickness parameters (not included in this survey)	-
ResI3	Residual of vertical constraints (not included in this survey)	-
ResI4	Total residual	-
Height	Filtered Height measurement	Meters above terrain
DOI	Depth of Investigation	-
Layers	Number of Layers in model	-
Ele0xx	Elevation of top of layer. [xx] refer to the res layer used to define the geosoft channel number*	Meter
Res0xx	Resistivity of layer. [xx] refer to the res layer used to define the geosoft channel number*	Ohmm
RUnc0xx	Relative uncertainty of layer. [xx] refer to the res layer used to define the geosoft channel number*	-

**) The Ele0xx, Res0xx, and RUnc0xx, fields are repeated once for each layer with the [xx] number incrementing from [01] to [30]. I.e Ele004 corresponds to the elevation of top of layer 4.*

Presentations - Model sections and grids

Inversion

The models resulting from inversion of the individual sounding data are displayed in model sections/profiles and as grids of resistivity calculated for each layer based on the inverted models.

A brief description of both is given in Appendix 6: Inversion results.

Residuals

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 response of the resulting model after inversion. If the residual is high, it might be caused by data that are noisier than the noise model takes into account. This can be seen where resistivities are very high and the signal consequently very low. A high data residual can also be due to the inconsistency between the 1D model assumed in the inversion and the 2D/3D character of the real world. These are found primarily at the edges of sharp lateral conductivity contrasts. Finally, coupling effects to power lines and other manmade conductors can also be a source of a high residual.

The total residual is a weighted sum of the data residual and the model residual. Where the latter is a measure of the roughness of the model, i.e. the deviation of the final model from the initial homogeneous halfspace model.

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.

/3/ Christensen, N.B., Reid, J.E. and Halkjær, M. (2009). Fast, laterally smooth inversion of airborne time-domain electromagnetic data, Near Surface Geophysics, 7, 599-612

Appendix list

Appendix 1: Instruments

Appendix 2: Time gates

Appendix 3: Calibration

Appendix 4: Control parameters

Appendix 5: Modelling and inversion of TEM data

Appendix 6: Inversion results

Appendix 7: Digital data

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.

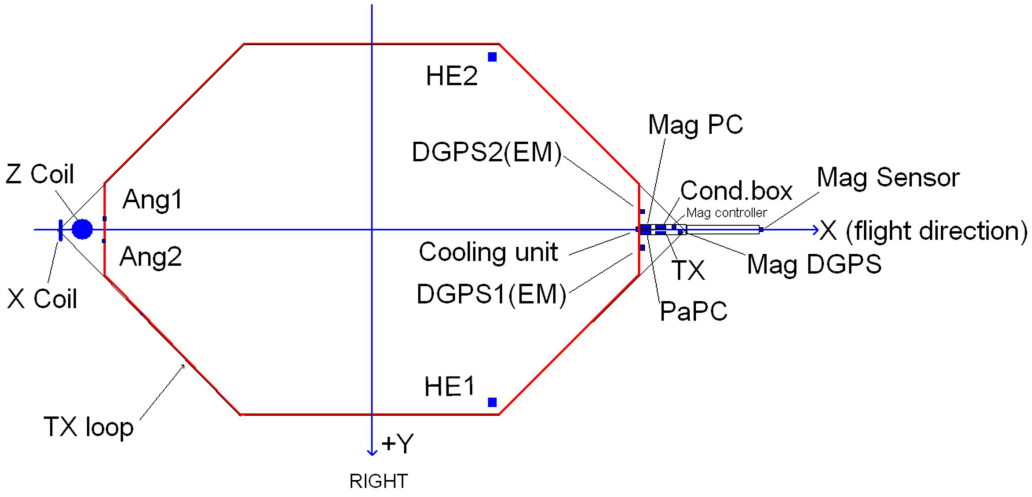


Figure 1 Sketch showing the frame and the position of the basic instruments. The red line defines the transmitter loop. The horizontal plane is defined by (x, y).

The location of instruments in respect to the frame is shown in Figure 1 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 generator used for powering of the transmitter is 10 m below the helicopter.

Device	X	Y	Z
DGPS1 (EM)	15.75	0.61	-0.23
DGPS2 (EM)	15.75	-0.59	-0.23
HE1 (altim.)	6.65	9.98	-0.05
HE2 (altim.)	6.65	-9.98	-0.05
Inclinometer 1	-15.50	-0.48	-0.12
Inclinometer 2	-15.50	0.48	-0.12
RX (Z Coil)	-16.05	0.00	-1.98
RX (X Coil)	-17.37	0.00	0.00
TX (transmit.)	15.85	0.20	-0.45
Condensator	15.85	-0.20	-0.45
Mag sensor	21.06	0.00	-0.30

For the location of instruments see Figure 1.

Transmitter

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

X	Y
-15.34	-2.03
-7.13	-10.26
7.13	-10.26
15.34	-2.03
15.34	2.03
7.13	10.26
-7.13	10.26
-15.34	2.03

The total area of the transmitter coil defined by the corner points is 494.4 m² and 81.1 m in circumference.

The key parameters defining the transmitter set up are:

Low moment

Parameter	Value
Number of transmitter turns	1
Transmitter area	494.4 m²
Peak current	11.4 Amp
Peak moment	~5400 NIA
Repetition frequency	200 Hz
On-time	1000 µs
Off-time	1500 µs
Duty cycle	40 %

High Moment

Parameter	Value
Number of transmitter turns	8
Transmitter area	494.4 m²
Peak current	126 Amp
Peak moment	~474500 NIA
Repetition frequency	25 Hz
On-time	5000 µs
Off-time	15000 µs
Duty cycle	25 %

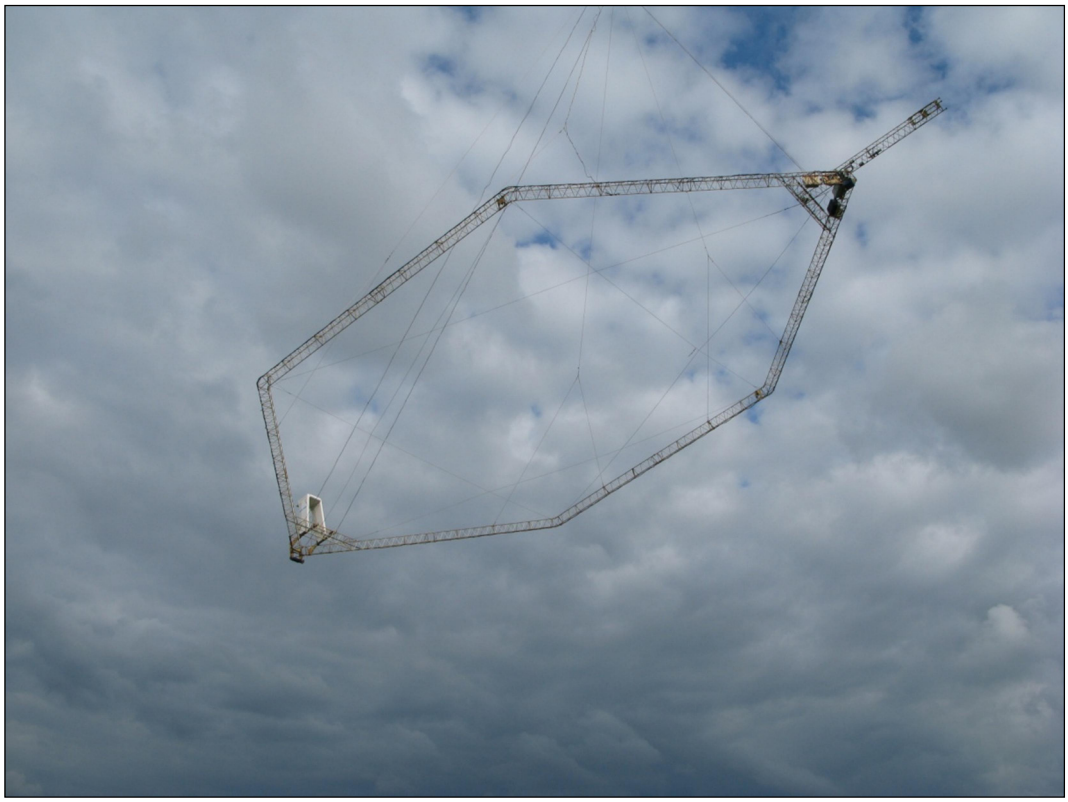


Figure 2 The 494.4 m² frame in production mode.

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), 105 m²(X coil) respectively.

The receiver coils are placed in a null-position:

Z coil (x, y, z) = (-16.05 m, 0.0 m, -1.89 m)
X coil (x, y, z) = (-17.37 m, 0.0 m, 0.0 m)

In the null-position, the primary field is damped with a factor of 0.01.



Figure 3 Rudder containing the Z coil located approximately in the top part of the tower.

The key parameters defining the receiver set up are:

Receiver parameters		
Sample rate		All decays are measured
Number of output gates		32 (HM) and 22 (LM)
Receiver coil low pass filter		112kHz (Z-coil) and 450 kHz (X-coil)
Receiver instrument low pass filter		300 kHz
Repetition frequency	LM HM	200 Hz 25 Hz
Front gate	LM HM	15.0 µs 200.0 µs

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 1.

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 0.5 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.

DGPS parameters	
Sample rate	1 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 1.

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

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 as a routine against well-defined targets.

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

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 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 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 less than 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 (in between each HM EM pulse)
Magnetometer on	HM Cycles
Magnetometer off	LM Cycles

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 1 nT absolute accuracy over its full temperature range.

The base station data are sampled with 1 Hz frequency.

Appendix 2: Time gates

Gate	GateOpen (µs)	Gatewidth (µs)	GateClose (µs)	GateCenter (µs)	Comment
1	0.390	15.610	16.000	8.195	Not used
2	16.390	2.610	19.000	17.695	Not used
3	19.390	3.610	23.000	21.195	Not used
4	23.390	4.610	28.000	25.695	LM only
5	28.390	5.610	34.000	31.195	LM only
6	34.390	7.610	42.000	38.195	LM only
7	42.390	9.610	52.000	47.195	LM only
8	52.390	11.610	64.000	58.195	LM only
9	64.390	14.610	79.000	71.695	LM only
10	79.390	18.610	98.000	88.695	LM only
11	98.390	23.610	122.000	110.195	LM only
12	122.390	29.610	152.000	137.195	LM only
13	152.390	37.610	190.000	171.195	LM only
14	190.390	47.610	238.000	214.195	LM only
15	238.390	60.610	299.000	268.695	LM only
16	299.390	75.610	375.000	337.195	LM & HM
17	375.390	95.610	471.000	423.195	LM & HM
18	471.390	120.610	592.000	531.695	LM & HM
19	592.390	152.610	745.000	668.695	LM & HM
20	745.390	191.610	937.000	841.195	LM & HM
21	937.390	241.610	1179.000	1058.195	LM & HM
22	1179.390	304.610	1484.000	1331.695	LM & HM
23	1484.390	384.610	1869.000	1676.695	HM only
24	1869.390	483.610	2353.000	2111.195	HM only
25	2353.390	609.610	2963.000	2658.195	HM only
26	2963.390	768.610	3732.000	3347.695	HM only
27	3732.390	968.610	4701.000	4216.695	HM only
28	4701.390	1220.610	5922.000	5311.695	HM only
29	5922.390	1538.610	7461.000	6691.695	HM only
30	7461.390	1938.610	9400.000	8430.695	HM only
31	9400.390	2442.610	11843.000	10621.695	HM only
32	11843.390	3077.610	14921.000	13382.195	HM only

Note: Gate 1 to 3 is not used in any of the moments in the present survey as it is in the transition zone.

Appendix 3: Calibration of the TEM system

The base frequencies used for the data acquisition are 200 Hz (denoted LM) and 25 Hz (denoted HM).

Transmitter waveform

LM

Parameter	Value
Base frequency	200 Hz
Current range	10.0 – 11.5 A

Table 1: Waveform parameters for LM

The waveform is measured using a current probe (turn-on ramp) and a pick-up coil (outputs dI/dt) for the (turn-off ramp). The approximation to the measured waveform can be applied in modelling of the data, which was also the case for inversion of the survey data in this report.

Time [s]	Normalized current
-1.00E-003	0.00E+000
-9.20E-004	3.61E-001
-8.29E-004	6.03E-001
-7.01E-004	8.02E-001
-4.98E-004	9.32E-001
-2.14E-004	9.90E-001
-2.42E-006	1.00E+000
0.00E+000	1.00E+000
9.82E-007	9.98E-001
1.43E-006	9.87E-001
1.92E-006	9.55E-001
2.82E-006	8.37E-001
5.48E-006	2.77E-001
6.46E-006	1.62E-001
7.51E-006	8.87E-002
9.23E-006	3.05E-002
1.09E-005	1.21E-002
1.32E-005	0.00E+000

Table 2: Normalized current for LM

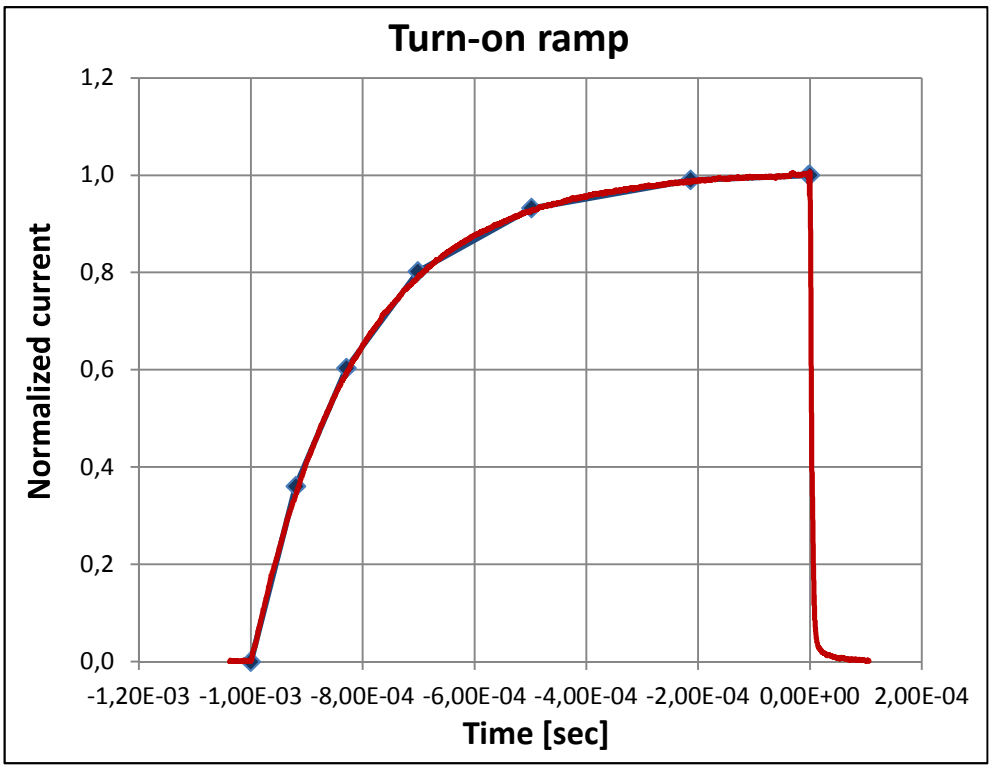


Figure 1: Turn-on ramp waveform at 200 Hz (LM). The red curved is the measured current waveform and the blue is the approximated waveform.

