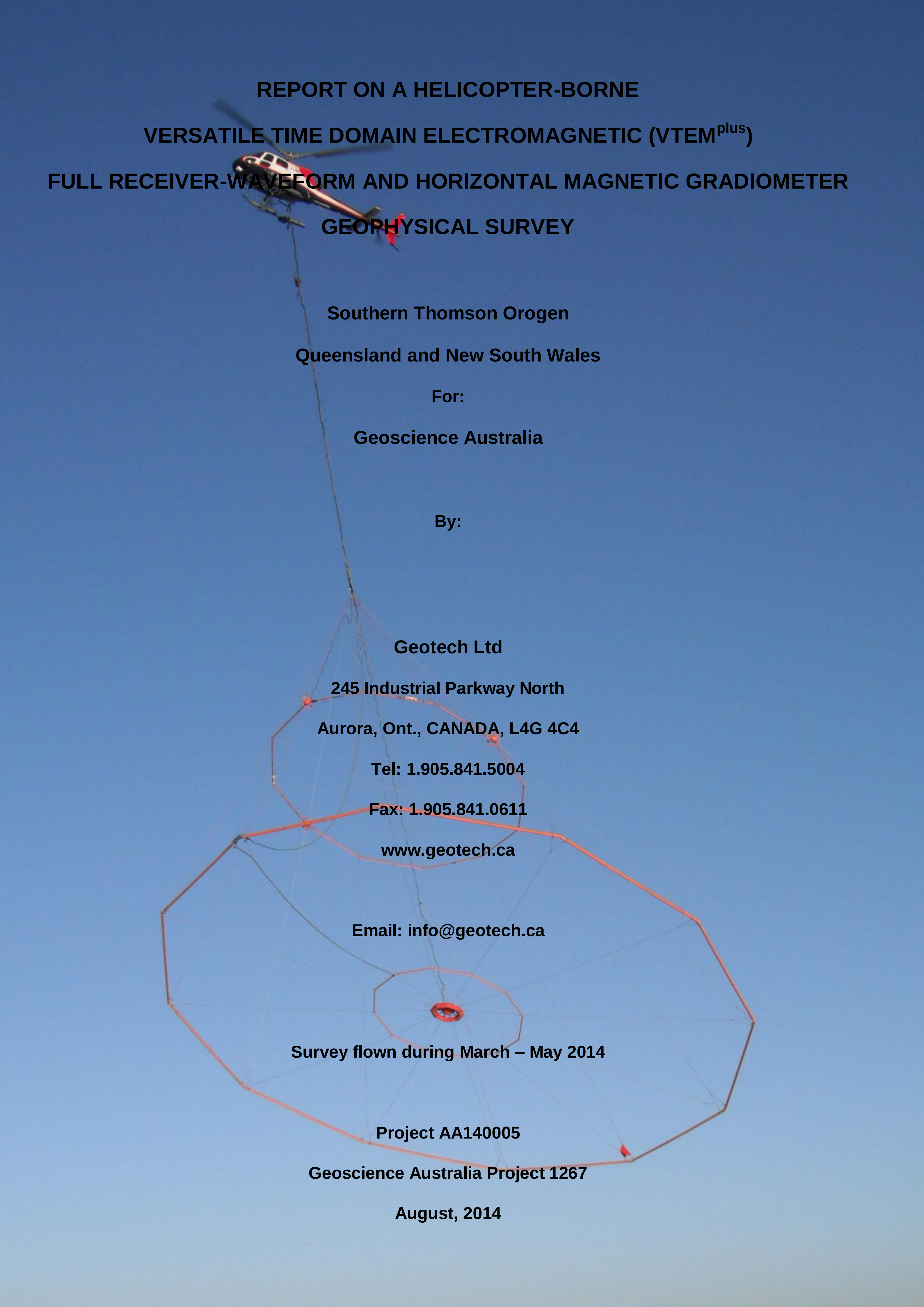

REPORT ON A HELICOPTER-BORNE VERSATILE TIME DOMAIN ELECTROMAGNETIC (VTEM^{plus}) FULL RECEIVER-WAVEFORM AND HORIZONTAL MAGNETIC GRADIOMETER GEOPHYSICAL SURVEY

Southern Thomson Orogen

Queensland and New South Wales

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Survey flown during March – May 2014

Project AA140005

Geoscience Australia Project 1267

August, 2014

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REPORT ON A HELICOPTER-BORNE VERSATILE TIME DOMAIN ELECTROMAGNETIC (VTEM^{plus}) FULL RECEIVER-WAVEFORM and HORIZONTAL MAGNETIC GRADIOMETER GEOPHYSICAL SURVEY

Southern Thomson Orogen
Queensland and New South Wales

EXECUTIVE SUMMARY

From March 25th, to May 5th 2014 Geotech Ltd. carried out a helicopter-borne geophysical survey over part of the Southern Thomson Orogen in Queensland and New South Wales. Operations were based at Hungerford, Queensland.

Principal geophysical sensors included a versatile time domain electromagnetic (VTEM^{plus}) full receiver-waveform system, and horizontal magnetic gradiometer. Ancillary equipment included a GPS navigation system, laser and radar altimeters, and inclinometer. A total of 4268 line-kilometres of geophysical data were acquired during the survey.

In-field data quality assurance and preliminary processing were carried out on a daily basis during the acquisition phase. Preliminary and final data processing, including generation of final digital data products were undertaken from the office of Geotech Ltd. in Aurora, Ontario.

Digital data includes all electromagnetic and magnetic data, conductivity imaging products, mulitplots plus ancillary data including the waveform.

This survey report describes the procedures for data acquisition, processing, final image presentation and the specifications for the digital data set.

1. INTRODUCTION

1.1 General Considerations

Geotech Ltd performed a helicopter-borne geophysical survey over part of the Southern Thomson Orogen in Queensland and New South Wales (Figure 1 & 2).

Mr. Murray Richardson and Dr. Ross Brodie represented Geoscience Australia during the data acquisition and data processing phases of this project respectively.

The geophysical survey consisted of helicopter borne EM using the versatile time-domain electromagnetic (VTEM^{plus}) full receiver-waveform streamed data recording system with Z and X component measurements and horizontal magnetic gradiometer using two cesium magnetometers. A total of 4268 line-km of geophysical data were acquired during the survey.

The crew was based out of Hungerford (Figure 2) in Queensland for the acquisition phase of the survey. Survey flying started on March 25th 2014 and was completed on May 5th, 2014.

Data quality control and quality assurance, and preliminary data processing were carried out on a daily basis during the acquisition phase of the project. Final data processing followed immediately after the end of the survey. Final reporting, data presentation and archiving were completed from the Aurora office of Geotech Ltd in August, 2014.

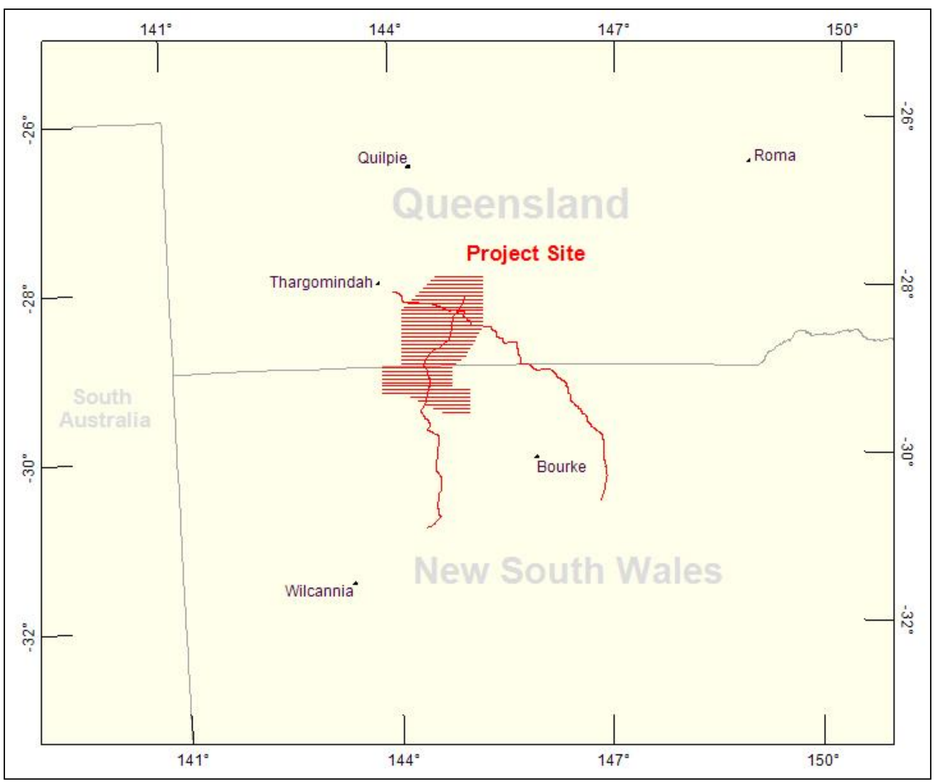

Figure 1: Survey Location.

1.2 Survey Location

The survey area is located near Hungerford in Queensland and straddles the border of Queensland and New South Wales (Figure 2).

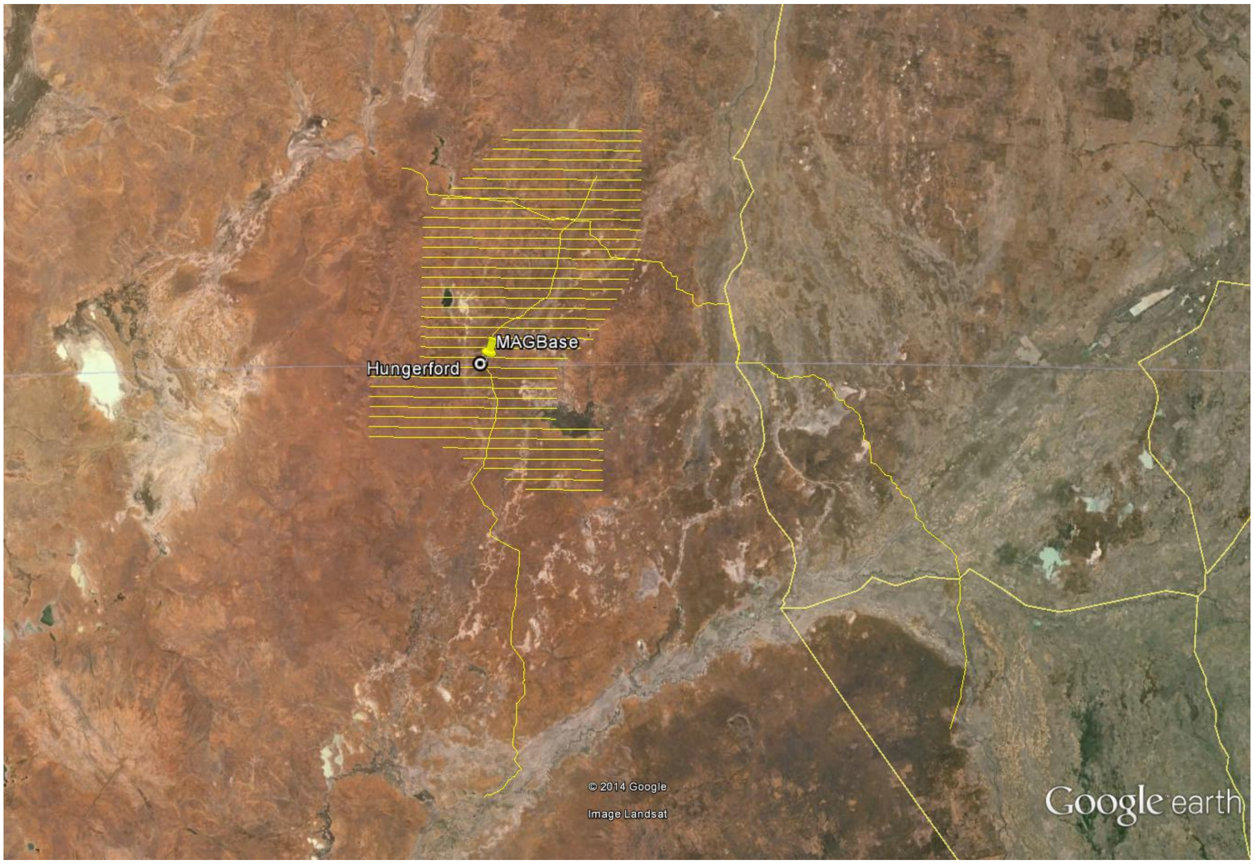

Figure 2: Survey area location on Google Earth.

The survey consisted of two parts:

1. A regional survey with 5000 m flight line spacing on East-West flight lines. Tie lines were neither flown nor planned. For more detailed information on the flight spacing and direction see Table 1
2. Two single-line traverses following roads, tracks, fence lines or cross-country.

1.3 Topographic Relief and Cultural Features

Topographically, the survey area exhibits a shallow relief with an elevation ranging from 105 to 286 metres above mean sea level over an area of 16,261 square kilometres (Figure 3).

There are various ephemeral rivers and streams running through the survey area which connect various lakes. There are visible signs of culture such as roads, power lines and the town of Hungerford is located in the middle of the survey area.

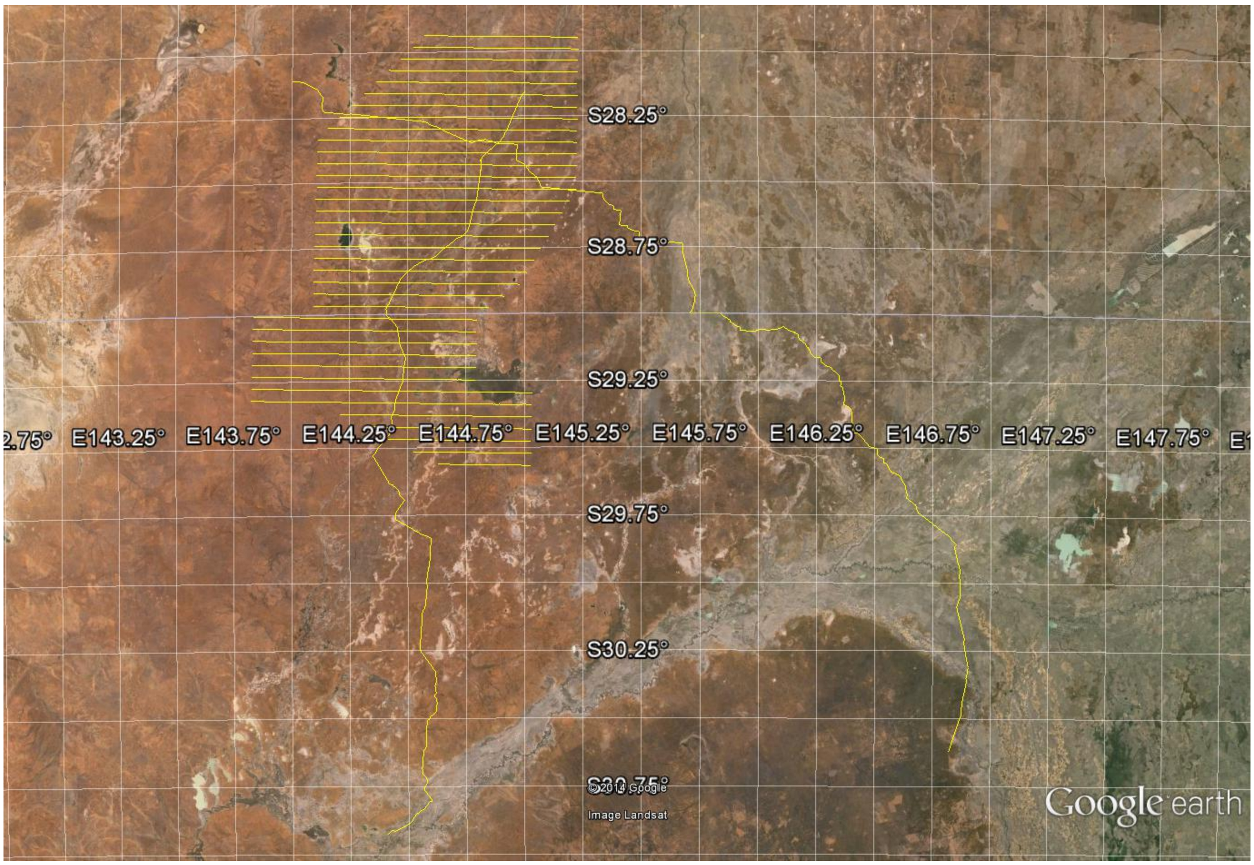

Figure 3: Flight path over a Google Earth image

2. DATA ACQUISITION

2.1 Flight Line Specifications

The regional survey block (see Figure 3 and Appendix A) and general flight line specifications are as follows:

Table 1: Survey Specifications

Survey block	Line spacing (m)	Area (km^2)	Planned[1] Line-km	Actual Line-km	Flight direction	Line numbers
Regional Survey Block	5000	16,261	3327	3352.5	N 90° E / N 270° E	L1000 – L1360
Traverse1	n/a	n/a	371	396.2	Variable(adjacent roads)	L3000 – L3006
Traverse2	n/a	n/a	500	518.9	Variable(adjacent roads)	L4000 – L4007
TOTAL		**16,261**	**4198**	**4267.6**		

Survey area boundaries co-ordinates are provided in Appendix B.

2.2 Flying Height Specifications

During the survey the helicopter was maintained at a mean altitude of 73 metres above the ground with an average survey speed of 92 km/hour. This allowed for an actual average EM Transmitter-receiver loop terrain clearance of 42 metres and a magnetic sensor clearance of 49 metres.

2.3 Survey Operations

Survey operations were based out of Hungerford in Queensland from March 25th, 2014 to May 5th 2014. The following table shows the timing of the flying.

Table 2: Survey schedule

Date	Flight #	Flown km	Block	Crew location	Comments
25-Mar-2014				Hungerford, QLD	System assembly
26-Mar-2014				Hungerford, QLD	System assembly
27-Mar-2014				Hungerford, QLD	Testing
28-Mar-2014				Hungerford, QLD	Testing
29-Mar-2014				Hungerford, QLD	Testing
30-Mar-2014				Hungerford, QLD	No testing due to weather
31-Mar-2014				Hungerford, QLD	Testing
1-Apr-2014				Hungerford, QLD	No production waiting for approval from client
2-Apr-2014				Hungerford, QLD	No production waiting for approval from client
3-Apr-2014				Hungerford, QLD	No production due to weather
4-Apr-2014				Hungerford, QLD	No production due to technical issues

[1] Note: Actual line kilometres represent the total line kilometres in the final database. These line kilometres normally exceed the planned line kilometres, as indicated in the survey NAV files.

Date	Flight #	Flown km	Block	Crew location	Comments
5-Apr-2014				Hungerford, QLD	No production due to technical issues
6-Apr-2014				Hungerford, QLD	No production due to technical issues
7-Apr-2014				Hungerford, QLD	No production due to technical issues
8-Apr-2014	1,2	187		Hungerford, QLD	187 km flown
9-Apr-2014	3,4,5	281		Hungerford, QLD	281 km flown
10-Apr-2014				Hungerford, QLD	No production due to technical issues
11-Apr-2014				Hungerford, QLD	No production due to technical issues
12-Apr-2014	6,7,8,9	404		Hungerford, QLD	404 km flown
13-Apr-2014				Hungerford, QLD	No production due to technical issues
14-Apr-2014	10,11,12, 13	335		Hungerford, QLD	335 km flown
15-Apr-2014	14,15,16, 17	356		Hungerford, QLD	356 km flown
16-Apr-2014	18	96		Hungerford, QLD	96 km flown limited due to technical issues
17-Apr-2014				Hungerford, QLD	No production due to helicopter inspection
18-Apr-2014	19	99		Hungerford, QLD	99 km flown
19-Apr-2014	20,21,22	316		Hungerford, QLD	316 km flown
20-Apr-2014	23,24,25	328		Hungerford, QLD	328 km flown
21-Apr-2014				Hungerford, QLD	No production due to technical issues
22-Apr-2014				Hungerford, QLD	No production due to technical issues
23-Apr-2014				Hungerford, QLD	No production due to technical issues
24-Apr-2014	26,27,28	320		Hungerford, QLD	320 km flown
25-Apr-2014	29,30,31	320		Hungerford, QLD	320 km flown
26-Apr-2014	32,33	290		Hungerford, QLD	290 km flown
27-Apr-2014				Hungerford, QLD	No production due to system maintenance
28-Apr-2014	34	35		Hungerford, QLD	35 km flown
29-Apr-2014	35	138		Hungerford, QLD	138 km flown
30-Apr-2014				Hungerford, QLD	No production due to weather
1-May-2014	36,37,38	220		Hungerford, QLD	220 km flown (production and test flight)
2-May-2014	39	111		Hungerford, QLD	111km flown
3-May-2014				Hungerford, QLD	No production due to weather
4-May-2014				Hungerford, QLD	No production due to weather
5-May-2014	40,41,42	369		Hungerford, QLD	Remaining 369 kms were flown – flying complete

2.4 Procedures

The on board operator was responsible for monitoring the system integrity. He also maintained a detailed flight log during the survey, tracking the times of the flight as well as any unusual geophysical or topographic features.

On return of the aircrew to the base camp the survey data was transferred from a compact flash card (PCMCIA) to the data processing computer. The data were then uploaded via ftp to the Geotech office in Aurora for daily quality assurance and quality control by qualified personnel.

2.5 Aircraft and Equipment

2.5.1 Survey Aircraft

The survey was flown using a Eurocopter Aerospatiale (Astar) 350 B3 helicopter, registration VH-VTN. The helicopter is owned and operated by United Aero Helicopters. Installation of the geophysical and ancillary equipment was carried out by a Geotech Ltd crew.

2.5.2 Electromagnetic System

The electromagnetic system was a Geotech Time Domain EM (VTEM^{plus}) with full receiver-waveform streamed data recording at 192 kHz. The "full waveform VTEM system" uses the streamed half-cycle recording of transmitter current and receiver voltage waveforms to obtain a complete system response calibration throughout the entire survey flight. VTEM hardware with the Serial number 12 was used for the survey. The VTEM transmitter current waveform is shown diagrammatically in Figure 4.

The VTEM transmitter loop and Z-component receiver coils were in a concentric-coplanar configuration and their axes are nominally vertical. An X-component receiver coil was also installed in the centre of the transmitter loop, with its axis nominally horizontal and in the flight line direction. The receiver coils measure the dB/dt response, and a B-Field response is calculated during the data processing. The EM transmitter-receiver loop assembly was towed at a mean distance of 34 metres below the aircraft. The configuration is shown in Figure 5.

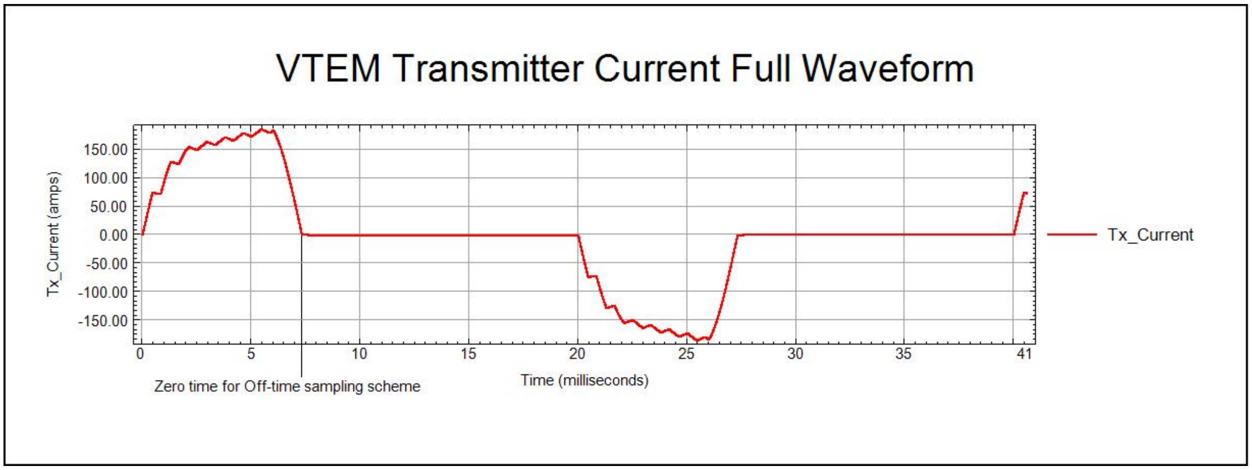

Figure 4: VTEM Transmitter Current Waveform

The VTEM decay sampling scheme is shown in Table 3 below. Forty-five time measurement gates were used for the final data processing with gate centers in the range from 0.021 to 10.667 msec. Zero time for the off-time sampling scheme is equal to the current pulse width and is defined as the time near the end of the turn-off ramp where the dI/dt waveform falls to 1/2 of its peak value.

Table 3: Off-Time Decay Sampling Scheme

VTEM Decay Sampling Scheme				
index	**Start**	**End**	**Middle**	**Width**
Milliseconds				
4	0.018	0.023	0.021	0.005
5	0.023	0.029	0.026	0.005
6	0.029	0.034	0.031	0.005
7	0.034	0.039	0.036	0.005
8	0.039	0.045	0.042	0.006
9	0.045	0.051	0.048	0.007
10	0.051	0.059	0.055	0.008
11	0.059	0.068	0.063	0.009
12	0.068	0.078	0.073	0.010
13	0.078	0.090	0.083	0.012
14	0.090	0.103	0.096	0.013
15	0.103	0.118	0.110	0.015
16	0.118	0.136	0.126	0.018
17	0.136	0.156	0.145	0.020
18	0.156	0.179	0.167	0.023
19	0.179	0.206	0.192	0.027
20	0.206	0.236	0.220	0.030
21	0.236	0.271	0.253	0.035
22	0.271	0.312	0.290	0.040
23	0.312	0.358	0.333	0.046
24	0.358	0.411	0.383	0.053
25	0.411	0.472	0.440	0.061
26	0.472	0.543	0.505	0.070
27	0.543	0.623	0.580	0.081
28	0.623	0.716	0.667	0.093
29	0.716	0.823	0.766	0.107
30	0.823	0.945	0.880	0.122
31	0.945	1.086	1.010	0.141
32	1.086	1.247	1.161	0.161
33	1.247	1.432	1.333	0.185
34	1.432	1.646	1.531	0.214
35	1.646	1.891	1.760	0.245
36	1.891	2.172	2.021	0.281

VTEM Decay Sampling Scheme				
index	Start	End	Middle	Width
Milliseconds				
37	2.172	2.495	2.323	0.323
38	2.495	2.865	2.667	0.370
39	2.865	3.292	3.063	0.427
40	3.292	3.781	3.521	0.490
41	3.781	4.341	4.042	0.560
42	4.341	4.987	4.641	0.646
43	4.987	5.729	5.333	0.742
44	5.729	6.581	6.125	0.852
45	6.581	7.560	7.036	0.979
46	7.560	8.685	8.083	1.125
47	8.685	9.977	9.286	1.292
48	9.977	11.458	10.667	1.482

Z Component: 4-48 time gates
X Component: 20-48 time gates.

VTEM system specifications:

Transmitter
- Transmitter loop diameter: 26 m
- Number of turns: 4
- Transmitter loop area: 530.92 m^2
- Effective Transmitter loop area: 2123.7 m^2
- Transmitter base frequency: 25 Hz
- Peak current: 185 A
- Pulse width: 7.32 ms
- Wave form shape: Bi-polar trapezoid
- Peak dipole moment: 392,884 nIA
- Actual average EM transmitter-receiver loop terrain clearance: 42 metres above the ground

Receiver
- X Coil diameter: 0.32 m
- Number of turns: 245
- Effective coil area: 19.69 m^2
- Z-Coil diameter: 1.2 m
- Number of turns: 100
- Effective coil area: 113.04 m^2

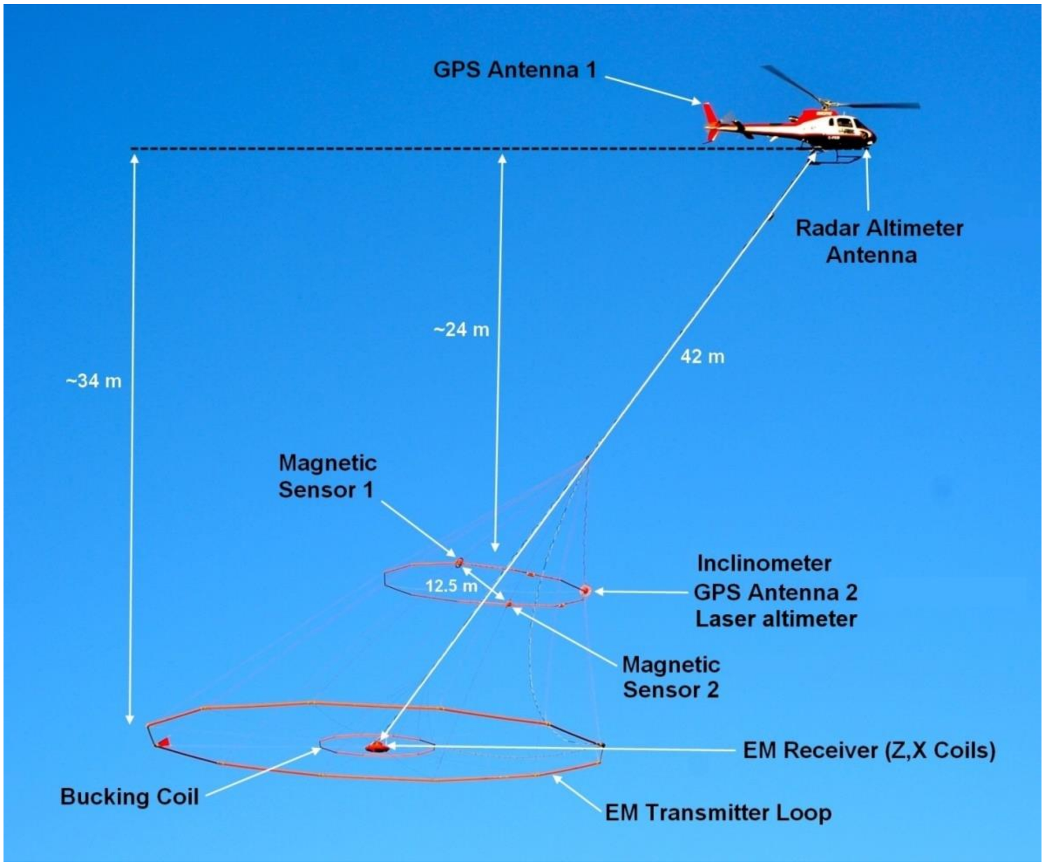

Figure 5: VTEM^{plus} System Configuration.

2.5.3 Horizontal Magnetic Gradiometer

The horizontal magnetic gradiometer consists of two Geometrics split-beam field magnetic sensors with a sampling interval of 0.1 seconds. These sensors are mounted 12.5 metres apart on the magnetic gradiometer loop 10 metres above the EM transmitter-receiver loop.

2.5.4 GPS Navigation System – Helicopter

The navigation system used a Geotech PC104 based navigation system utilizing NovAtel's WAAS (Wide Area Augmentation System) enabled GPS receiver, Geotech navigate software, a full screen display with controls in front of the pilot to direct the flight and a NovAtel GPS antenna mounted on the helicopter tail (Figure 5). As many as 11 GPS and two WAAS satellites may be monitored at any one time. The positional accuracy or circular error probability (CEP) is 1.8 m, with WAAS active, it is 1.0 m. The co-ordinates of the regional AEM survey were set-up prior to the survey and the information was fed into the airborne navigation system.

2.5.5 GPS – Magnetic Gradiometer Loop

A NovAtel GPS antenna was installed on the front centre of the magnetic gradiometer loop to accurately record the position of the loop (Figure 5). GPS data were sampled every 0.2 seconds. The final GPS coordinates were differentially corrected by post-processing the gradiometer loop data along with GPS data obtained simultaneously from a base station setup nearby the survey area. Final horizontal coordinates are referenced to GDA94 MGA zone 55 and the height is referenced to the EGM96 geoid. The positional accuracy or circular error probability (CEP) is 1.0 m.

2.5.6 Inclinometer – Magnetic Gradiometer Loop

An Anlalog Devices ADIS16405 gyroscopic inclinometer was installed on the magnetic gradiometer loop (Figure 5) to accurately record the orientation of the loop with a sampling interval of 0.1 seconds.

The orientation of the magnetic gradiometer loop is determined by three rotation angles based on the local reference frame of the loop: roll (rotation about the x-axis), pitch (rotation about the y-axis) and yaw (rotation about the z-axis). The loop's reference frame is a right-handed coordinate system with the positive x-axis pointing in the flight direction, positive y-axis pointing to the left of the flight direction and the positive z-axis points vertically upward. Positive rotation for each angle is counter-clockwise about the axis when looking toward the origin.

2.5.7 Radar Altimeter

A Terra TRA 3000/TRI 40 radar altimeter was used to record terrain clearance. The antenna was mounted beneath the bubble of the helicopter cockpit (Figure 5) and is 2.5 metres below the GPS antenna located on the tail of the helicopter.

2.5.8 Laser Altimeter

A Schmitt Industries AR300 laser altimeter was used which has an altitude range 0.5 to 300m and accuracy ±5cm. The laser altimeter was located at the front of the horizontal magnetic gradient loop with a GPS antenna and inclinometer and the data was sampled at an interval of 0.2 seconds.

2.5.9 Digital Acquisition System

A Geotech data acquisition system recorded the digital survey data on an internal compact flash card. Data is displayed on an LCD screen as traces to allow the operator to monitor the integrity of the system. The data type and sampling interval as provided in Table 4.

Table 4: Acquisition sampling rates

Data Type	Sampling
TDEM	0.1 sec
Magnetometer	0.1 sec
GPS position	0.2 sec
Radar altimeter	0.2 sec
Laser altimeter	0.2 sec
Gyro Inclinometer	0.1 sec

2.6 Base Station

A combined magnetometer/GPS base station was utilized on this project. A Geometrics cesium vapour magnetometer was used as a magnetic sensor with a sensitivity of 0.001 nT. The base station recorded the magnetic field together with the GPS time at 1 Hz on a base station computer.

The base station magnetometer sensor was installed in an open area (28º59.8822'S, 144º25.6847'E), away from electric transmission lines and moving ferrous objects such as motor vehicles. The base station data were backed-up to the data processing computer at the end of each survey day.

2.7 Test Lines and Calibration Procedures

2.7.1 Full Waveform VTEM Calibration

The calibration is performed with the completely assembled VTEM system connected to the helicopter at the survey site on the ground. Measurements of the half-cycles are collected and used to calculate a sensor calibration consisting of a single stacked half-cycle waveform. The purpose of the stacking is to attenuate natural and man-made magnetic signals, leaving only the response to the calibration signal. The stacked half-cycle allows the transfer functions between the receiver and data acquisition system, $H_D(\omega)$, and current sensor and data acquisition system, $H_R(\omega)$, to be determined. These transfer functions are used as a part of the system response correction during processing to correct the half-cycle waveforms and data acquired on a survey flight to a common transfer function:

$$D(\omega) = [H_C(\omega)/H_D(\omega)]\, D_R(\omega)$$
$$A(\omega) = [H_C(\omega)/H_R(\omega)]\, A_R(\omega)$$

where $H_C(\omega)$ is the common transfer function, and $D_R(\omega)$ and $A_R(\omega)$ are the FFT's of the raw receiver and current sensor responses recorded by the data acquisition system.

This process allows for the receiver response, $R(\omega)$, to become independent of the sensor characteristics determined by the transfer functions $H_D(\omega)$ and $H_R(\omega)$ and acts similar to a deconvolution of the data.

$$R(\omega) = \frac{D(\omega)I(\omega)}{A(\omega)}$$

where, $D(\omega)$ is the FFT of the actual receiver data sample $D(t)$, $I(\omega)$ is the FFT of a reference or "Ideal waveform" and $A(\omega)$ is the FFT of the actual waveform.

2.7.2 High Altitude Calibration

High altitude calibrations were conducted at the beginning, during, and end of each flight. The calibration's objective is to determine the EM "zero level" by climbing to an altitude of 1,000 metres above ground to measure the receiver's response absent of response due to the ground.

When at the required altitude, at least 60 seconds of data were acquired in normal operation mode. The final delivered dataset contains these processed windowed high altitude data for the forty-one (41) survey flights in ASCII column format (Table 7).

Reference transmitter current and receiver voltage waveforms, each sampled at 192 kHz, were also recorded at high altitude for all survey flights. The recorded waveforms were transformed into an ideal form, having zero current at the beginning of the off-time, by the Full Waveform calibration (see Section 2.7.1). A graphical representation of a VTEM waveform is shown in Figure 4. The waveforms for each flight were also delivered in the final dataset in ASCII column format.

2.7.3 Plate Test

This test is performed on ground to verify the sensitivity of the system. An aluminium plate of known conductive response is positioned in alternated positions (vertical and horizontal) for about 10 seconds for three time measurements. Response of corresponding dB/dt and B-field data is then verified.

The Plate test was performed at the beginning of the survey. Result of the test performed on March 27th, 2014 is presented in a Geosoft database view in Appendix F.

2.7.4 Repeat Lines

Repeat lines were acquired in an east-west direction to ensure that the airborne system is operating repeatability and as expected. Two repeat line locations were selected, one in the northern part, and one in the southern part of the survey area (Figure 6 and Table 5).

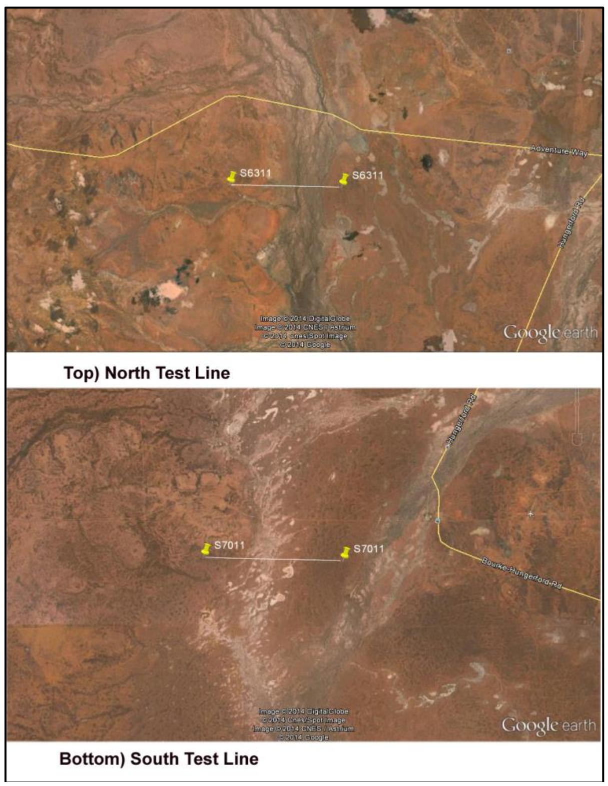

Figure 6: Location of Repeat Lines on Google Earth™

Table 5: Coordinates of the Repeat Lines in the survey area.

Test Lines	Longitude (°) Min	Longitude (°) Max	Latitude (°) Min	Latitude (°) Max
North	144.8178	144.8697	-28.1671	-28.1663
South	144.2998	144.3635	-29.0153	-29.0147

Twelve (12) passes of the southern repeat line were flown and four (4) passes of the northern repeat line were flown, as indicated in Table 6 below.

Table 6: Repeat lines flown in the survey area; left) southern part; right) northern part

Repeat Line	Date	Direction
S7011	Apr-8-14	W-E
S7020	Apr-5-14	E-W
S7021	Apr-5-14	W-E
S7031	Apr-9-14	E-W
S7061	Apr-12-14	W-E
S7101	Apr-13-14	E-W
S7141	Apr-15-14	E-W
S7181	Apr-16-14	W-E
S7191	Apr-18-14	E-W
S7261	Apr-24-14	E-W
S7361	May-1-14	E-W
S7391	May-2-14	E-W

Repeat Line	Date	Direction
S6311	Apr-25-14	E-W
S6331	Apr-26-14	E-W
S6341	Apr-28-14	E-W
S6351	Apr-29-14	E-W

Data acquired for the repeat lines were processed the same as all survey lines and are provided as ASCII columns format data.

Additionally, as part of the deliverable products, multi-parameter plots are presented for each repeat line. These plots include, from top to bottom, (1) pitch and roll of the transmitter-receiver, (2) transmitter-receiver height, (3) power line monitor, 4) magnetics TMI and first vertical derivative, (5) dBz/dt profiles, (6) conductivity-depth image (CDI) in logarithmic colour scale, and (7) CDI in linear colour scale. Multi-parameter plots are presented in Appendix F.