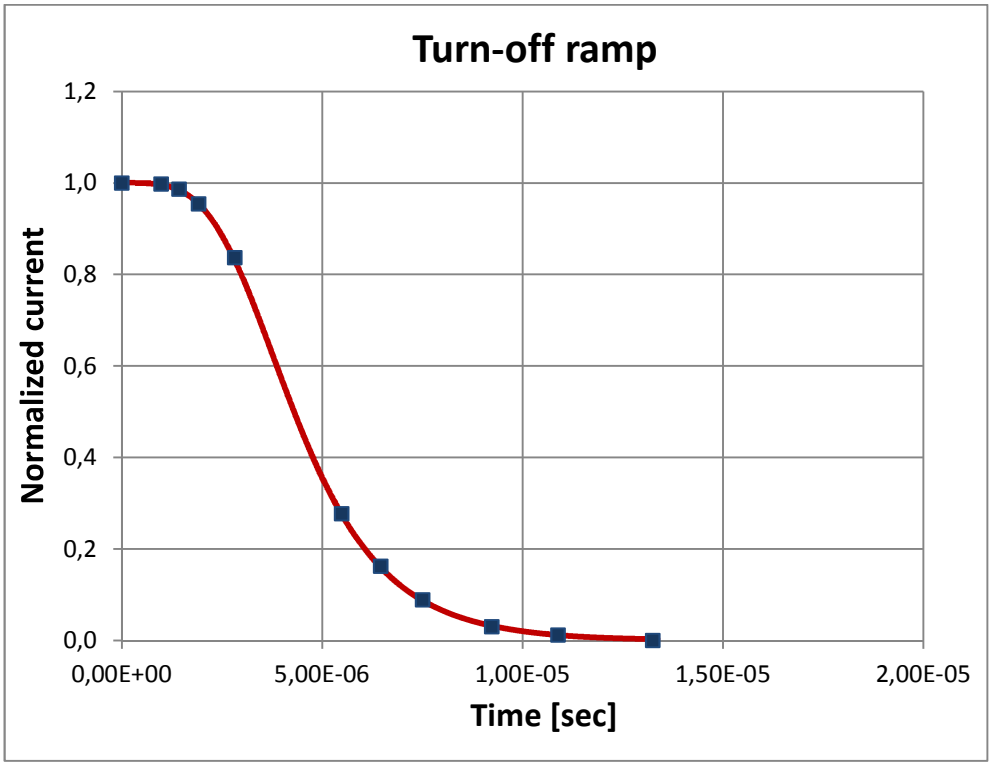


Figure 2: Ramp down at 200 Hz (LM). The red curve is the measured current waveform and the blue is the approximated waveform.

The data (dI/dt) measured using the pick-up coil are integrated to obtain the current (I). As can be seen the current waveform is a little noisy at the onset of the turn-off owing to the use of the pick-up coil.

HM

The waveform is measured using a current probe and a close approximation to the measured waveform is shown in the subsequent table and figure. The waveform approximation can be applied in modelling of the data, which was also the case for the inversion of the survey data in this report. It should be noticed that the transmitter operating at HM is having a nearly square shaped waveform.

Parameter	Value
Base frequency	25 Hz
Current range	120.0 – 125.0 A

Table 3: Waveform parameters for HM

Time [s]	Normalized current
-5.00E-003	0.00E+000
-4.89E-003	5.97E-001
-4.81E-003	9.63E-001
-4.78E-003	9.74E-001
-1.99E-003	9.85E-001
-3.57E-007	1.00E+000
0.00E+00	1.00E+000
1.35E-06	9.99E-001
2.04E-05	9.00E-001
8.17E-05	5.53E-001
1.26E-04	2.99E-001
1.69E-04	4.73E-002
1.77E-04	3.58E-003
1.86E-04	0.00E+000

Table 4: Normalized current for HM

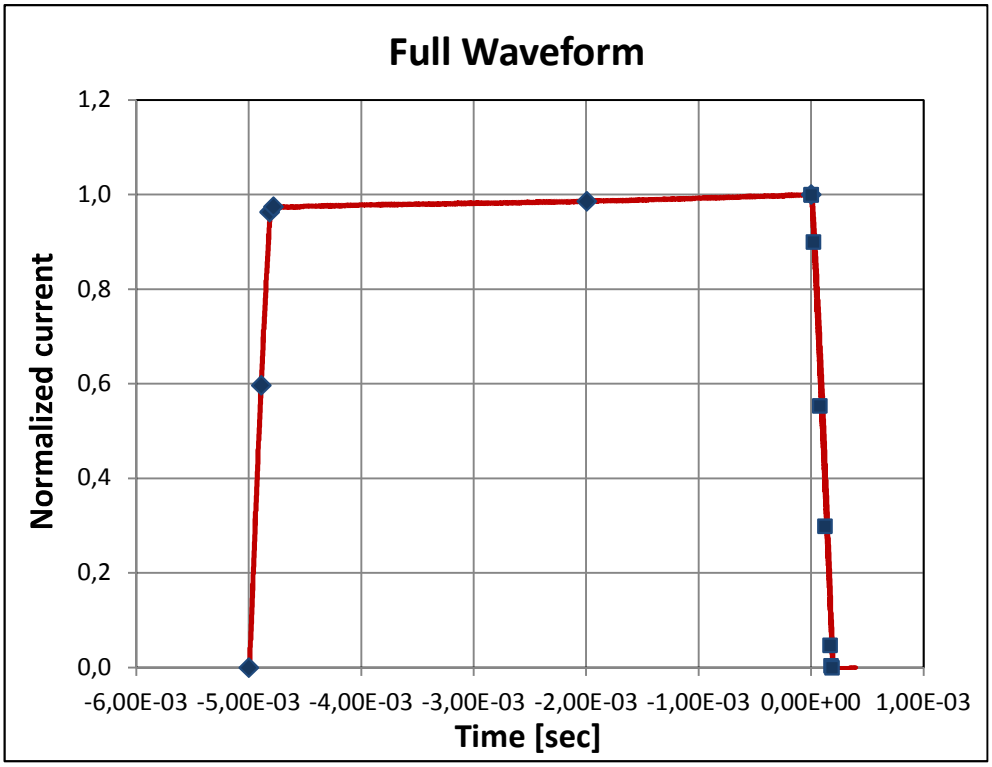


Figure 3: Full waveform at 25 Hz. The red curve is the measured current waveform and the blue is the approximated waveform.

Calibration at the National Danish Reference Site

The complete SkyTEM equipment has been calibrated at the National Danish Reference Site. The following plots, Figure 4 to Figure 7, show the measured data as well as the forward response in altitudes 5 m, 10 m, 15 m, 20 m and 30 m.

The reference data for both LM and HM data are shown as blue curves and the measured data for LM and HM as red curves.

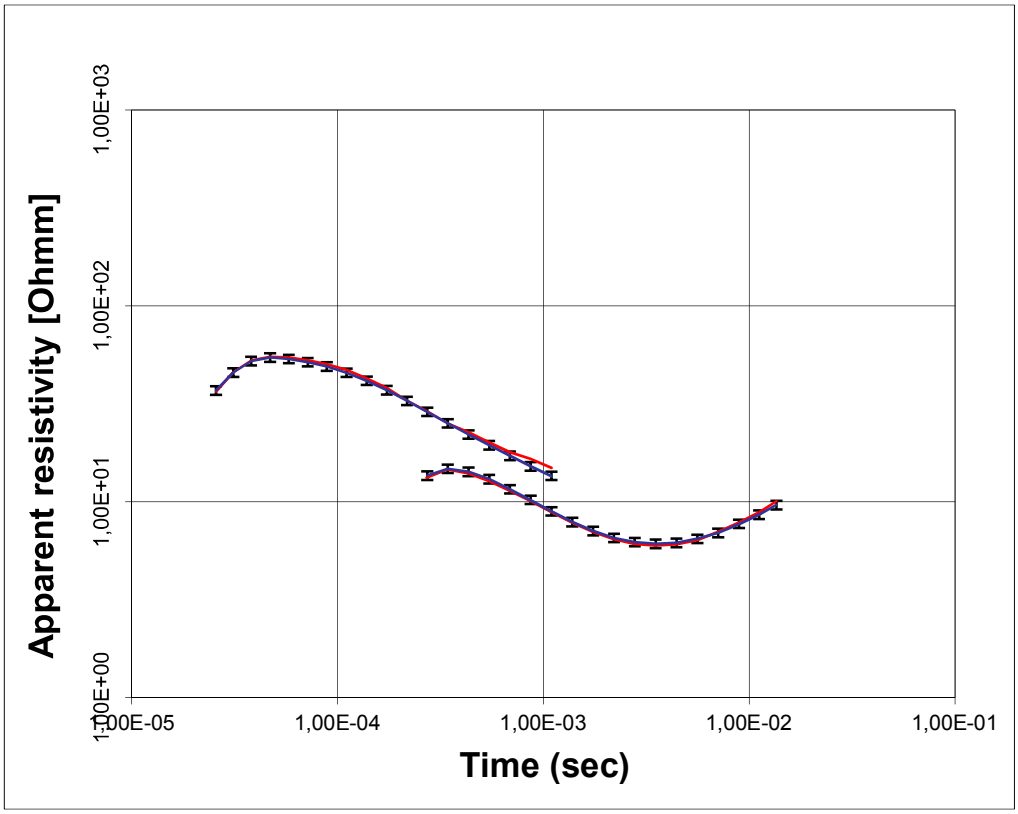


Figure 4 The frame is in 5 m altitude. Blue curves are the forward response, and the red curves are the actual measurements.

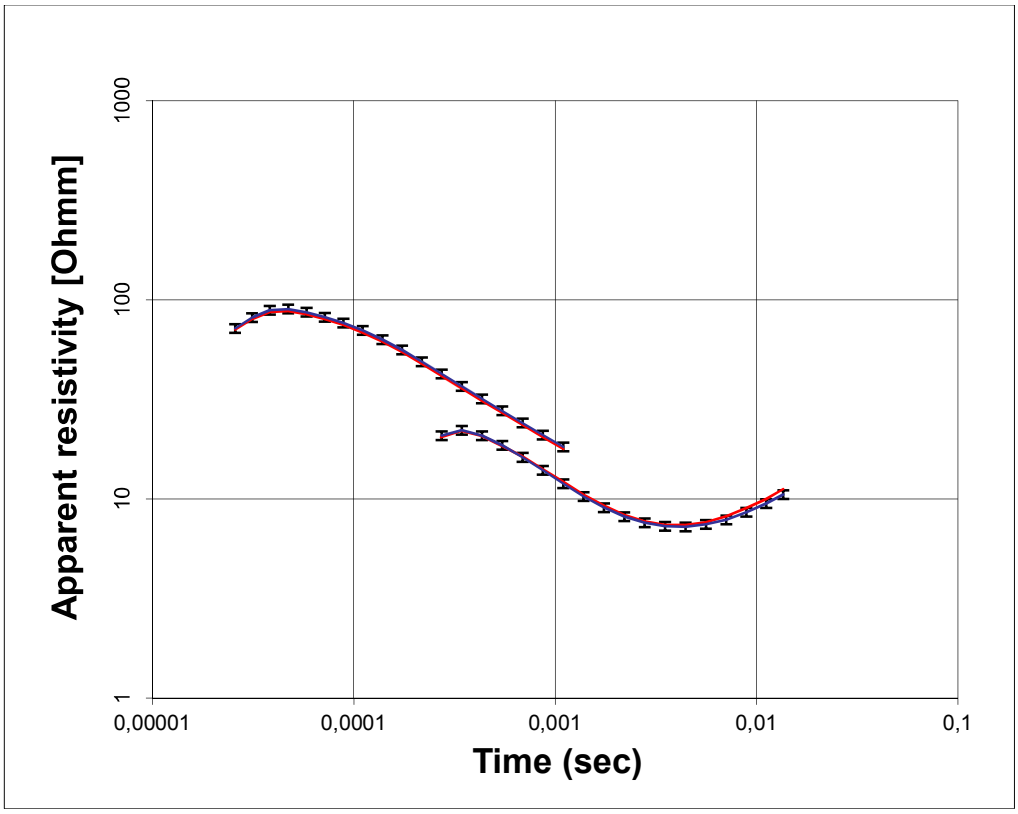


Figure 5: The frame is in 19 m altitude. Blue curves are the expected response, and red curves are the actual measurements.

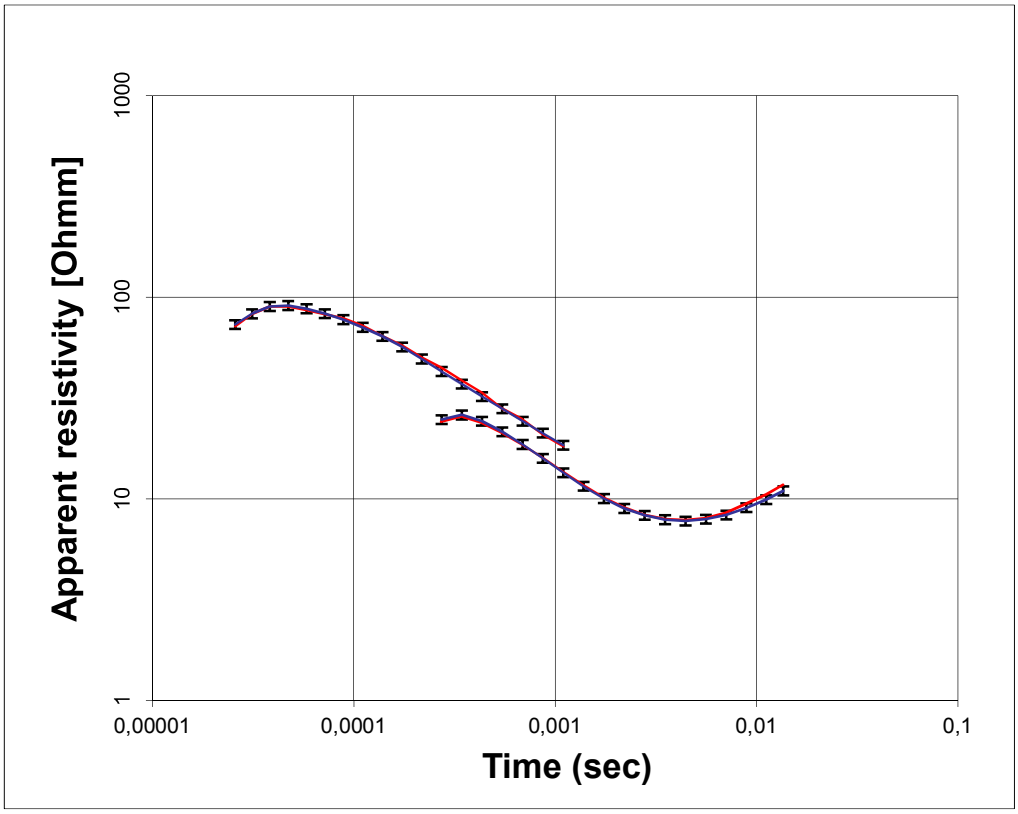


Figure 6: The frame is in 25 m altitude. Blue curves are the expected response, and red curves are the actual measurements.

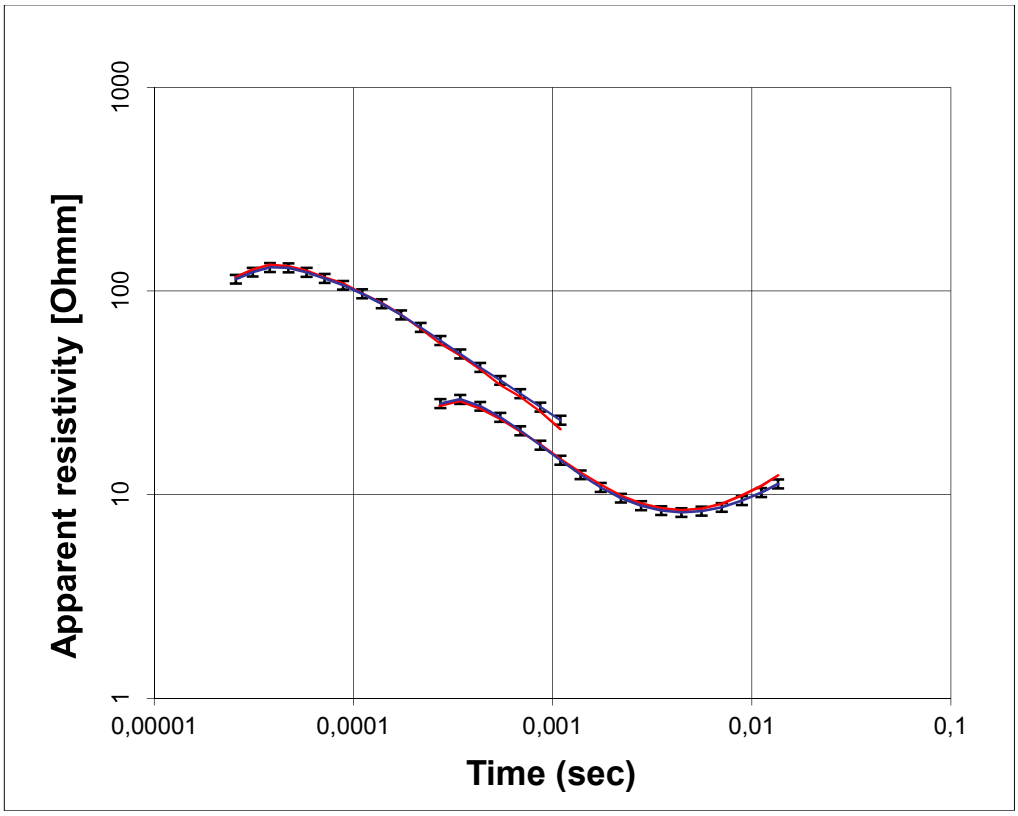


Figure 7 The frame is in 30 m altitude. Blue curves are the expected response and red curves are the actual measurements.

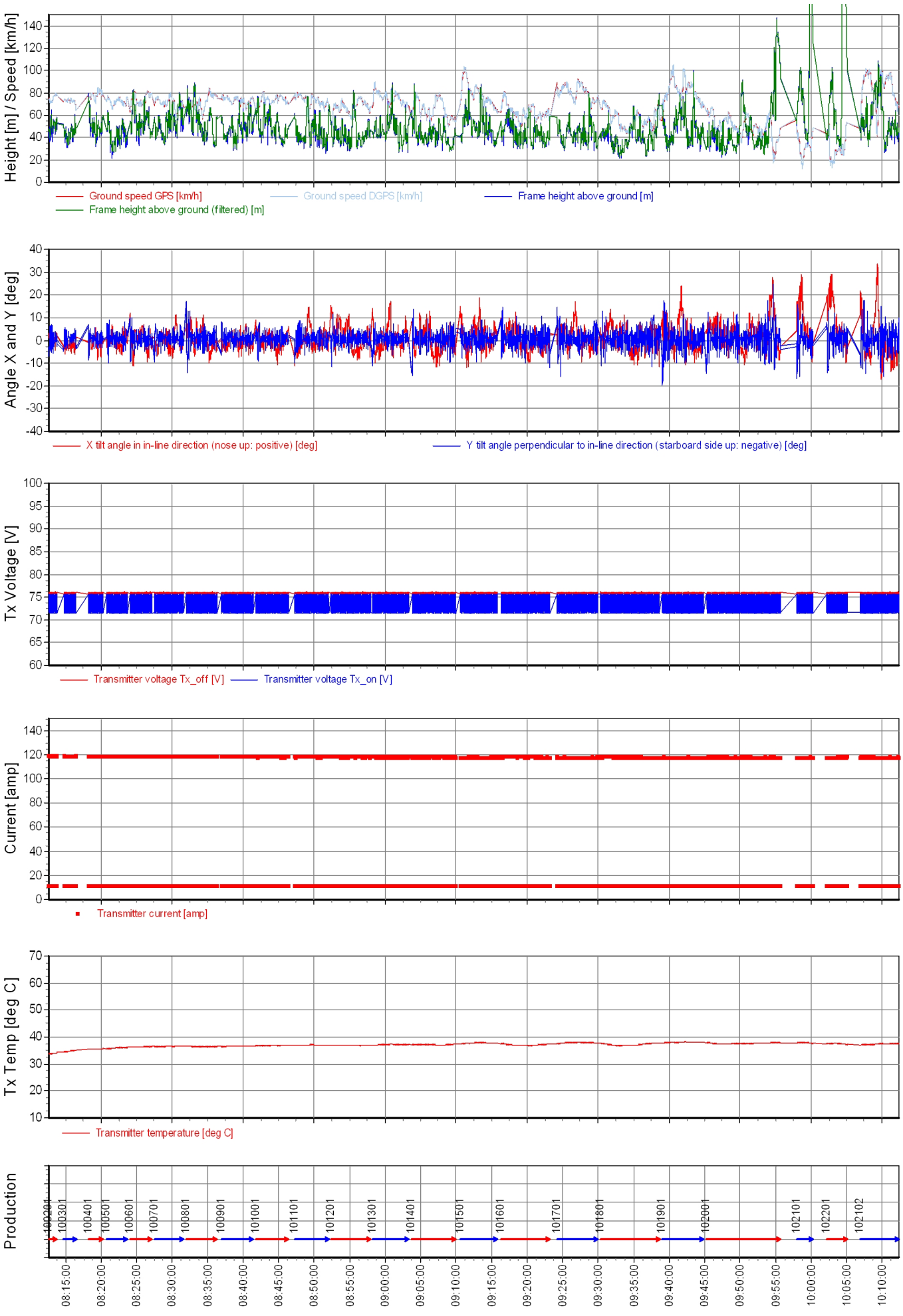
Appendix 4 Control parameters

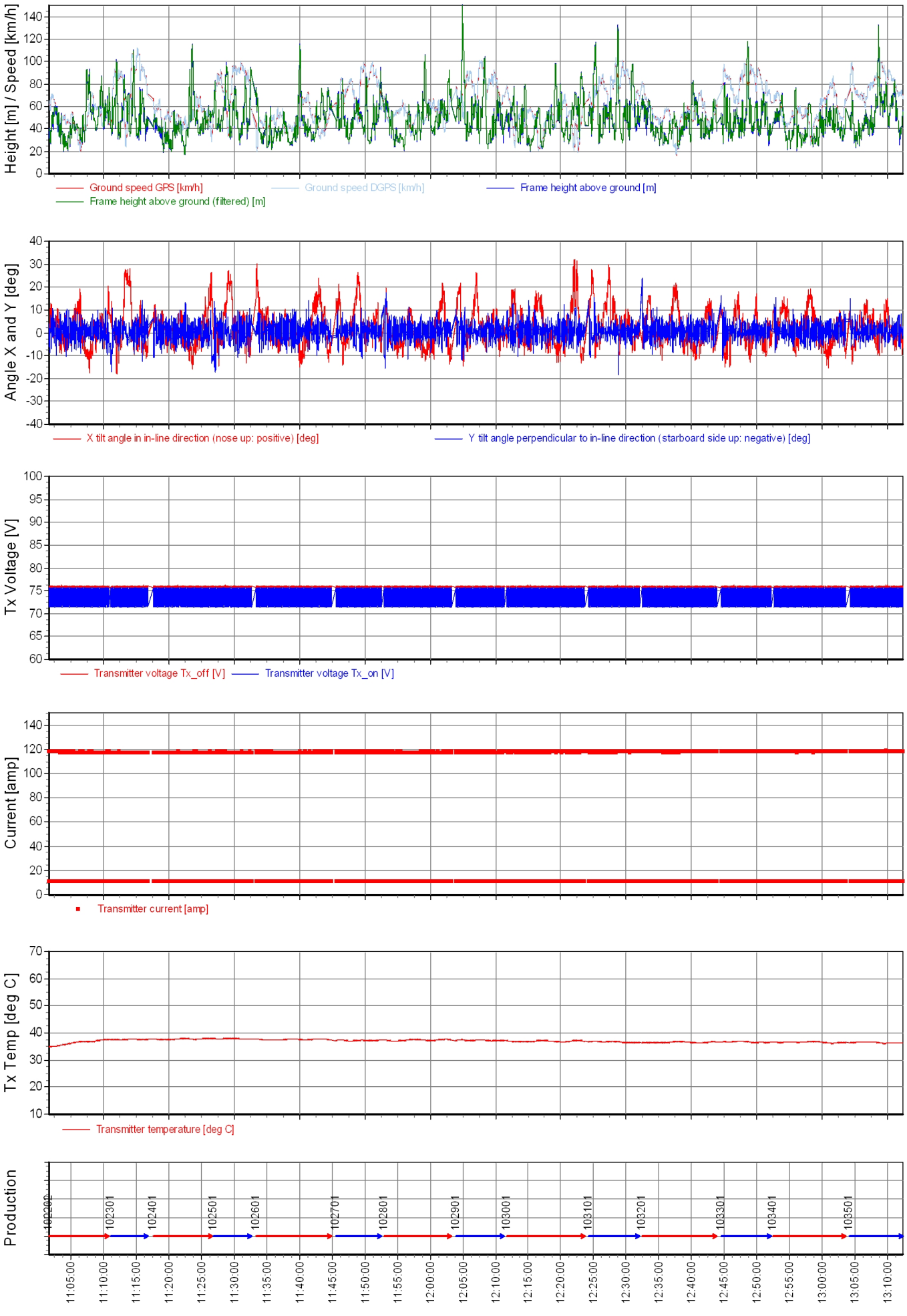
The following plots show the speed, altitude and the angle of the frame for every flight. Variations in the current, voltage on the transmitter and transmitter temperature are also shown.