2.7.5 Radar and Laser Altimeters

The purpose of radar and laser altimeter calibration is to verify the performance of the altimeter readings using the GPS height data as the reference.

The calibration was performed by flying over the same spot at various altitudes, ranging from 61m (200 ft) to 133m (435 ft) according to the radar altimeter which is positioned on the helicopter front. The selected spot in the Hungerford airport has known elevation and flat terrain (Figure 7). These tests were performed on March 27th, 2014.

Figure 7: Location of the radar and laser altimeter calibrations on Goggle Earth™ image

The calibration results are presented in Appendix F. The graphs of the GPS heights plotted against the radar and laser altimeter readings demonstrate that there is a linear relationship between all GPS and altimeter instruments (R^2 = 0.99), for the range of flying heights tested.

3. PERSONNEL

The following Geotech Ltd personnel were involved in the project.

Field:

Project Manager:	Leon Lovelock (Office) Dan Delaney (Office)
Data QC:	Nick Venter (Office) Neil Fiset (Office)
Crew chief:	Cong Phan Paul White
Operator:	Vickus Prinsloo Jared White

The survey pilot and the mechanical engineer were employed directly by the helicopter operator – United Aero Helicopters.

Pilot:	Colby Tyrrel Mark Loughridge
Mechanical Engineer:	n/a

Office:

Preliminary Data Processing:	Nick Venter Neil Fiset
Final Data Processing:	Timothy Eadie Nasreddine Bournas
Final Data QA/QC:	Geoffrey Plastow
Reporting/Mapping:	Wendy Acorn

The data acquisition phase was carried out under the supervision of Andrei Bagrianski, P. Geo, Chief Operating Officer. The processing and interpretation phases were carried out under the supervision of Geoffrey Plastow, P. Geo, Data Processing Manager. The customer relations were looked after by Keith Fisk.

4. DATA PROCESSING AND PRESENTATION

Data compilation and processing were carried out using Geosoft OASIS Montaj software and software proprietary to Geotech Ltd.

4.1 Flight Path, Coordinates and Parallax Correction

The flight path data, recorded by the acquisition program as WGS 84 latitude/longitude, were differentially corrected using the base station GPS and converted into the GDA94 Datum, Map Grid of Australia Zone 55 coordinate system in Oasis Montaj.

Both sets of GPS coordinate, from helicopter GPS and magnetic gradiometer GPS, were linearly interpolated between each measurement sampled every 0.2 seconds to match the sampling rate of the TDEM and magnetic datasets at every 0.1 seconds.

The coordinates labelled "GradLoop_*" in Tables 7 and 8 refer to the position of the magnetic gradiometer GPS antenna located at the front of the magnetic gradiometer loop.

A further set of coordinates, labelled "EM_Mag_Data_*" were then calculated for the position halfway between the two magnetometers that are located on the left and right hand sides of the magnetic gradiometer loop. This position represents the centre of the magnetic gradiomter loop and is the point where the tow cable intersects the plane of the magnetic gradiometer loop. This was achieved by projecting backwards along the flight line by 6.25 m, the radius of the gradiometer loop, from the gradiometer loop GPS antenna position.

A parallax correction was applied to the EM data to account for the distance by which the EM transmitter-receiver loop lags behind the centre of the magnetic gradiometer loop. In this parallax correction the EM data are shuffled toward lower fiducial numbers by the nearest integer number of fiducials that it would take to travel the average horizontal distance Δx_2 (see Figure 8 and formulae below) which separates the centres of the magnetic gradiometer and EM loops based on the average helicopter speed for each line.

Thus the "EM_Mag_Data_*" coordinates are the set of coordinates that the EM and magnetic data are parallax corrected for, and to which all EM and magnetic data and interpretations should be referred.

4.2 Calculation of EM Transmitter-Receiver Loop Height

The EM transmitter-receiver loop height above ground was calculated from data from the radar altimeter located on the helicopter, and data from the laser altimeter and gyroscopic inclinometer located on the front of the magnetic gradiometer loop, and knowledge of the tow cable lengths.

The procedure requires calculation of the unknown vertical distance between the magnetic gradiometer loop and EM transmitter-receiver loop. This process is summarized in the formula below, where; laser is the laser altimeter measurement, radar is the radar altimeter measurement, l_1 is the length along the tow cable from the helicopter to the center of the gradiometer loop equal to 29.65 metres, l_2 is the length along the tow cable from the center of the gradiometer loop to the center of the transmitter-receiver loop equal to 12.35 meters, and δz is the vertical deflection of the front of the gradiometer loop from the center which can be calculated from the pitch angle and magnetic gradiometer loop radius of 6.25m. These variables are illustrated in Figure 8 showing the VTEM system with an exaggerated pitch.

$$\text{TxRx Height} = \text{laser} + \delta z - l_2 \left(\frac{\text{radar} - \text{laser} - \delta z}{l_1} \right)$$

$$\Delta x_2 = \sqrt{(l_2)^2 - (\Delta z_2)^2},$$

where,

$$\Delta z_2 = l_2 \left(\frac{\text{radar} - \text{laser} - \delta z}{l_1} \right).$$

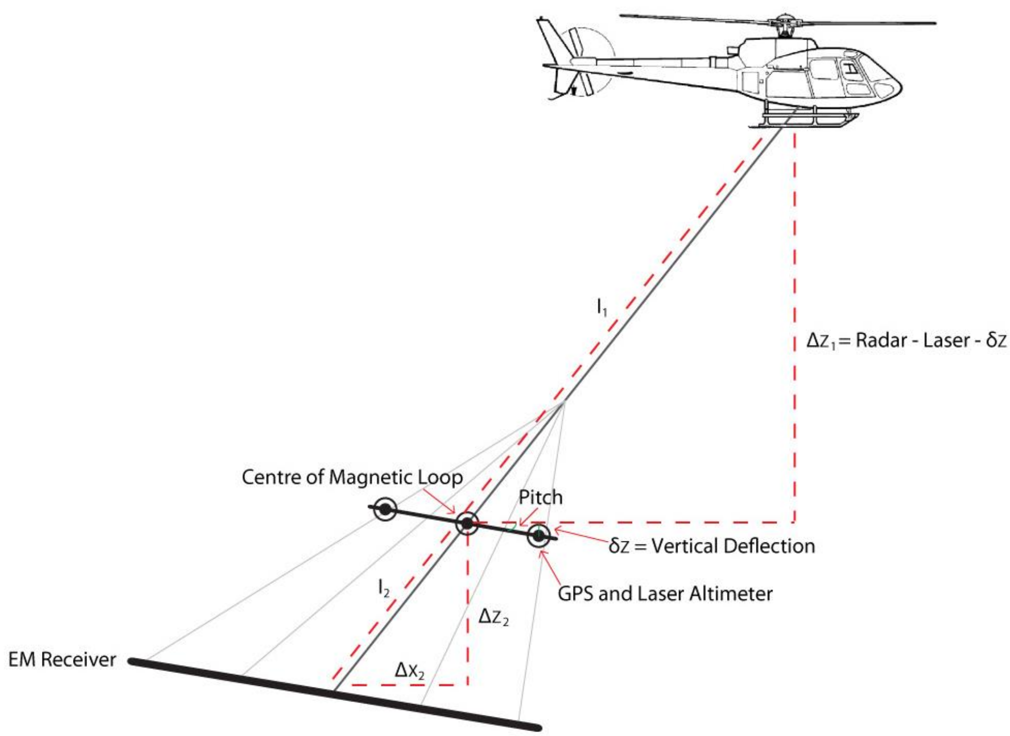

Figure 8: Calculation of EM transmitter loop height.

4.3 Digital elevation model

Two digital elevation models (DEMs) were calculated. They were calculated from the helicopter GPS and radar altimeter, and also from the magnetic gradiometer loop GPS and laser altimeter. The formulas used to calculate the DEMs are shown below.

$$\mathrm{DEM_{radar}} = (\mathrm{Z_{GPS\ Heli}} + \mathrm{N_{EGM96}} - \mathrm{N_{AUSGEOID09}}) - \mathrm{radar} - 2.5$$

$$\mathrm{DEM_{laser}} = \left(\mathrm{Z_{GPS\ GradLoop}} + \mathrm{N_{EGM96}} - \mathrm{N_{AUSGEOID09}}\right) - \mathrm{laser}$$

The term N_{EGM96} - $N_{AUSGEOID09}$, accounts for the difference between the EGM96 geoid, which the GPS heights are referenced to, and the AUSGEOID09, which both DEMs are referenced to. The 2.5 metre offset, for the radar altimeter derived DEM, accounts for the vertical separation between the helicopter GPS antenna located on the tail and the radar altimeter located below the noise of the helicopter.

On average the radar altimeter derived DEM is 4.5 metres higher than the laser altimeter derived DEM. The reason for this is unknown. However, the DEM_{radar} more closely matches the Shuttle Radar Topography Mission (SRTM) digital elevation model.

4.4 Electromagnetic Data

As the data are acquired by the data acquisition system on the helicopter, it goes through a digital filter to reject major sferic events and is stacked to further reduce system noise. Afterward, the streamed data is processed by applying a system response correction, B-field integration, time window binning, compensation, filtering, and leveling. Four stages of processing of the EM data have been delivered. They are denoted in the final point-located EM dataset (Table 7) as;

1. Raw (Raw),
2. Compensated (Comp),
3. Filtered (Flt),
4. Final (F).

The digital filtering process is a three stage filter used to reject major sferic events and reduce system noise. Local sferic activity can produce sharp, large amplitude events that cannot be removed by conventional filtering procedures. Smoothing or stacking will reduce their amplitude but leave a broader residual response that can be confused with geological phenomena. To avoid this possibility, a computer algorithm searches out and rejects the major sferic events. The data was then stacked using 15 half cycles, 0.3 seconds, to create a stacked half-cycle waveform at 0.1 second intervals. The stacking coefficients are tapered with a shape that approximates a Gaussian function.

During post-flight processing, the streamed data have a sensor response correction applied which corrects the receiver channels and current monitor to a common impulse response based on the Full Waveform calibration (see Section 2.7.1). The B-field data are calculated by integrating the dB/dt cycles from the 192 kHz streamed data. Then, the streamed data are converted into a set of time window channels (see Table 3) to reduce noise levels further. The output of this stage is the data denoted as “Raw” in Table 7.

The data have noise levels reduced further by the use of an EM compensation procedure which removes characteristic noise from each fiducial determined by the difference between the transmitter and bucking loop fields at the receiver during the flight. This is achieved by a statistical correlation between each time window channel and primary field measurement taken during the on-time. The data channels which have been processed to this point are denoted by “Compensated” in Table 7.

Next, filtering of the electromagnetic data was performed in two steps. The first is a 4 fiducial wide non-linear filter to eliminate any large spikes remaining in the dataset. The second filter is a low pass symmetric linear digital filter that has zero phase shift which prevents any lag or peak displacement from occurring, and it suppresses only variations with a wavelength less than about 1 second or 25 metres. The output of this stage is the data channels denoted as “Filtered” in Table 7.

To remove the remaining system response from the data, a “zero level” estimate was subtracted from the data at each fiducial. First, the “zero level” correction was applied which was calculated by linear interpolation of the high altitude backgrounds (see Section 2.7.2) recorded two or more times during each survey flight. Second, a statistical leveling correction was applied to the EM data which utilizes the high altitude data recorded for each flight and the survey line data to compute the additional leveling correction. This produces the EM data denoted as “Final” in Table 7.

VTEM has two receiver coil orientations. The axis of the Z-component coil is oriented parallel to the transmitter coil axis and both are nominally vertical. The axis of the X-component coil is oriented parallel to the ground and along the line-of-flight. This combined two-coil configuration provides information on the position, depth, dip and thickness of a conductor. Generalized modeling results of VTEM data, are shown in Appendix D.

In general X-component data produce cross-over type anomalies: from “+ to – “in the direction of flight for “thin” sub-vertical targets and from “- to +” in the direction of flight for “thick” targets. Z component data produce double peak type anomalies for “thin” sub vertical targets and single peak for “thick” targets.

The limits and change-over of “thin-thick” depends on dimensions of a TEM system (Appendix D, Figure D-16).

4.5 Conductivity Depth Imaging

A set of Conductivity Depth Images (CDI) were generated using EM Flow version 3.3, developed by Encom Technologies Pty Ltd. A total of forty-three (43) dB/dt Z component channels, starting from channel 5 (26 µsec) to channel 47 (9286 µsec), were used for the CDI calculation. Time channel 4 (21 µsec) and channel 48 (10667 µsec) were not inputted to avoid artefacts caused by fitting these channels which have greater uncertainty. Time channel 4 can be affected by over or underestimation of the compensation while time channel 48 has the weakest signal-to-noise ratio of all time channels. An averaged waveform at the receiver was used for the calculation since it was consistent for the majority of the flights with minor deviation from the average. The waveform used is consistent with those supplied and outlined in Table 8. The main steps to calculate the CDI in EM Flow are described in the following points:

1. System definition (units, waveform shape and half period, system geometry and input data format)
2. Conversion from ASCII file format to Binary file format (smoothing option disabled)
3. Basis Function creation. Number of Taus equalled 40 (approximately equal to the number of channels). Tau range was 0.02 to 0.7 msec. Number of Eigenvectors was 12.
4. Deconvolution: PLS algorithm. Smoothing set to 0.2 and minimum length to 0. Normalization by absolute maximum. Error tolerance at 1.0e-04. No error weighting.
5. CDI Matrix Calculation: Tau range at all (1-40). Maximum altitude at 500 metres and maximum depth at 350 metres. Depth resolution of 1 metre. Depth of investigation cut-off factor equal to 1. Both exponential and layered models were generated.
6. Data export: Geosoft Line Database.

The final delivered CDI dataset (Table 8) contains estimated conductivities as an array with 70 elements with a depth resolution of 5 metres, for depths from 5 metres to 350 metres.

Conductivity Depth Slices were calculated from the 1 metre depth resolution data output from EM Flow by averaging conductivity values within the specified depth ranges, inclusively.

4.6 Horizontal Magnetic Gradiometer Data

The horizontal gradients data from the VTEM^{plus} are measured by two magnetometers 12.5 m apart on an independent magnetic gradiometer loop mounted 10m above the transmitter-receiver loop. A GPS and a gyro inclinometer help to determine the positions and orientations of the magnetometers. The data from the two magnetometers are corrected for position and orientation variations, as well as for the diurnal variations using the base station data.

The position of the centre of the horizontal magnetic gradiometer loop is calculated from the GPS utilizing an in-house processing tool in Geosoft. Following this total magnetic intensity is calculated at the center of the gradiometer loop by calculating the mean values from both sensors. In-line and cross-line gradient and advanced magnetic gradient products were not contracted for this project.

5. DELIVERABLES

5.1 Survey Report

This survey report describes the data acquisition, processing, and final presentation of the survey results. The survey report is provided in two paper copies and digitally in PDF format.

5.2 Digital Data

Point located data files in ASCII column format, with accompanying README header files that describe the data file content, were supplied for the processed EM and ancillary data. This included files for the regular survey lines, traverses, repeat lines and high altitude lines. The delivered data channels listed in Table 7. Refer to Table 3 for the time definitions for channels 4 to 48.

Table 7: Contents of the ASCII columns datasets for the point located EM data

Channel name	Units	Description
GAproject		Geoscience Australia Project Number
GTproject		Geotech Ltd Project Number
FltNo		Flight Number
LineNo		Line Number
Fiducial		Fiducial Number
Date		Date
Time	Seconds	Seconds since midnight local time
Bearing	Degrees	Flight Direction Azimuth
Heli_Longitude	Degrees	Helicopter GPS Longitude (GDA94)
Heli_Latitude	Degrees	Helicopter GPS Latitude (GDA94)
Heli_Easting	metres	Helicopter GPS Easting (GDA94, MGA55†)
Heli_Northing	metres	Helicopter GPS Northing (GDA94, MGA55)
Heli_Height	metres	Helicopter GPS height above EGM96 Geoid
Heli_GPSTime	seconds	Helicopter GPS second of the GPS week
Radar_altimeter	metres	Helicopter radar altimeter height above ground
GradLoop_Longitude	degrees	Gradiometer Loop GPS Longitude (GDA94)
GradLoop_Latitude	degrees	Gradiometer Loop GPS Latitude (GDA94)
GradLoop_Easting	metres	Gradiometer Loop GPS Easting (GDA94, MGA55)
GradLoop_Northing	metres	Gradiometer Loop GPS Northing (GDA94, MGA55)
GradLoop_Height	metres	Gradiometer Loop GPS height above EGM96 Geoid
GradLoop_GPSTime	seconds	Gradiometer Loop GPS second of the GPS week
Laser_altimeter	metres	Gradiometer Loop laser altimeter height above ground
Roll	degrees	Gradiometer Loop rotation about the in-line (x) axis
Pitch	degrees	Gradiometer Loop rotation about the cross-line (y) axis
Yaw	degrees	Gradiometer Loop rotation about the vertical (z) axis
EM_Mag_Data_Longitude	degrees	Derived longitude of centre of magnetic

Channel name	Units	Description
		gradiometer loop – reference point for EM and Magnetic data (GDA94)
EM_Mag_Data_Latitude	degrees	Derived latitude of centre of magnetic gradiometer loop – reference point for EM and Magnetic data (GDA94)
EM_Mag_Data_Easting	metres	Derived easting of centre of magnetic gradiometer loop – reference point for EM and Magnetic data (GDA94, MGA55)
EM_Mag_Data_Northing	metres	Derived northing of centre of magnetic gradiometer loop – reference point for EM and Magnetic data (GDA94, MGA55)
EM_Loop_Height	metres	Derived height of centre of the EM Loop above ground
Ground_elevation_laser	metres	Digital Elevation Model (Australian Height Datum) derived from laser altimeter and Gradiometer Loop GPS
Ground_elevation_radar	metres	Digital Elevation Model (Australian Height Datum) derived from radar altimeter and Helicopter GPS
Mag1L	nT	Measured Total Magnetic field - left sensor
Mag1R	nT	Measured Total Magnetic field - right sensor
Mag2L	nT	Diurnal and IGRF corrected Total Magnetic field - left sensor
Mag2R	nT	Diurnal and IGRF corrected Total Magnetic field - right sensor
Mag_average	nT	Total Magnetic field (average of left and right sensors)
Basemag	nT	Base station mag
IGRF_Tot	nT	IGRF Total Field
Tx_Current	Amps	Transmitter Current
PLM		60 Hz power line monitor
SRawz[4-48]	pV/(A*m4)	Raw Z dB/dt data channels 4 to 48
SCompz[4-48]	pV/(A*m4)	Compensated Z dB/dt data channels 4 to 48
SFltz[4-48]	pV/(A*m4)	Filtered Z dB/dt data channels 4 to 48
SFz[4-48]	pV/(A*m4)	Final Z dB/dt data channels 4 to 48
BRawz[4-48]	(pV*ms)/(A*m4)	Raw Z B-Field data channels 4 to 48
BCompz[4-48]	(pV*ms)/(A*m4)	Compensated Z B-Field data channels 4 to 48
BFltz[4-48]	(pV*ms)/(A*m4)	Filtered Z B-Field data channels 4 to 48
BFz[4-48]	(pV*ms)/(A*m4)	Final Z B-Field data channels 4 to 48
SRawx[20-48]	pV/(A*m4)	Raw X dB/dt data channels 20 to 48
SCompx[20-48]	pV/(A*m4)	Compensated X dB/dt data channels 20 to 48
SFltx[20-48]	pV/(A*m4)	Filtered X dB/dt data channels 20 to 48
SFx[20-48]	pV/(A*m4)	Final X dB/dt data channels 20 to 48
BRawx[20-48]	(pV*ms)/(A*m4)	Raw X B-Field data channels 20 to 48
BCompx[20-48]	(pV*ms)/(A*m4)	Compensated X B-Field data channels 20 to 48
BFltx[20-48]	(pV*ms)/(A*m4)	Filtered X B-Field data channels 20 to 48
BFx[20-48]	(pV*ms)/(A*m4)	Final X B-Field data channels 20 to 48

†MGA55 = Map Grid of Australia Zone 55

Point located data files were supplied in ASCII column format, with accompanying README header files, for the processed conductivity depth imaging results and ancillary data. This included files for the regular survey lines, traverses, and repeat lines. The delivered data channels are listed in Table 8.

Table 8: Contents of the ASCII columns dataset for the point located CDI data

Channel name	Units	Description
GAproject		Geoscience Australia Project Number
GTproject		Geotech Ltd Project Number
FltNo		Flight Number
LineNo		Line Number
Fiducial		Fiducial Number
Date		Date
Time	Seconds	Seconds since midnight local time
Bearing	Degrees	Flight Direction Azimuth
Heli_Longitude	Degrees	Helicopter GPS Longitude (GDA94)
Heli_Latitude	Degrees	Helicopter GPS Latitude (GDA94)
Heli_Easting	metres	Helicopter GPS Easting (GDA94, MGA55)
Heli_Northing	metres	Helicopter GPS Northing (GDA94, MGA55)
Heli_Height	metres	Helicopter GPS height above EGM96 Geoid
Heli_GPSTime	seconds	Helicopter GPS second of the GPS week
Radar_altimeter	metres	Helicopter radar altimeter height above ground
GradLoop_Longitude	degrees	Gradiometer Loop GPS Longitude (GDA94)
GradLoop_Latitude	degrees	Gradiometer Loop GPS Latitude (GDA94)
GradLoop_Easting	metres	Gradiometer Loop GPS Easting (GDA94, MGA55)
GradLoop_Northing	metres	Gradiometer Loop GPS Northing (GDA94, MGA55)
GradLoop_Height	metres	Gradiometer Loop GPS height above EGM96 Geoid
GradLoop_GPSTime	seconds	Gradiometer Loop GPS second of the GPS week
Laser_altimeter	metres	Gradiometer Loop laser altimeter height above ground
Roll	degrees	Gradiometer Loop rotation about the in-line (x) axis
Pitch	degrees	Gradiometer Loop rotation about the cross-line (y) axis
Yaw	degrees	Gradiometer Loop rotation about the vertical (z) axis
EM_Mag_Data_Longitude	degrees	Derived longitude of centre of magnetic gradiometer loop – reference point for EM and Magnetic data (GDA94)
EM_Mag_Data_Latitude	degrees	Derived latitude of centre of magnetic gradiometer loop – reference point for EM and Magnetic data (GDA94)
EM_Mag_Data_Easting	metres	Derived easting of centre of magnetic gradiometer loop – reference point for EM and Magnetic data (GDA94, MGA55)
EM_Mag_Data_Northing	metres	Derived northing of centre of magnetic gradiometer loop – reference point for EM and Magnetic data (GDA94, MGA55)
EM_Loop_Height	metres	Derived height of centre of the EM Loop above ground
Ground_elevation_laser	metres	Digital Elevation Model (Australian Height Datum) derived from laser altimeter and Gradiometer Loop GPS

Channel name	Units	Description
Ground_elevation_radar	metres	Digital Elevation Model (Australian Height Datum) derived from radar altimeter and Helicopter GPS
Mag1L	nT	Measured Total Magnetic field - left sensor
Mag1R	nT	Measured Total Magnetic field - right sensor
Mag2L	nT	Diurnal and IGRF corrected Total Magnetic field - left sensor
Mag2R	nT	Diurnal and IGRF corrected Total Magnetic field - right sensor
Mag_average	nT	Total Magnetic field (average of left and right sensors)
Basemag	nT	Base station mag
IGRF_Tot	nT	IGRF Total Field
Tx_Current	Amps	Transmitter Current
PLM		60 Hz power line monitor
Conductivity[0-69]	S/m	Conductivity Depth Imaging from 5 to 350 metres depth for every 5 metres
Cond_Depth_Slice_0_5m	S/m	Conductivity Depth Slice between 0 and 5 metres depth
Cond_Depth_Slice_5_10m	S/m	Conductivity Depth Slice between 5 and 10 metres depth
Cond_Depth_Slice_10_15m	S/m	Conductivity Depth Slice between 10 and 15 metres depth
Cond_Depth_Slice_15_20m	S/m	Conductivity Depth Slice between 15 and 20 metres depth
Cond_Depth_Slice_20_30m	S/m	Conductivity Depth Slice between 20 and 30 metres depth
Cond_Depth_Slice_30_40m	S/m	Conductivity Depth Slice between 30 and 40 metres depth
Cond_Depth_Slice_40_60m	S/m	Conductivity Depth Slice between 40 and 60 metres depth
Cond_Depth_Slice_60_100m	S/m	Conductivity Depth Slice between 60 and 100 metres depth
Cond_Depth_Slice_100_150m	S/m	Conductivity Depth Slice between 100 and 150 metres depth
Cond_Depth_Slice_150_200m	S/m	Conductivity Depth Slice between 150 and 200 metres depth
Cond_Depth_Slice_200_300m	S/m	Conductivity Depth Slice between 200 and 300 metres depth

Data files were supplied in ASCII column format, with accompanying README header files, for the 192 kHz sampling of the waveform acquired at high altitude for every flight. The delivered waveform data are listed in Table 9.

Table 9: Contents of the ASCII columns datasets for the waveform data

Channel name	Units	Description
Flight		Flight number
Time	Seconds	Time of current sample
Tx_Current	Amps	Transmitter Current
Rx_Voltage	volts	Receiver voltage

Gridded data were supplied in ER Mapper (.ers) format at 500 metre cell size.

Table 10: List of gridded data included in the final dataset

Grid name	Description
Ground_elevation_radar	Radar altimeter derived digital elevation model
Mag_average	Total magnetic intensity
CDI_Depth_Slice_0_5	Conductivity Depth Slice between 0 and 5 metres depth
CDI_Depth_Slice_5_10	Conductivity Depth Slice between 5 and 10 metres depth
CDI_Depth_Slice_10_15	Conductivity Depth Slice between 10 and 15 metres depth
CDI_Depth_Slice_15_20	Conductivity Depth Slice between 15 and 20 metres depth
CDI_Depth_Slice_20_30	Conductivity Depth Slice between 20 and 30 metres depth
CDI_Depth_Slice_30_40	Conductivity Depth Slice between 30 and 40 metres depth
CDI_Depth_Slice_40_60	Conductivity Depth Slice between 40 and 60 metres depth
CDI_Depth_Slice_60_100	Conductivity Depth Slice between 60 and 100 metres depth
CDI_Depth_Slice_100_150	Conductivity Depth Slice between 100 and 150 metres depth
CDI_Depth_Slice_150_200	Conductivity Depth Slice between 150 and 200 metres depth
CDI_Depth_Slice_200_300	Conductivity Depth Slice between 200 and 300 metres depth

Respectfully submitted[2],

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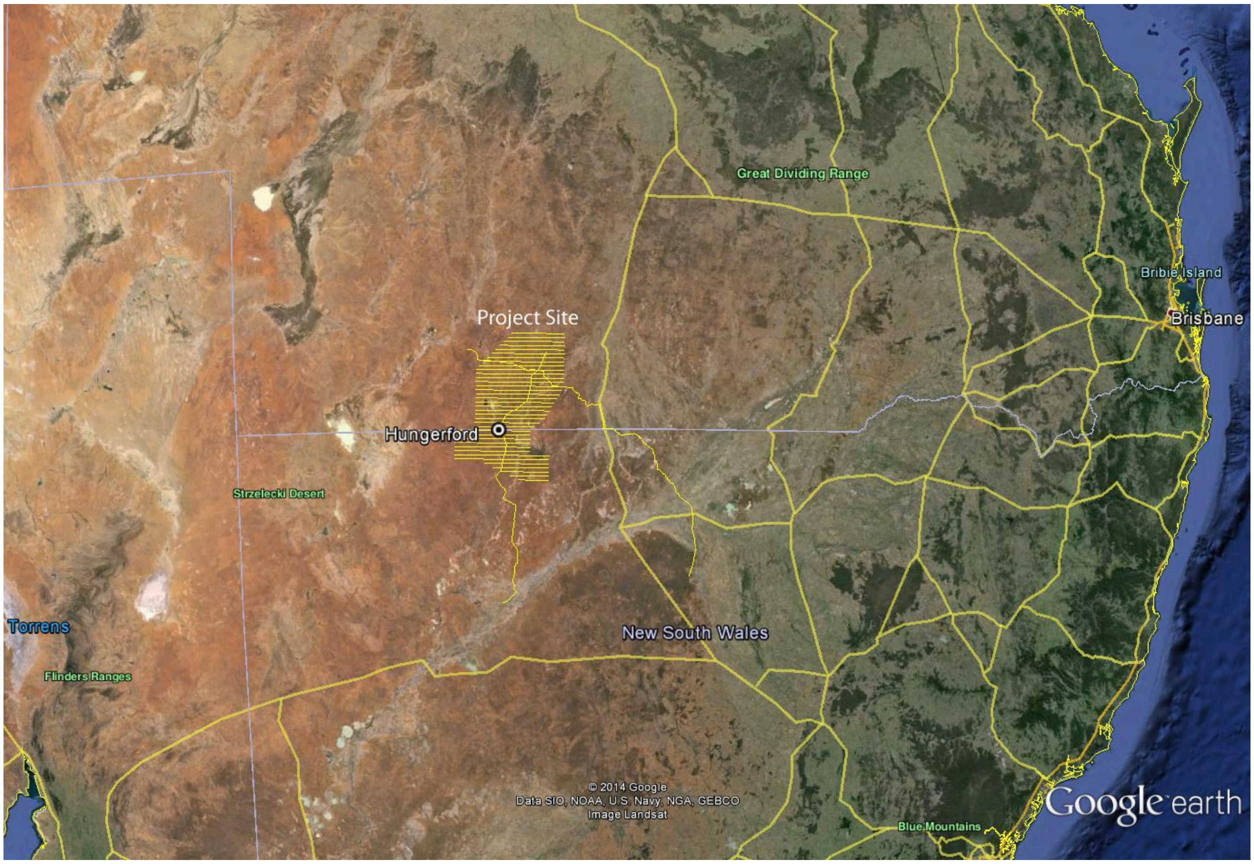
June, 2014

[2] Final data processing of the EM and magnetic data were carried out by Nick Venter, Nasreddine Bournas and Timothy Eadie, from the office of Geotech Ltd in Aurora, Ontario, under the supervision of Geoffrey Plastow, P.Geo. Data Processing Manager.

APPENDIX A

SURVEY BLOCK LOCATION MAP



Overview of the Survey Area

APPENDIX B

SURVEY BLOCK COORDINATES

(GDA94, MGA Zone 55 South)

X	Y
324980.4	6910941.6
265983	6911176.5
265766.5	6911179.7
217750	6863228.1
217750	6788053.2
192784.6	6787928.8
192784.6	6749353.3
226051.4	6749353.3
274639.1	6725912.9
307858	6725912.9
307858	6759700
284268	6759700
284268	6788497
301966.9	6802340.5
325038.3	6842160.8

APPENDIX C

Flight Line Summary

Line number	Start Fiducial	End Fiducial
1000	54090	65619
1001	67974	79477
1010	30485	45172
1011	18506	28004
1012	25778	32860
1020	60568	87440
1030	18460	51493
1040	43203	75385
1050	14600	32898
1051	46409	64234
1060	45408	65949
1061	15242	35570
1070	18749	36383
1071	43494	65779
1080	45492	66336
1081	13534	32304
1090	12003	35368
1091	59927	85029
1100	38674	61363
1101	29745	49731
1110	8788	30585
1111	45897	68762
1120	46958	69175
1121	15681	37568
1130	18484	39735
1131	42552	67506
1140	43110	65530
1141	14620	34390
1150	14033	34869
1151	72468	93045
1160	68921	88580
1161	43639	65083
1170	39018	60257
1171	53097	70096
1180	40607	59958
1181	28488	46527
1190	13815	31864
1191	38383	56605

Line number	Start Fiducial	End Fiducial
1200	34717	54094
1201	11430	30074
1210	10802	26403
1211	57075	72553
1220	29935	46920
1221	32185	50131
1230	9317	22708
1231	54259	67725
1240	33416	49060
1241	37601	53013
1250	57233	76076
1251	10822	30695
1260	26810	41641
1261	38856	56060
1270	48741	68976
1271	11956	31823
1280	12908	30085
1281	55619	73466
1290	38270	56259
1291	30229	47430
1300	11791	33041
1301	41786	64583
1310	40469	48789
1311	12462	33528
1312	50398	65679
1320	37097	53340
1321	12672	27620
1330	61982	74368
1331	35451	49058
1340	8871	20989
1341	29365	42292
1350	49197	66579
1360	16245	32442

Traverse 1

Line number	Start Fiducial	End Fiducial
3000	28899	47592
3001	59025	101838
3003	29396	50626
3004	58709	104283
3005	10731	25458
3006	34377	65513

Traverse 2

Line number	Start Fiducial	End Fiducial
4000	45198	66531
4001	75053	97313
4002	16939	40131
4003	48843	79459
4004	84666	107119
4005	12219	36861
4006	43866	113219
4007	11001	29384

APPENDIX D

GENERALIZED MODELING RESULTS OF THE VTEM SYSTEM

Introduction

The VTEM system is based on a concentric or central loop design, whereby, the receiver is positioned at the centre of a transmitter loop that produces a primary field. The wave form is a bi-polar, modified square wave with a turn-on and turn-off at each end.

During turn-on and turn-off, a time varying field is produced (dB/dt) and an electro-motive force (emf) is created as a finite impulse response. A current ring around the transmitter loop moves outward and downward as time progresses. When conductive rocks and mineralization are encountered, a secondary field is created by mutual induction and measured by the receiver at the centre of the transmitter loop.

Efficient modeling of the results can be carried out on regularly shaped geometries, thus yielding close approximations to the parameters of the measured targets. The following is a description of a series of common models made for the purpose of promoting a general understanding of the measured results.

A set of models has been produced for the Geotech VTEM® system dB/dT Z and X components (see models D1 to D15). The Maxwell ™ modeling program (EMIT Technology Pty Ltd Midland, WA, AU) used to generate the following responses assumes a resistive half-space. The reader is encouraged to review these models, so as to get a general understanding of the responses as they apply to survey results. While these models do not begin to cover all possibilities, they give a general perspective on the simple and most commonly encountered anomalies.

As the plate dips and departs from the vertical position, the peaks become asymmetrical.

As the dip increases, the aspect ratio (Min/Max) decreases and this aspect ratio can be used as an empirical guide to dip angles from near 90º to about 30º. The method is not sensitive enough where dips are less than about 30º.

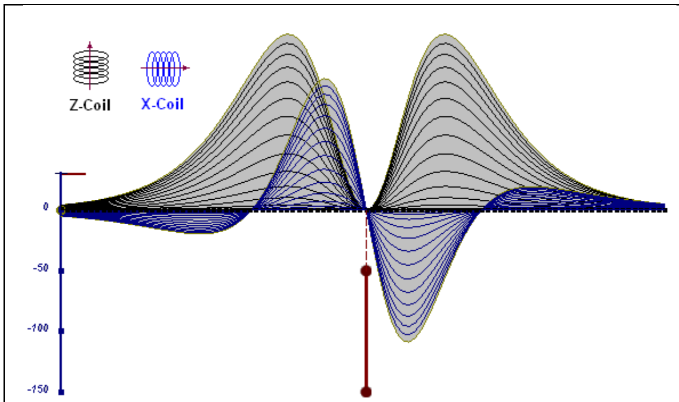


Figure D-1: vertical thin plate

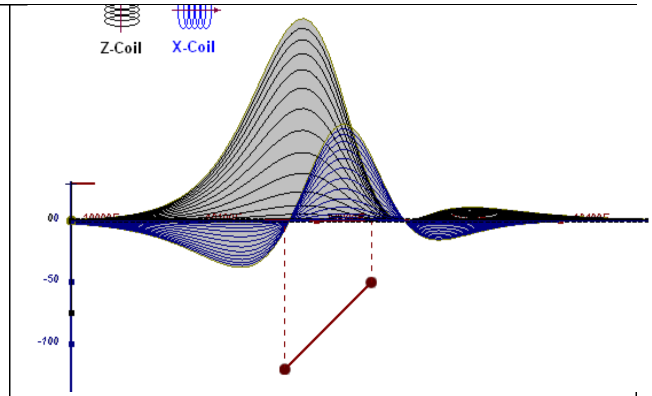


Figure D-2: inclined thin plate

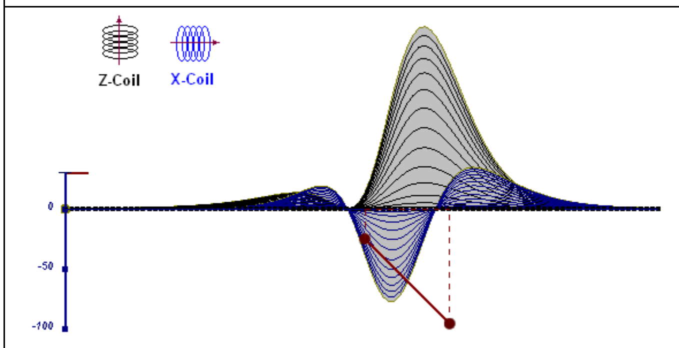


Figure D-3: inclined thin plate

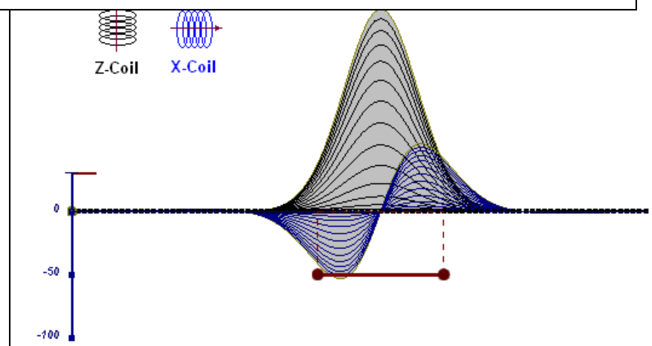


Figure D-4: horizontal thin plate

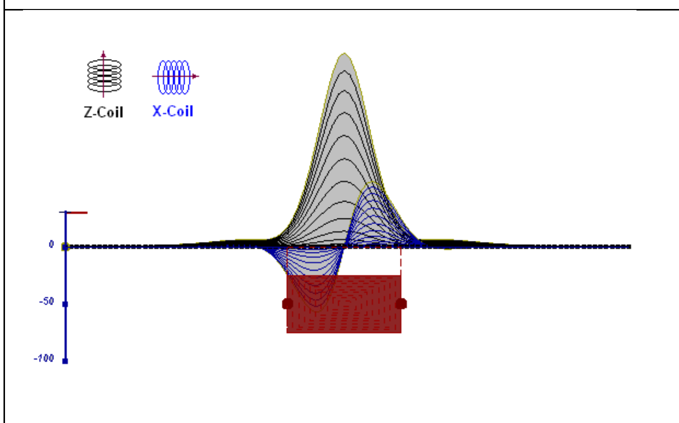


Figure D-5: horizontal thick plate (linear scale of the response)

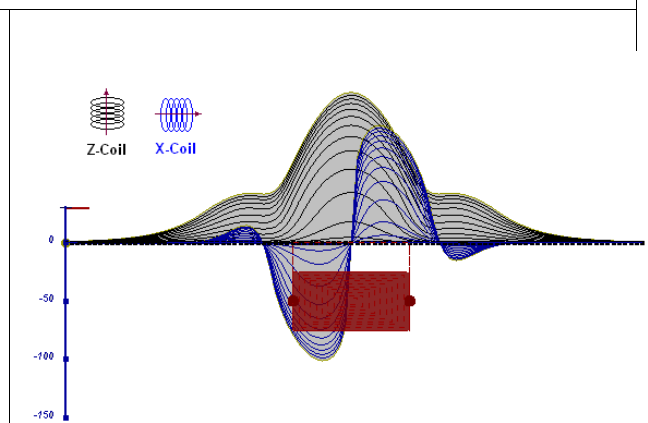


Figure D-6: horizontal thick plate (log scale of the response)

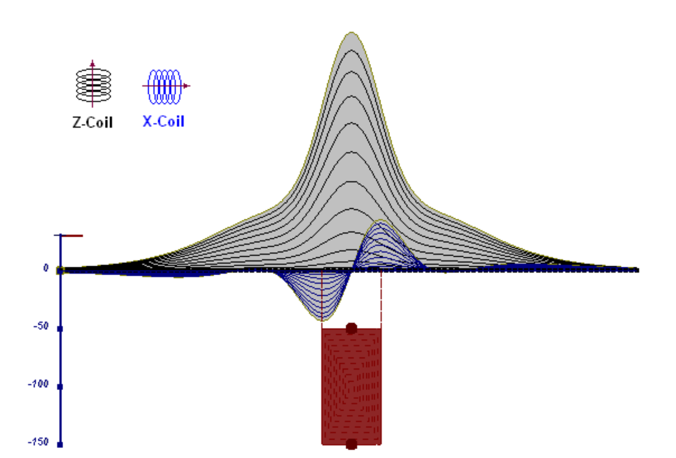


Figure D-7: vertical thick plate (linear scale of the response). 50 m depth

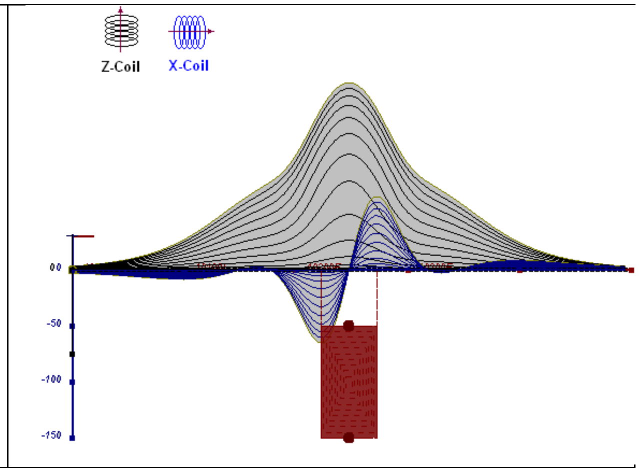


Figure D-8: vertical thick plate (log scale of the response). 50 m depth

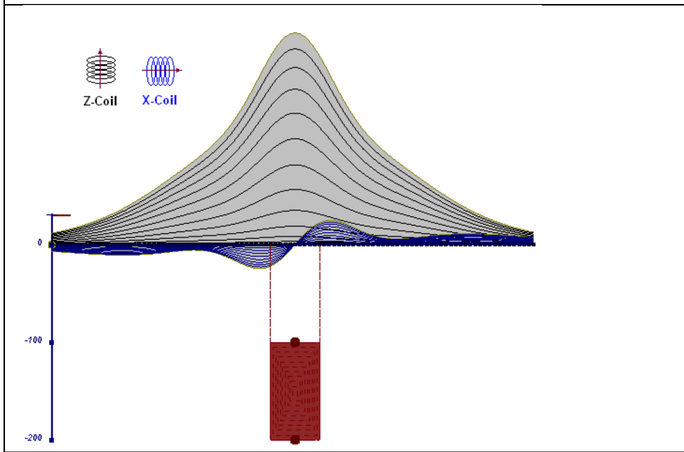


Figure D-9: vertical thick plate (linear scale of the response). 100 m depth

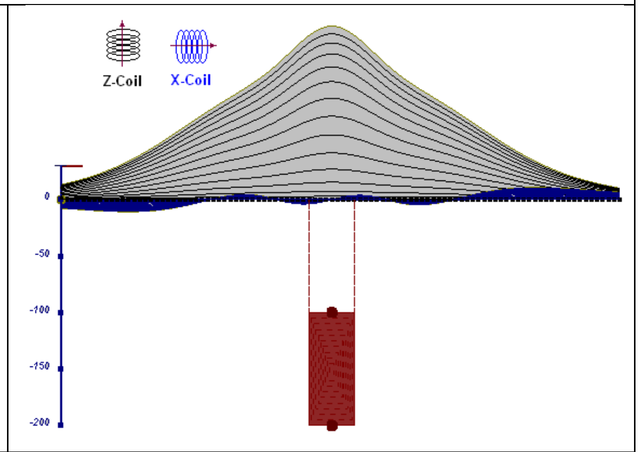


Figure D-10: vertical thick plate (linear scale of the response). Depth/hor.thickness=2.5

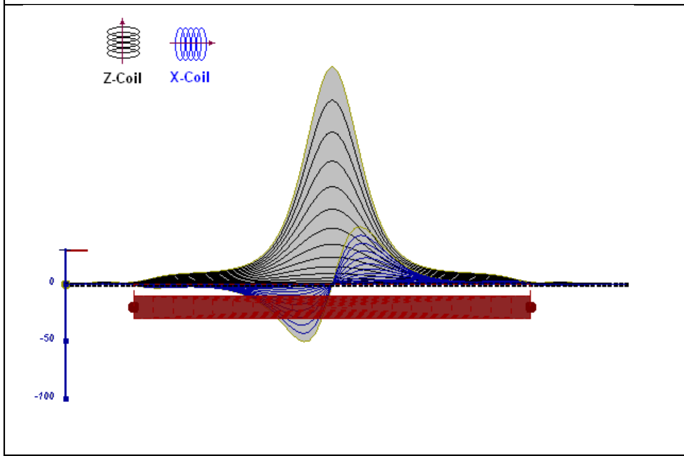


Figure D-10: horizontal thick plate (linear scale of the response)

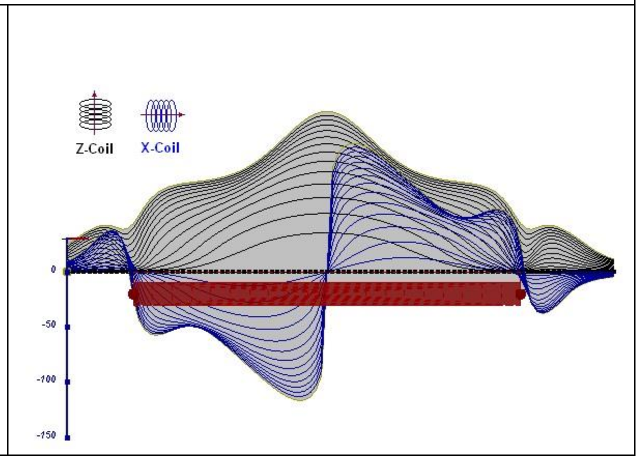


Figure D-11: horizontal thick plate (log scale of the response)

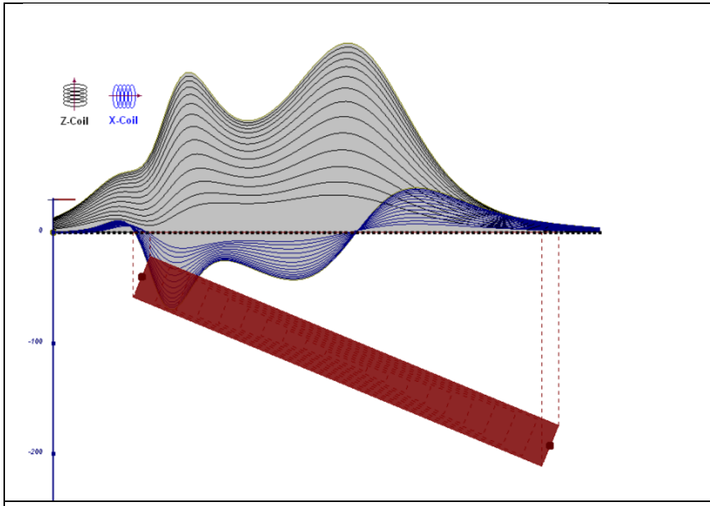


Figure D-12: inclined long thick plate

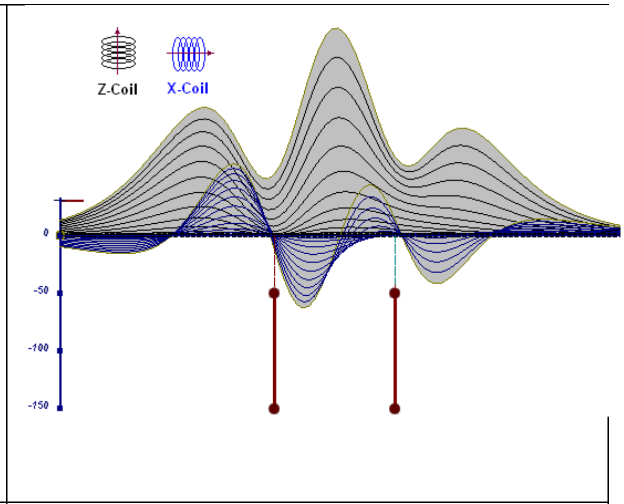


Figure D-13: two vertical thin plates

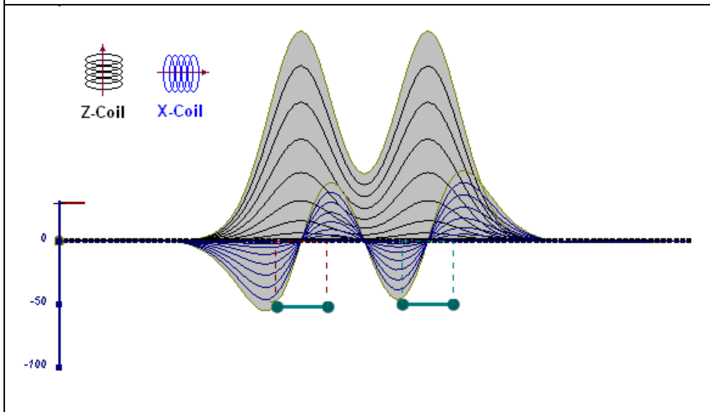


Figure D-14: two horizontal thin plates

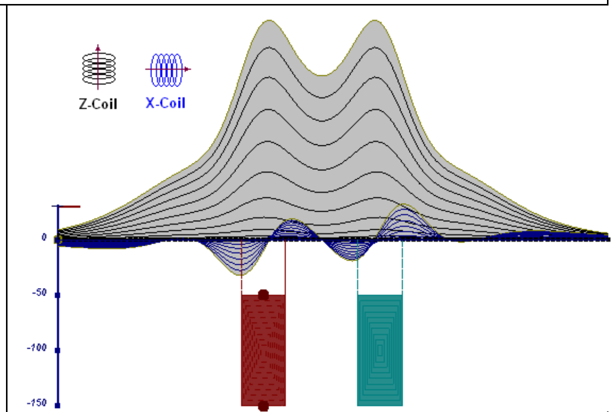
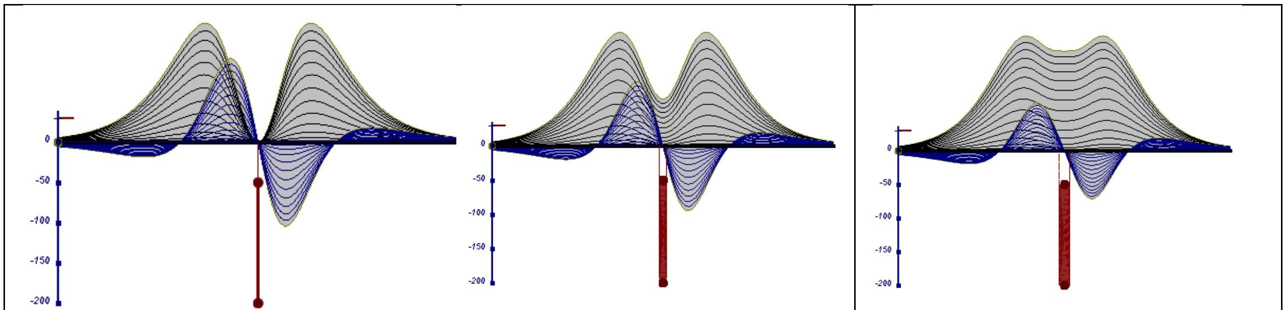
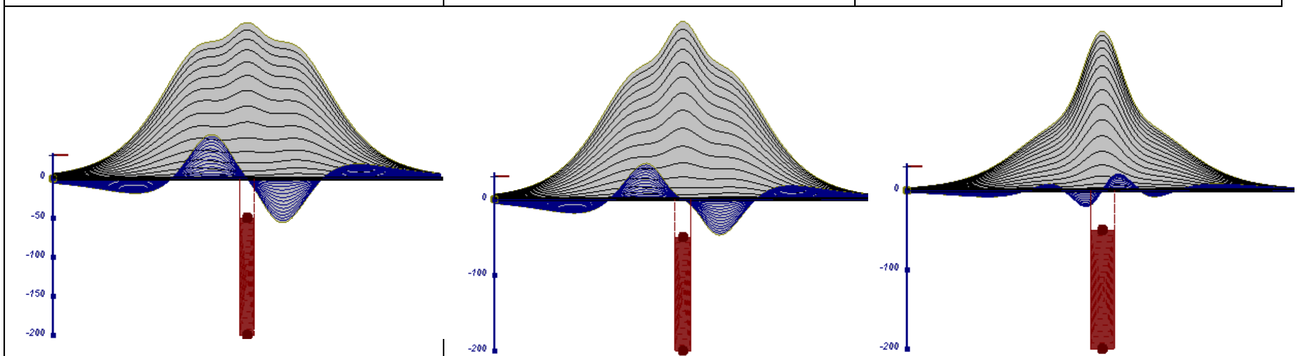


Figure D-15: two vertical thick plates

The same type of target but with different thickness, for example, creates different form of the response:



"thin"	10 m thickness	15 m thickness



18 m thickness	20 m thickness	30 m thickness

Figure D-16: Conductive vertical plate, depth 50 m, strike length 200 m, depth extends 150 m.

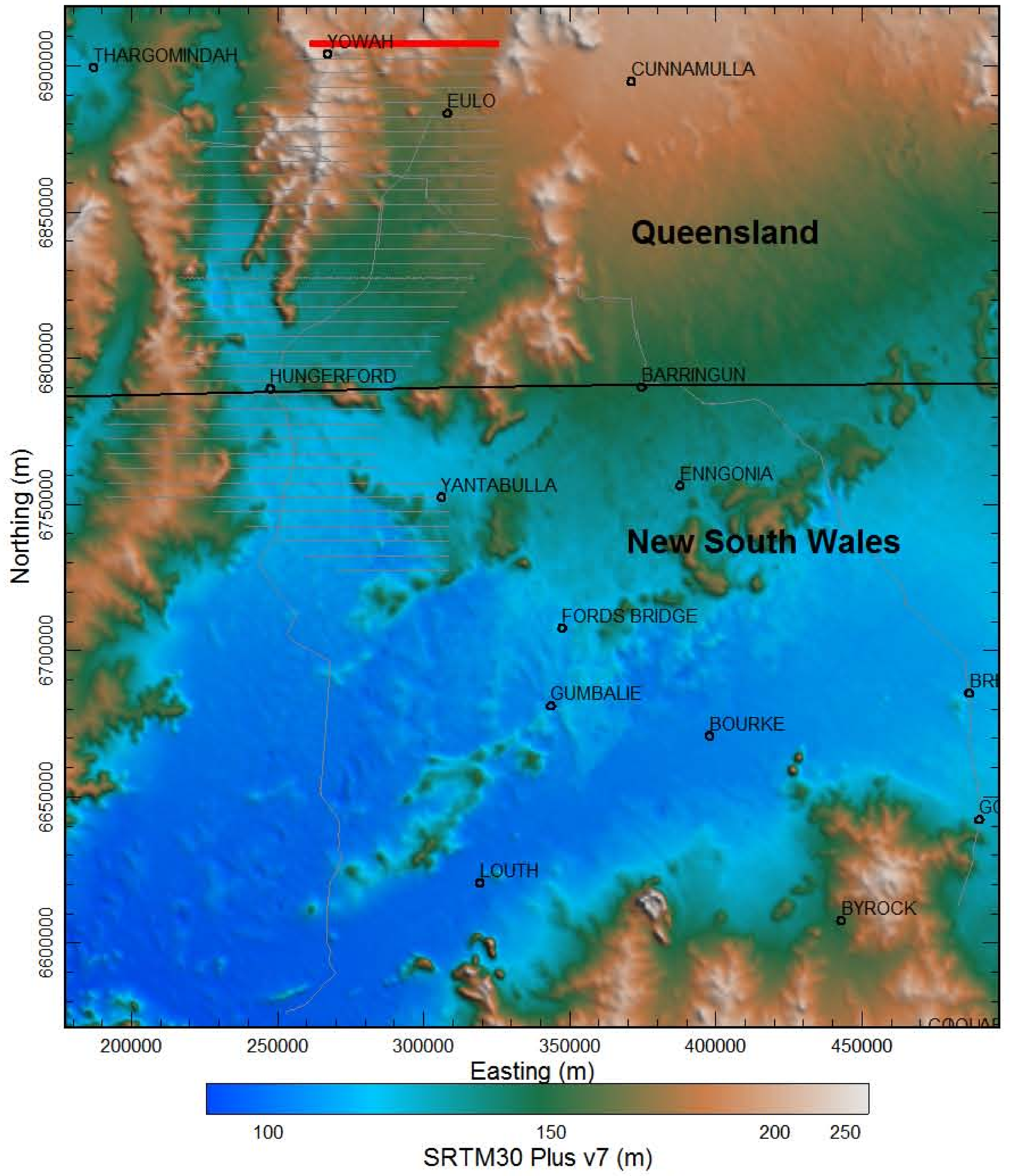
Alexander Prikhodko, PhD, P.Geo
Geotech Ltd.

September 2010

APPENDIX E

Conductivity Depth Images Multi Plots

FLIGHT PATH



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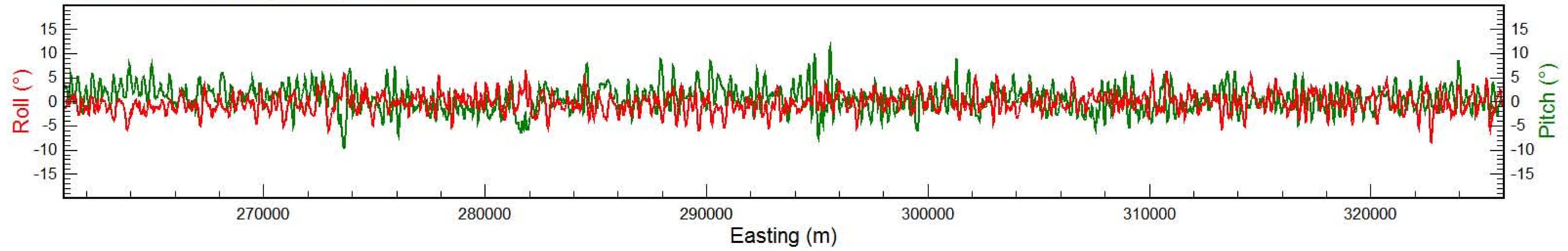
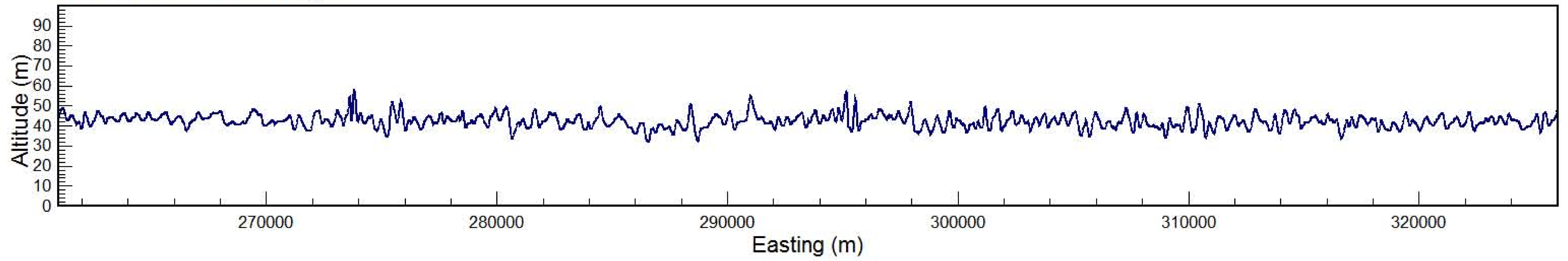
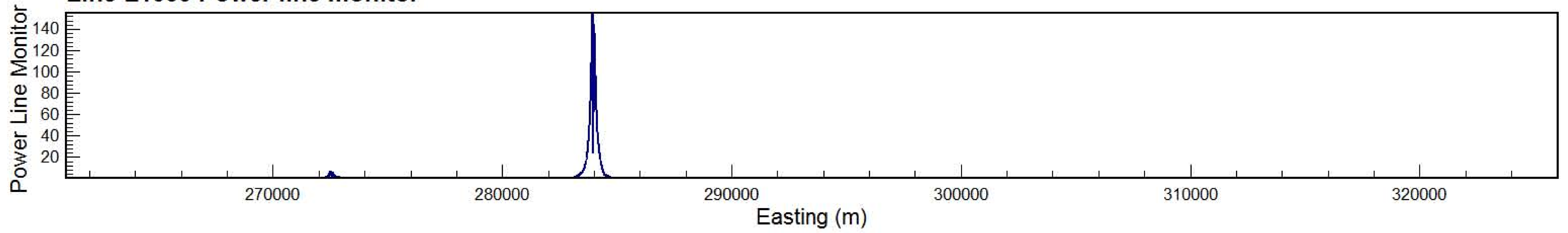
Line L1000 TX-RX pitch and roll



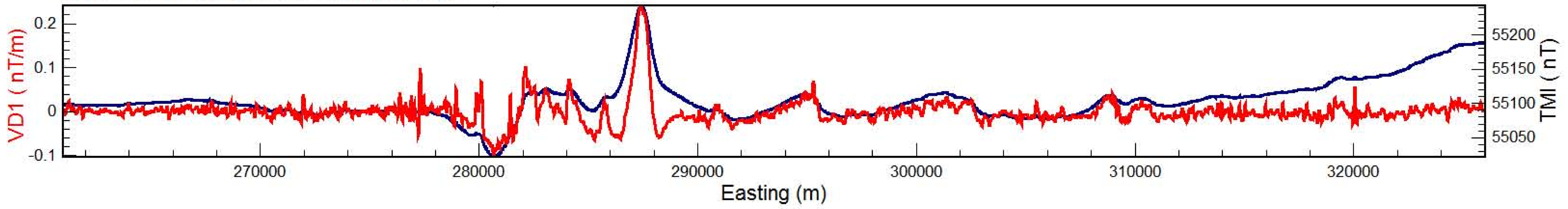
Line L1000 TX-RX height



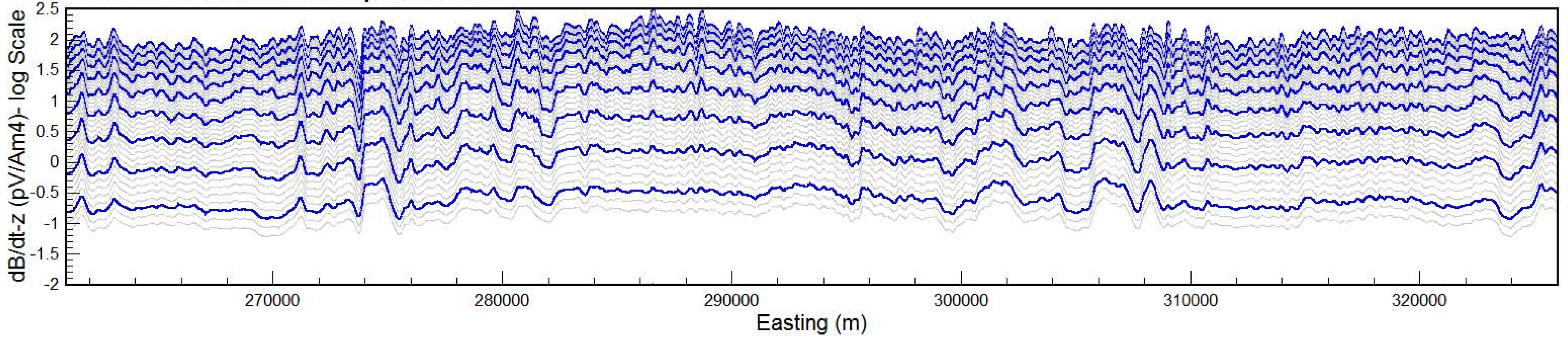
Line L1000 Power line monitor



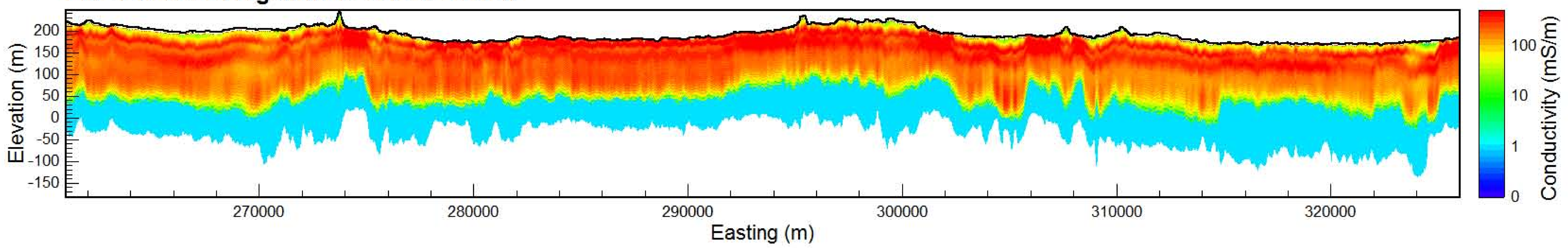
Line L1000 Magnetics TMI and 1VD



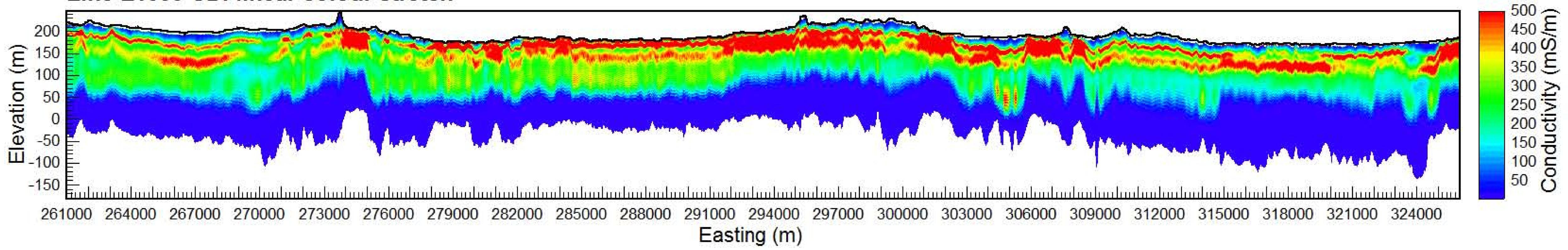
Line L1000 Windowed amplitude data



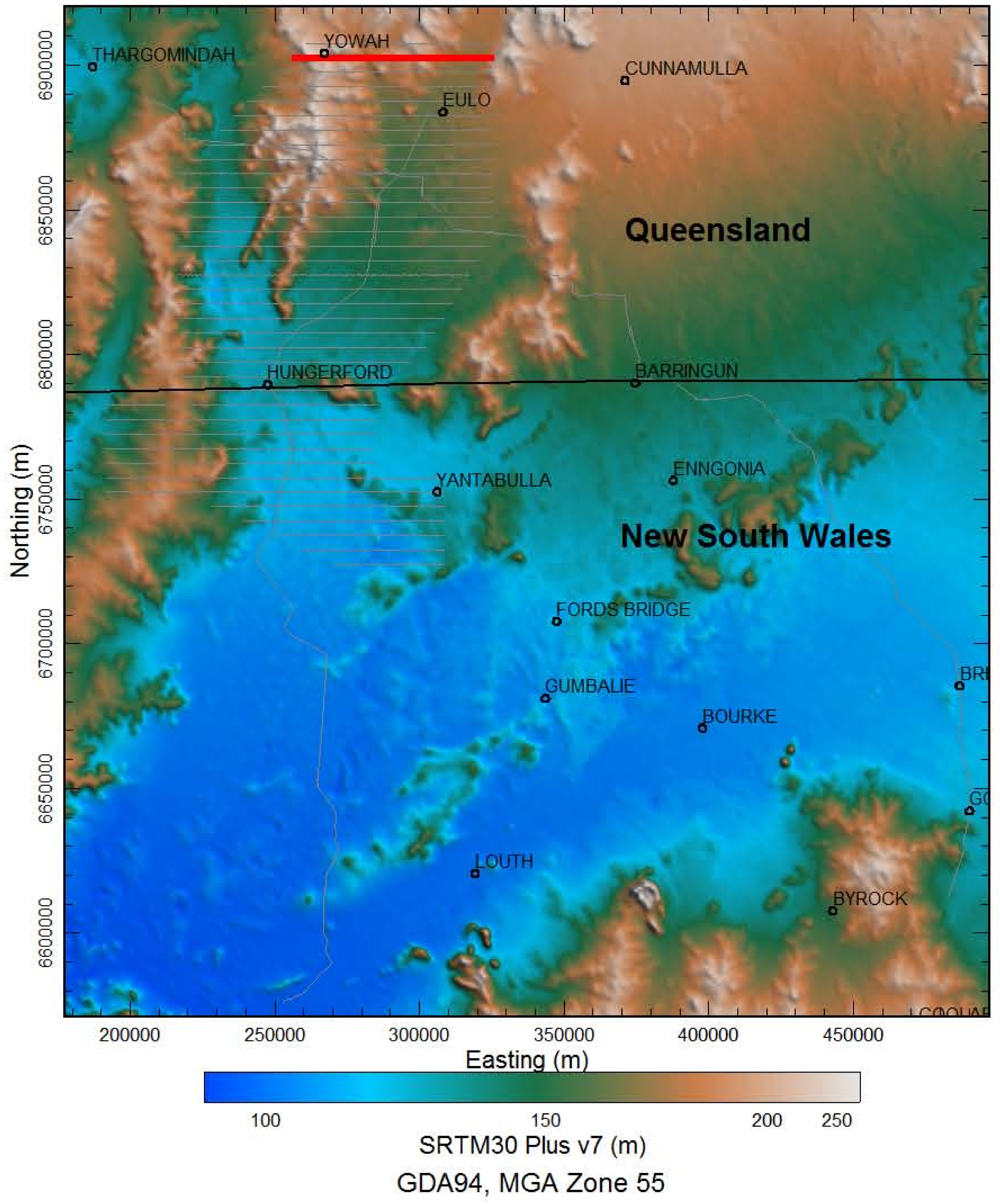
Line L1000 CDI logarithmic colour stretch



Line L1000 CDI linear colour stretch



FLIGHT PATH



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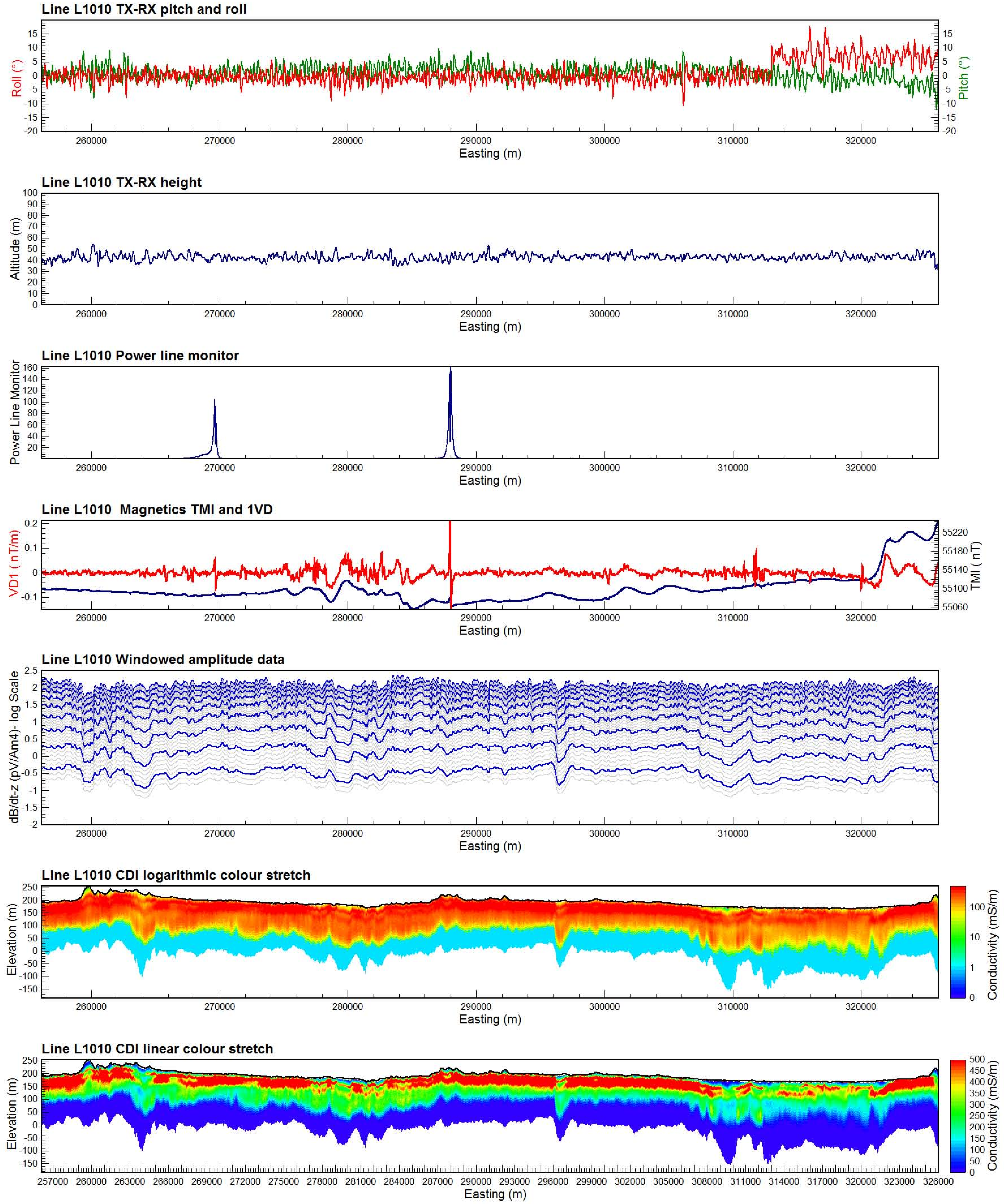
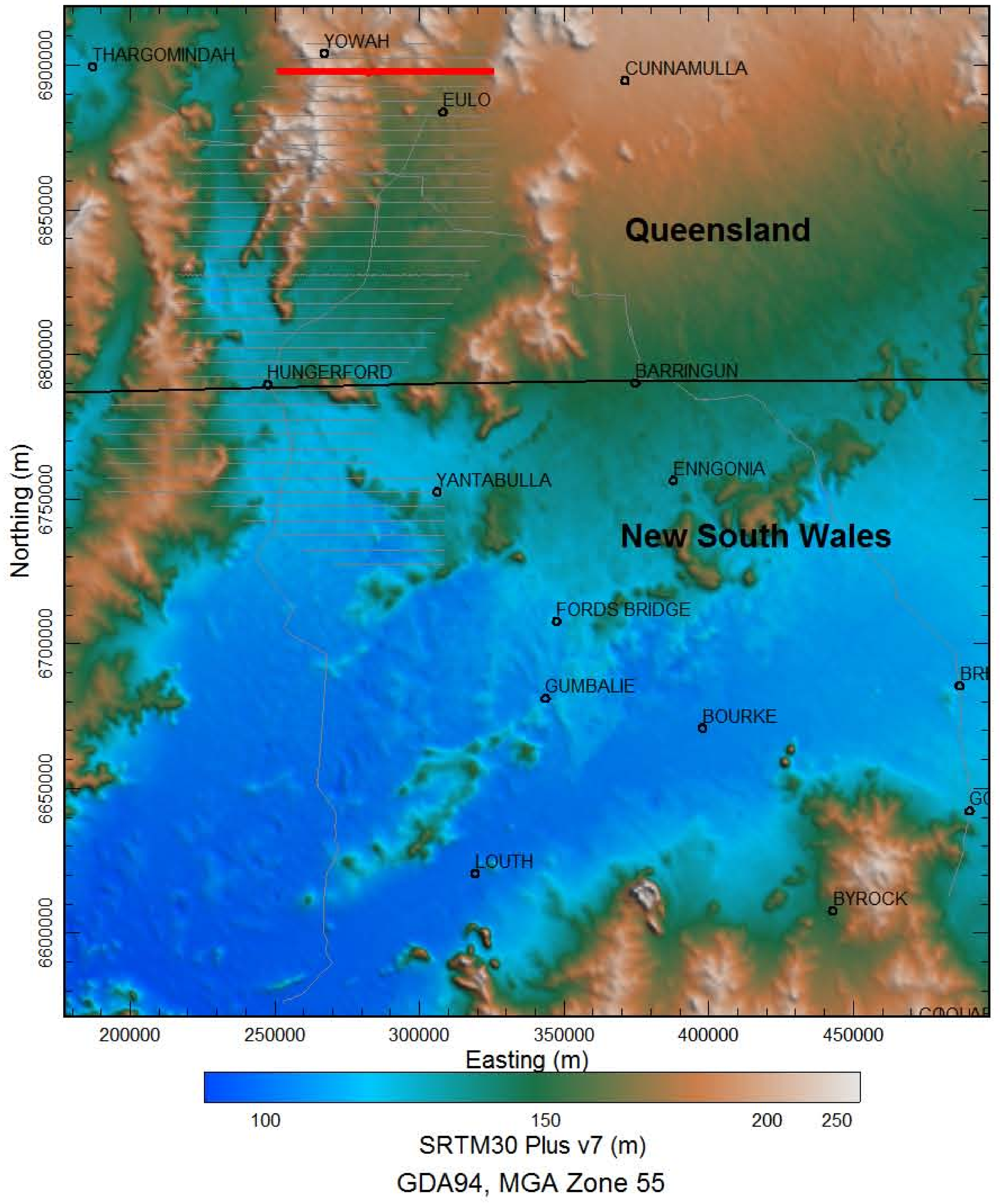


FLIGHT PATH



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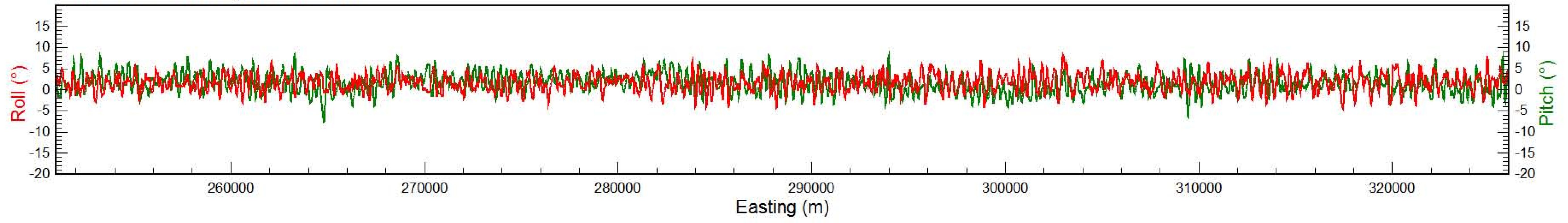
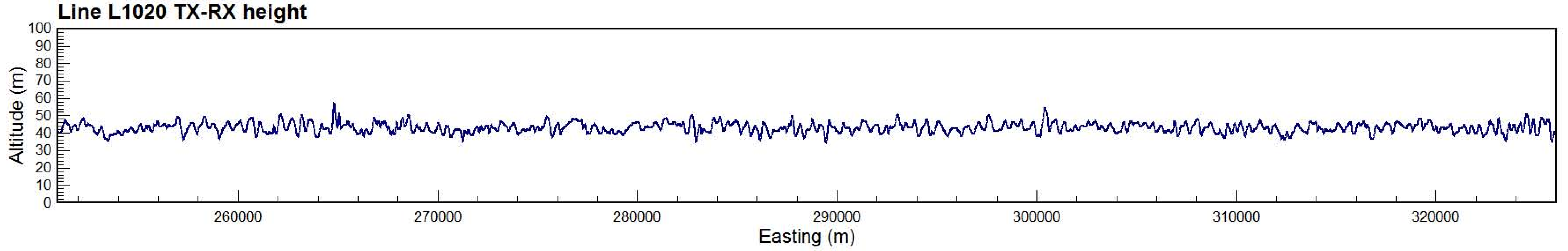
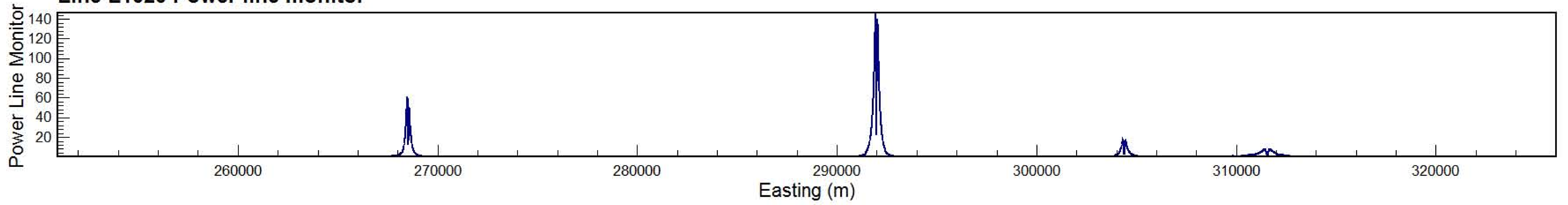