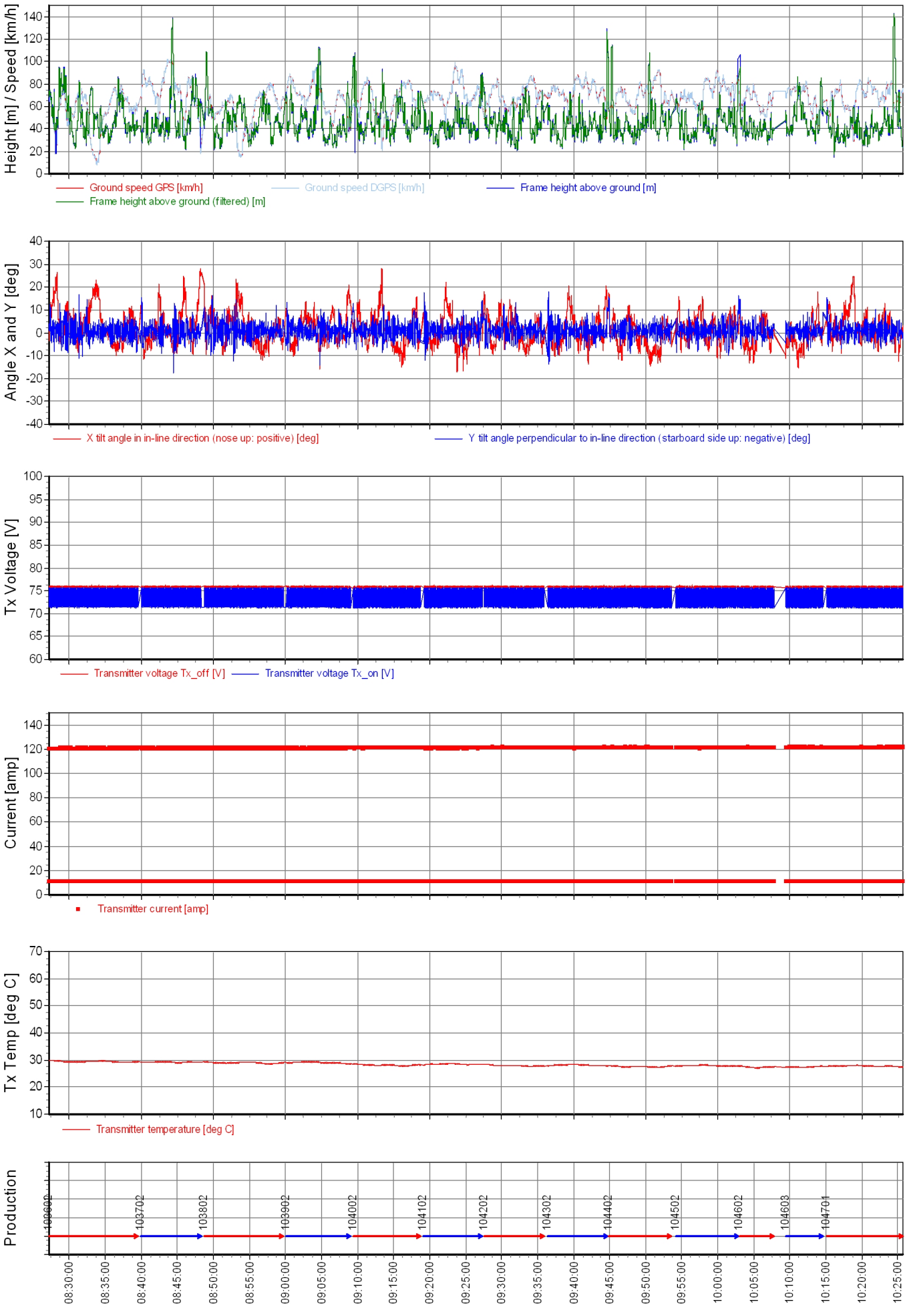
The green line, depicting processed frame height, shows the input from HE1 and HE2 after the frame has been corrected from deviations, away from the horizontal plane and any obstacles on the ground e.g. trees.

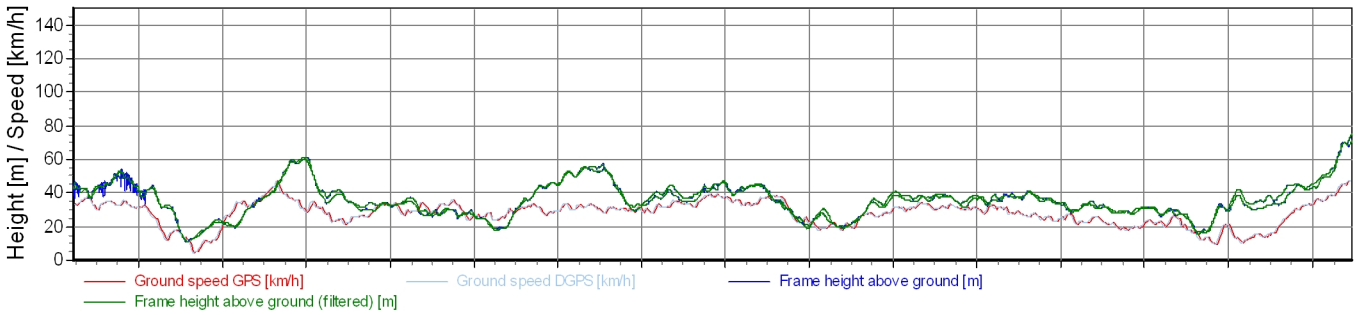
Turns at the end of flight lines and transport are shown as gaps in the bottom of the display.

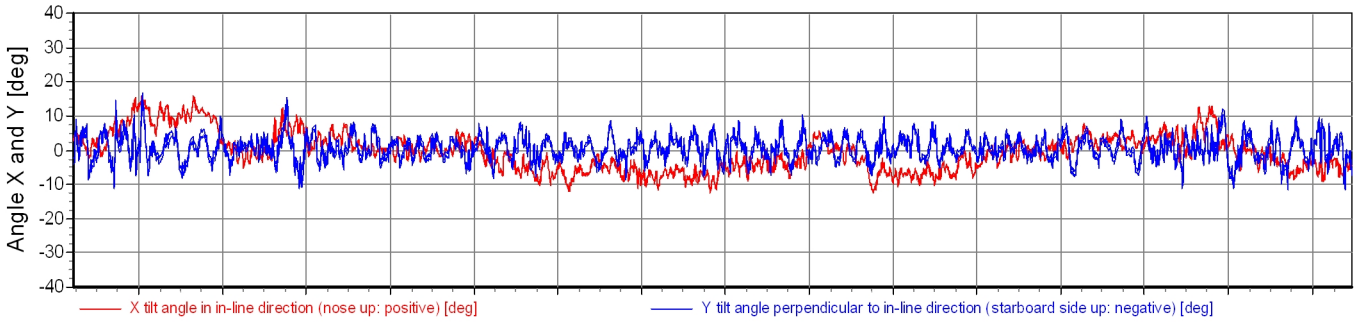
The ground speed in the uppermost window displays the signal from both gps GP1 and GP2.

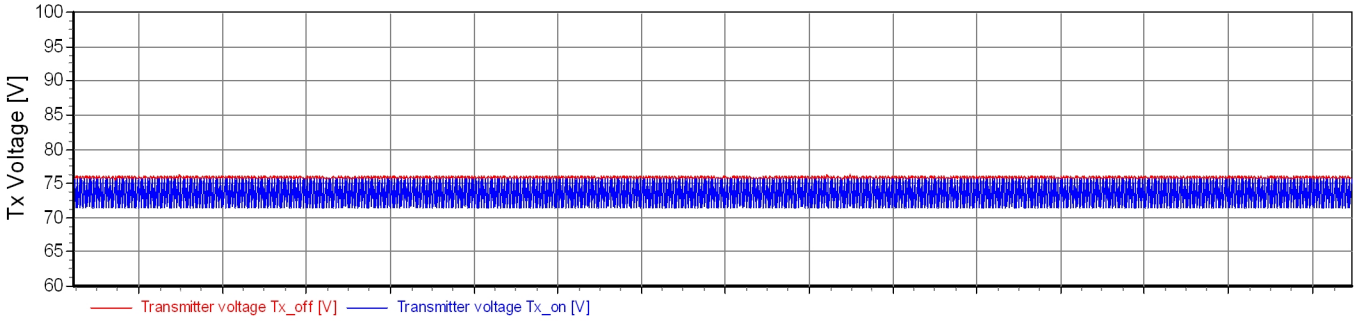

Height [m] / Speed [km/h]
Ground speed GPS [km/h]
Ground speed DGPS [km/h]
Frame height above ground [m]
Frame height above ground (filtered) [m]
Angle X and Y [deg]
X tilt angle in in-line direction (nose up: positive) [deg]
Y tilt angle perpendicular to in-line direction (starboard side up: negative) [deg]
Tx Voltage [V]
Transmitter voltage Tx_off [V]
Transmitter voltage Tx_on [V]
Current [amp]
Transmitter current [amp]
Tx Temp [deg C]
Transmitter temperature [deg C]
Production
100201
100301
100401
100501
100601
100701
100801
100901
101001
101101
101201
101301
101401
101501
101601
101701
101801
101901
102001
102101
102201
102102
08:15:00
08:20:00
08:25:00
08:30:00
08:35:00
08:40:00
08:45:00
08:50:00
08:55:00
09:00:00
09:05:00
09:10:00
09:15:00
09:20:00
09:25:00
09:30:00
09:35:00
09:40:00
09:45:00
09:50:00
09:55:00
10:00:00
10:05:00
10:10:00

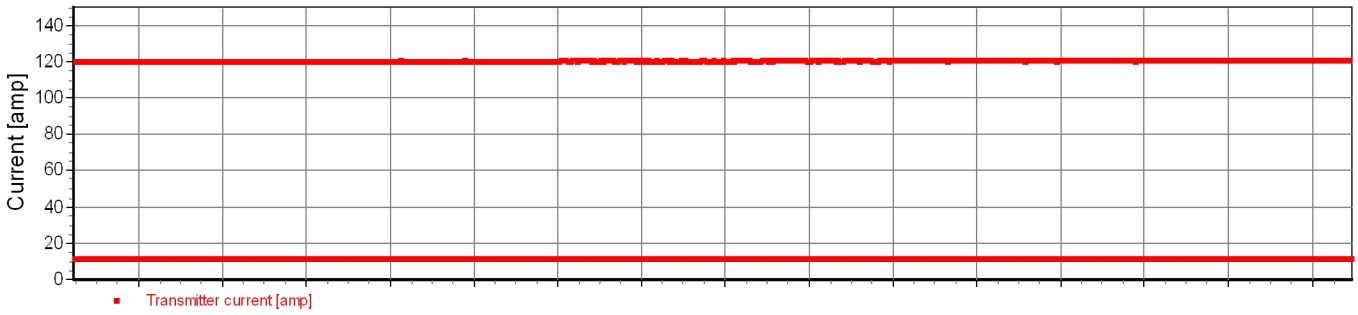

Height [m] / Speed [km/h]
Ground speed GPS [km/h]
Ground speed DGPS [km/h]
Frame height above ground [m]
Frame height above ground (filtered) [m]
Angle X and Y [deg]
X tilt angle in in-line direction (nose up: positive) [deg]
Y tilt angle perpendicular to in-line direction (starboard side up: negative) [deg]
Tx Voltage [V]
Transmitter voltage Tx_off [V]
Transmitter voltage Tx_on [V]
Current [amp]
Transmitter current [amp]
Tx Temp [deg C]
Transmitter temperature [deg C]
Production
102201
102301
102401
102501
102601
102701
102801
102901
103001
103101
103201
103301
103401
103501
11:05:00
11:10:00
11:15:00
11:20:00
11:25:00
11:30:00
11:35:00
11:40:00
11:45:00
11:50:00
11:55:00
12:00:00
12:05:00
12:10:00
12:15:00
12:20:00
12:25:00
12:30:00
12:35:00
12:40:00
12:45:00
12:50:00
12:55:00
13:00:00
13:05:00
13:10:00

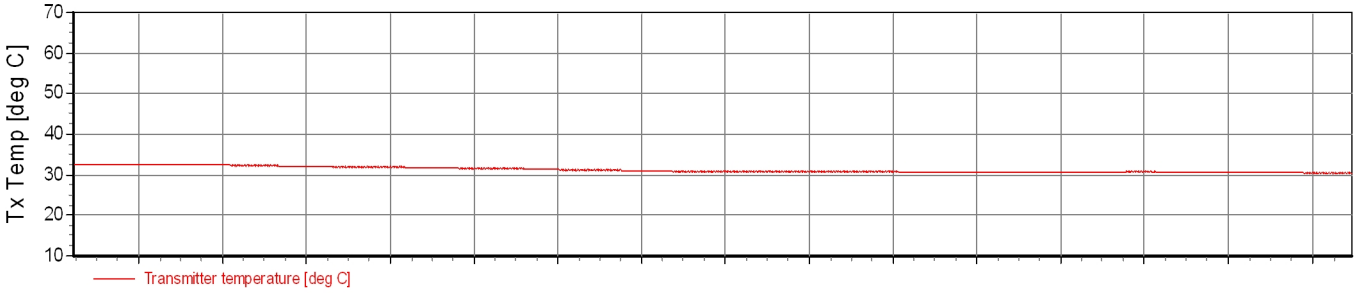

Height [m] / Speed [km/h]
Ground speed GPS [km/h]
Ground speed DGPS [km/h]
Frame height above ground [m]
Frame height above ground (filtered) [m]
Angle X and Y [deg]
X tilt angle in in-line direction (nose up: positive) [deg]
Y tilt angle perpendicular to in-line direction (starboard side up: negative) [deg]
Tx Voltage [V]
Transmitter voltage Tx_off [V]
Transmitter voltage Tx_on [V]
Current [amp]
Transmitter current [amp]
Tx Temp [deg C]
Transmitter temperature [deg C]
Production
103600
103702
103802
103902
104002
104102
104202
104302
104402
104502
104602
104603
104701
08:30:00
08:35:00
08:40:00
08:45:00
08:50:00
08:55:00
09:00:00
09:05:00
09:10:00
09:15:00
09:20:00
09:25:00
09:30:00
09:35:00
09:40:00
09:45:00
09:50:00
09:55:00
10:00:00
10:05:00
10:10:00
10:15:00
10:20:00
10:25:00

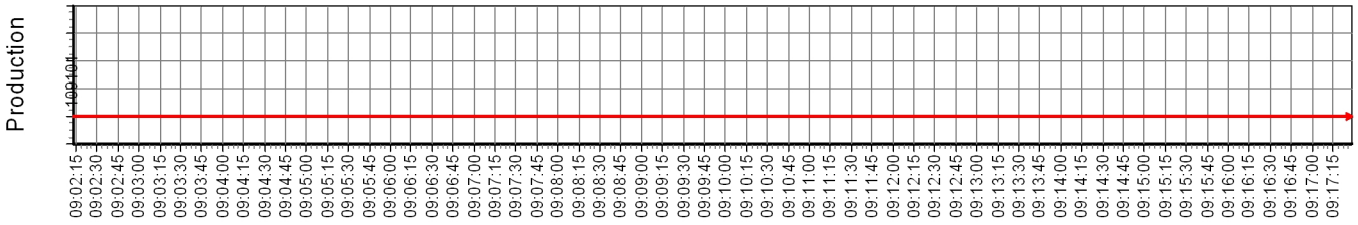

Height [m] / Speed [km/h]
Ground speed GPS [km/h]
Ground speed DGPS [km/h]
Frame height above ground [m]
Frame height above ground (filtered) [m]