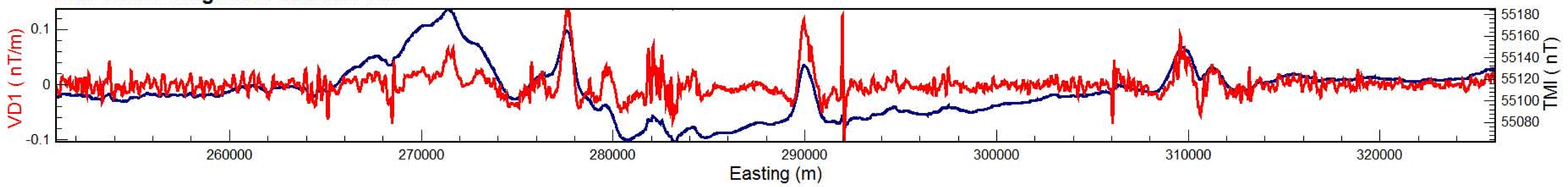
Line L1020 TX-RX height



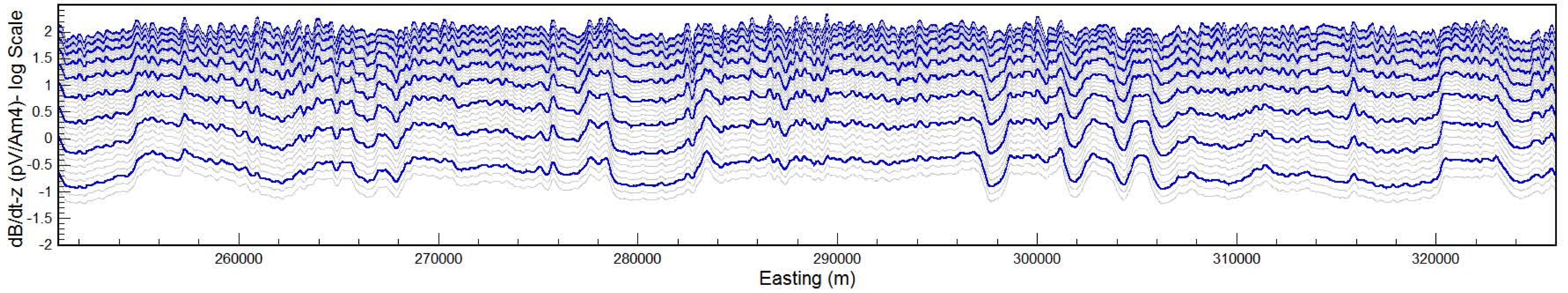
Line L1020 Power line monitor



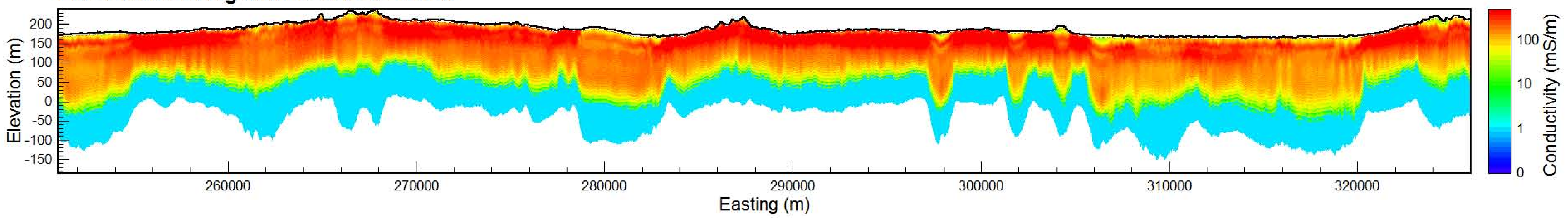
Line L1020 Magnetics TMI and 1VD



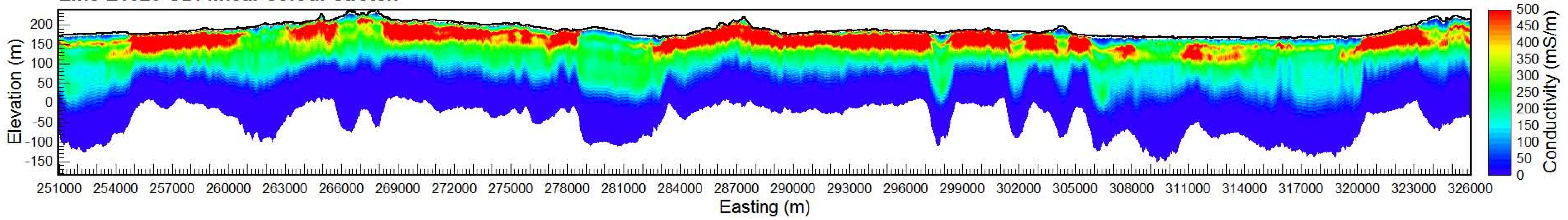
Line L1020 Windowed amplitude data



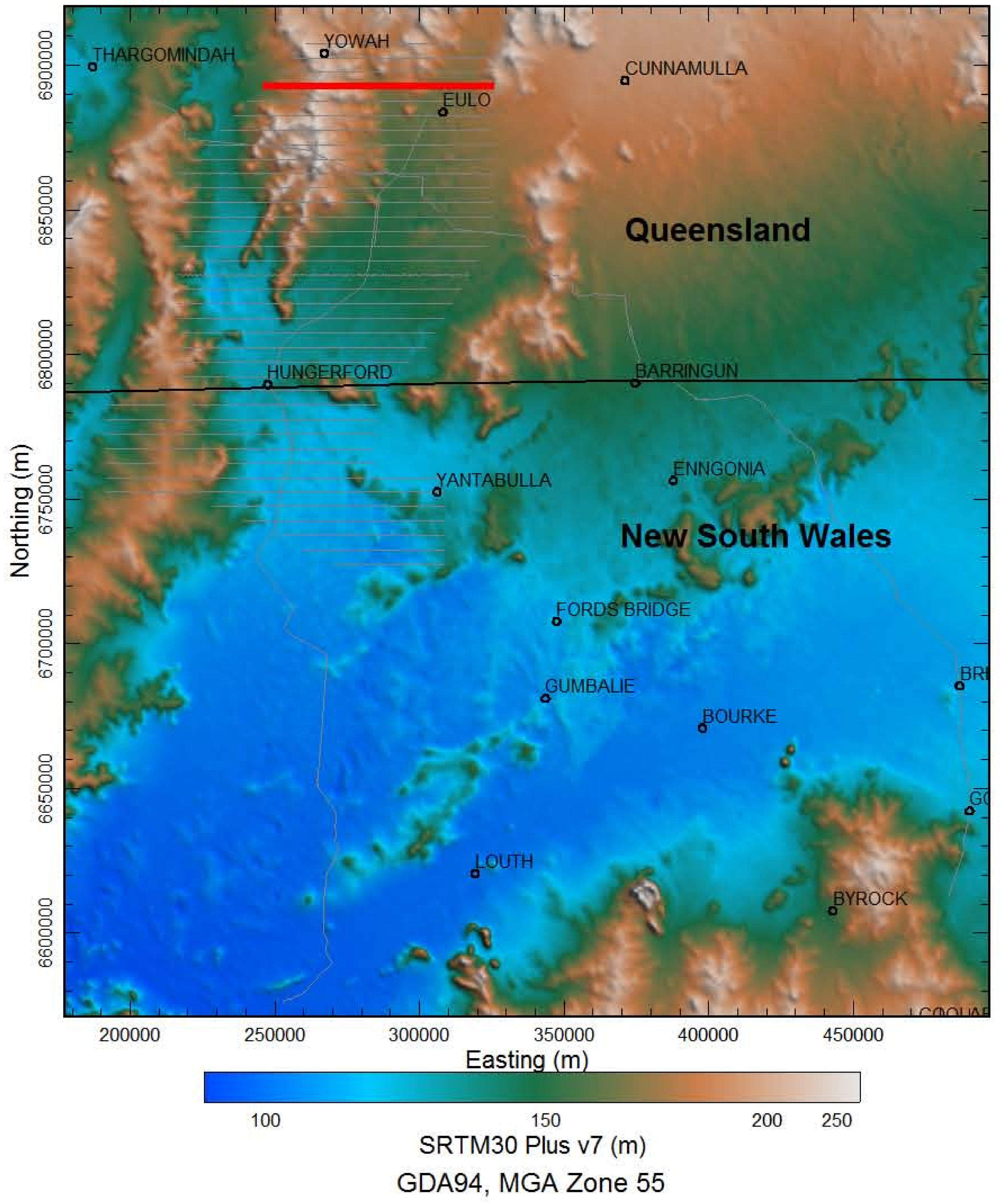
Line L1020 CDI logarithmic colour stretch



Line L1020 CDI linear colour stretch



FLIGHT PATH



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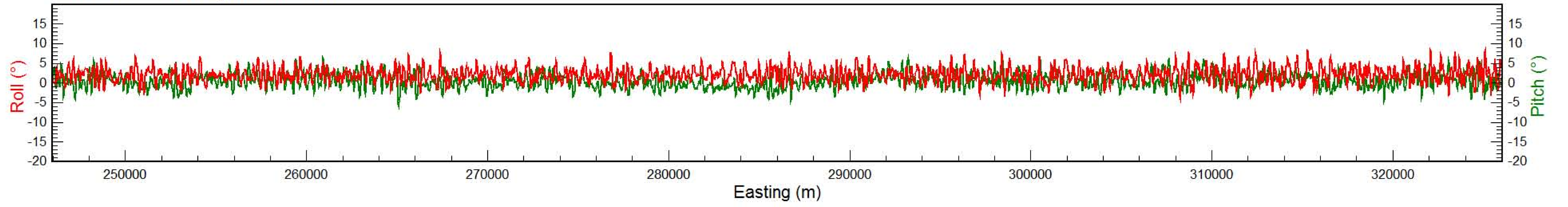
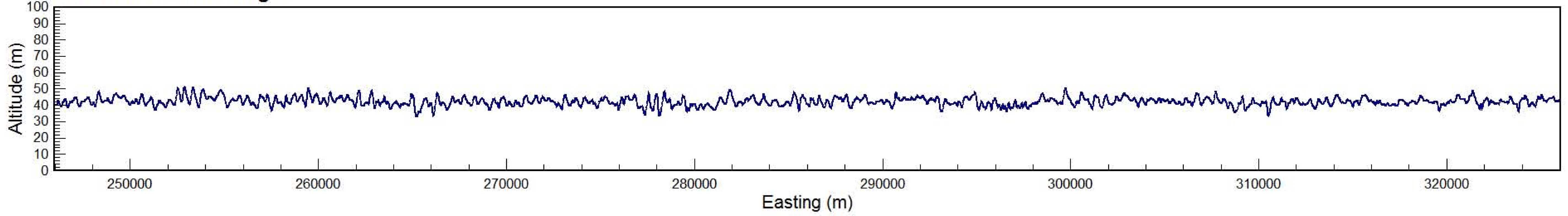
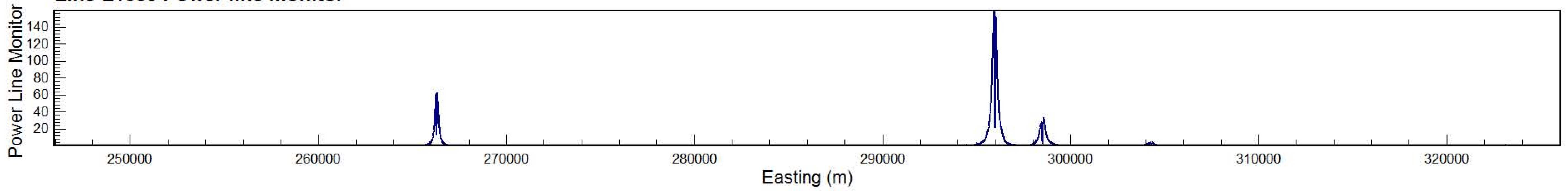
Line L1030 TX-RX pitch and roll



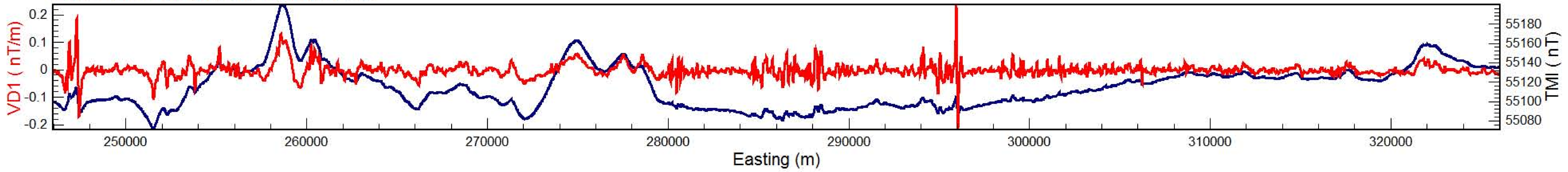
Line L1030 TX-RX height



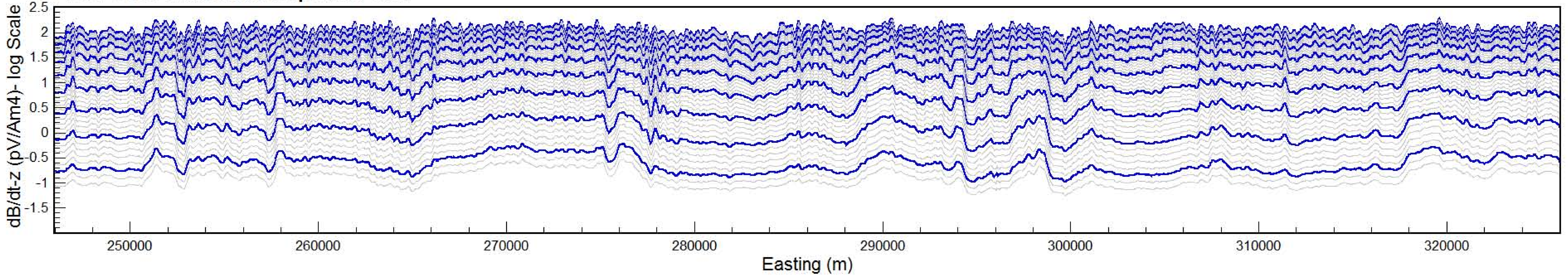
Line L1030 Power line monitor



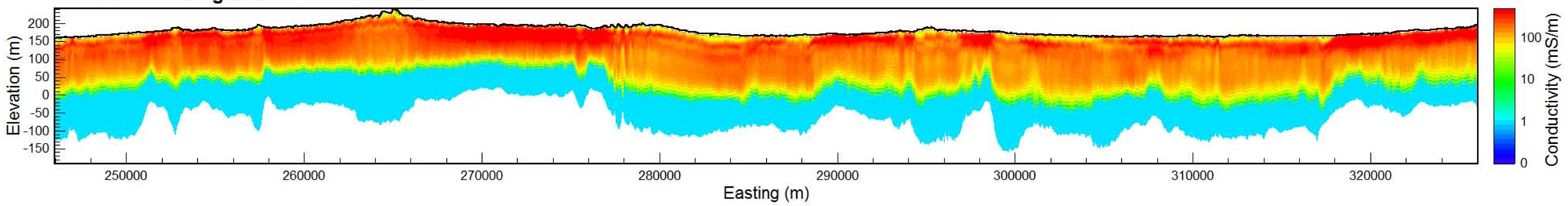
Line L1030 Magnetics TMI and 1VD



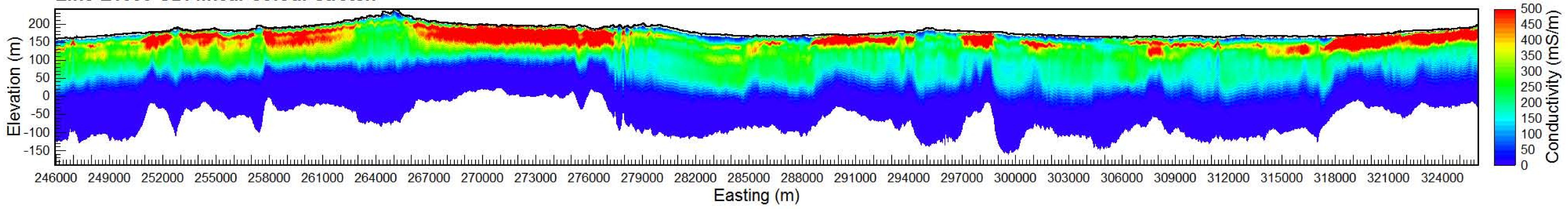
Line L1030 Windowed amplitude data



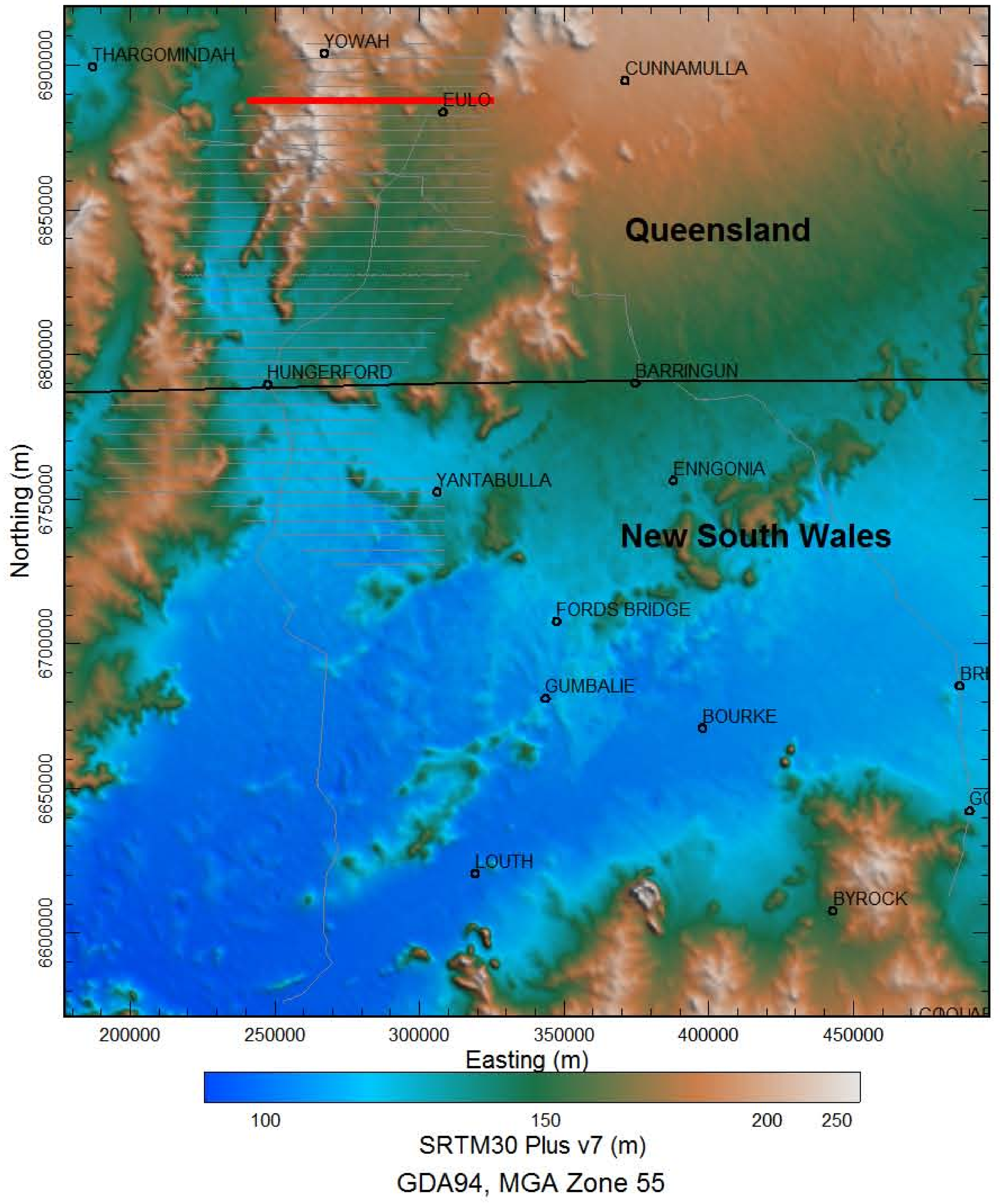
Line L1030 CDI logarithmic colour stretch



Line L1030 CDI linear colour stretch



FLIGHT PATH



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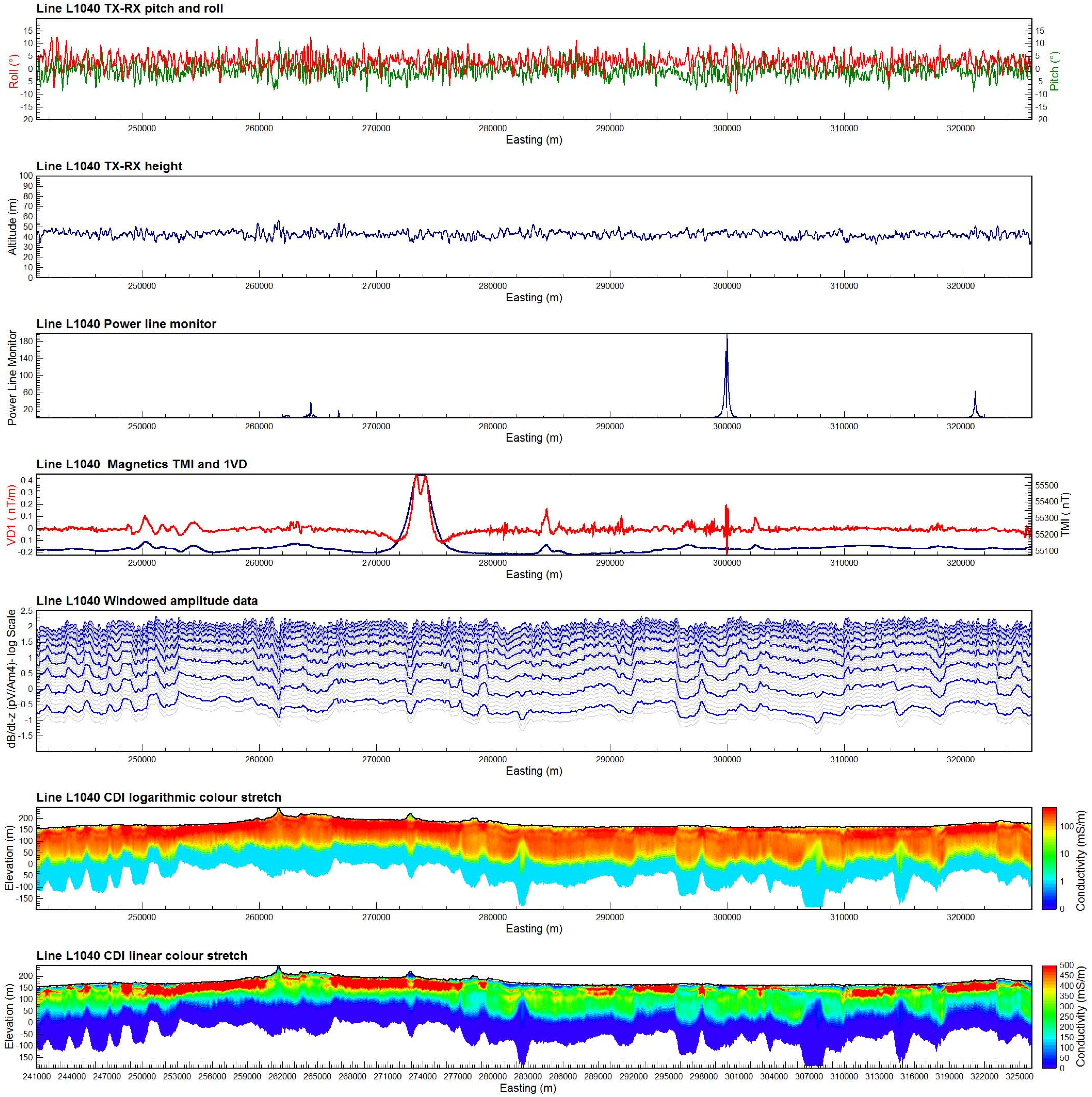

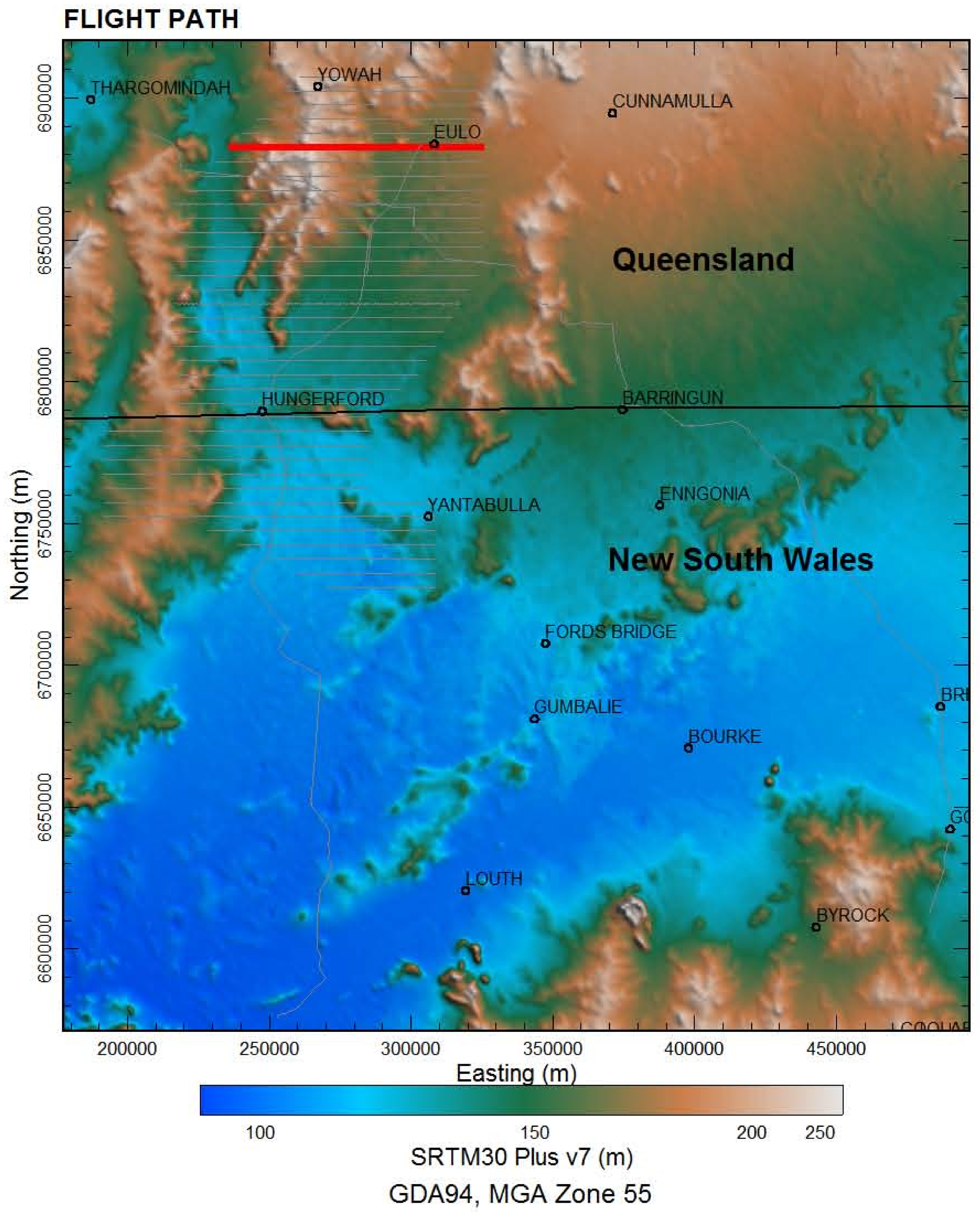

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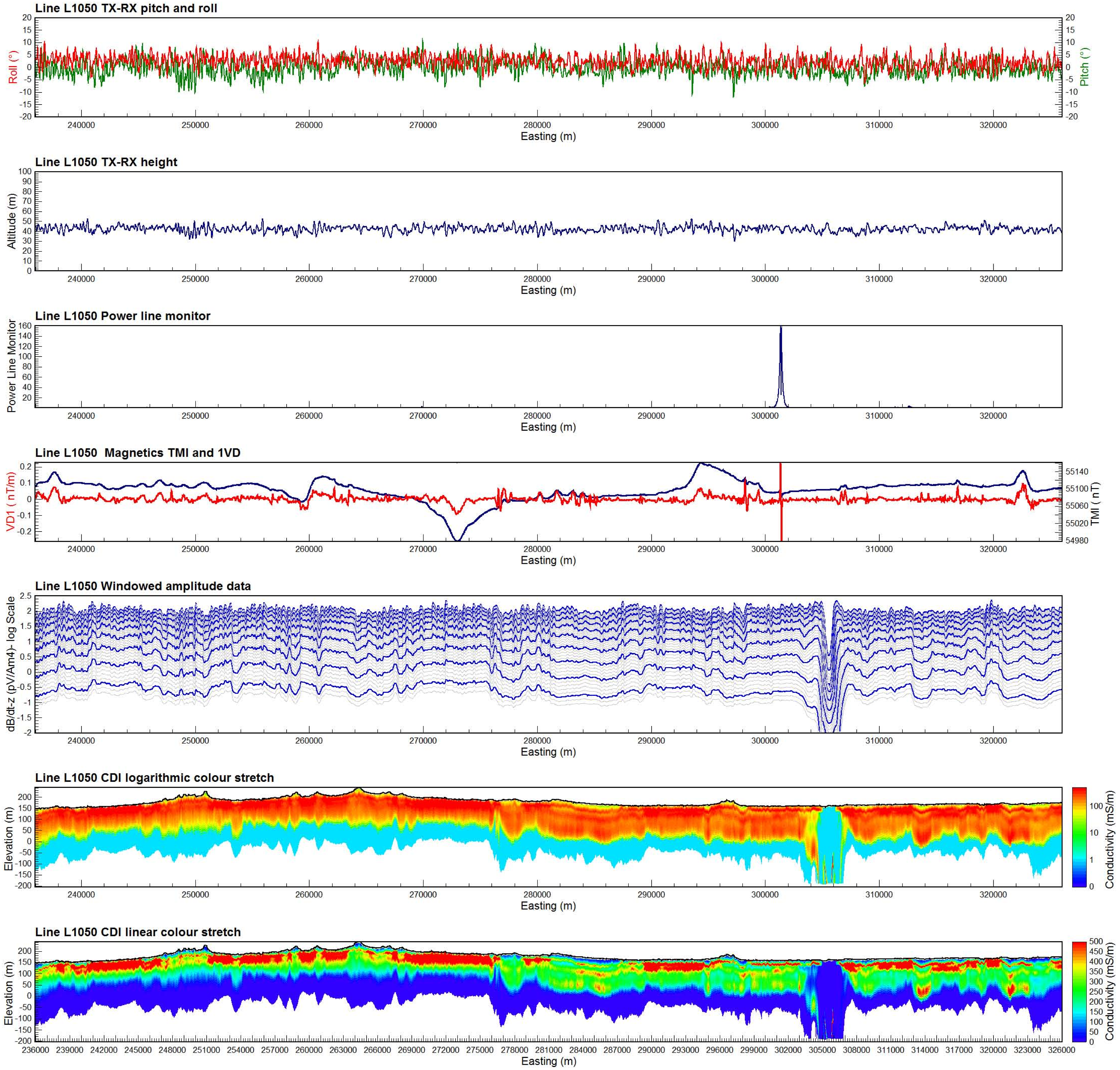

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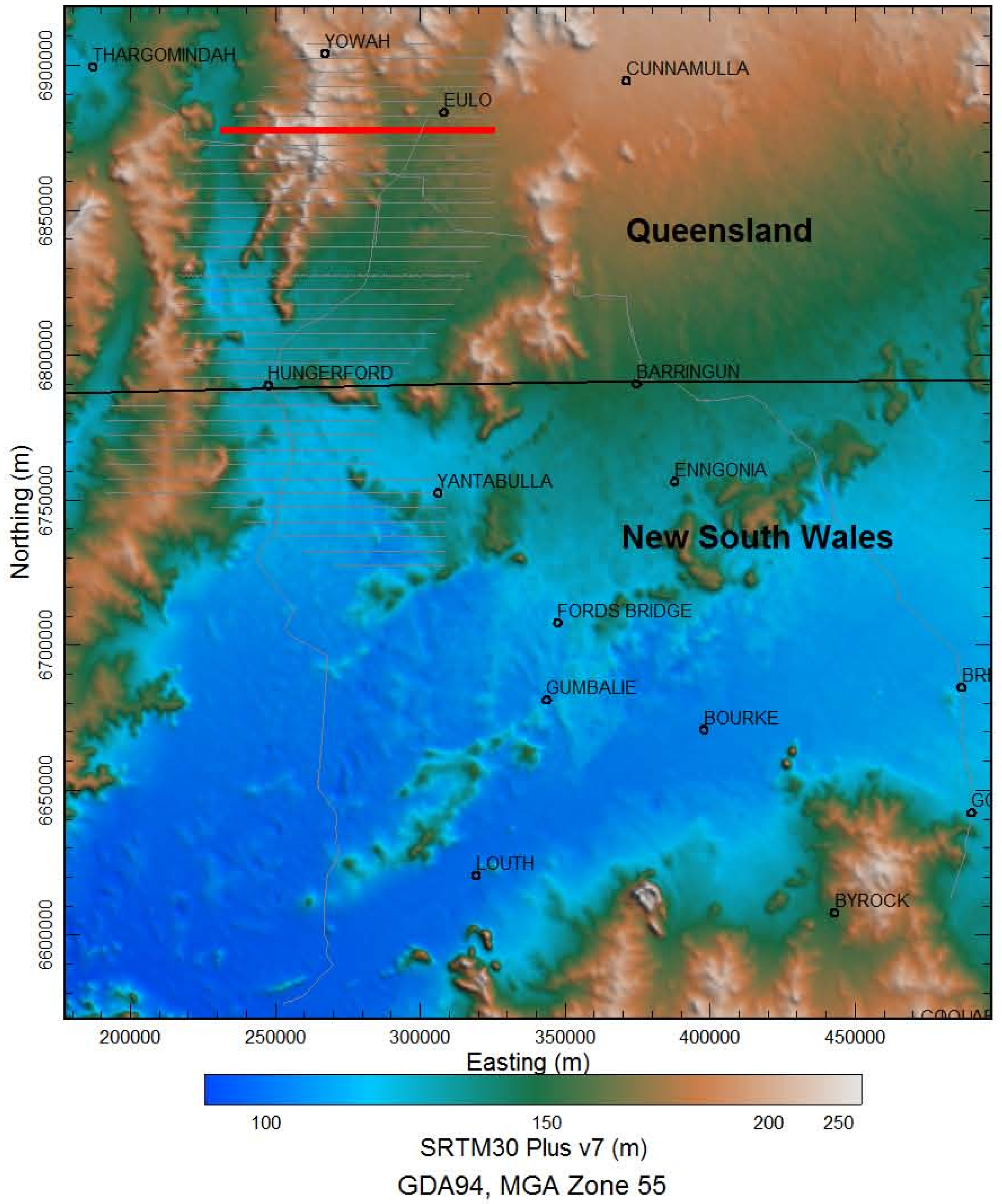

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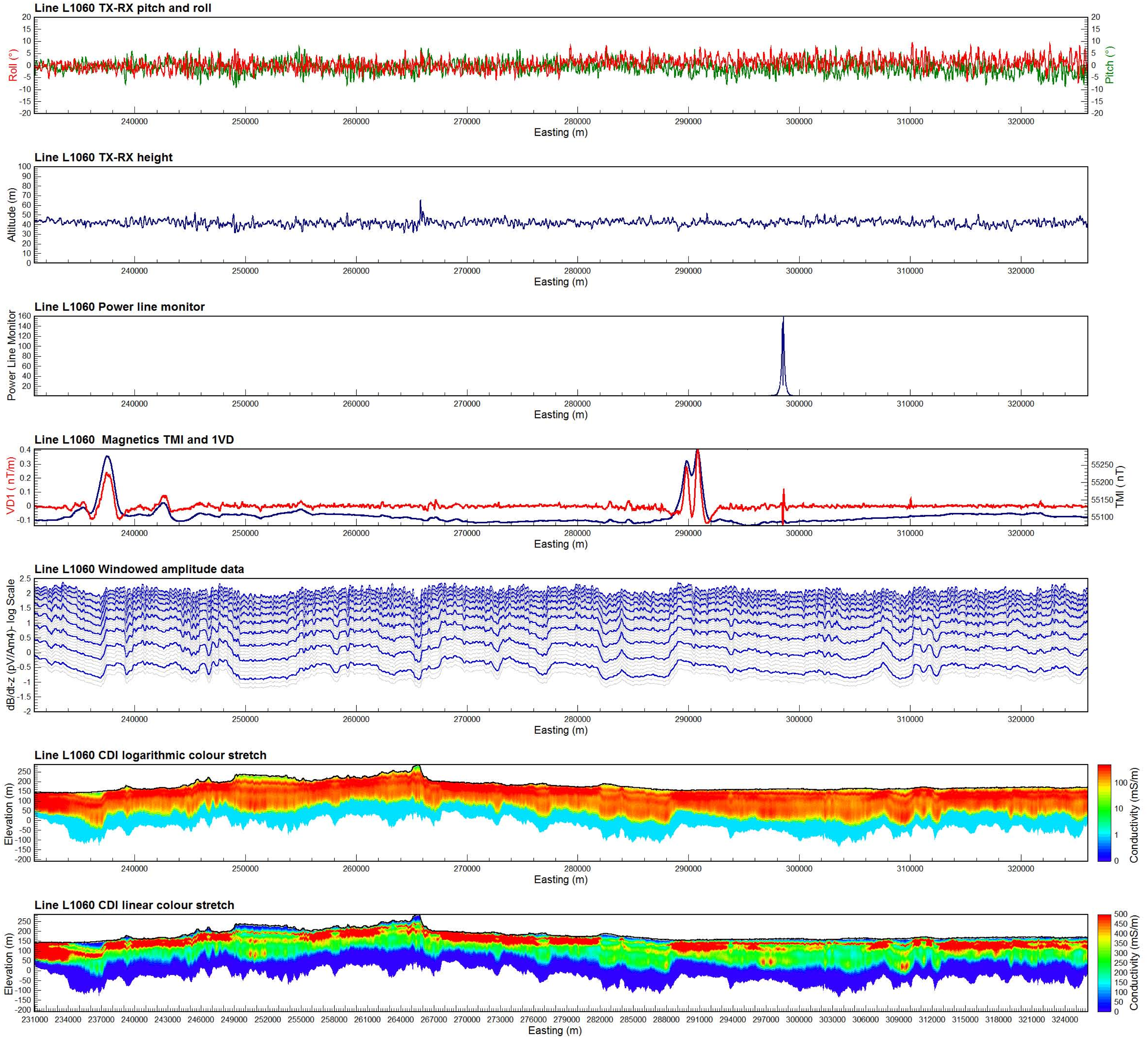
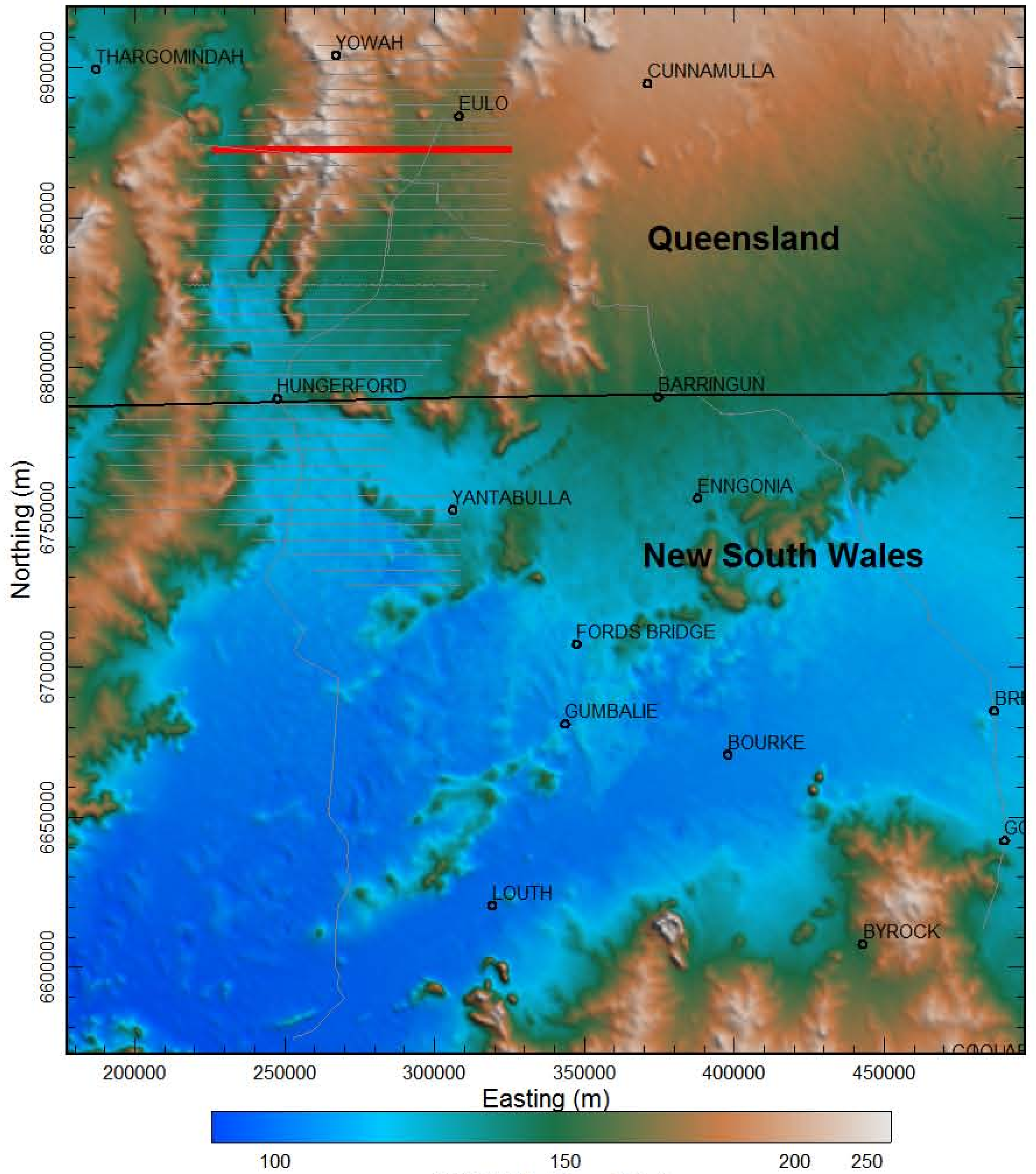


FLIGHT PATH



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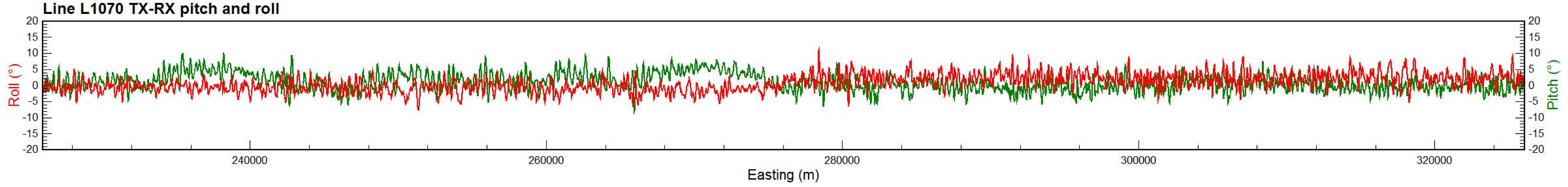
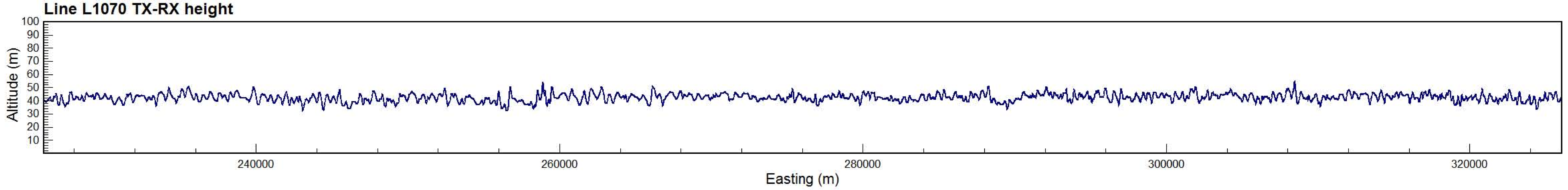
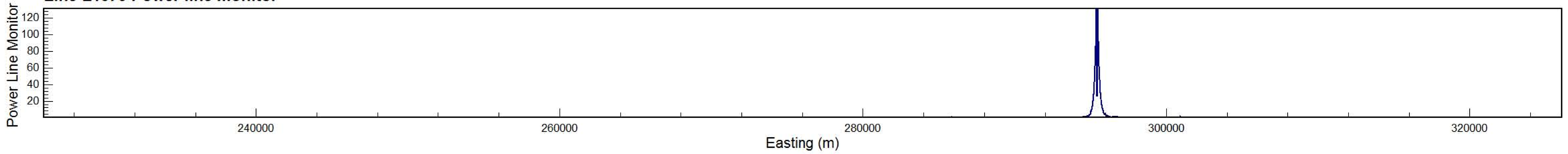


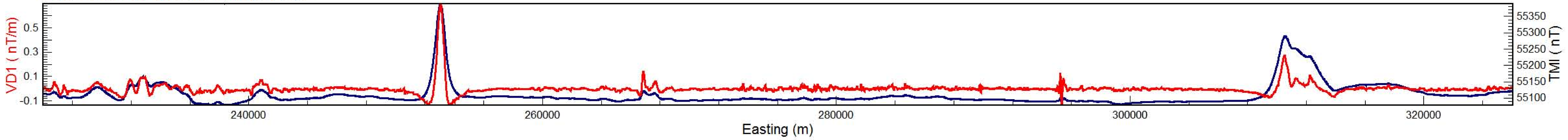
Line L1070 TX-RX height



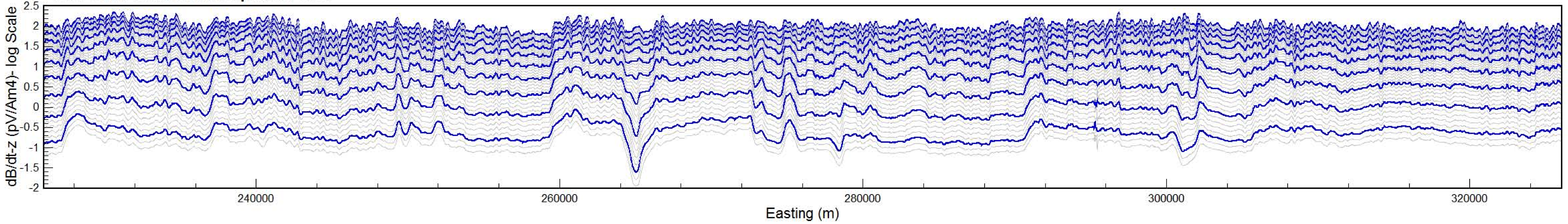
Line L1070 Power line monitor



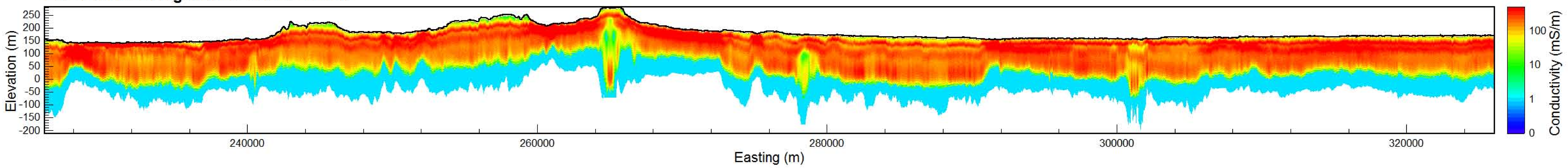
Line L1070 Magnetics TMI and 1VD



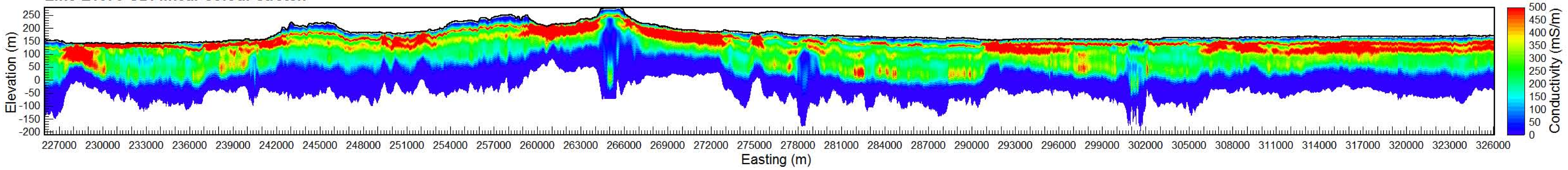
Line L1070 Windowed amplitude data



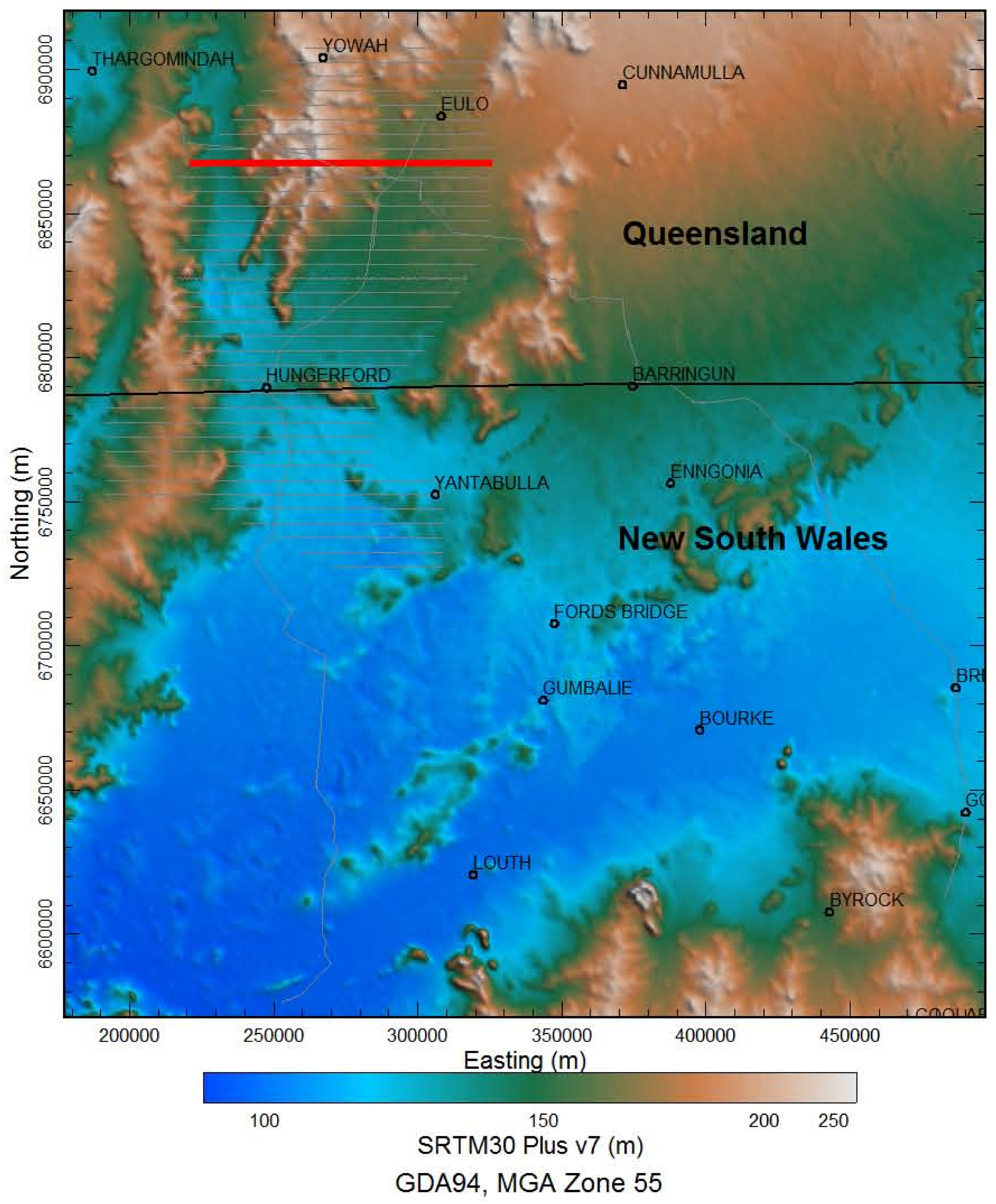
Line L1070 CDI logarithmic colour stretch



Line L1070 CDI linear colour stretch



FLIGHT PATH



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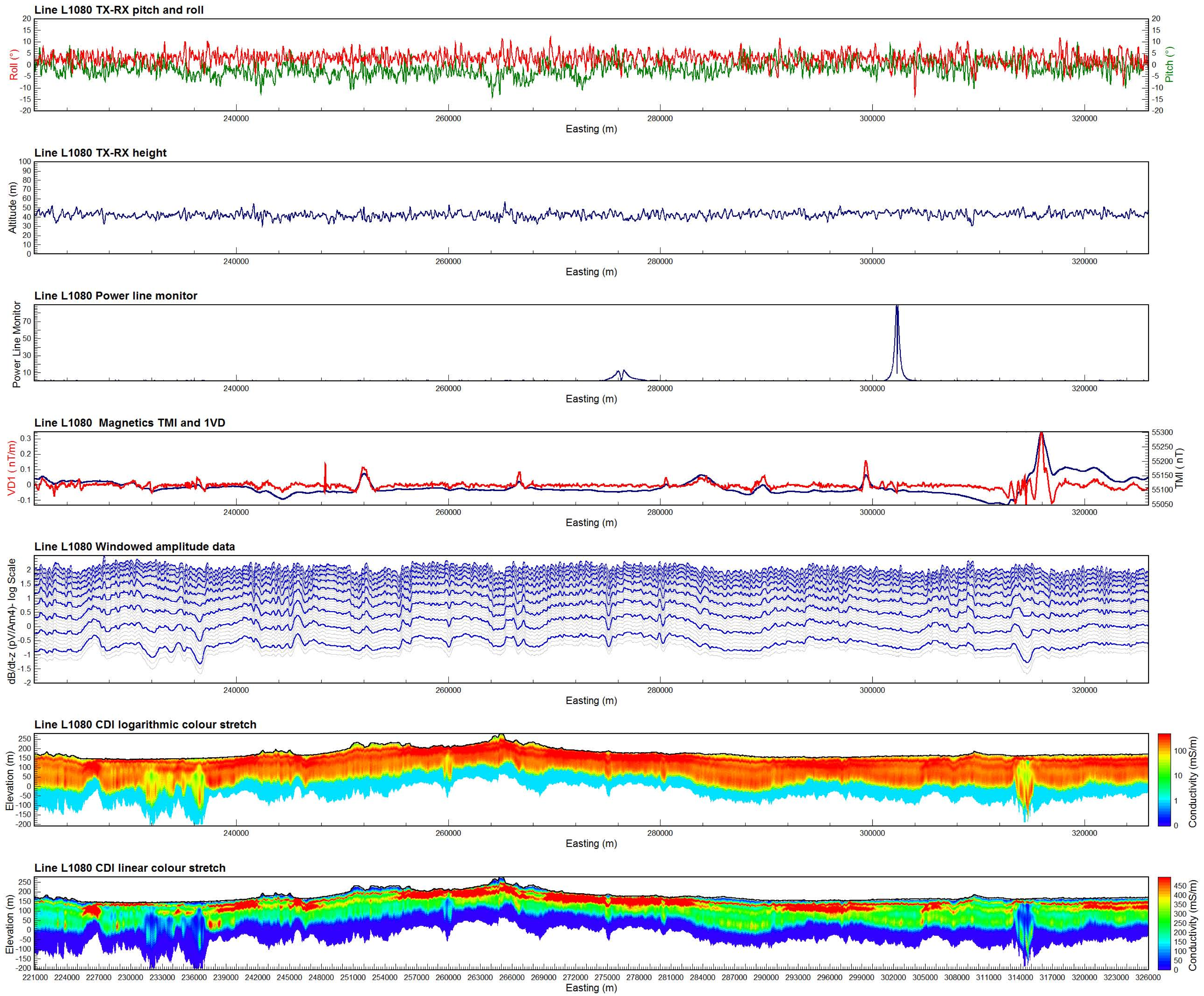

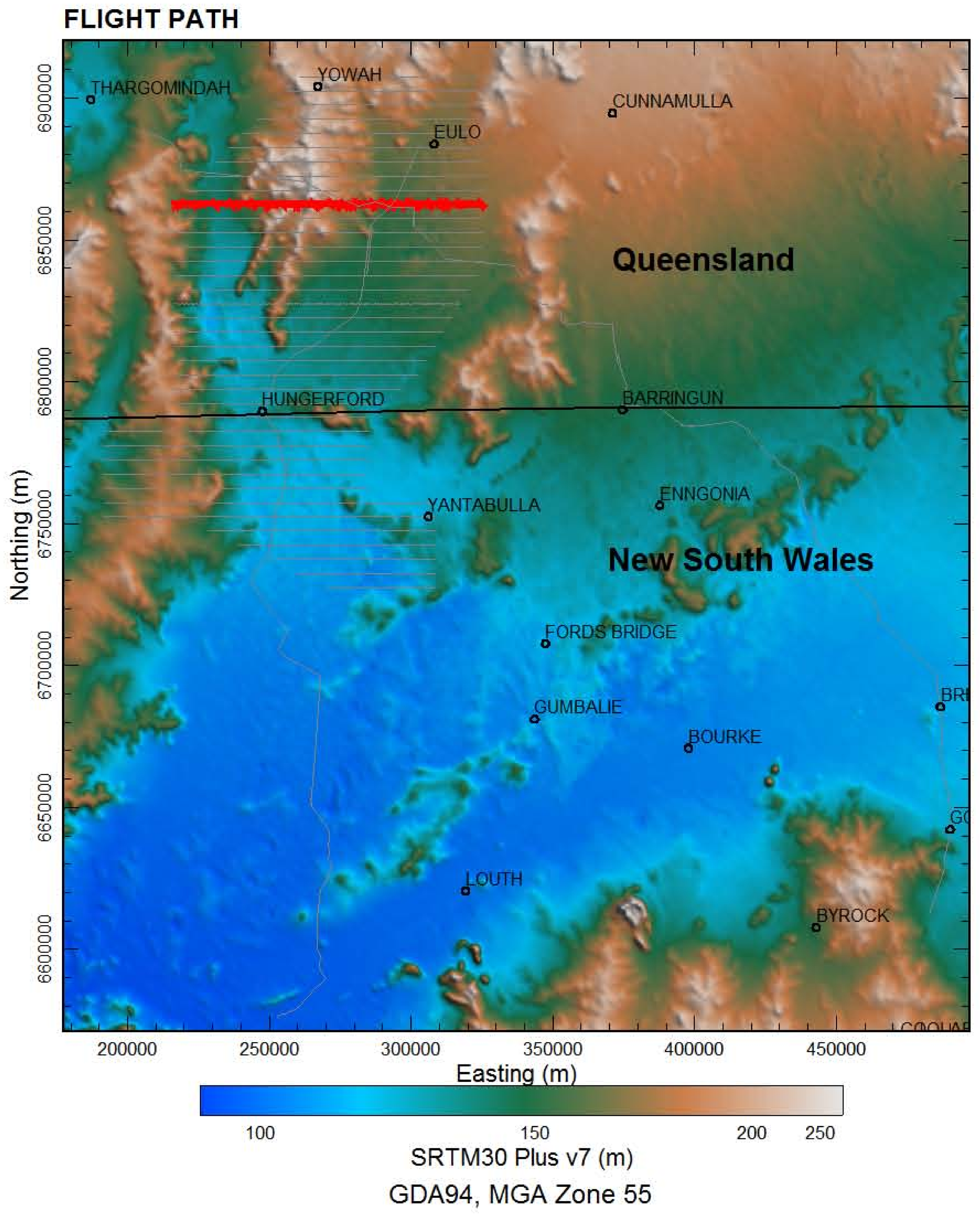

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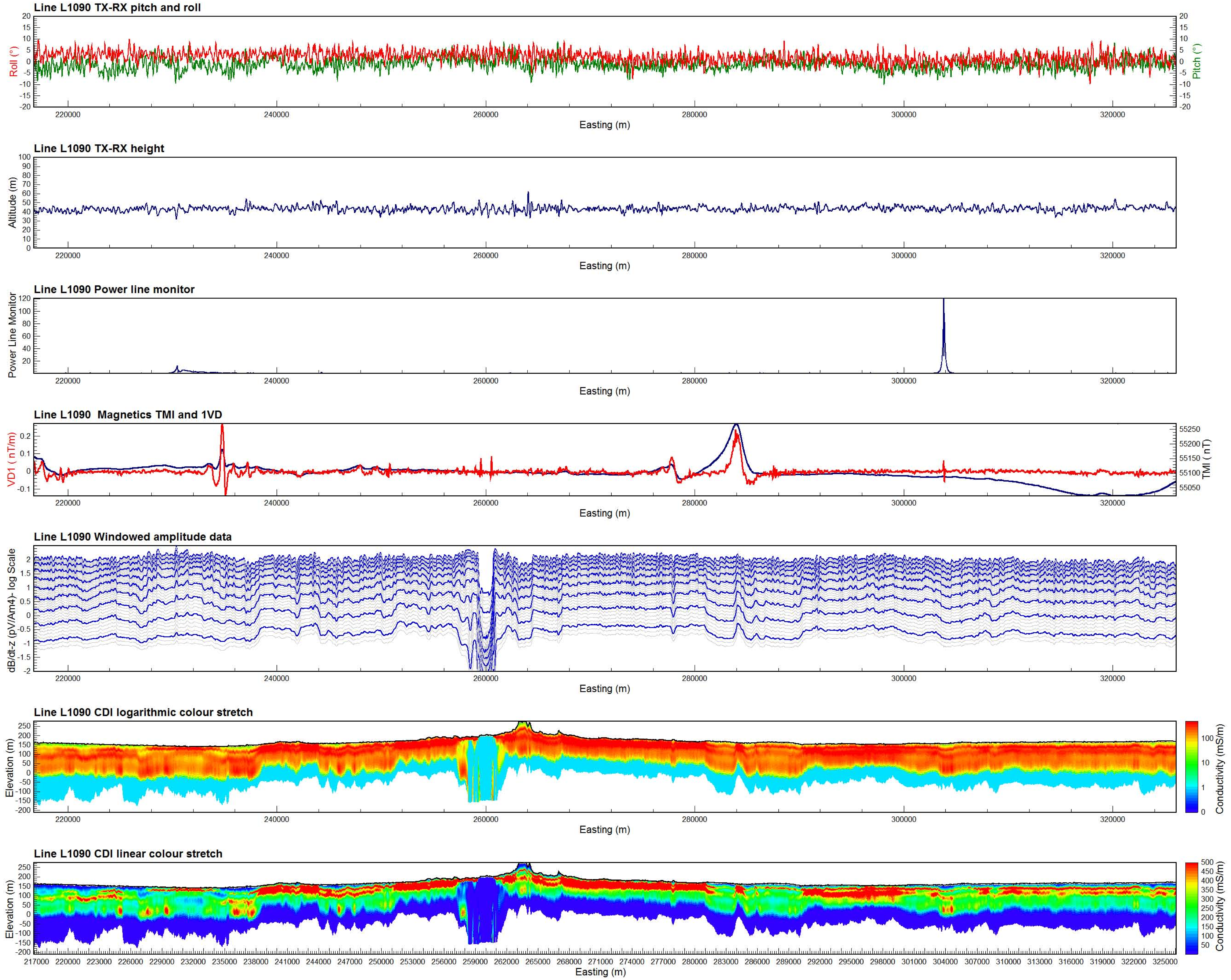
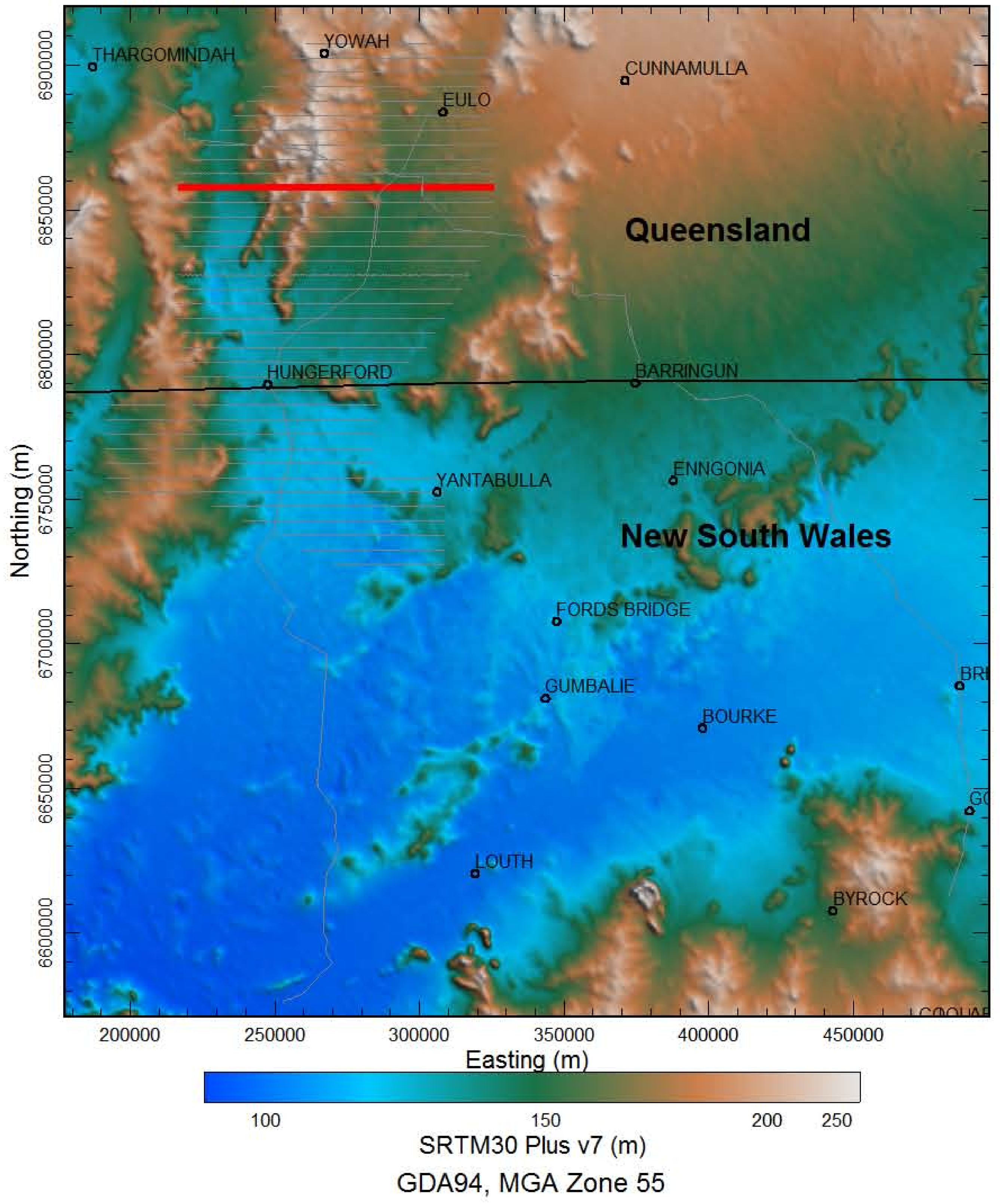


FLIGHT PATH



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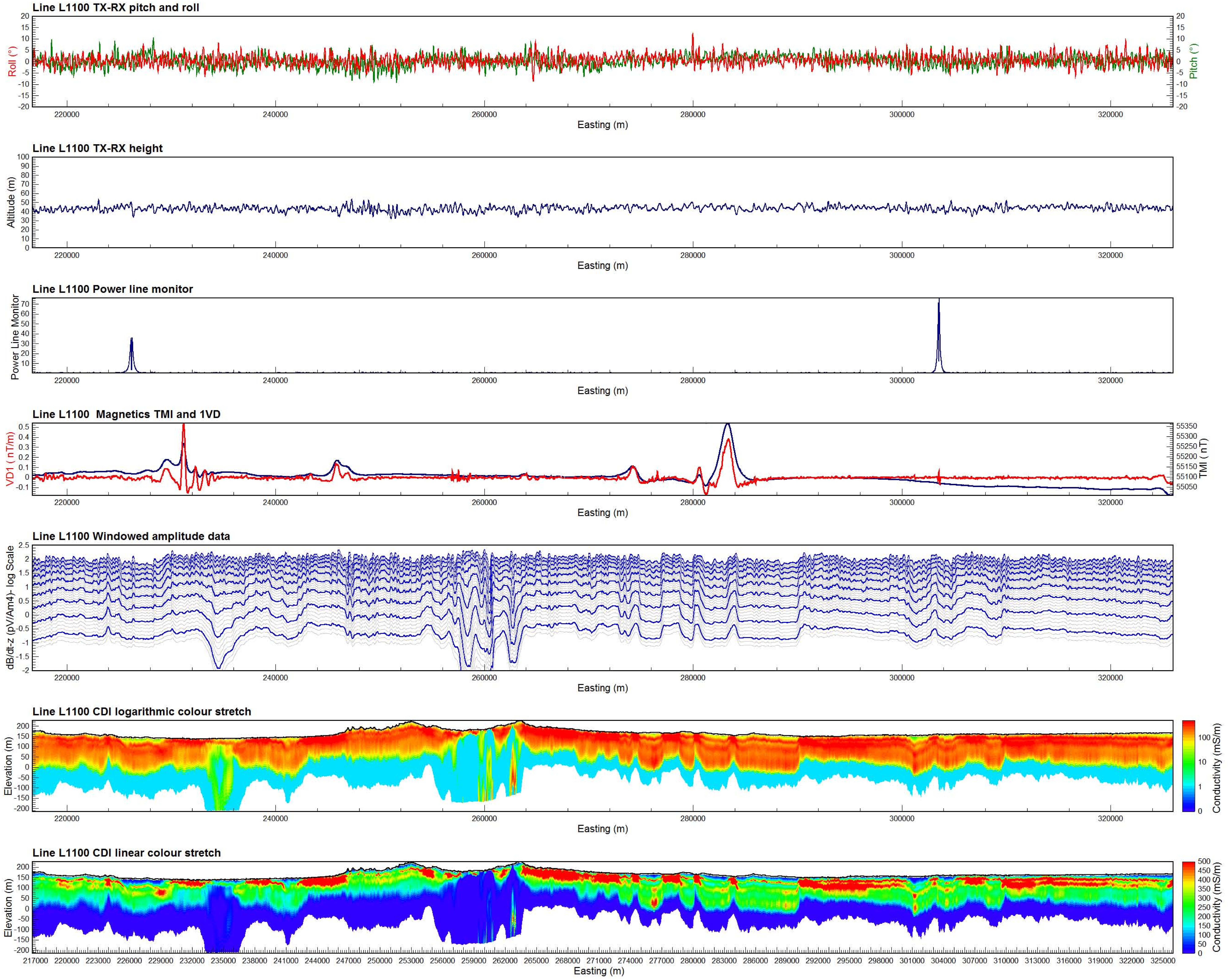
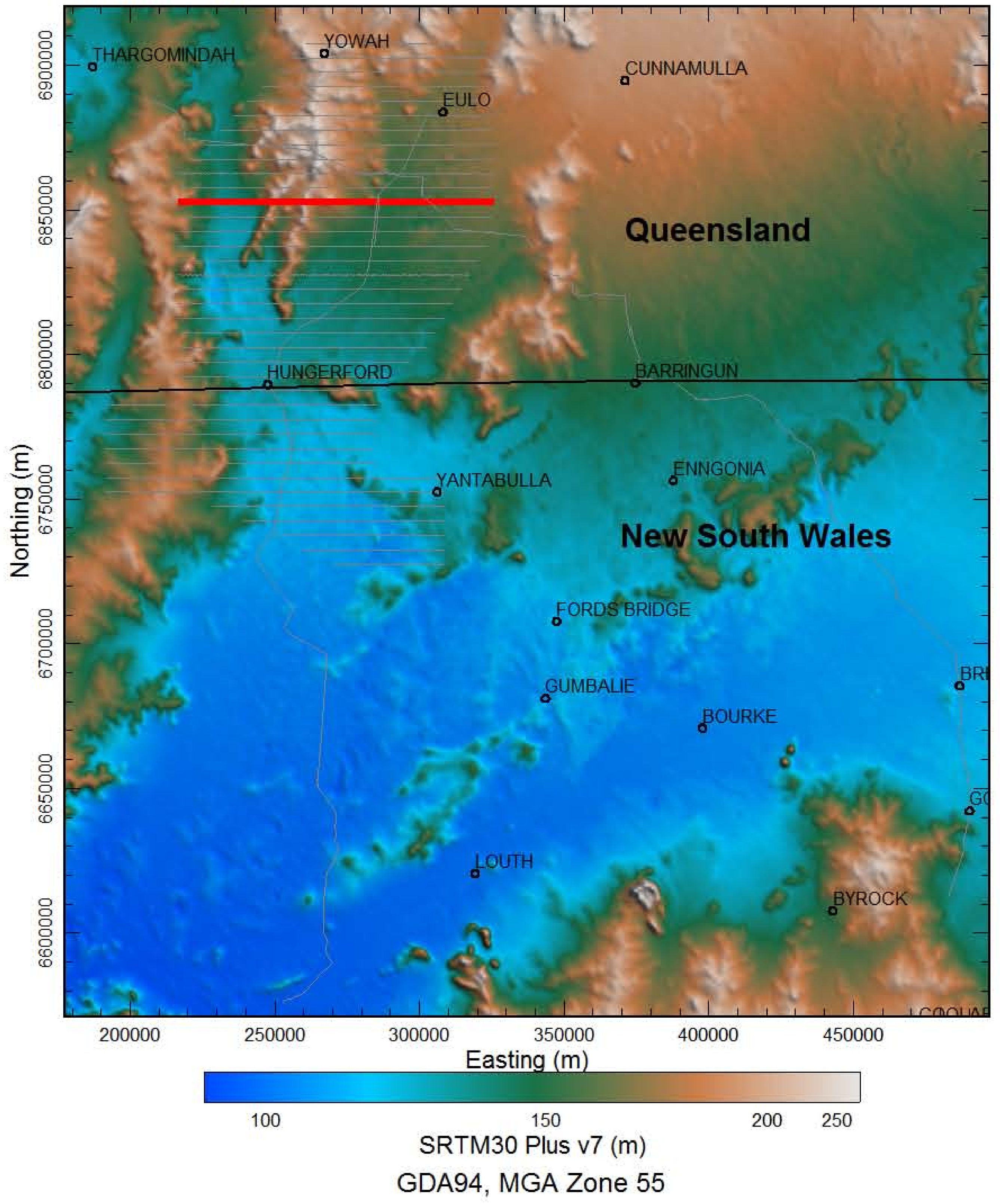


FLIGHT PATH



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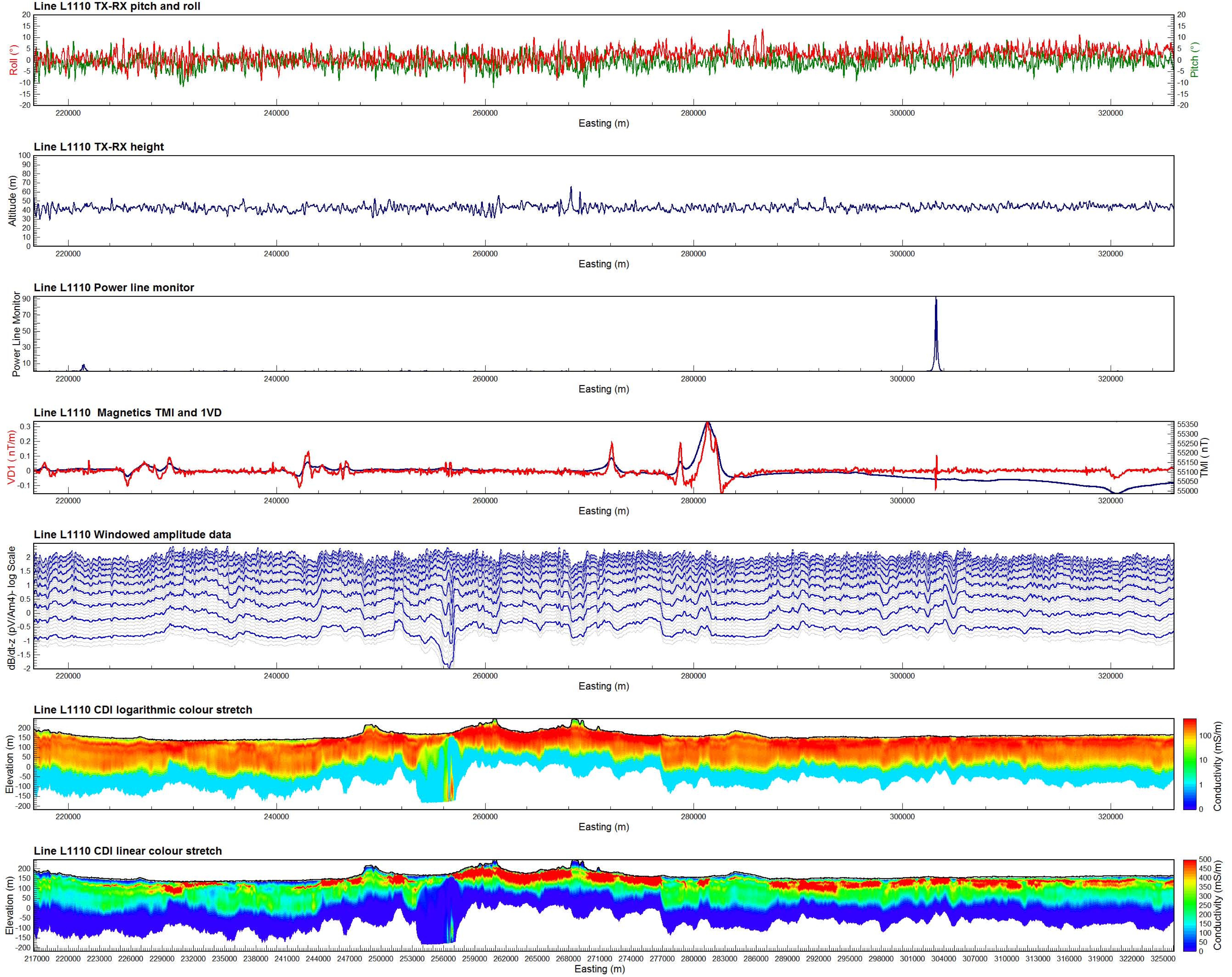
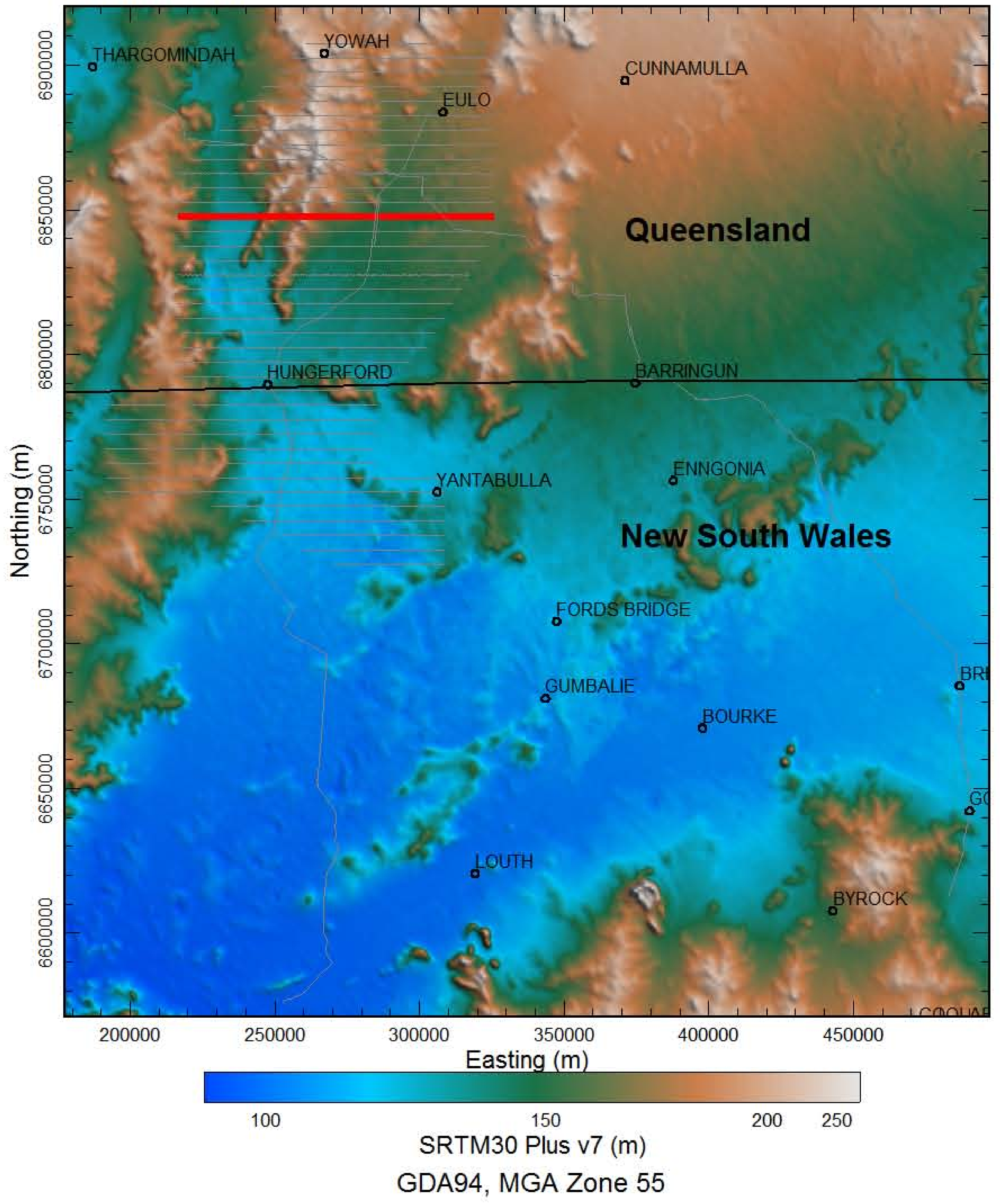