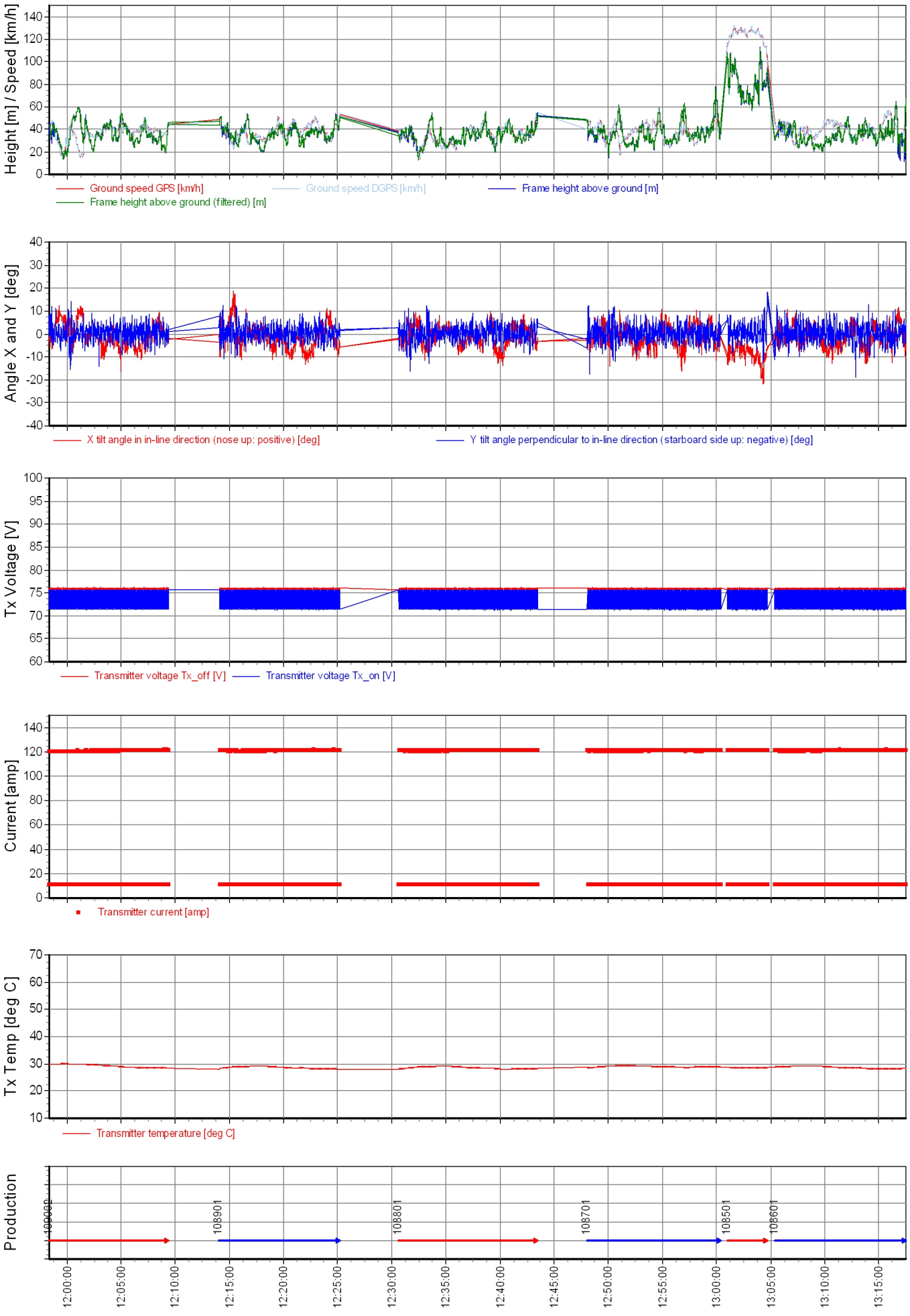

Angle X and Y [deg]
X tilt angle in in-line direction (nose up: positive) [deg]
Y tilt angle perpendicular to in-line direction (starboard side up: negative) [deg]

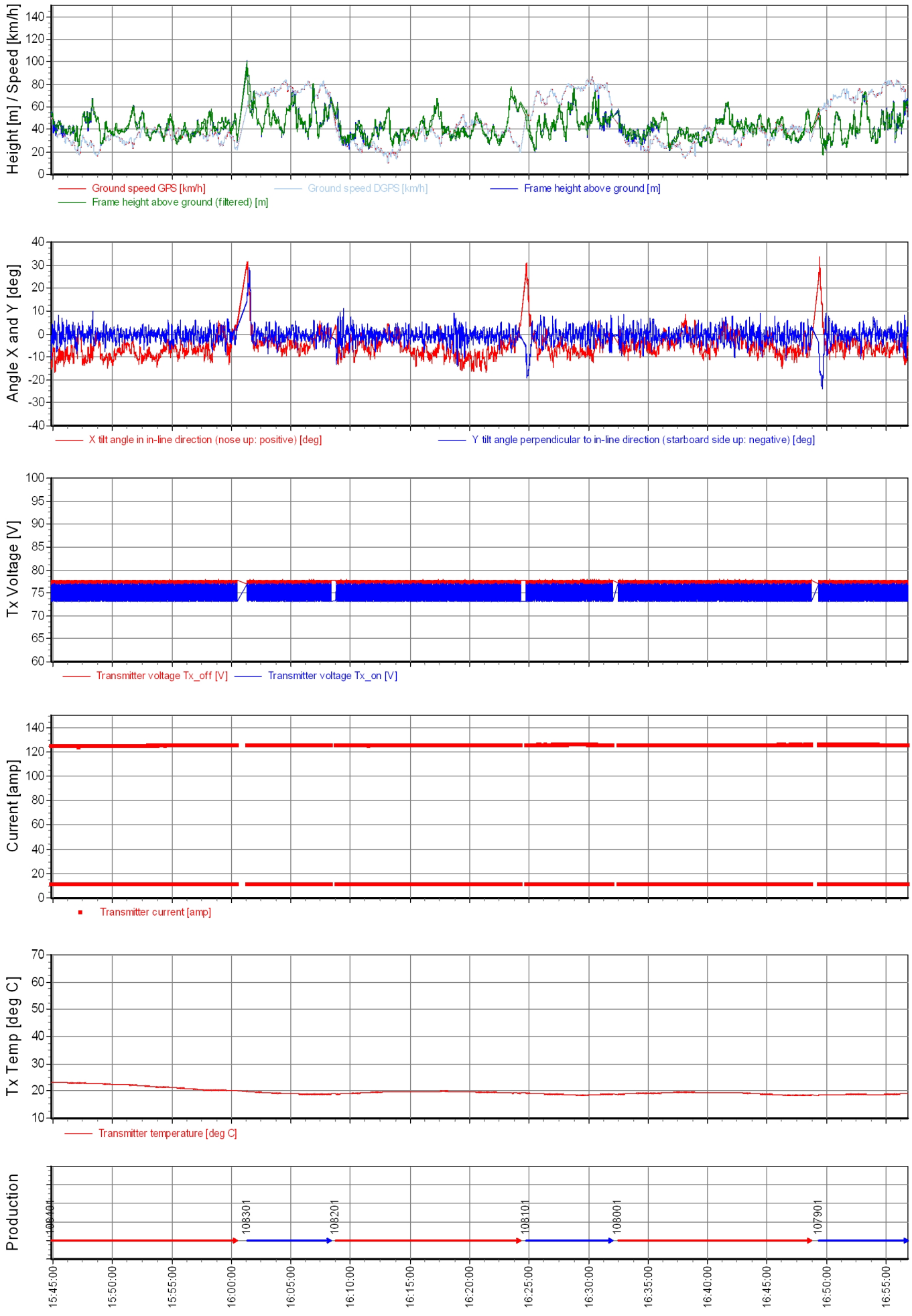

Tx Voltage [V]
Transmitter voltage Tx_off [V]
Transmitter voltage Tx_on [V]

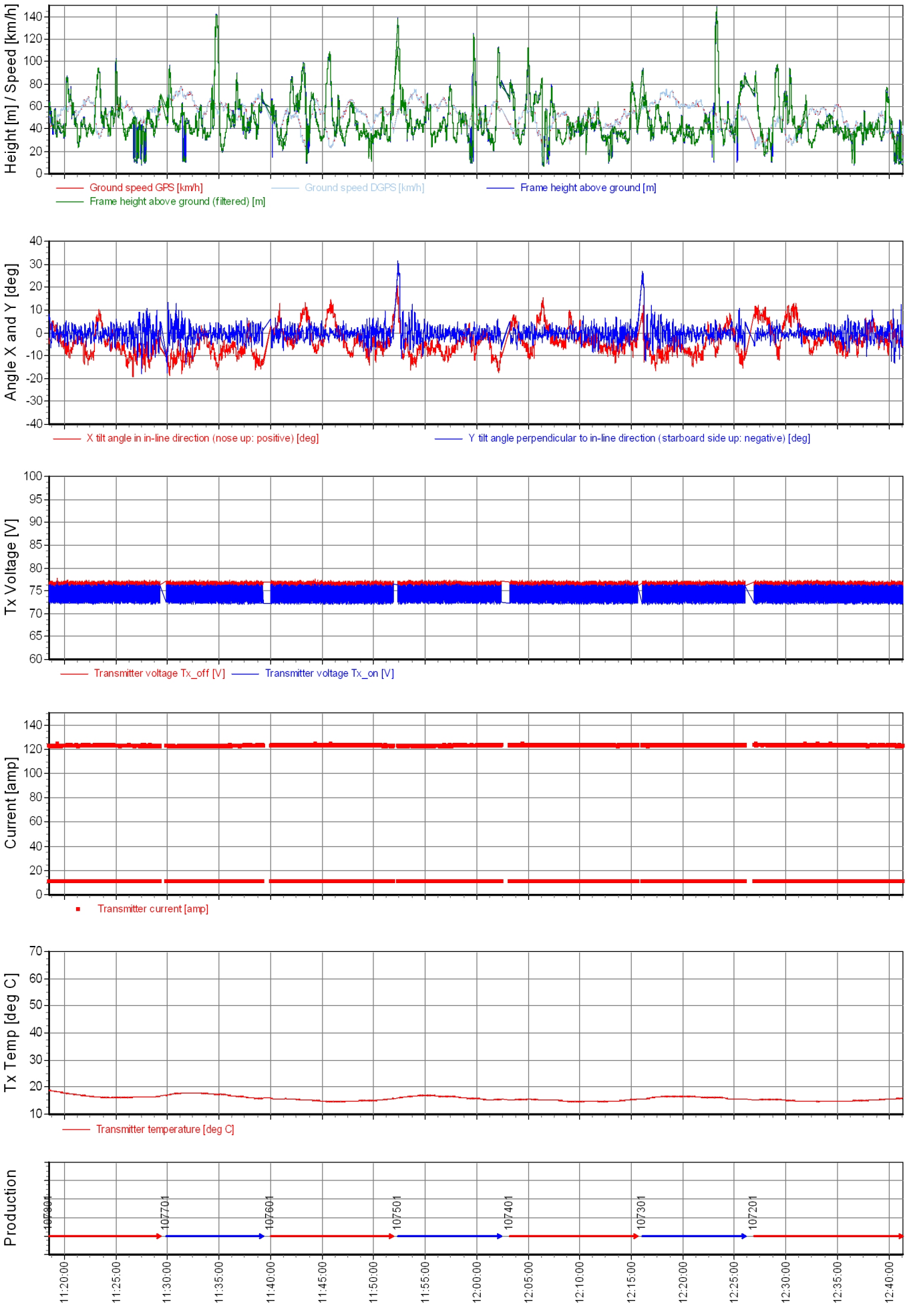

Current [amp]
Transmitter current [amp]

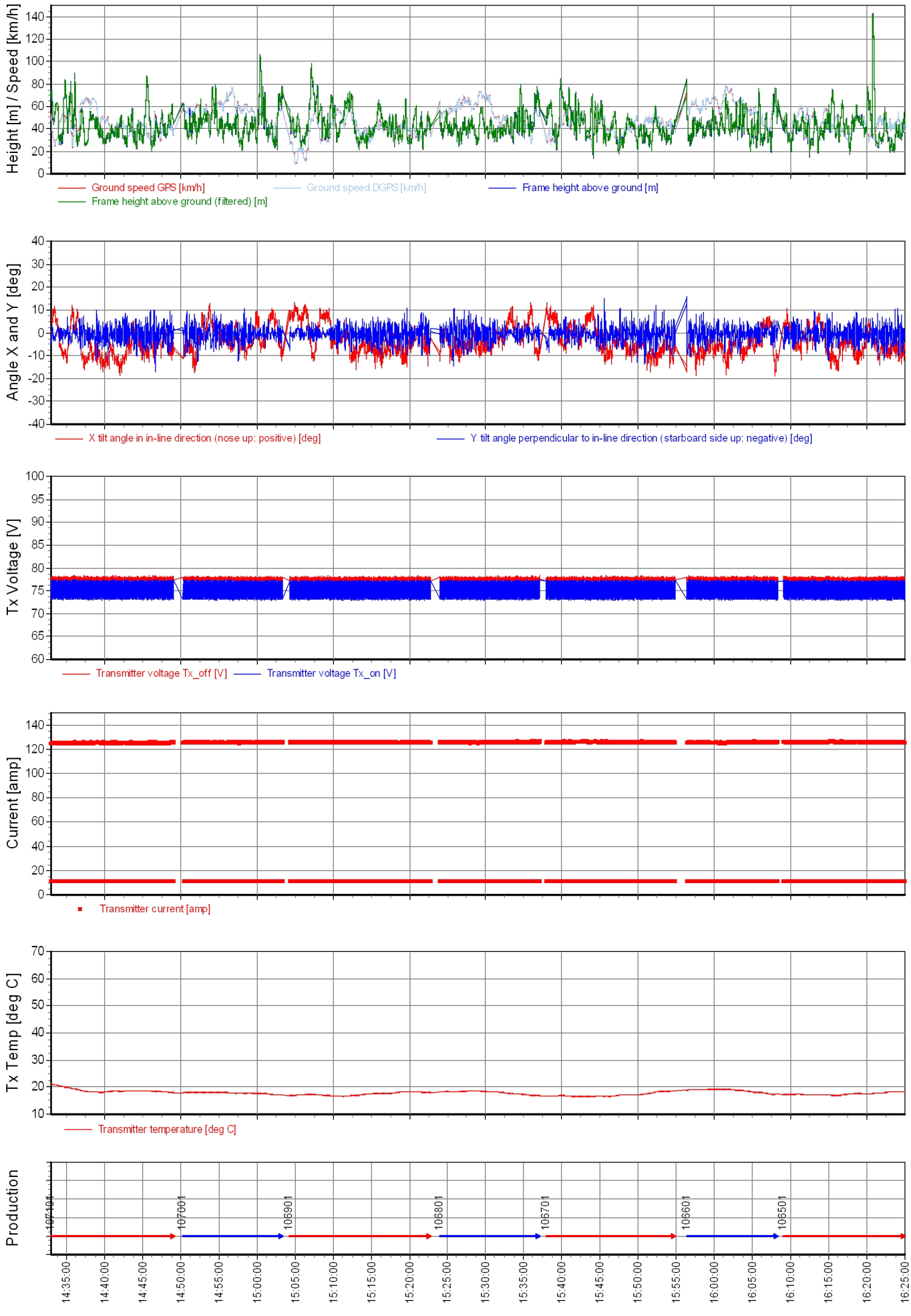

Tx Temp [deg C]
Transmitter temperature [deg C]