FLIGHT PATH



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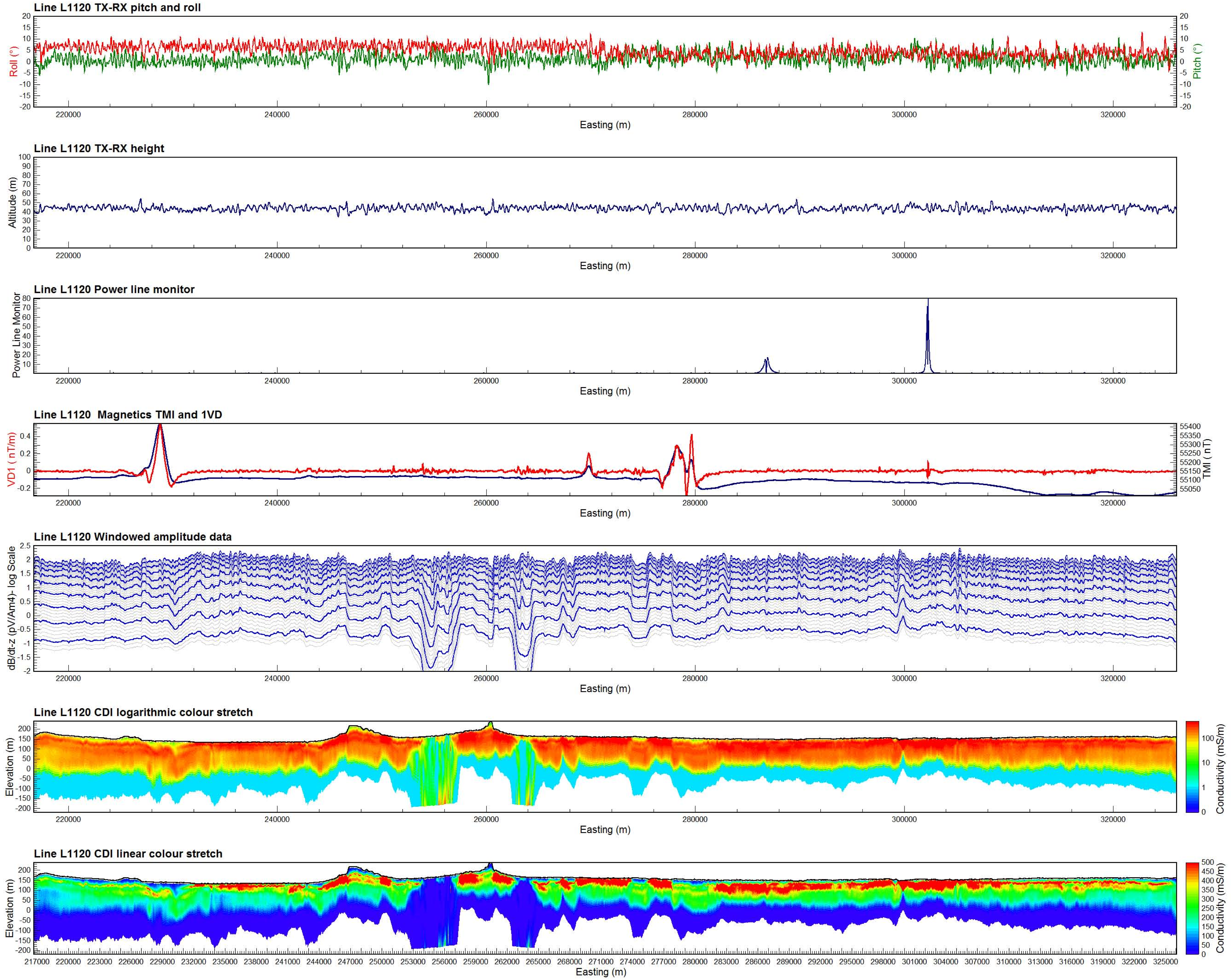
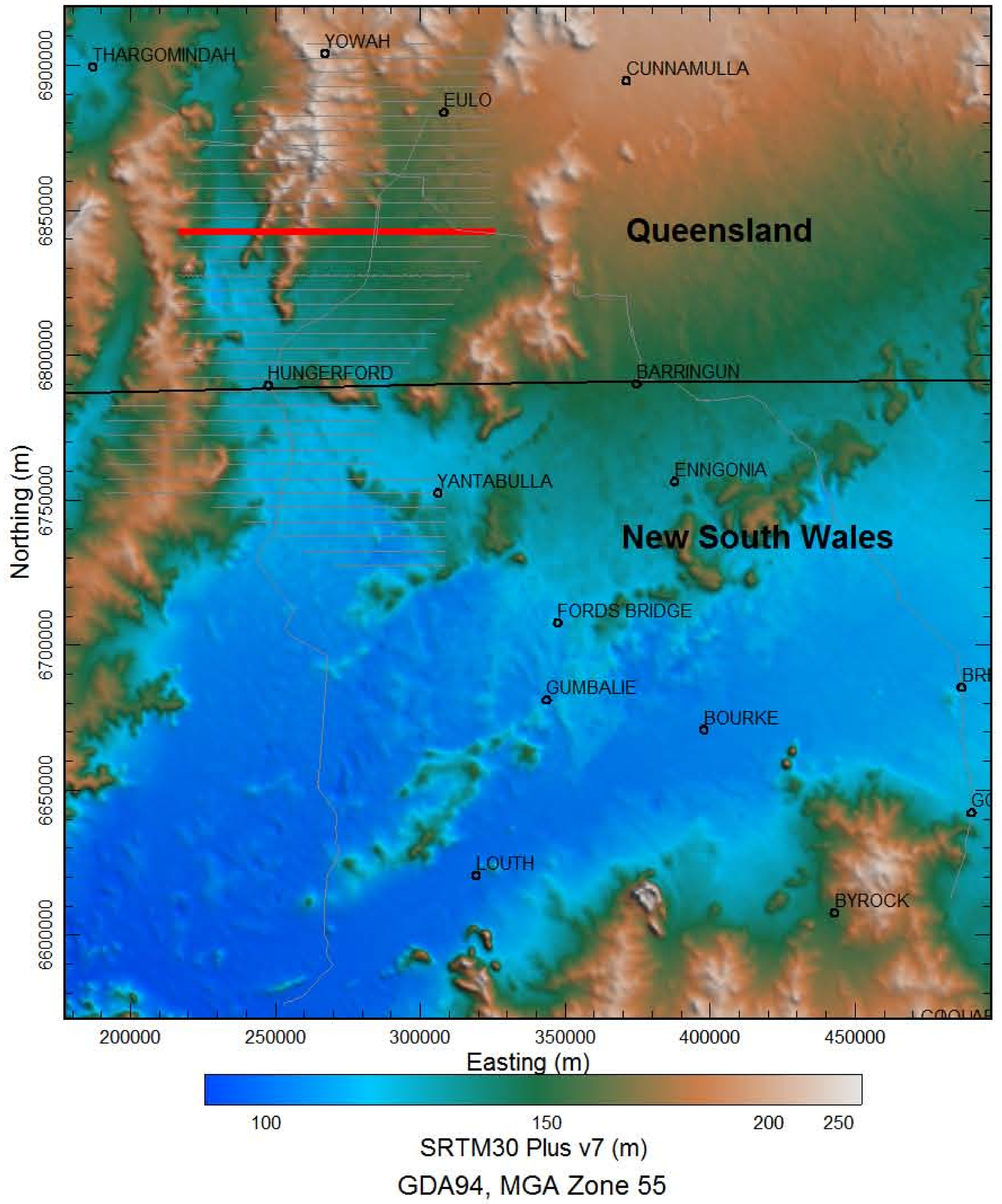


FLIGHT PATH



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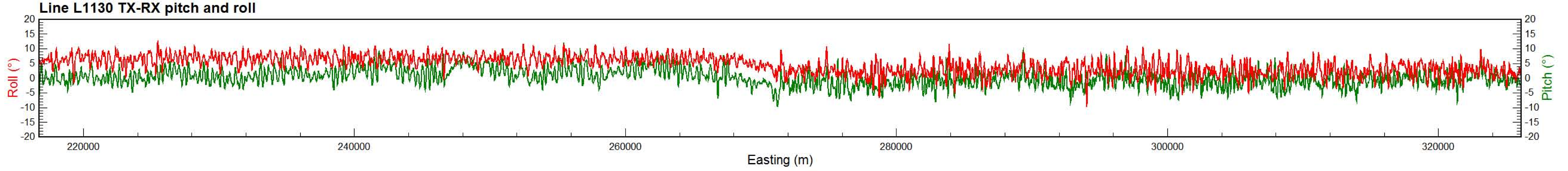
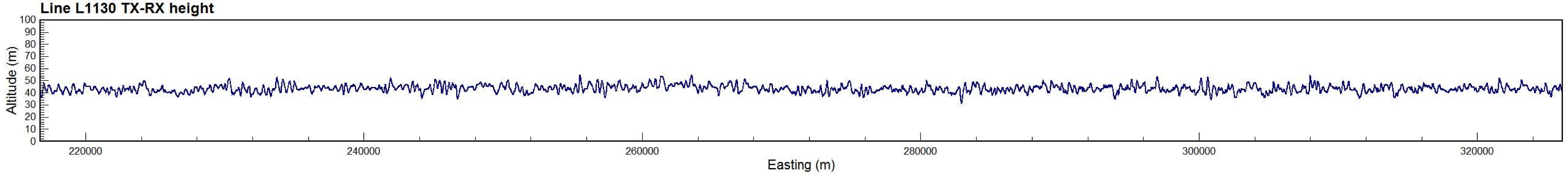
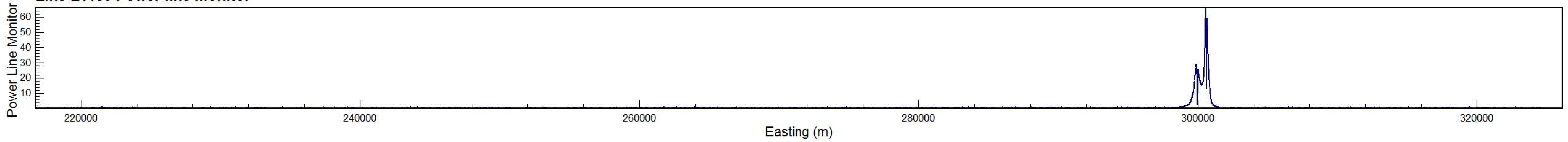
Line L1130 TX-RX pitch and roll



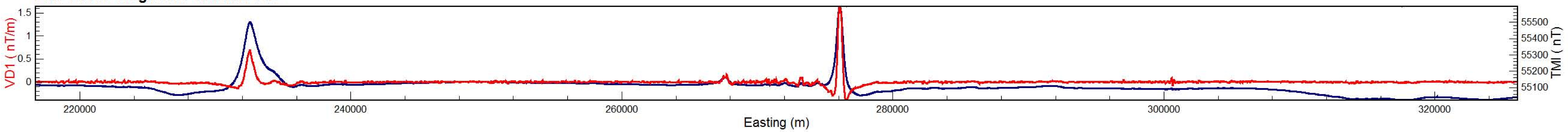
Line L1130 TX-RX height



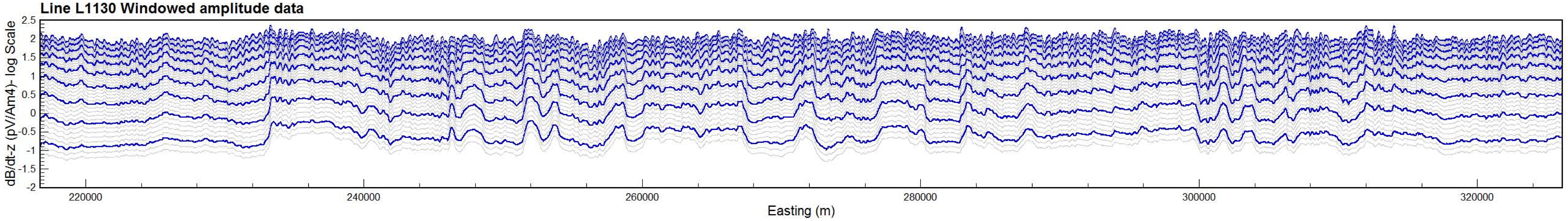
Line L1130 Power line monitor



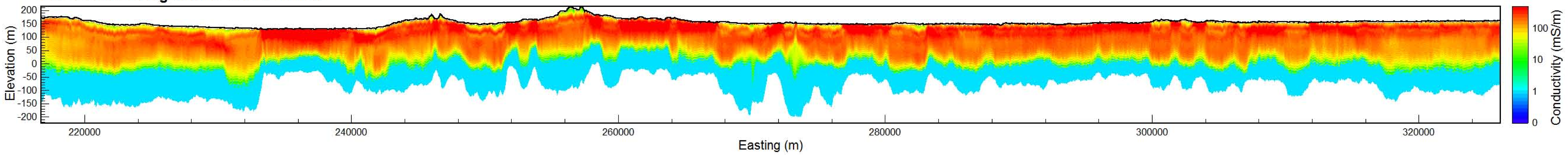
Line L1130 Magnetics TMI and 1VD



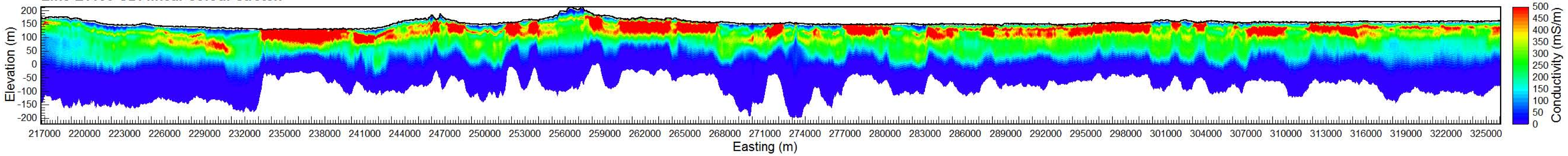
Line L1130 Windowed amplitude data



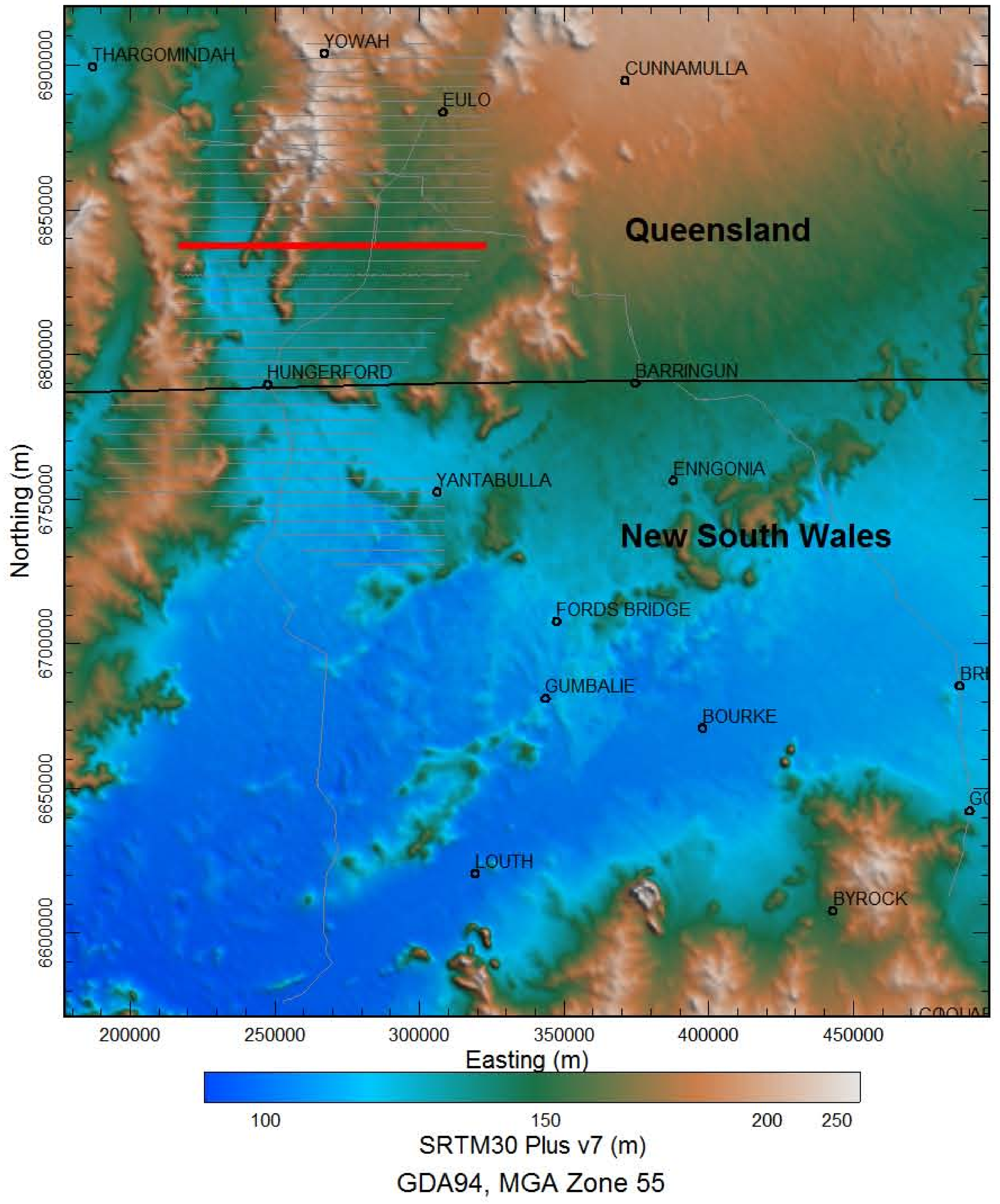
Line L1130 CDI logarithmic colour stretch



Line L1130 CDI linear colour stretch



FLIGHT PATH



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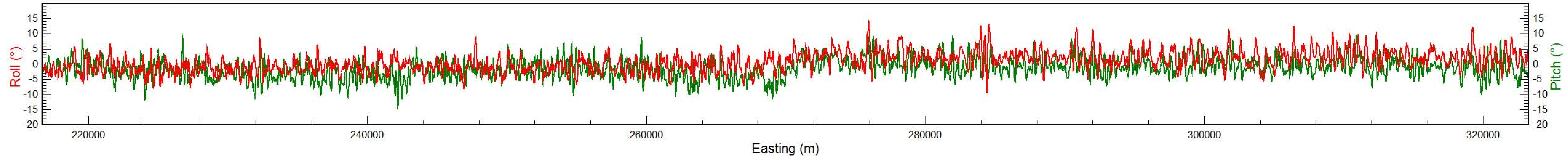
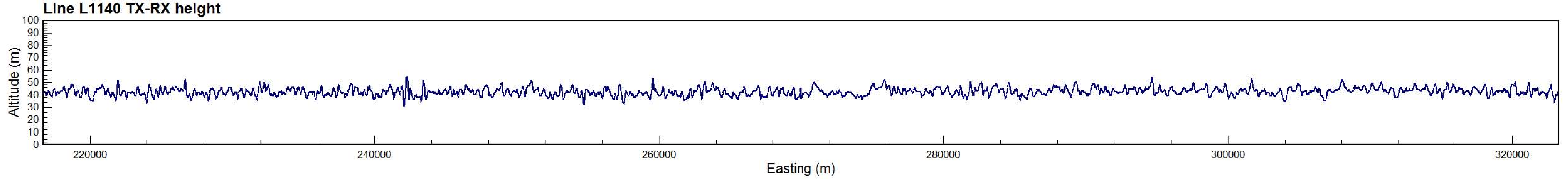
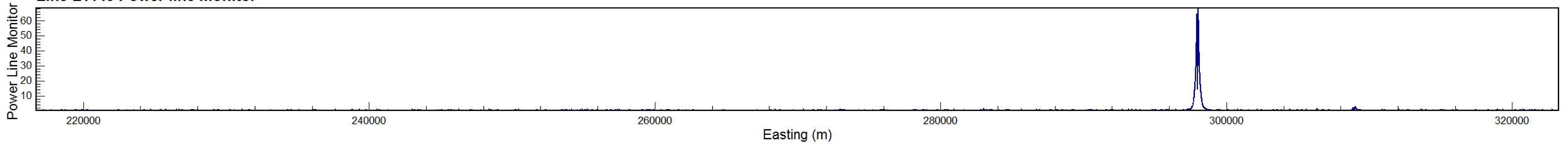
Line L1140 TX-RX pitch and roll



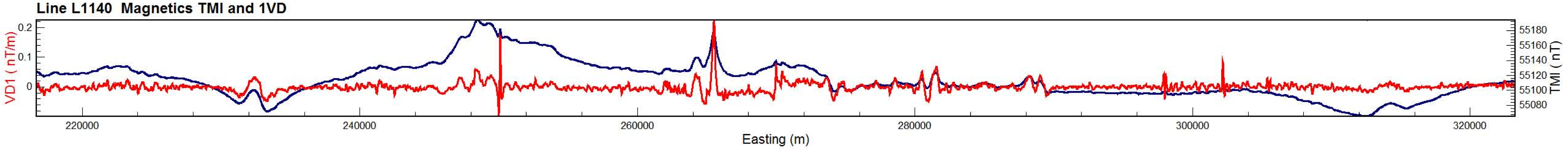
Line L1140 TX-RX height



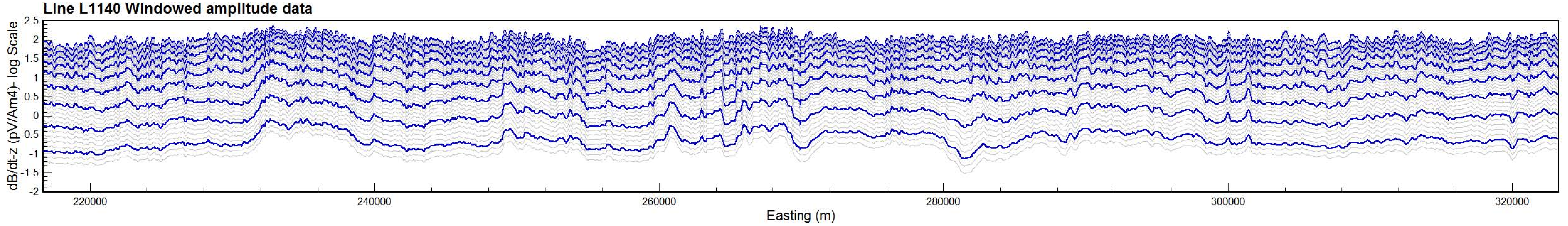
Line L1140 Power line monitor



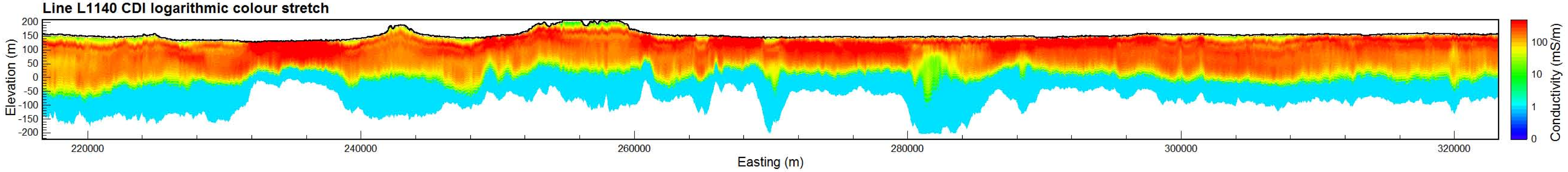
Line L1140 Magnetics TMI and 1VD



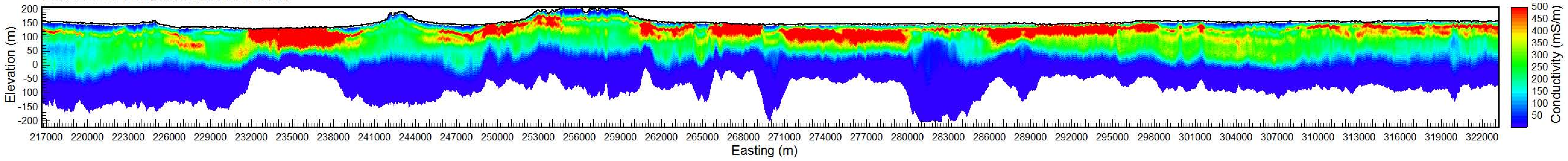
Line L1140 Windowed amplitude data



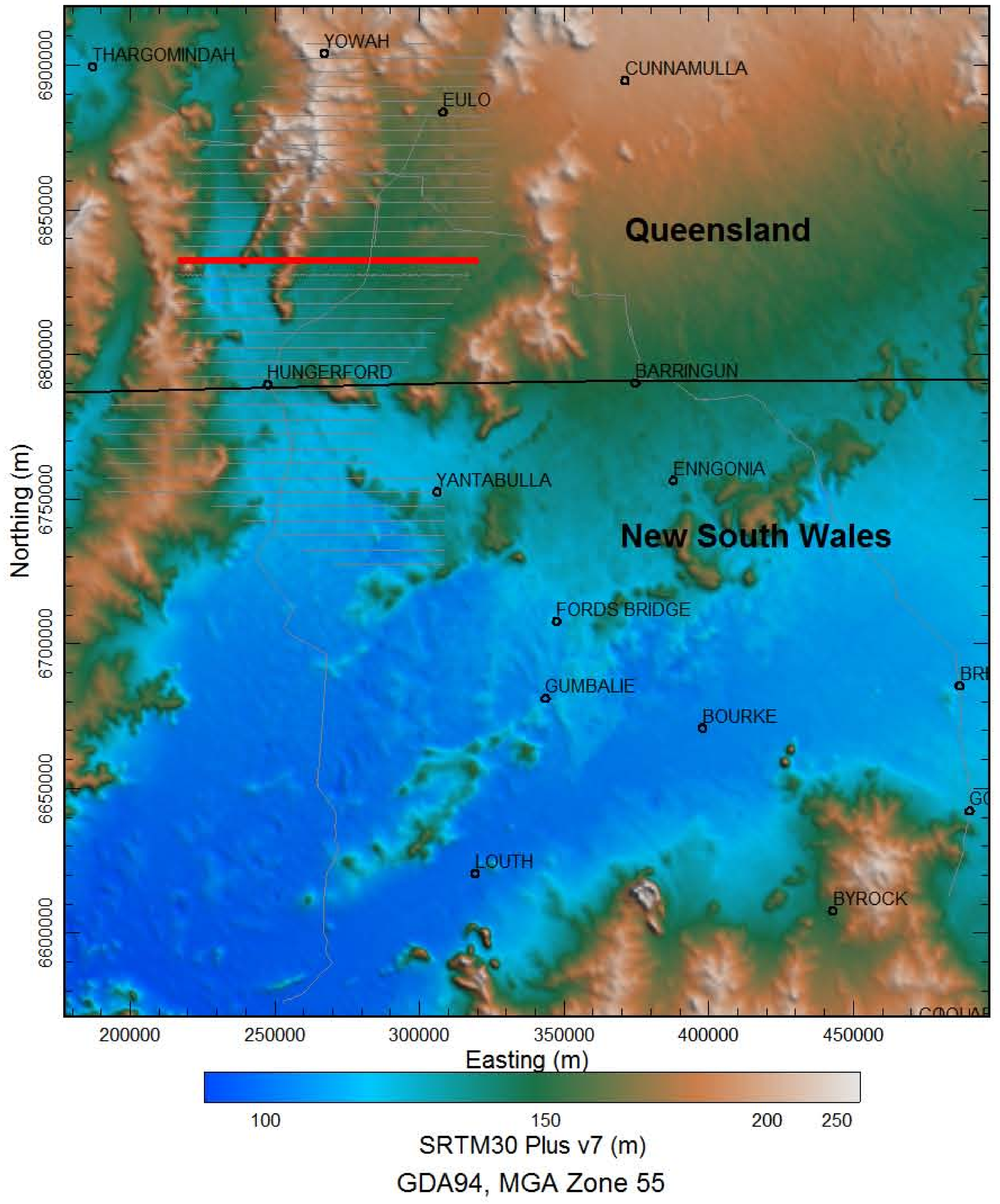
Line L1140 CDI logarithmic colour stretch



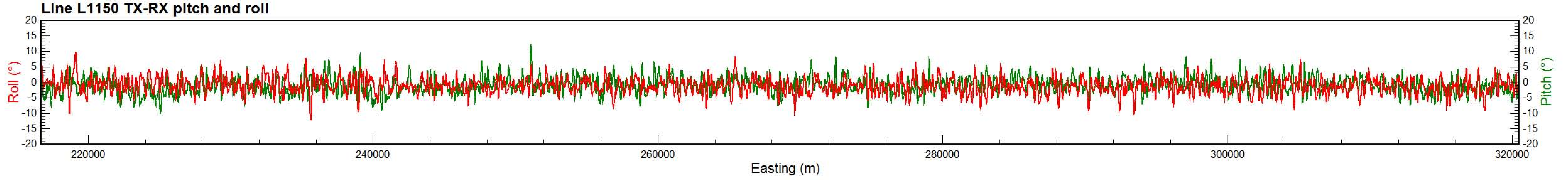
Line L1140 CDI linear colour stretch



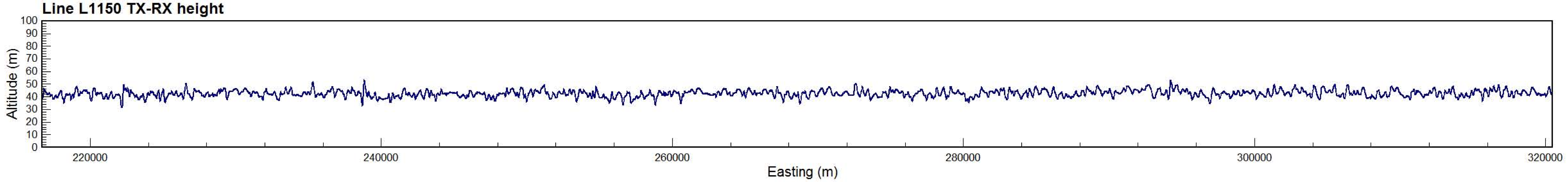
FLIGHT PATH



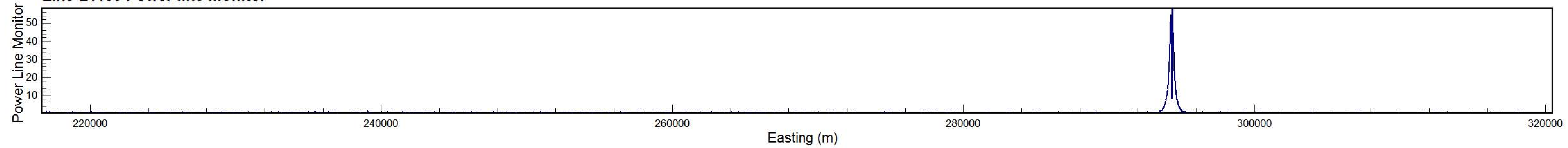
Line L1150 TX-RX pitch and roll



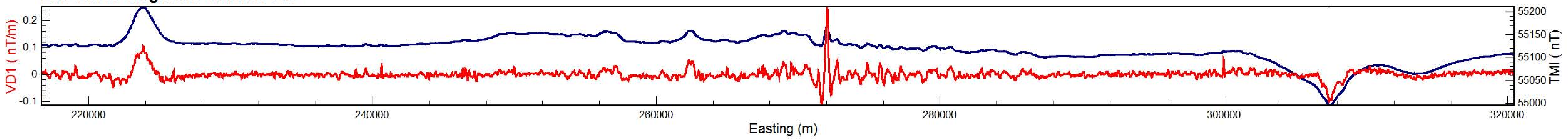
Line L1150 TX-RX height



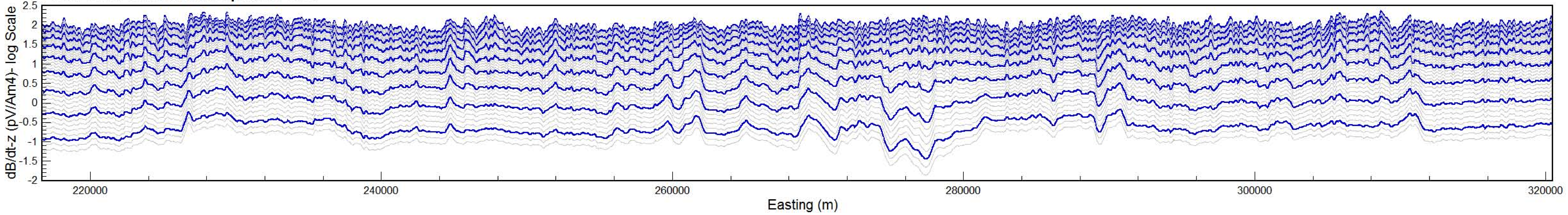
Line L1150 Power line monitor



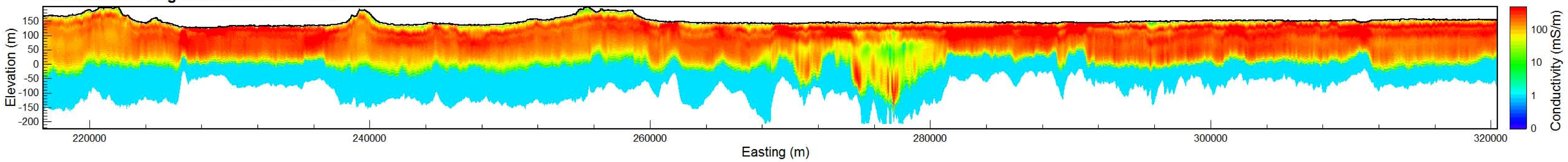
Line L1150 Magnetics TMI and 1VD



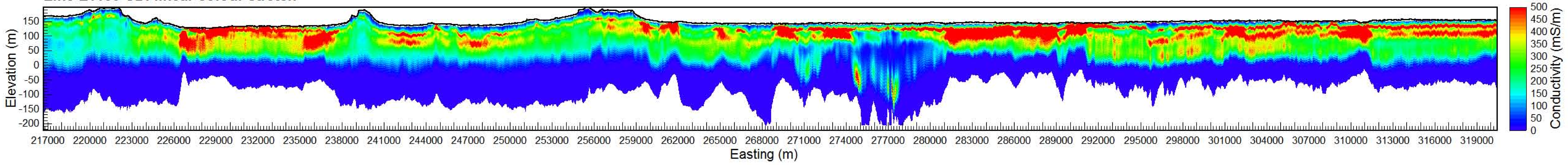
Line L1150 Windowed amplitude data



Line L1150 CDI logarithmic colour stretch



Line L1150 CDI linear colour stretch



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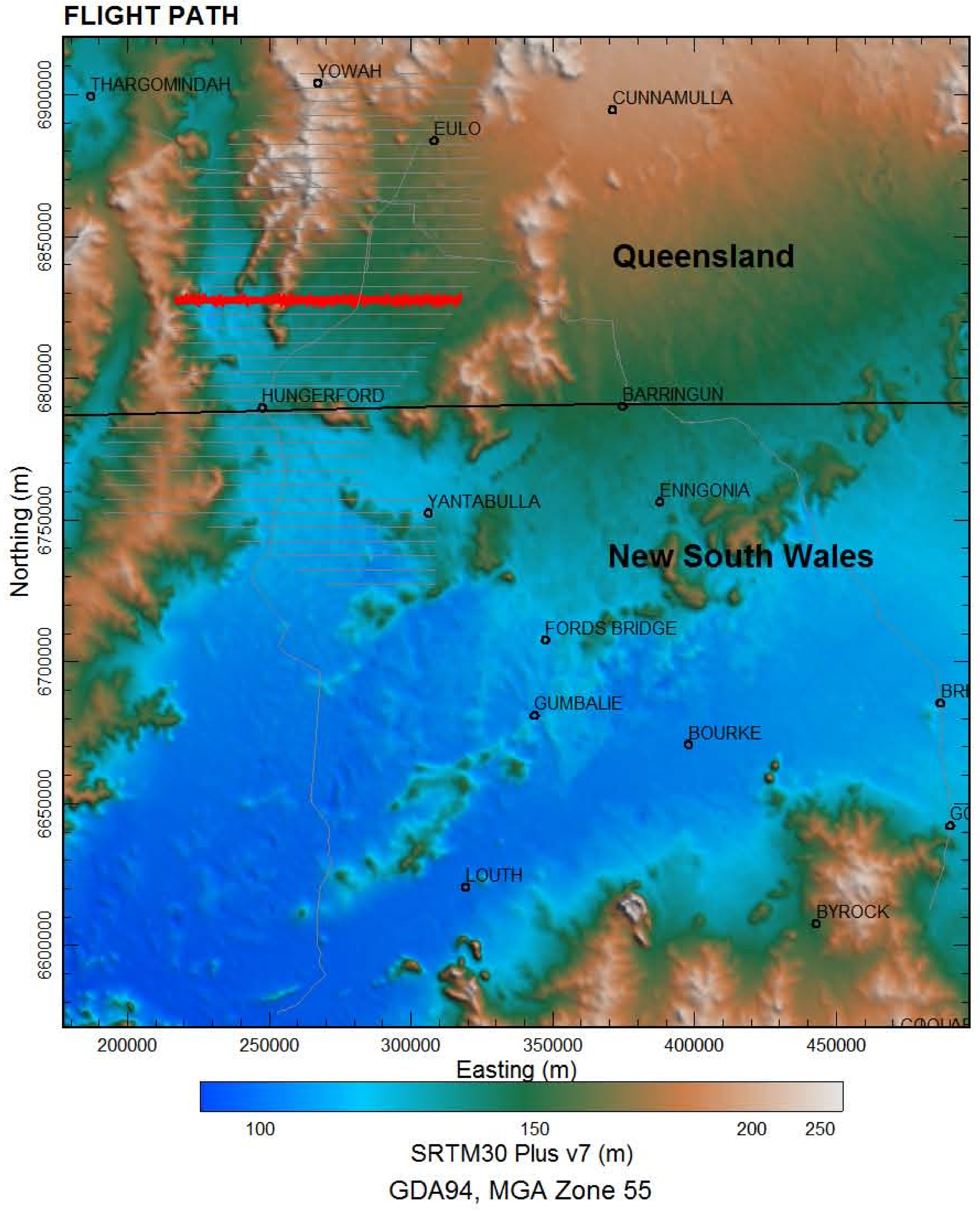