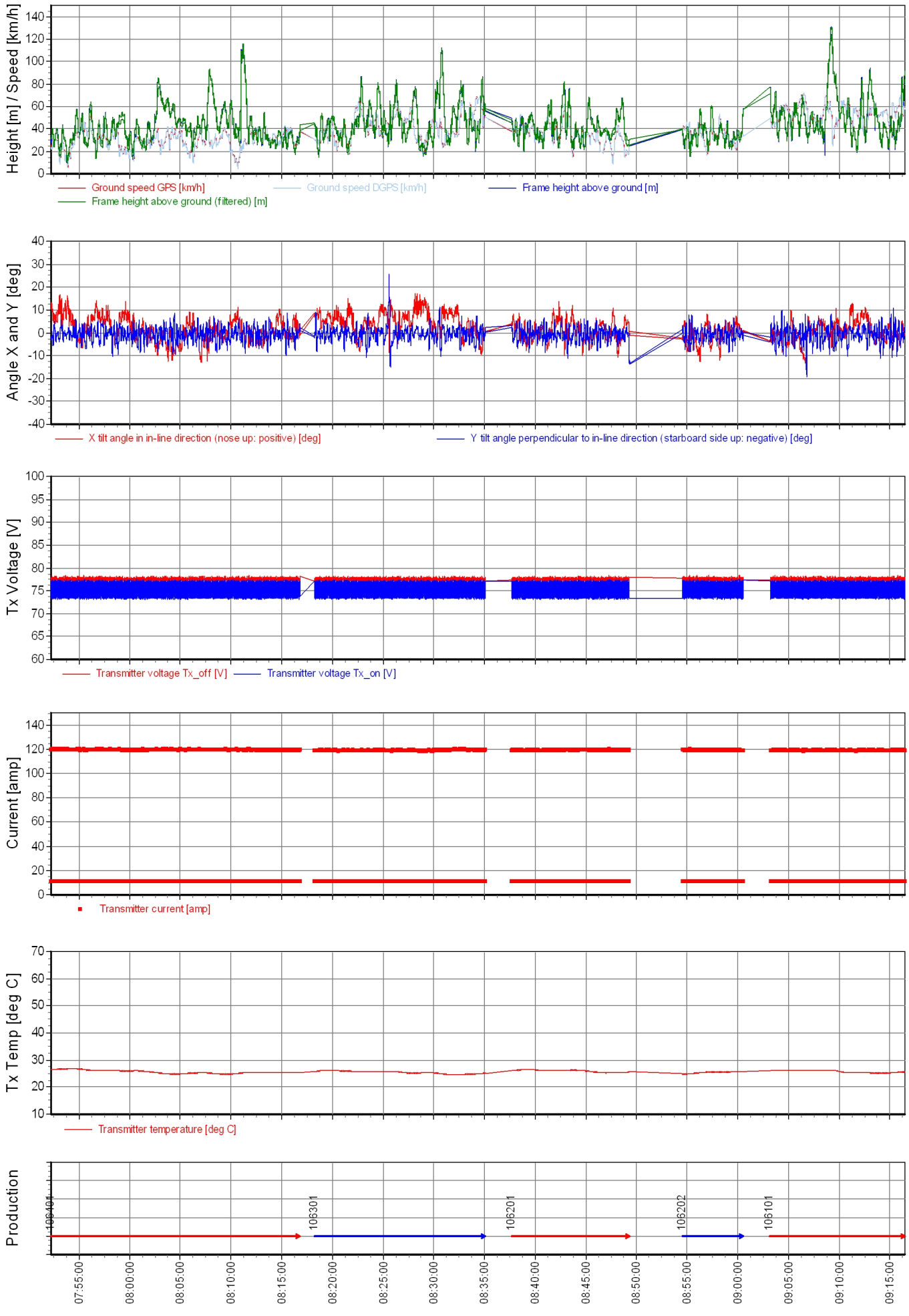

Production

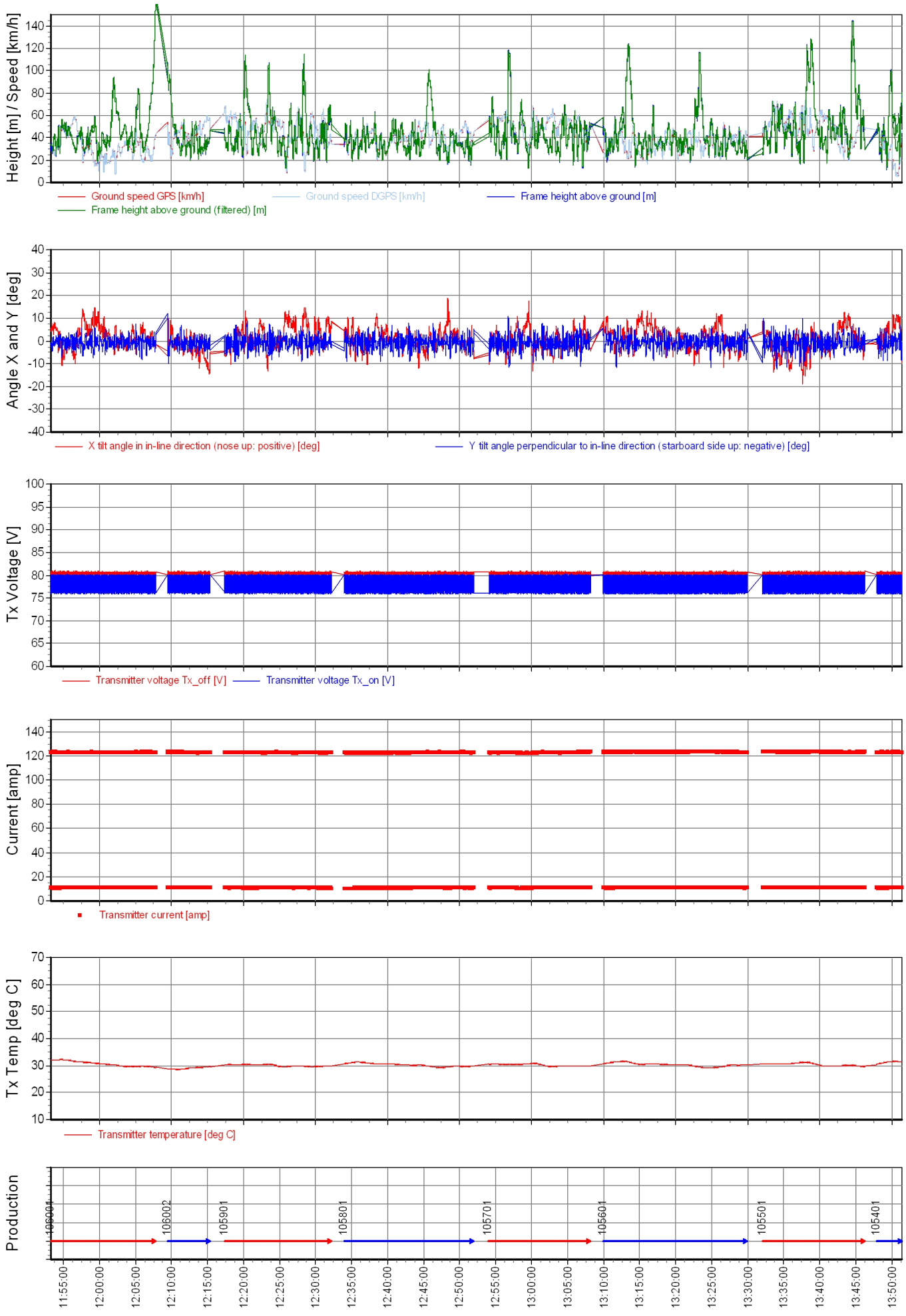

Height [m] / Speed [km/h]
Ground speed GPS [km/h]
Ground speed DGPS [km/h]
Frame height above ground [m]
Frame height above ground (filtered) [m]
Angle X and Y [deg]
X tilt angle in in-line direction (nose up: positive) [deg]
Y tilt angle perpendicular to in-line direction (starboard side up: negative) [deg]
Tx Voltage [V]
Transmitter voltage Tx_off [V]
Transmitter voltage Tx_on [V]
Current [amp]
Transmitter current [amp]
Tx Temp [deg C]
Transmitter temperature [deg C]
Production
109001
108901
108801
108701
108501
108601
12:00:00
12:05:00
12:10:00
12:15:00
12:20:00
12:25:00
12:30:00
12:35:00
12:40:00
12:45:00
12:50:00
12:55:00
13:00:00
13:05:00
13:10:00
13:15:00

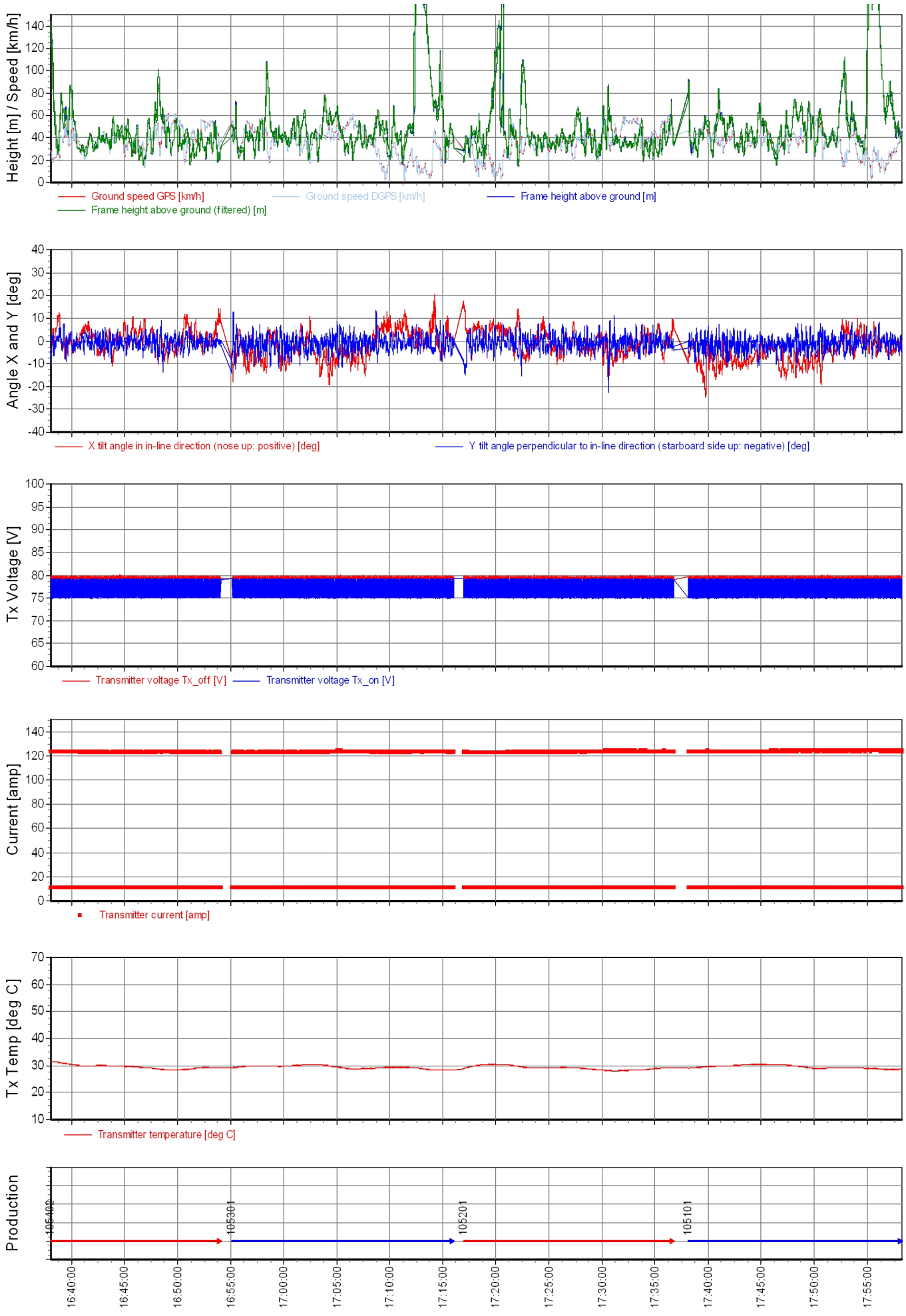

Height [m] / Speed [km/h]
Ground speed GPS [km/h]
Ground speed DGPS [km/h]
Frame height above ground [m]
Frame height above ground (filtered) [m]
Angle X and Y [deg]
X tilt angle in in-line direction (nose up: positive) [deg]
Y tilt angle perpendicular to in-line direction (starboard side up: negative) [deg]
Tx Voltage [V]
Transmitter voltage Tx_off [V]
Transmitter voltage Tx_on [V]
Current [amp]
Transmitter current [amp]
Tx Temp [deg C]
Transmitter temperature [deg C]
Production
108401
108301
108201
108101
108001
107901
15:45:00
15:50:00
15:55:00
16:00:00
16:05:00
16:10:00
16:15:00
16:20:00
16:25:00
16:30:00
16:35:00
16:40:00
16:45:00
16:50:00
16:55:00