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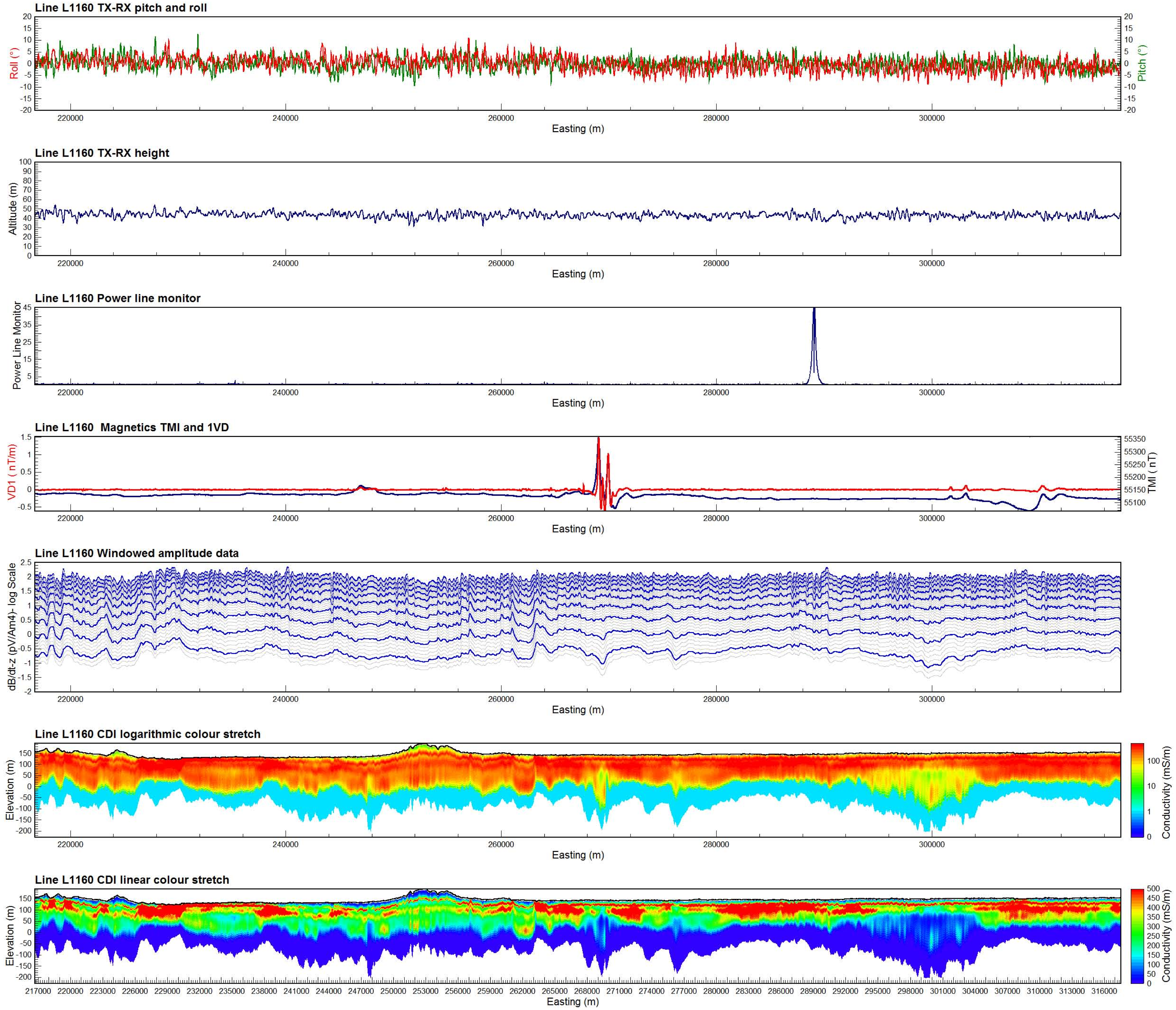
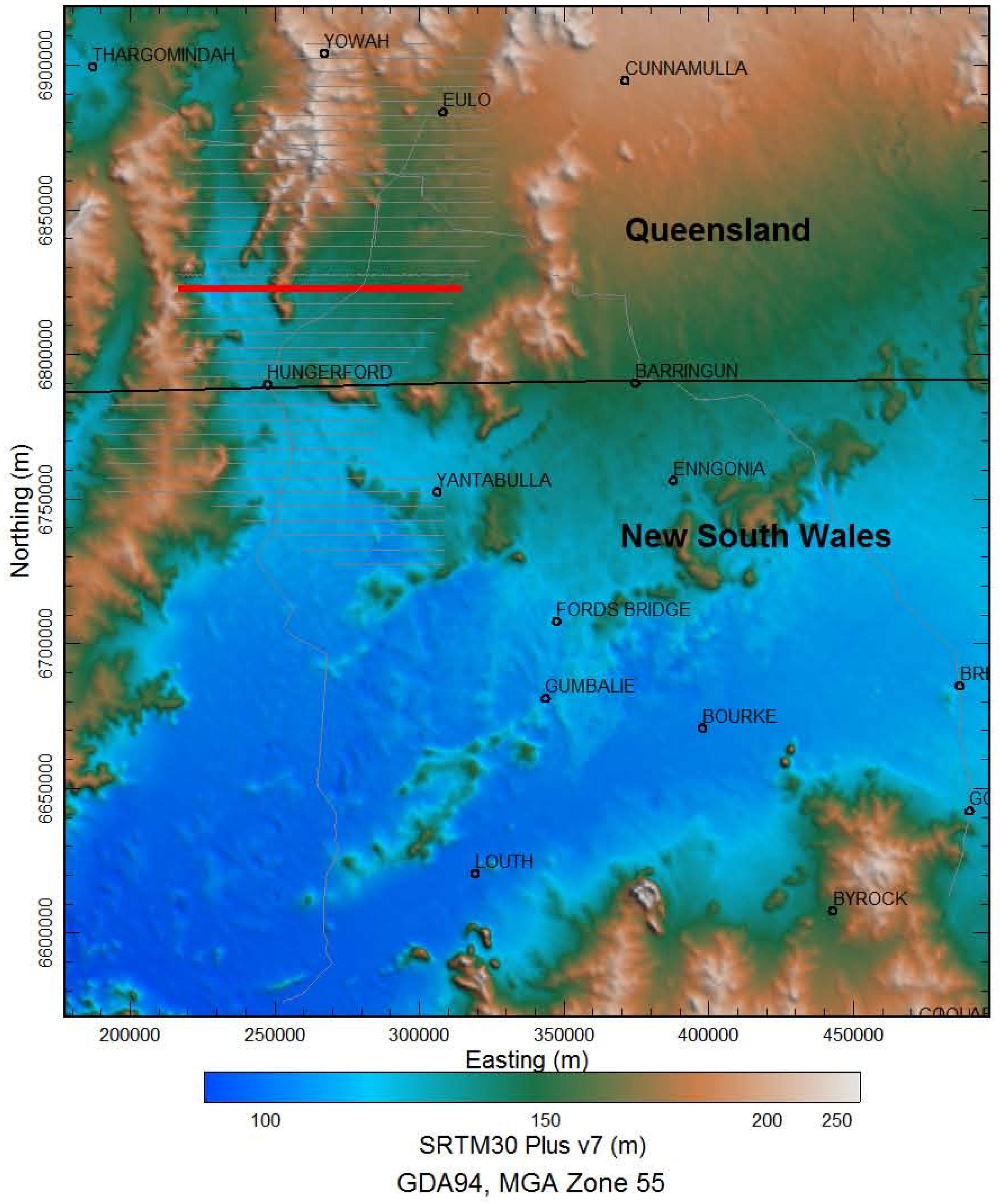


FLIGHT PATH



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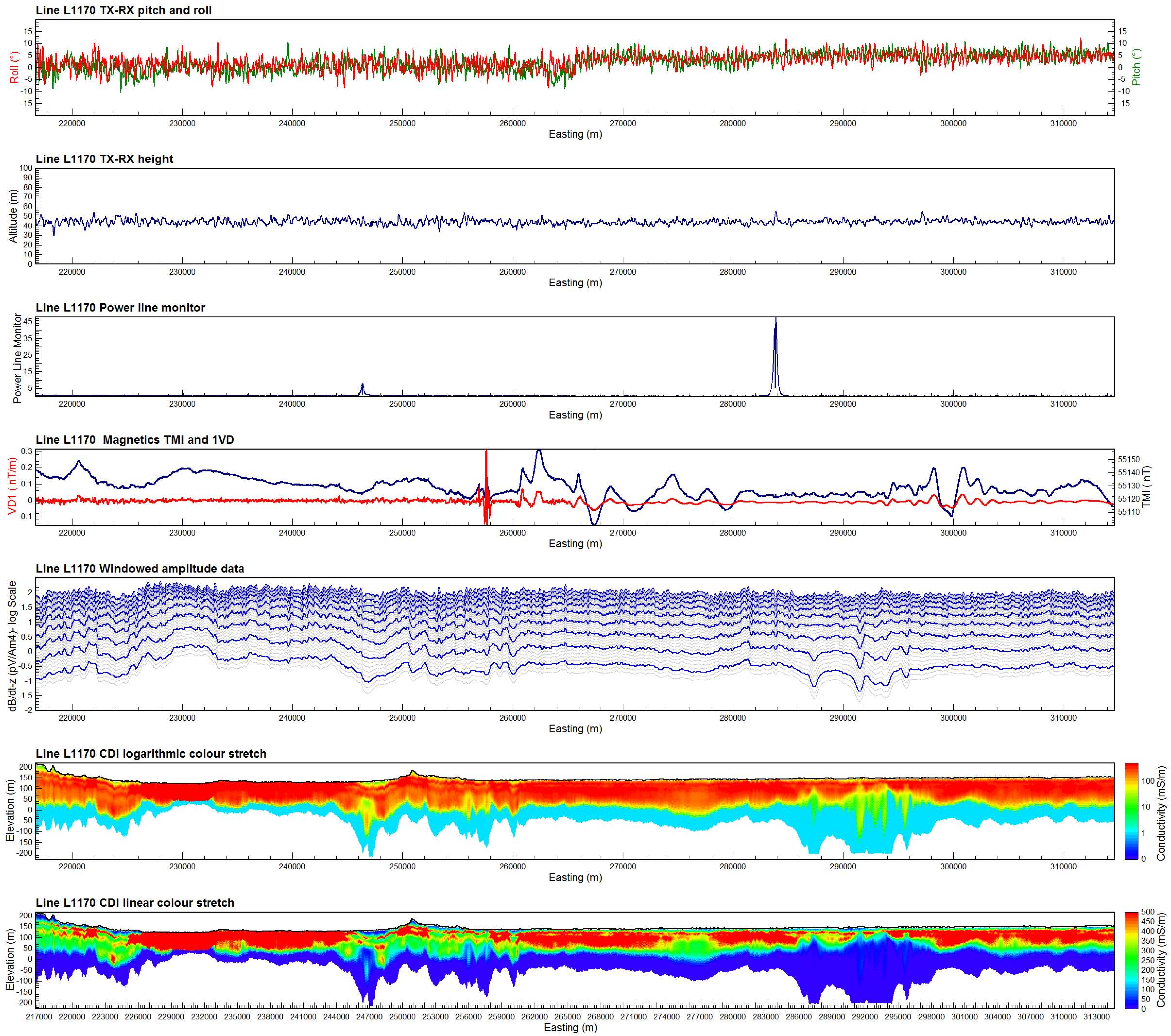

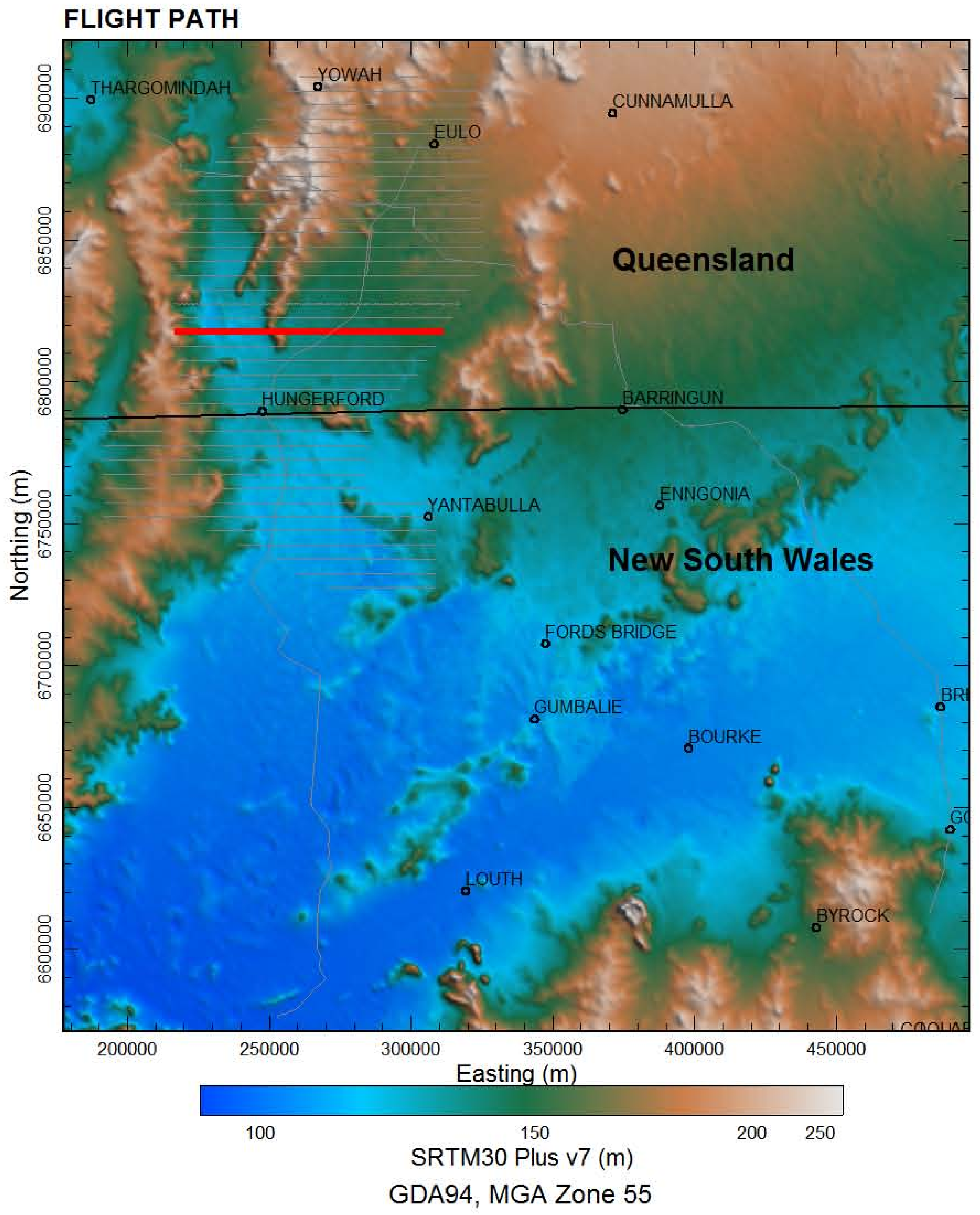

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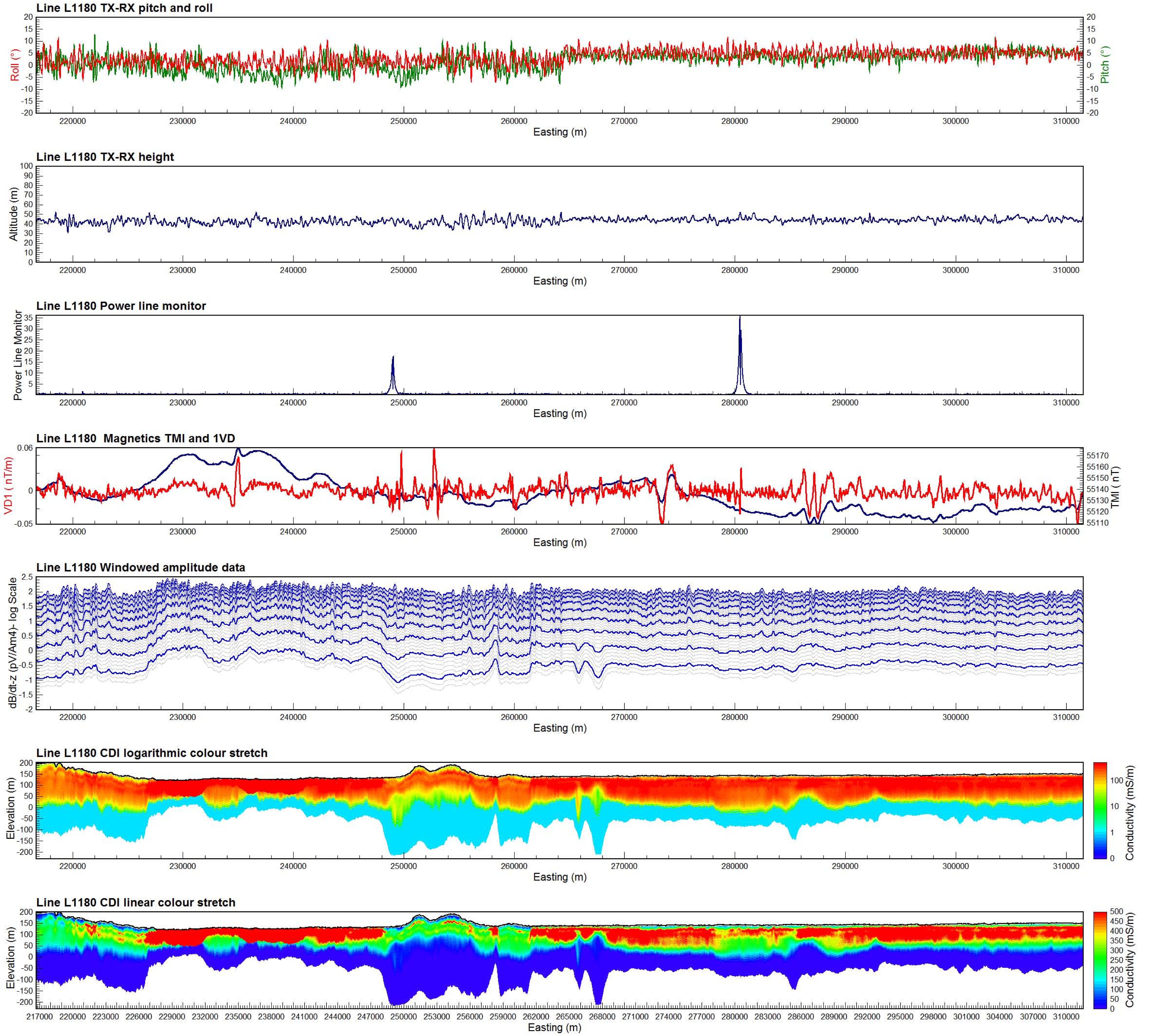
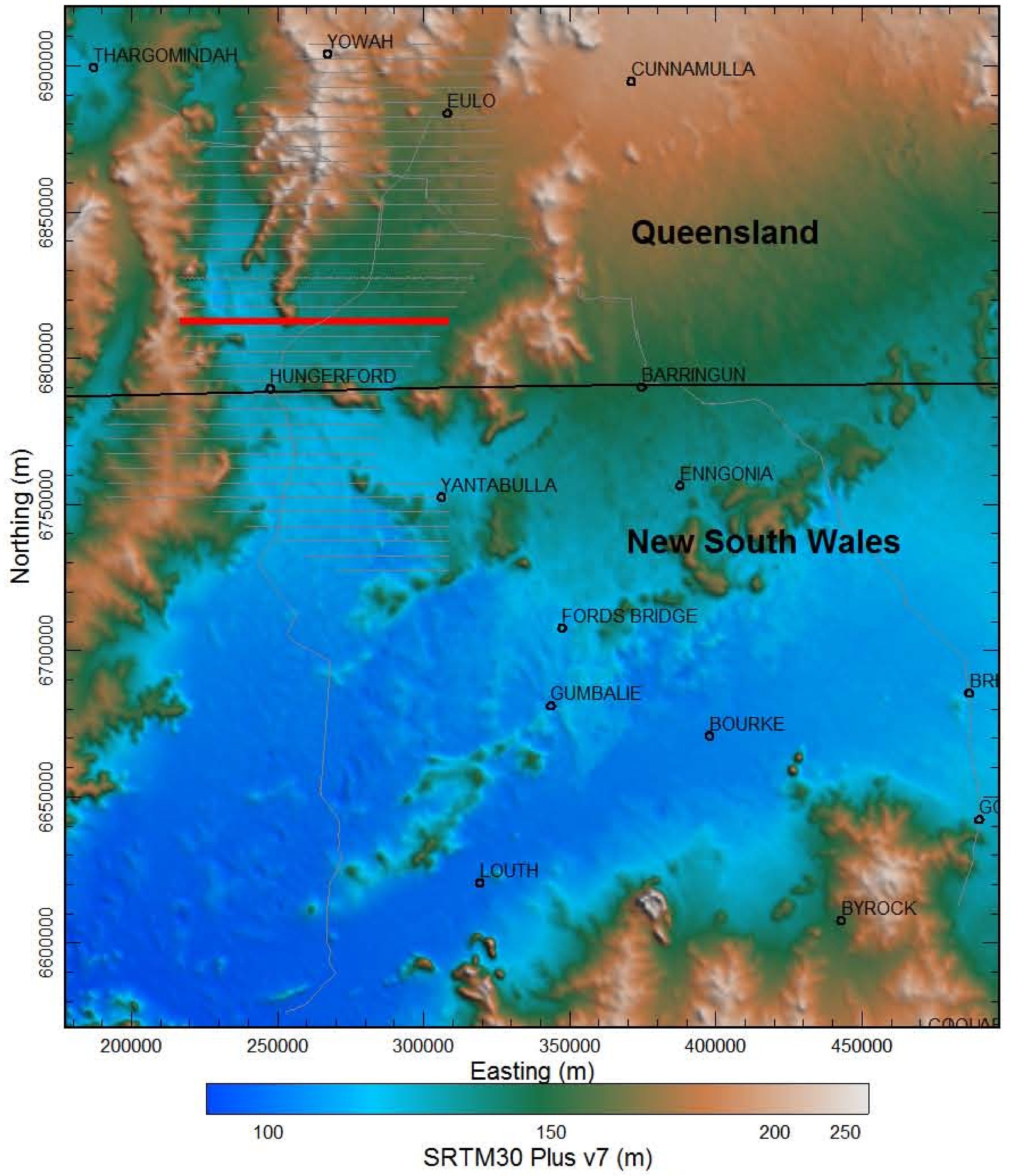


FLIGHT PATH



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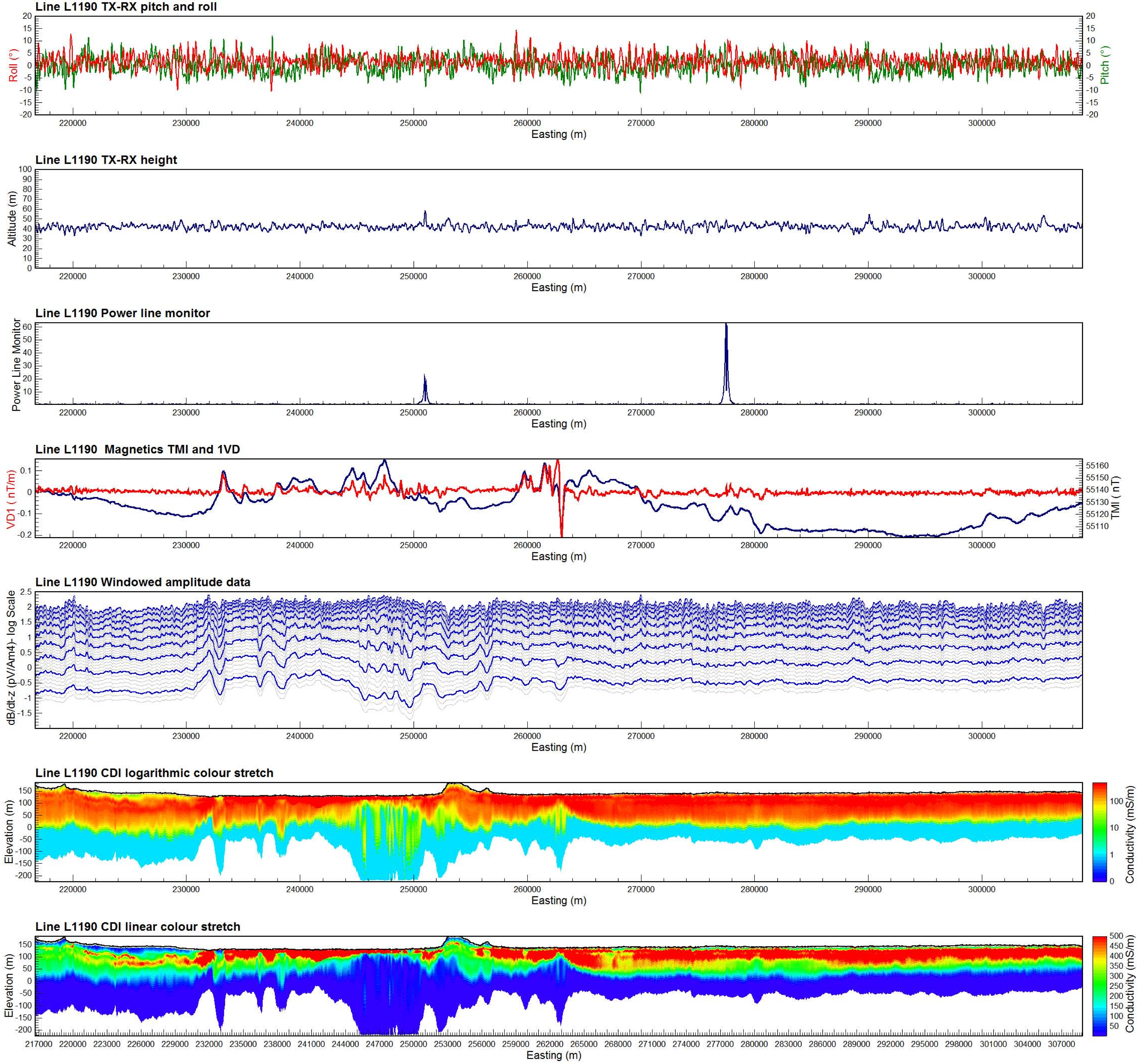
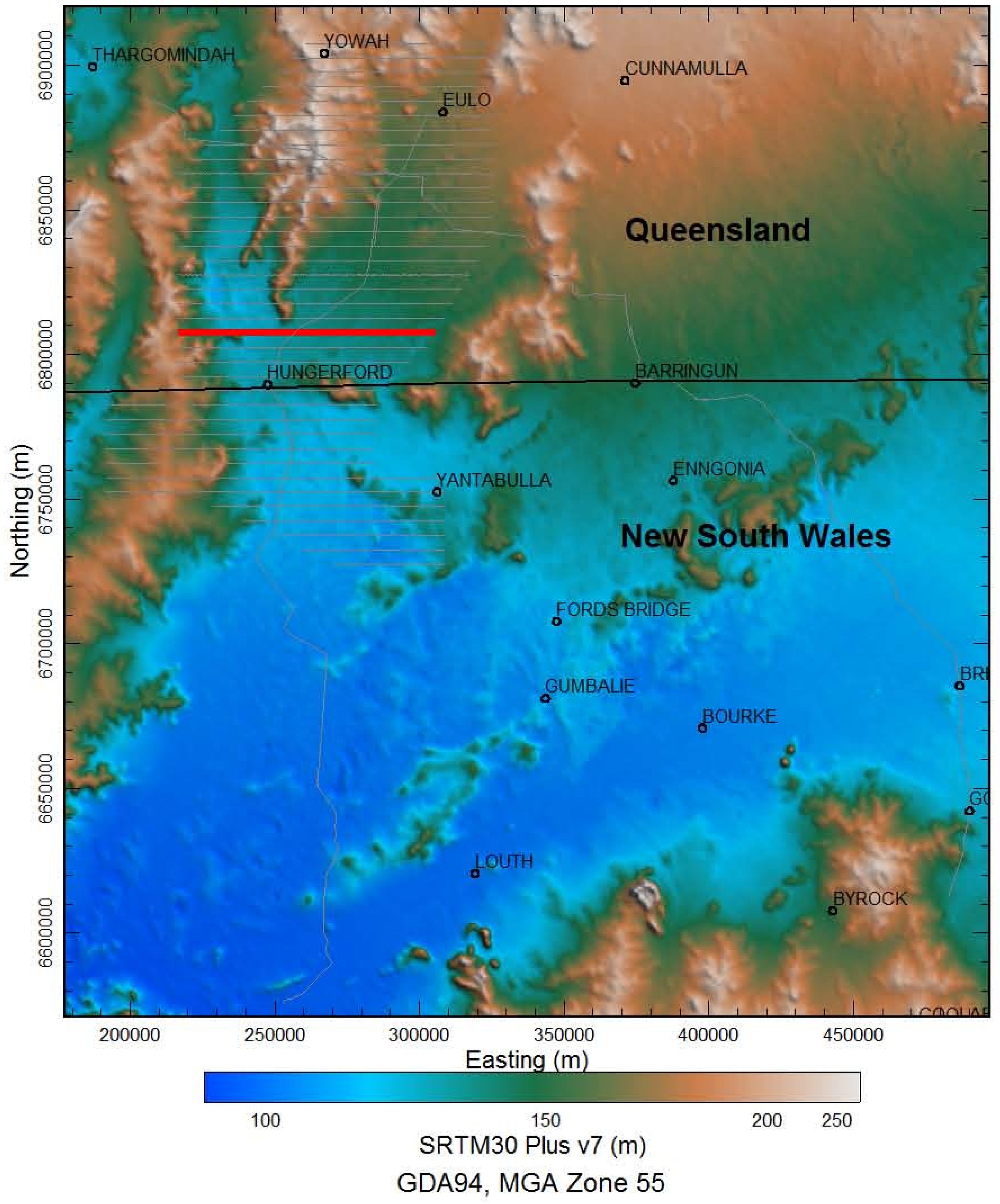


FLIGHT PATH



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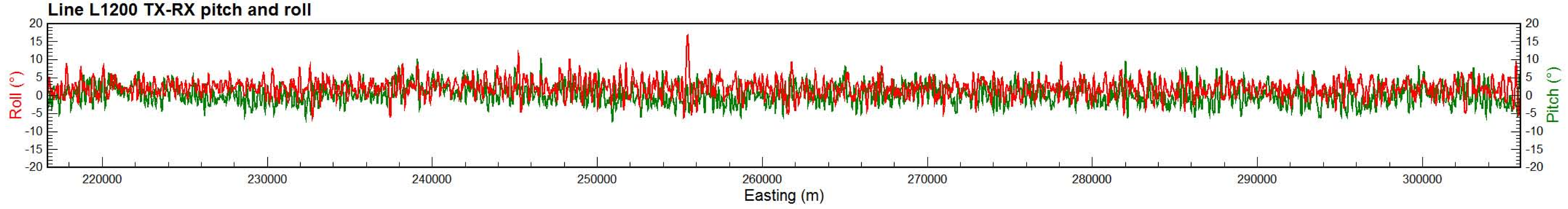
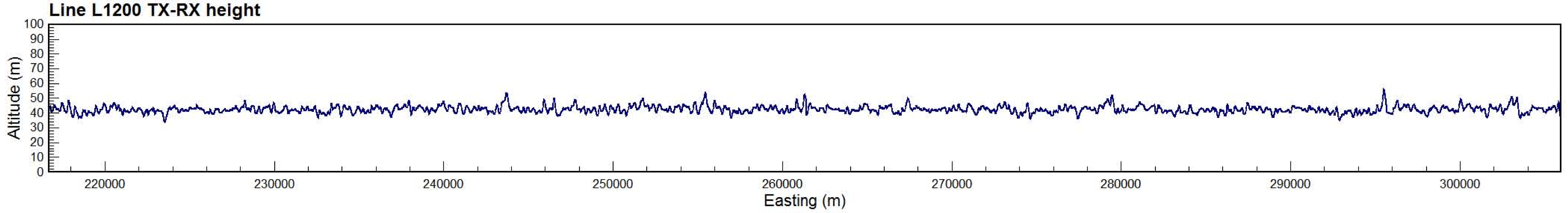
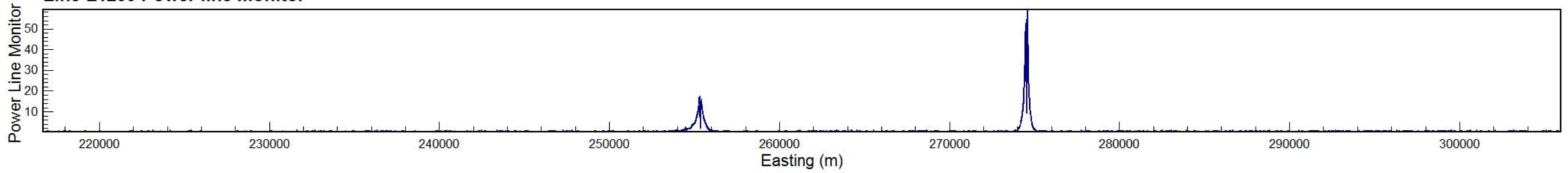
Line L1200 TX-RX pitch and roll



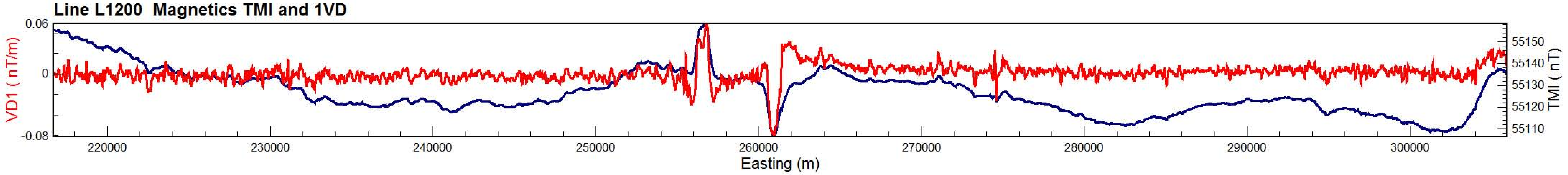
Line L1200 TX-RX height



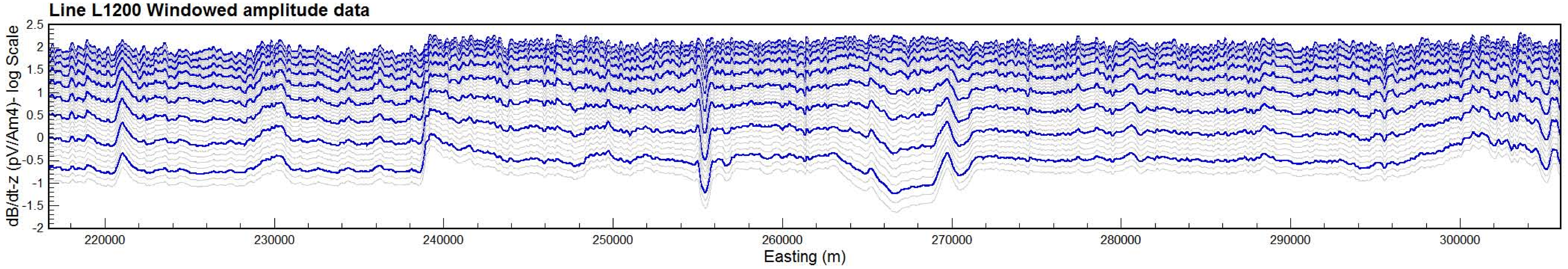
Line L1200 Power line monitor



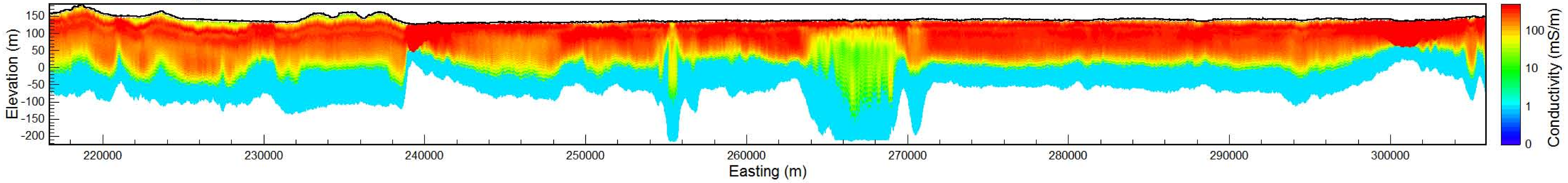
Line L1200 Magnetics TMI and 1VD



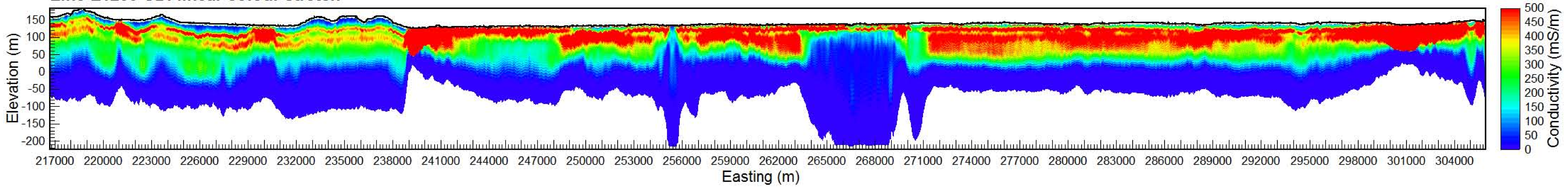
Line L1200 Windowed amplitude data



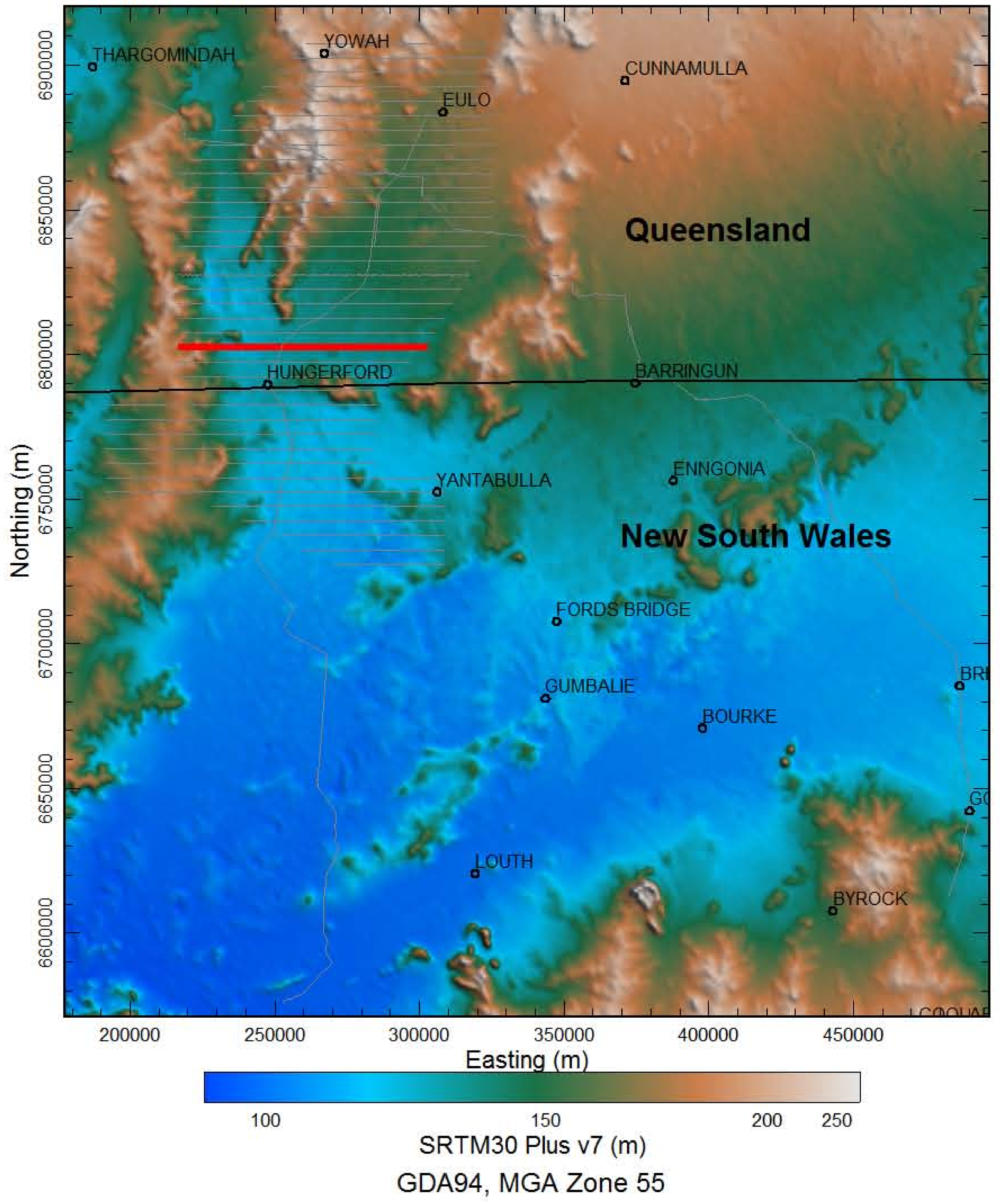
Line L1200 CDI logarithmic colour stretch