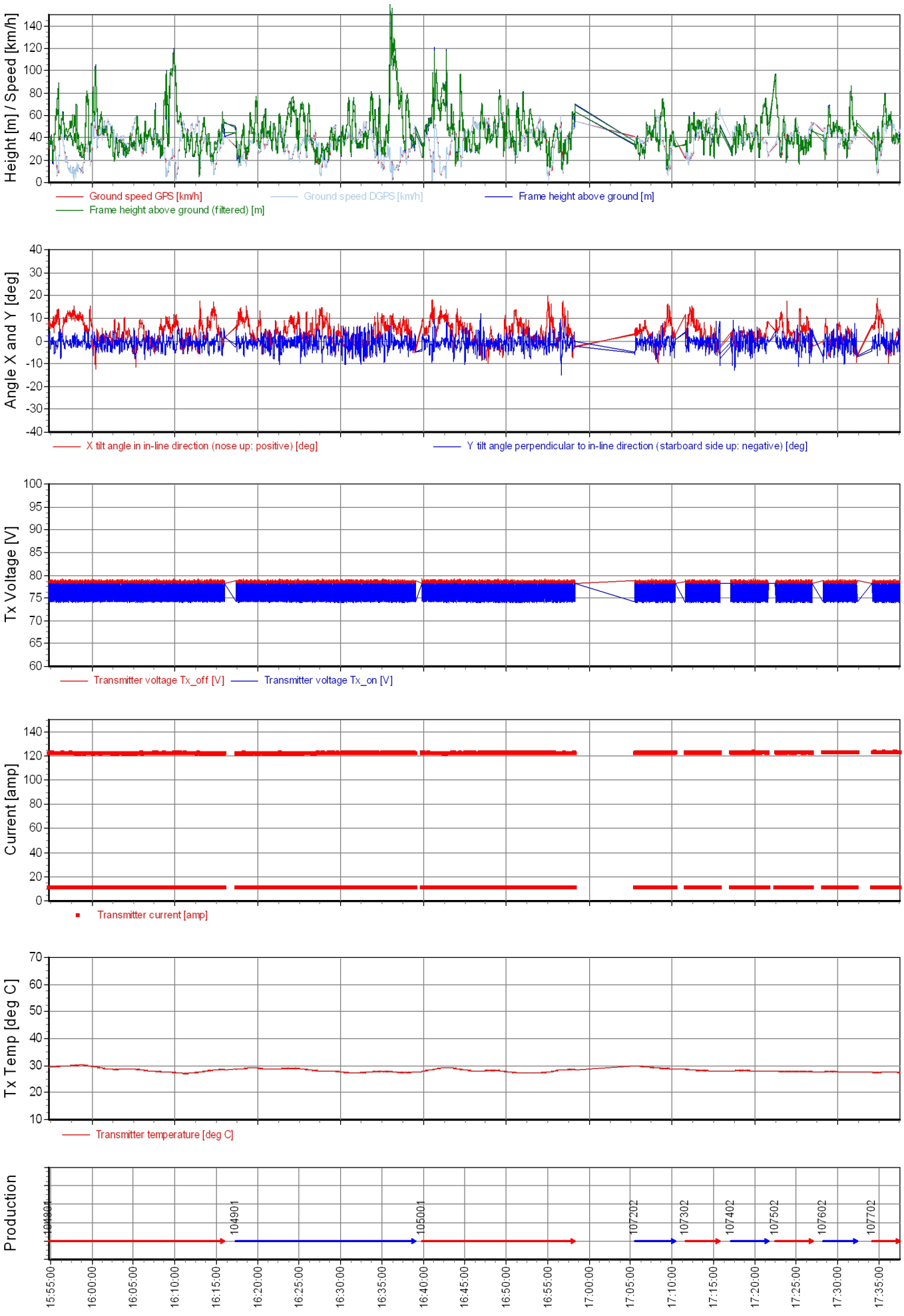

Height [m] / Speed [km/h]
Ground speed GPS [km/h]
Ground speed DGPS [km/h]
Frame height above ground [m]
Frame height above ground (filtered) [m]
Angle X and Y [deg]
X tilt angle in in-line direction (nose up: positive) [deg]
Y tilt angle perpendicular to in-line direction (starboard side up: negative) [deg]
Tx Voltage [V]
Transmitter voltage Tx_off [V]
Transmitter voltage Tx_on [V]
Current [amp]
Transmitter current [amp]
Tx Temp [deg C]
Transmitter temperature [deg C]
Production
107801
107701
107601
107501
107401
107301
107201
11:20:00
11:25:00
11:30:00
11:35:00
11:40:00
11:45:00
11:50:00
11:55:00
12:00:00
12:05:00
12:10:00
12:15:00
12:20:00
12:25:00
12:30:00
12:35:00
12:40:00

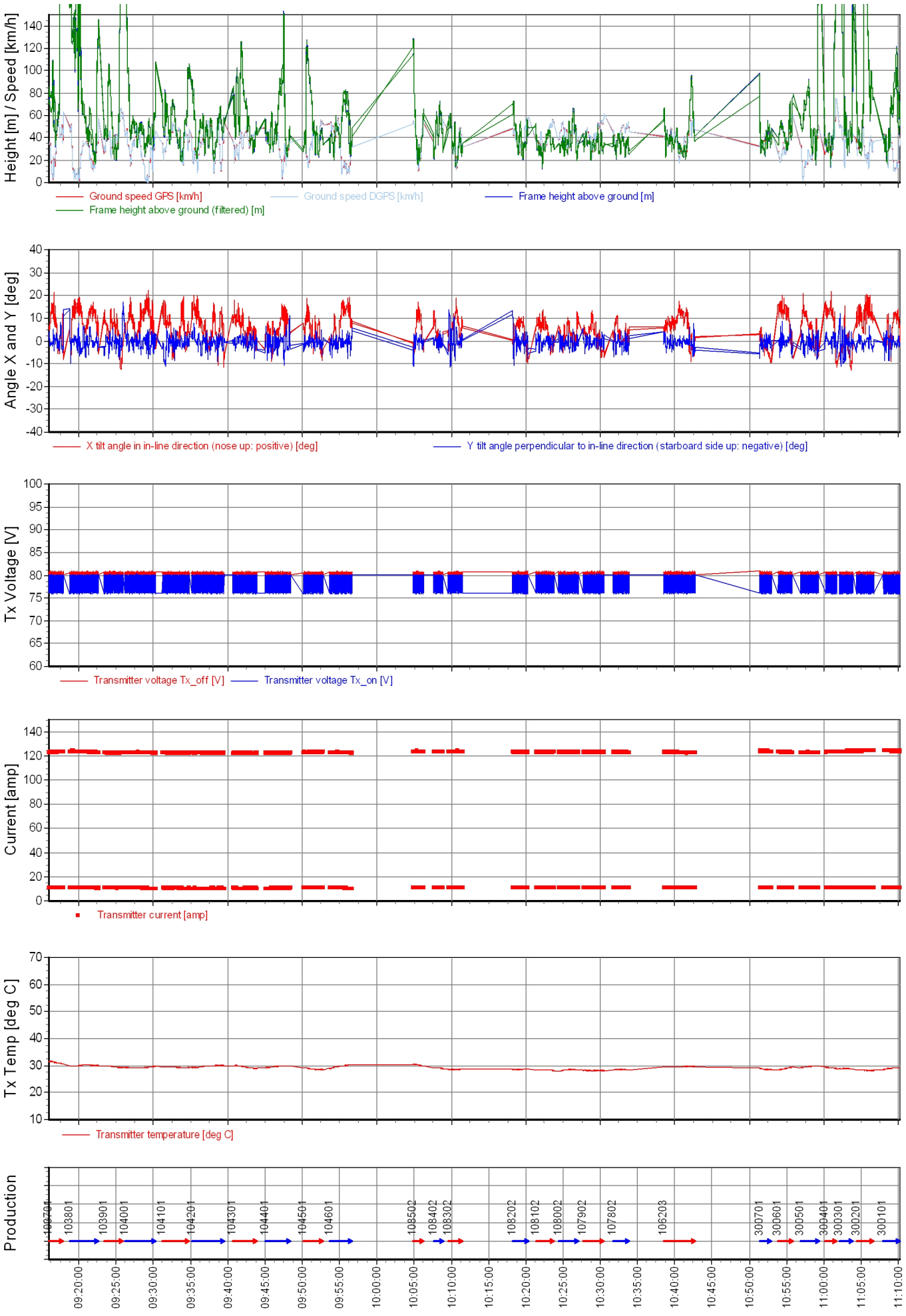

Height [m] / Speed [km/h]
Ground speed GPS [km/h]
Ground speed DGPS [km/h]
Frame height above ground [m]
Frame height above ground (filtered) [m]
Angle X and Y [deg]
X tilt angle in in-line direction (nose up: positive) [deg]
Y tilt angle perpendicular to in-line direction (starboard side up: negative) [deg]
Tx Voltage [V]
Transmitter voltage Tx_off [V]
Transmitter voltage Tx_on [V]
Current [amp]
Transmitter current [amp]
Tx Temp [deg C]
Transmitter temperature [deg C]
Production
107101
107001
106901
106801
106701
106601
106501
14:35:00
14:40:00
14:45:00
14:50:00
14:55:00
15:00:00
15:05:00
15:10:00
15:15:00
15:20:00
15:25:00
15:30:00
15:35:00
15:40:00
15:45:00
15:50:00
15:55:00
16:00:00
16:05:00
16:10:00
16:15:00
16:20:00
16:25:00

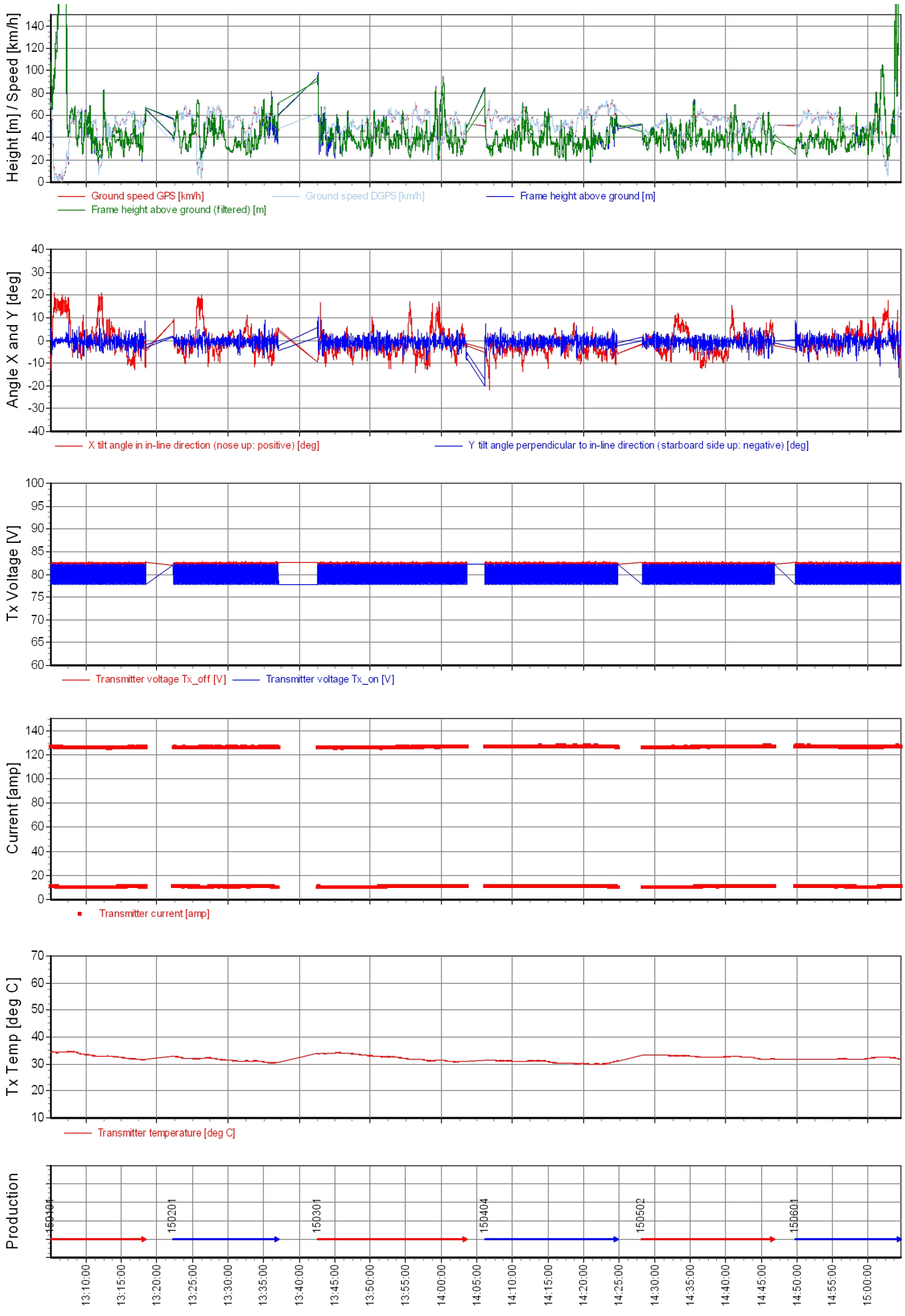

Height [m] / Speed [km/h]
Ground speed GPS [km/h]
Ground speed DGPS [km/h]
Frame height above ground [m]
Frame height above ground (filtered) [m]
Angle X and Y [deg]
X tilt angle in in-line direction (nose up: positive) [deg]
Y tilt angle perpendicular to in-line direction (starboard side up: negative) [deg]
Tx Voltage [V]
Transmitter voltage Tx_off [V]
Transmitter voltage Tx_on [V]
Current [amp]
Transmitter current [amp]
Tx Temp [deg C]
Transmitter temperature [deg C]
Production
106401
106301
106201
106202
106101
07:55:00
08:00:00
08:05:00
08:10:00
08:15:00
08:20:00
08:25:00
08:30:00
08:35:00
08:40:00
08:45:00
08:50:00
08:55:00
09:00:00
09:05:00
09:10:00
09:15:00


Height [m] / Speed [km/h]
Ground speed GPS [km/h]
Ground speed DGPS [km/h]
Frame height above ground [m]
Frame height above ground (filtered) [m]
Angle X and Y [deg]
X tilt angle in in-line direction (nose up: positive) [deg]
Y tilt angle perpendicular to in-line direction (starboard side up: negative) [deg]
Tx Voltage [V]
Transmitter voltage Tx_off [V]
Transmitter voltage Tx_on [V]
Current [amp]
Transmitter current [amp]
Tx Temp [deg C]
Transmitter temperature [deg C]
Production
106001
106002
105901
105801
105701
105601
105501
105401
11:55:00
12:00:00
12:05:00
12:10:00
12:15:00
12:20:00
12:25:00
12:30:00
12:35:00
12:40:00
12:45:00
12:50:00
12:55:00
13:00:00
13:05:00
13:10:00
13:15:00
13:20:00
13:25:00
13:30:00
13:35:00
13:40:00
13:45:00
13:50:00


Height [m] / Speed [km/h]
Ground speed GPS [km/h]
Ground speed DGPS [km/h]
Frame height above ground [m]
Frame height above ground (filtered) [m]
Angle X and Y [deg]
X tilt angle in in-line direction (nose up: positive) [deg]
Y tilt angle perpendicular to in-line direction (starboard side up: negative) [deg]
Tx Voltage [V]
Transmitter voltage Tx_off [V]
Transmitter voltage Tx_on [V]
Current [amp]
Transmitter current [amp]
Tx Temp [deg C]
Transmitter temperature [deg C]
Production
105401
105301
105201
105101
16:40:00
16:45:00
16:50:00
16:55:00
17:00:00
17:05:00
17:10:00
17:15:00
17:20:00
17:25:00
17:30:00
17:35:00
17:40:00
17:45:00
17:50:00
17:55:00


Height [m] / Speed [km/h]
Ground speed GPS [km/h]
Ground speed DGPS [km/h]
Frame height above ground [m]
Frame height above ground (filtered) [m]
Angle X and Y [deg]
X tilt angle in in-line direction (nose up: positive) [deg]
Y tilt angle perpendicular to in-line direction (starboard side up: negative) [deg]
Tx Voltage [V]
Transmitter voltage Tx_off [V]
Transmitter voltage Tx_on [V]
Current [amp]
Transmitter current [amp]
Tx Temp [deg C]
Transmitter temperature [deg C]
Production
104801
104901
105001
107202
107302
107402
107502
107602
107702
15:55:00
16:00:00
16:05:00
16:10:00
16:15:00
16:20:00
16:25:00
16:30:00
16:35:00
16:40:00
16:45:00
16:50:00
16:55:00
17:00:00
17:05:00
17:10:00
17:15:00
17:20:00
17:25:00
17:30:00
17:35:00


Height [m] / Speed [km/h]
Ground speed GPS [km/h]
Ground speed DGPS [km/h]
Frame height above ground [m]
Frame height above ground (filtered) [m]
Angle X and Y [deg]
X tilt angle in in-line direction (nose up: positive) [deg]
Y tilt angle perpendicular to in-line direction (starboard side up: negative) [deg]
Tx Voltage [V]
Transmitter voltage Tx_off [V]
Transmitter voltage Tx_on [V]
Current [amp]
Transmitter current [amp]
Tx Temp [deg C]
Transmitter temperature [deg C]
Production
109701
103801
103901
104001
104101
104201
104301
104401
104501
104601
108502
108402
108302
108202
108102
108002
107902
107802
106203
300701
300601
300501
300401
300301
300201
300101
09:20:00
09:25:00
09:30:00
09:35:00
09:40:00
09:45:00
09:50:00
09:55:00
10:00:00
10:05:00
10:10:00
10:15:00
10:20:00
10:25:00
10:30:00
10:35:00
10:40:00
10:45:00
10:50:00
10:55:00
11:00:00
11:05:00
11:10:00


Height [m] / Speed [km/h]
Ground speed GPS [km/h]
Ground speed DGPS [km/h]
Frame height above ground [m]
Frame height above ground (filtered) [m]
Angle X and Y [deg]
X tilt angle in in-line direction (nose up: positive) [deg]
Y tilt angle perpendicular to in-line direction (starboard side up: negative) [deg]
Tx Voltage [V]
Transmitter voltage Tx_off [V]
Transmitter voltage Tx_on [V]
Current [amp]
Transmitter current [amp]
Tx Temp [deg C]
Transmitter temperature [deg C]
Production
150101
150201
150301
150404
150502
150601
13:10:00
13:15:00
13:20:00
13:25:00
13:30:00
13:35:00
13:40:00
13:45:00
13:50:00
13:55:00
14:00:00
14:05:00
14:10:00
14:15:00
14:20:00
14:25:00
14:30:00
14:35:00
14:40:00
14:45:00
14:50:00
14:55:00
15:00:00

Appendix 5: Modelling and inversion of TEM Data

This appendix gives a brief introduction to modelling and inversion of SkyTEM data.

The model

The model used for inversion of SkyTEM data is a multi-layer model (MLM) with typically 30 layers. The layer thicknesses increase downwards as a hyperbolic sine function of the layer number. This means that the depth to the layer boundaries increases linearly for small depths, so that the top layers are all of approximately the same thickness. For large depths, the depth to the layer boundaries increases exponentially with depth, so that the thickness of a layer is a factor times the previous one.

Inversion - The initial model

The initial model for the deep inversion is a 30-layer MLM with a homogeneous resistivity layers, i.e. the initial model is essentially a homogeneous half space. Model optimization can be carried out in both a L1- and a L2- norm formulation where the former produces more blocky models than the latter.

Data and noise model

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

For SkyTEM data experience shows that the noise voltage most often can be described with a simple model: log(noise) is a linear function of log(time). When the width of the time gates increases proportional to delay time - as is the case with the SkyTEM system - the slope of the linear function is close to -0.5. The noise model used can therefore be described as:

$$V = V_0 \cdot \left(\frac{t}{t_0} \right)^{\alpha}$$

Where V is the noise voltage, V_0 is the noise voltage at time t_0 and α is the slope of the noise voltage as a function of time in a double logarithmic plot. Choosing t_0 = 1 ms, the noise model is defined by the values of V_0 and slope α. These values are chosen pragmatically by inspection of a subset of the data volume.

LM:
V_0 = 3.7e-13 in field units normalized with Tx moment
α = -0.6

HM:
V_0 = 6.0e-15 in field units normalized with Tx moment
α = -1.0

Regularization

Inversion of TEM data is a highly non-linear problem which means regularization is needed in order to guide the inversion routine to produce geologically feasible models. In the broadband statistical approach a model covariance matrix is build by stacking single-scale exponential covariance functions with different correlation lengths. This function describes the covariance between any two points in the sub-surface.

The approach has proven very useful as the expected sub-surface variability can be described through the prior covariance matrix.

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 turnoff 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 also increase the turnoff time and thus remove early-time gates, thereby making the near-surface resolution poorer. This trade-off is 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.

Data inconsistency

When using 1D models in the interpretation of SkyTEM data, inconsistency arises where the lateral gradient of conductivity is not small, e.g. typically in mining applications. However, also in environmental investigations, inconsistencies can arise, typically where near-surface good conductors have abrupt boundaries.

Appendix 6: Model sections and resistivity intervals

Model sections and resistivity interval maps can be found in grids and as PDF files.

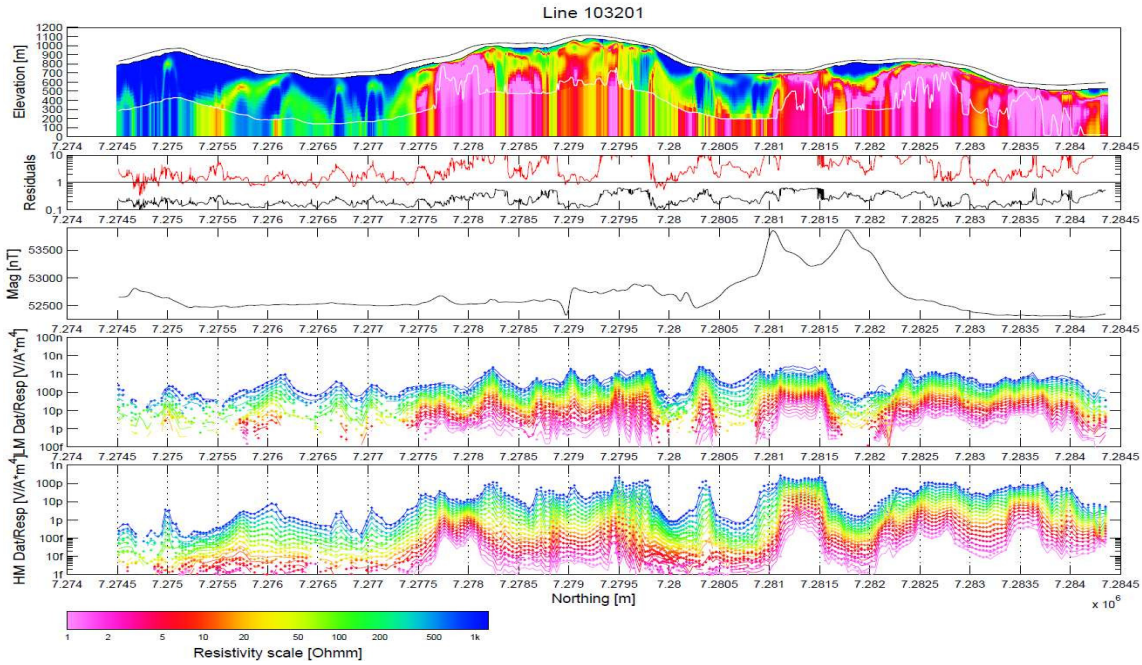


Figure 1 Resistivity model section from Raudvatnet showing the resistivity, the uncertainty, the residuals, TMI and gate plots.

Model sections

The top plot in the PDF model sections shows the inverted models with topography and color-coded resistivity of the individual layers according to the colour bar. The actual flight elevation is shown with a red line above the model section (see Figure 1 above).

The resistivity model along the profile can at times appear "blocky". This can be due to capacitive couplings in the data caused by cultural noise in the survey area.

The flight lines have been projected onto straight lines running from begin to end of a flight line.

The resistivity (the inverse of conductivity) is shown on a logarithmic scale, thus conductive and resistive feature appear with the same weight.

Superimposed on the section is the depth of investigation (DOI). The DOI is calculated based on the standard deviation.

Below the plot of the resistivity model is a plot of the total- and data residual of the inversions. The total residual is a weighted sum of the data residual and the model residual, where the latter is a measure of the roughness of the model, i.e. the deviation of the final model from the initial homogeneous half space model.

Below the residual plot is a plot of the processed TMI along the flight line.

The gate plots at the bottom shows the forward response (thin line) compared to the actual values of chosen gate numbers (dots) for each moment.

Average resistivity intervals

For the complete survey area interval resistivity grids are produced by gridding the average resistivity in a certain depth or elevation interval.

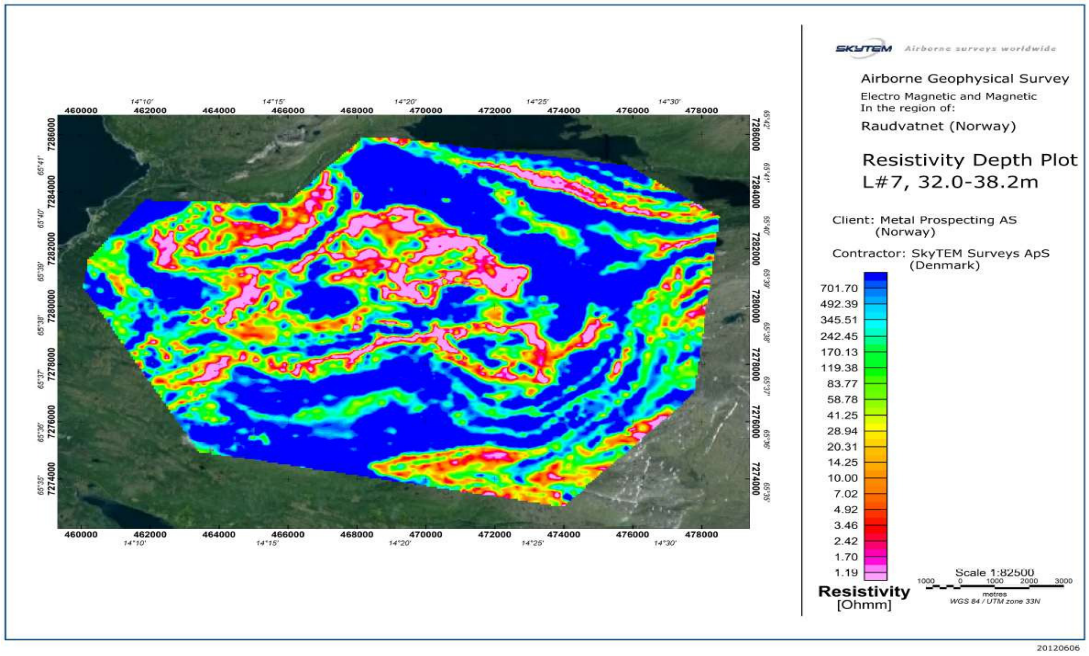


Figure 2. Mean resistivity plot

Appendix 7: Digital data

The digital data for Raudvatnet are listed in the following folders.

Data delivery folder	Sub folder	Sub folder	File format	Comment
01_Data	01_Data		Geosoft.gdb	Database of EM and MAG ready for import in Geosoft
	02_EM_Channels_grid	HM_Z	Geosoft.grd	Channel plots of raw data. Gate 16-32
		LM_Z	Geosoft.grd	Channel plots of raw data. Gate 4-22
	03_MAG_Grids		Geosoft.grd GeoTIFF MapInfoTIFF	TMI and RMF
	04_MAG_Maps		.pdf .map	Maps and PDF's of RMF and TMI
02_Inversion	01_Data		Geosoft.gdb Ascii .xyz	Database ready for import in Geosoft Ascii.xyz
	02_Layer_Resistivity_Grids		Geosoft.grd	Grids of the resistivity in each layer
	03_Layer_Resistivity_Maps		.pdf .map	Maps and pdf's of the resistivity of selected layers
	04_Layer_Resistivity_Maps_MapinfoTiff		.tab .tiff	GeoTiff images with mapinfo .tab
	05_Sections		.pdf .png	Resistivity and analysis of all lines
03_MISC	DEM		Geosoft.grd .pdf .map .tab/.tif	Digital Elevation Model of the area.
	FlownLines		.pdf .map	Flown vs planned flight lines
	PlannedFlightLines		Geosoft.gdb .xyz	Planned flight lines in WGS84 UTM z33N
	Ply_Selections		.ply	Geosoft polygon file
04_Report			.pdf	The report and appendices