Line L1200 CDI linear colour stretch



FLIGHT PATH



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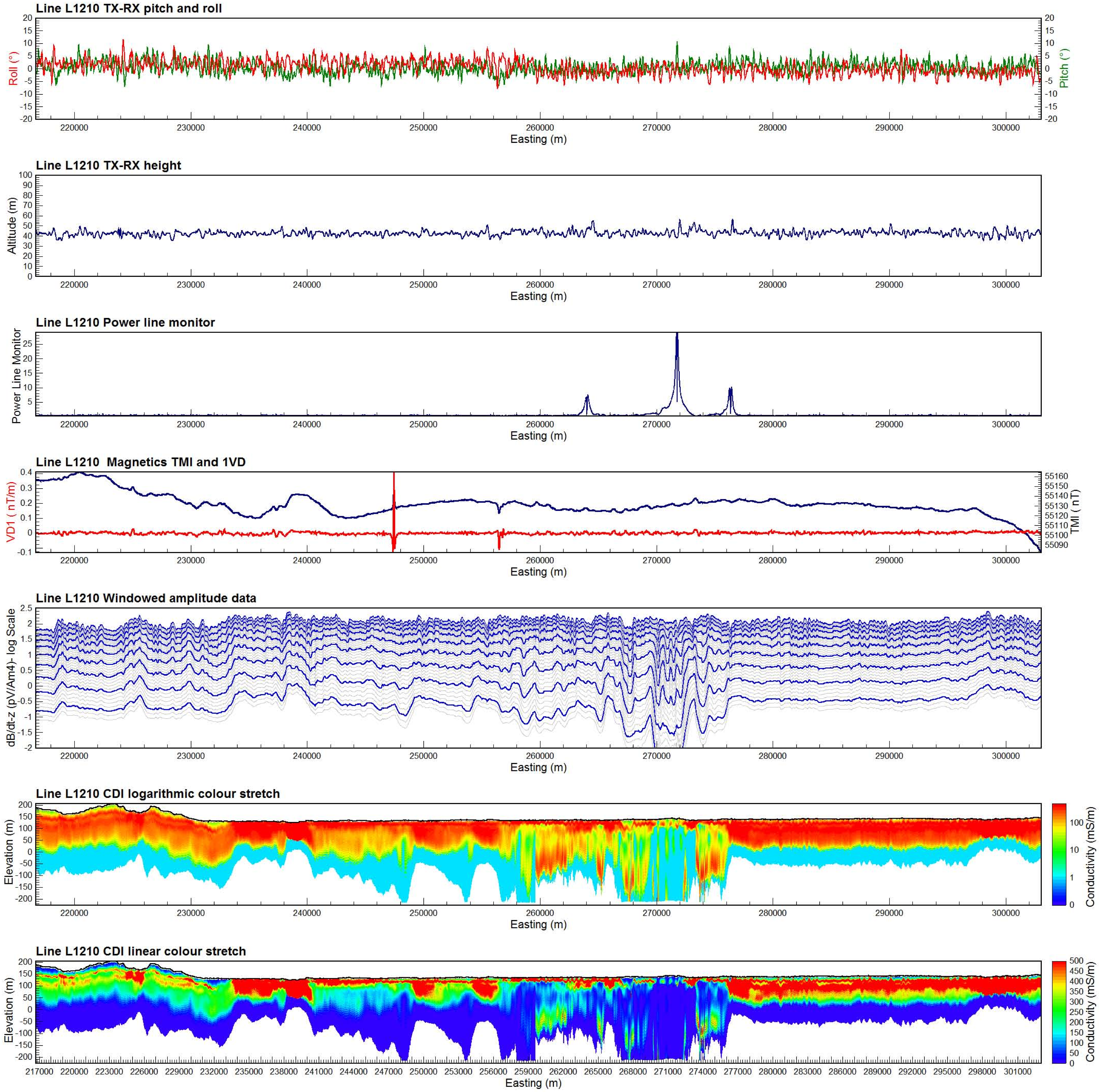
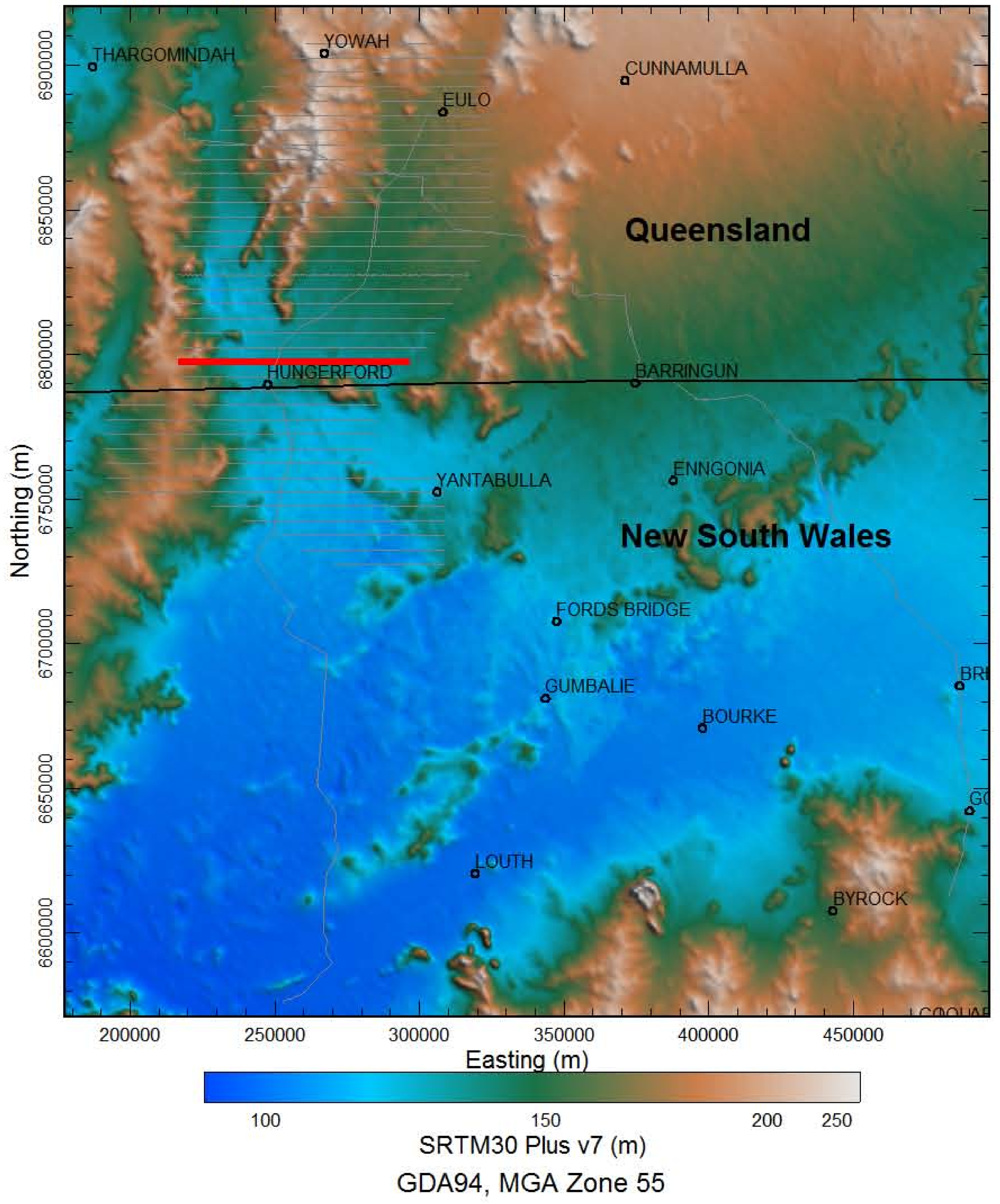


FLIGHT PATH



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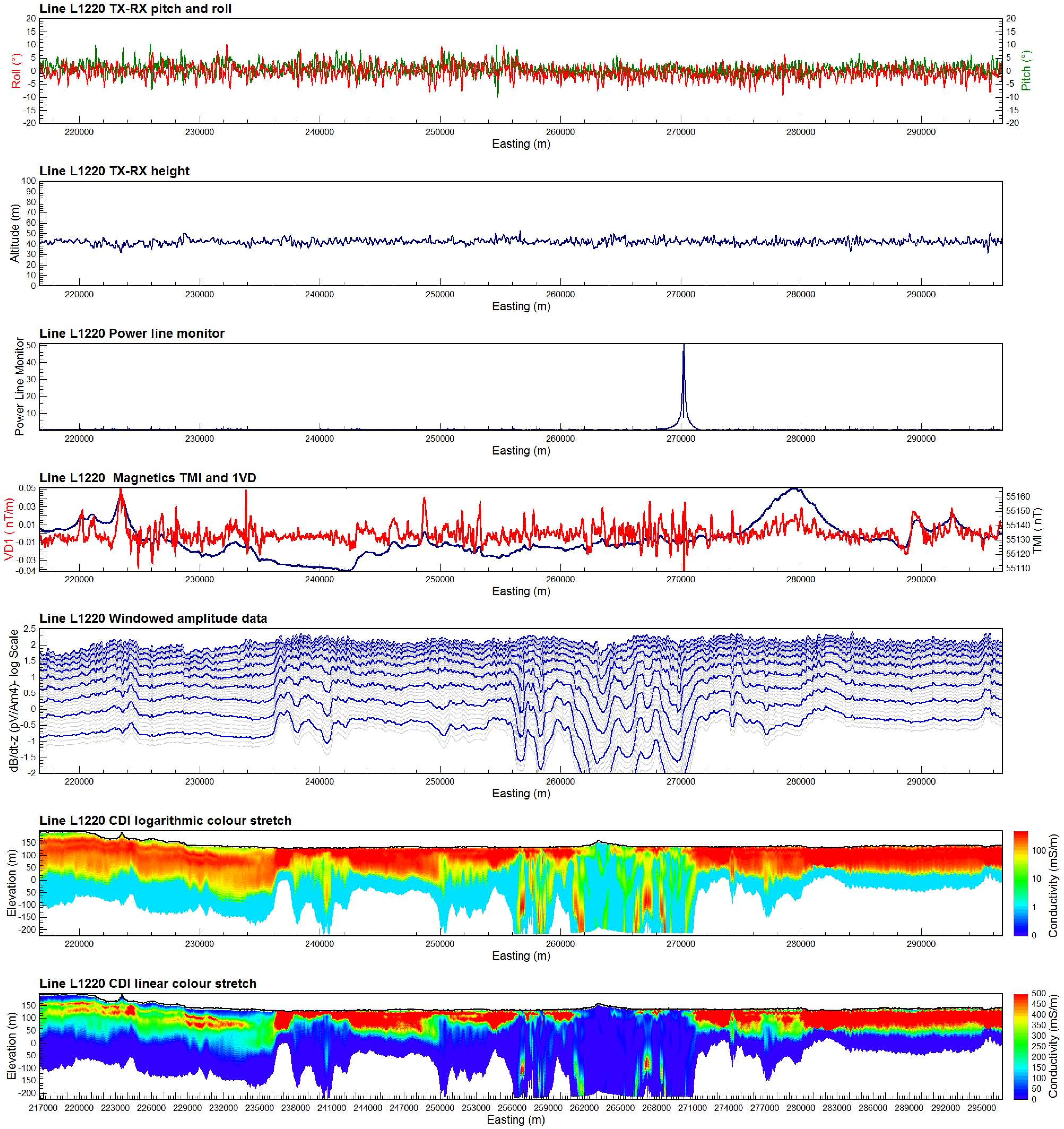
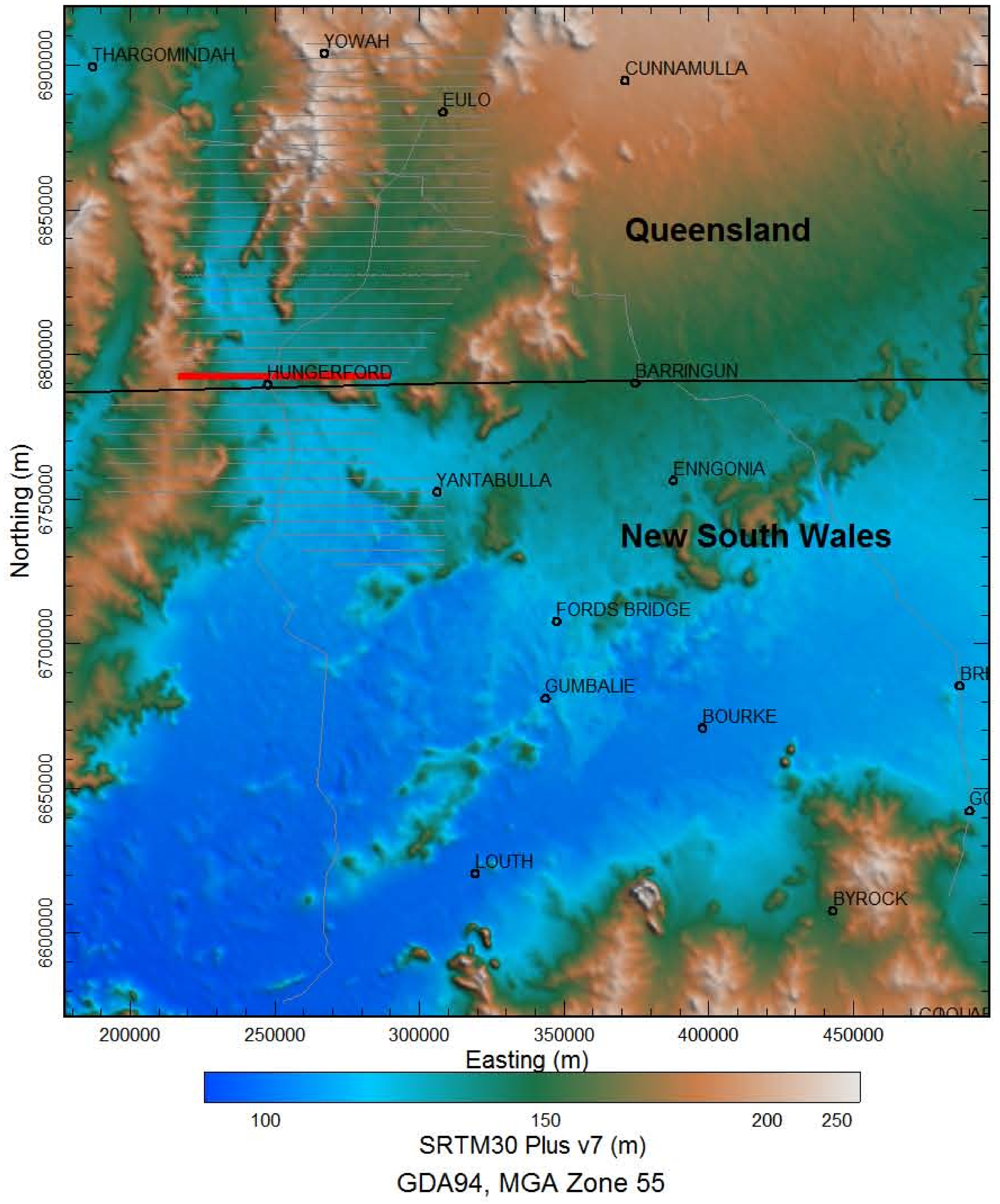


FLIGHT PATH



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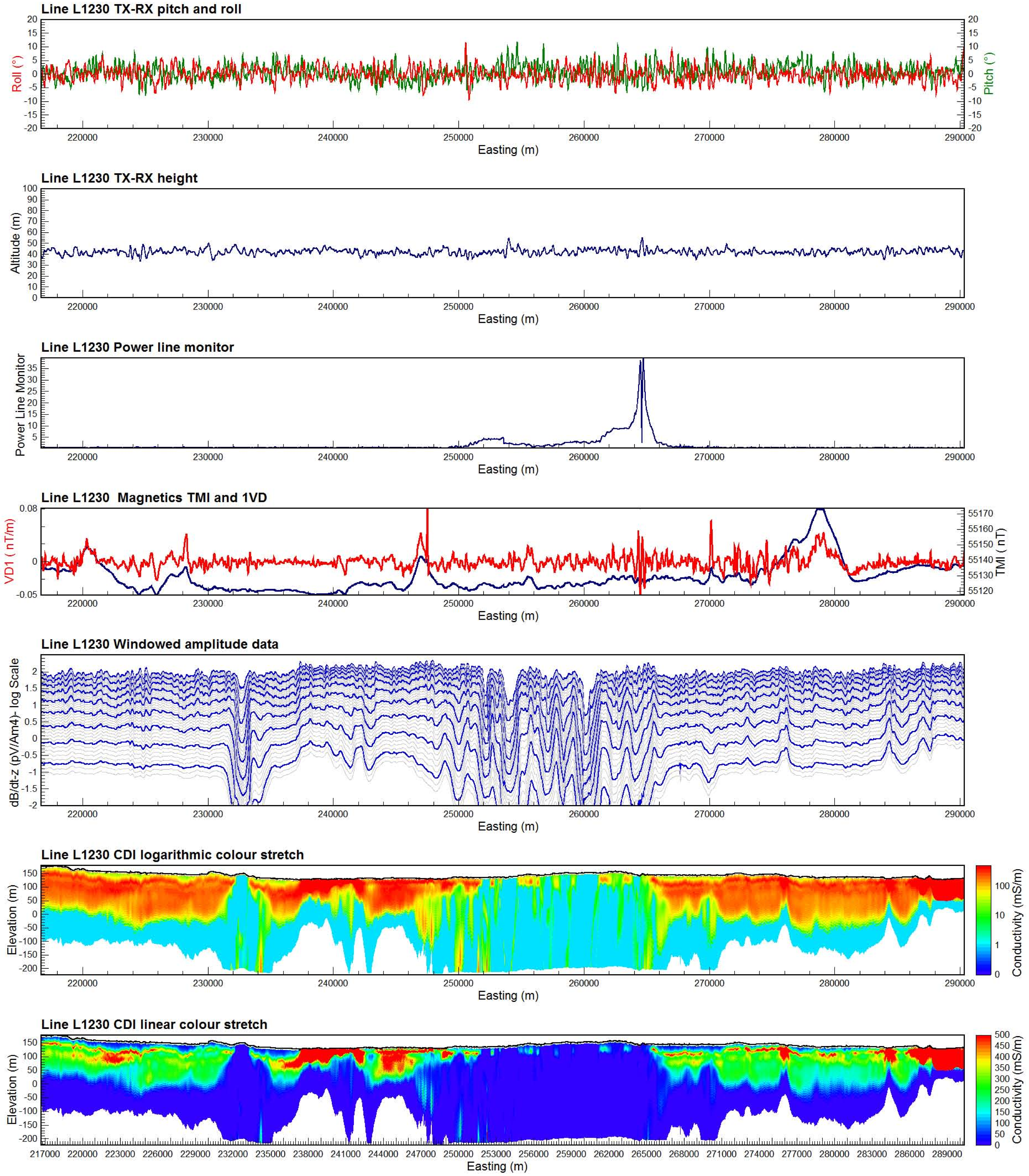
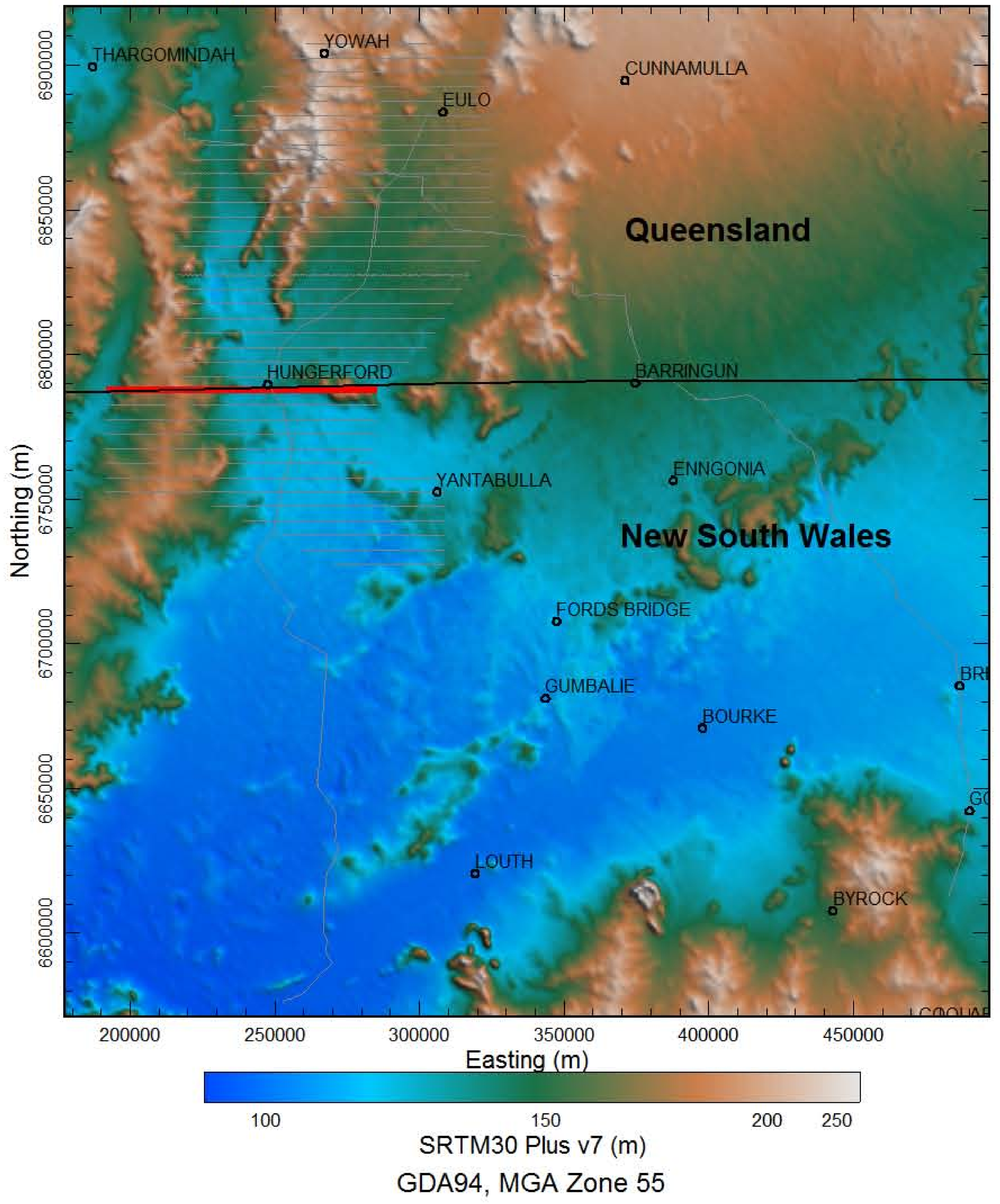


FLIGHT PATH



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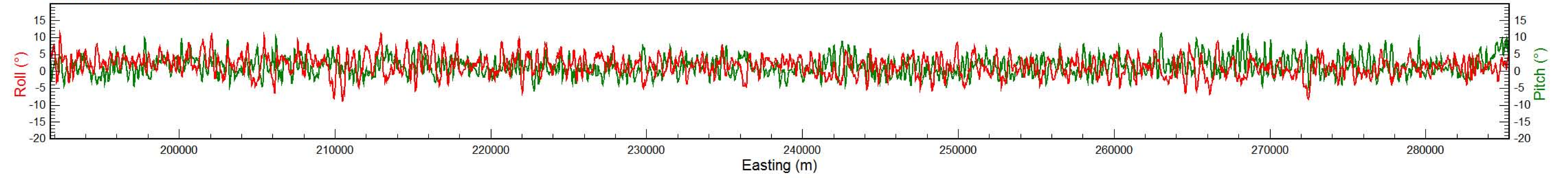
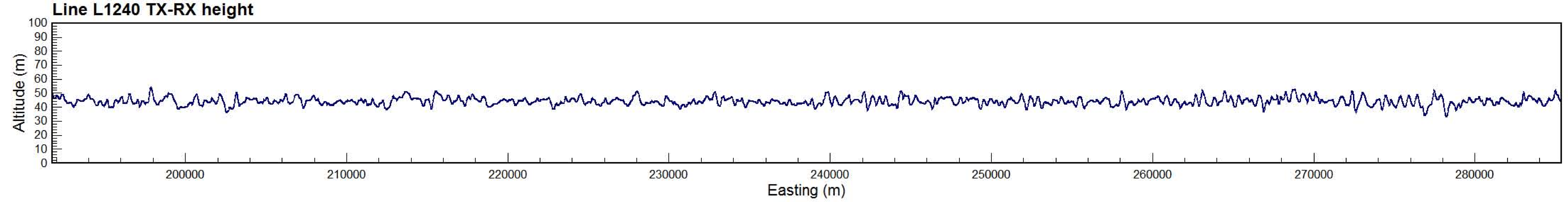
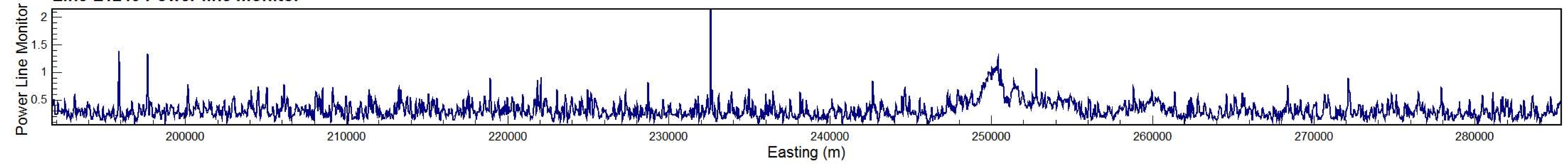
Line L1240 TX-RX pitch and roll



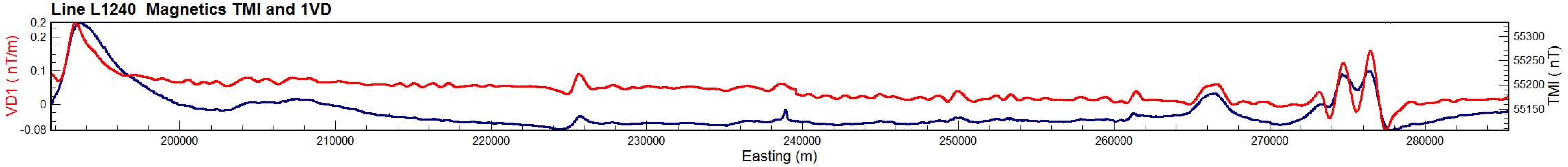
Line L1240 TX-RX height



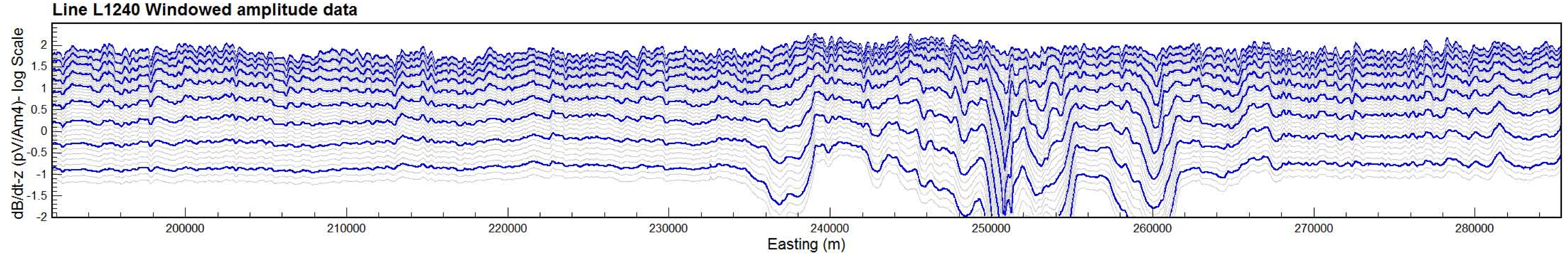
Line L1240 Power line monitor



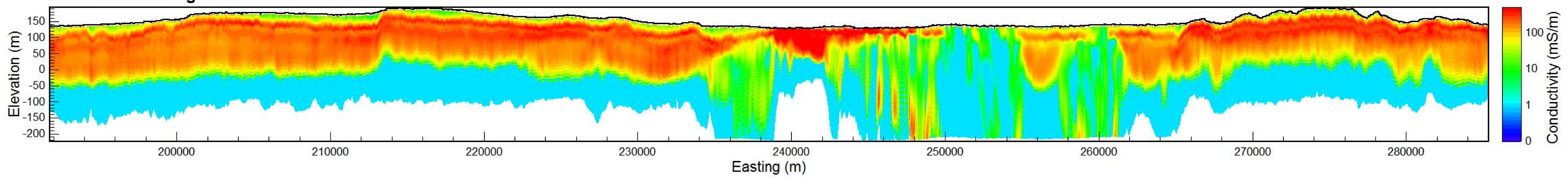
Line L1240 Magnetics TMI and 1VD



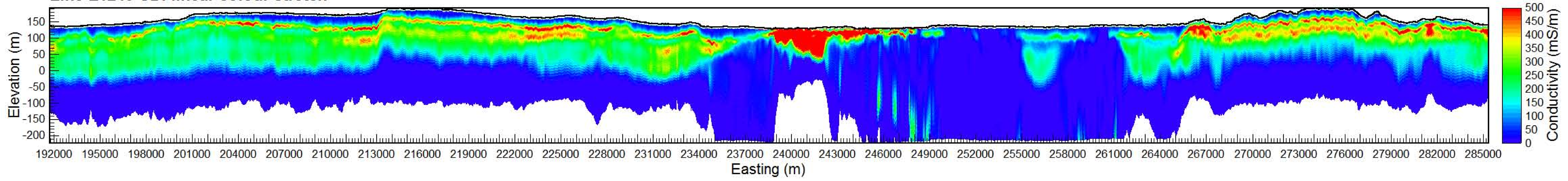
Line L1240 Windowed amplitude data



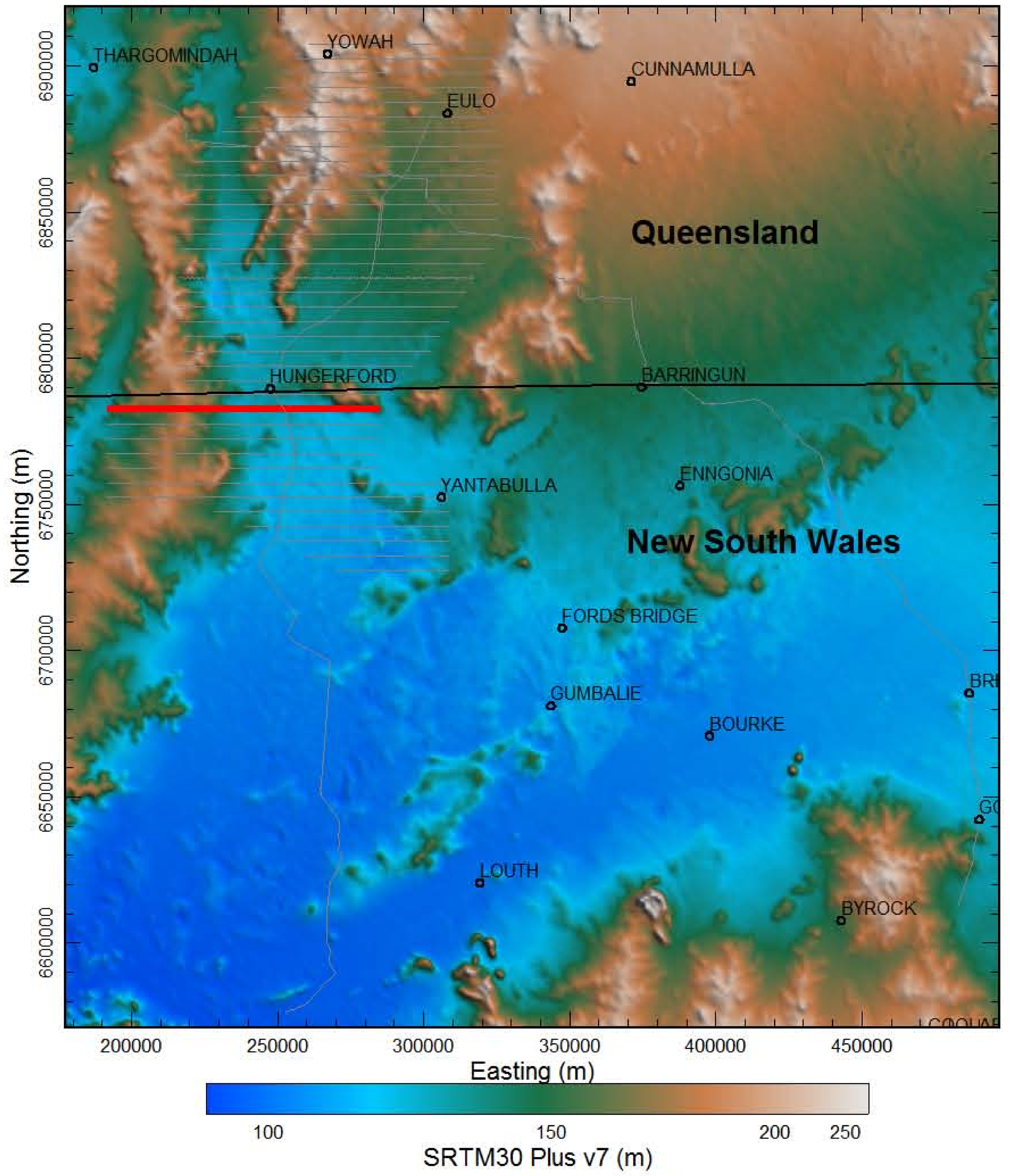
Line L1240 CDI logarithmic colour stretch



Line L1240 CDI linear colour stretch



FLIGHT PATH



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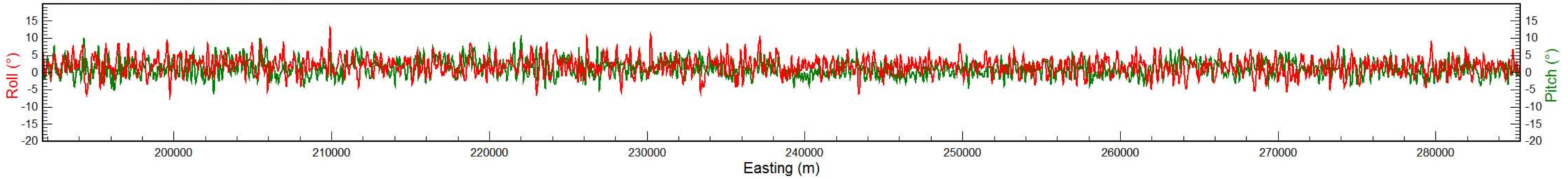
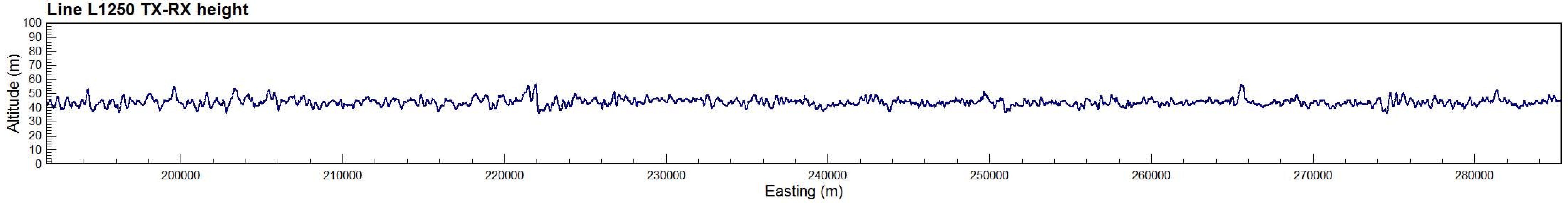
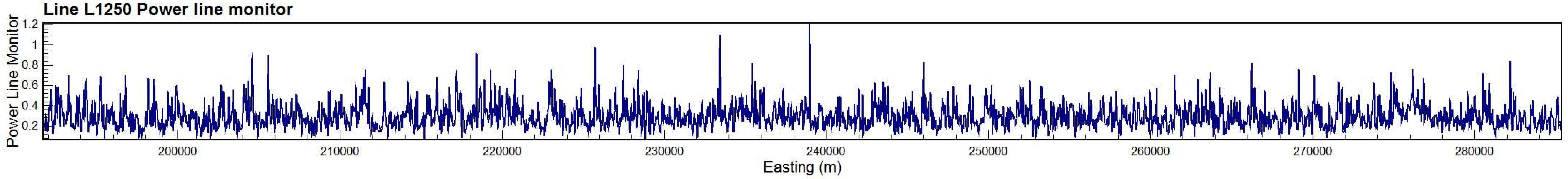
Line L1250 TX-RX pitch and roll



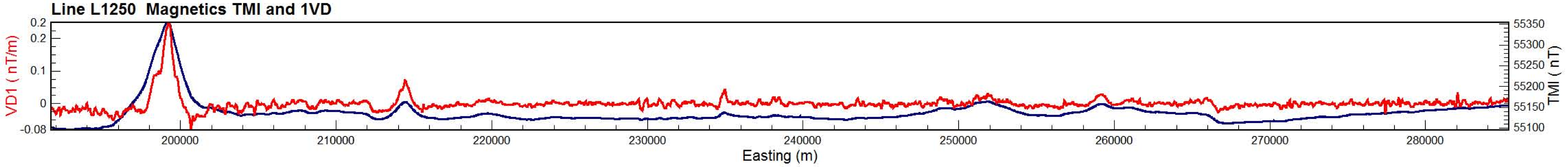
Line L1250 TX-RX height



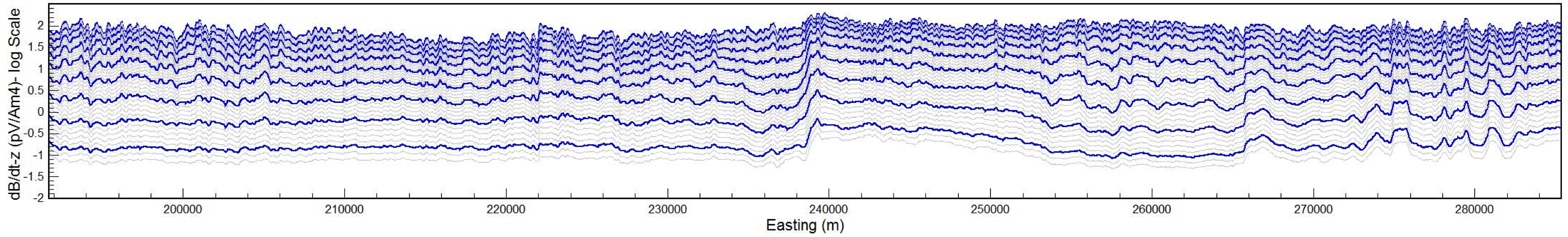
Line L1250 Power line monitor



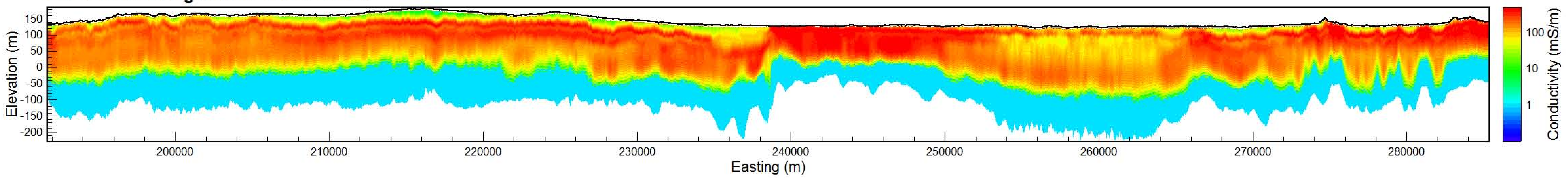
Line L1250 Magnetics TMI and 1VD



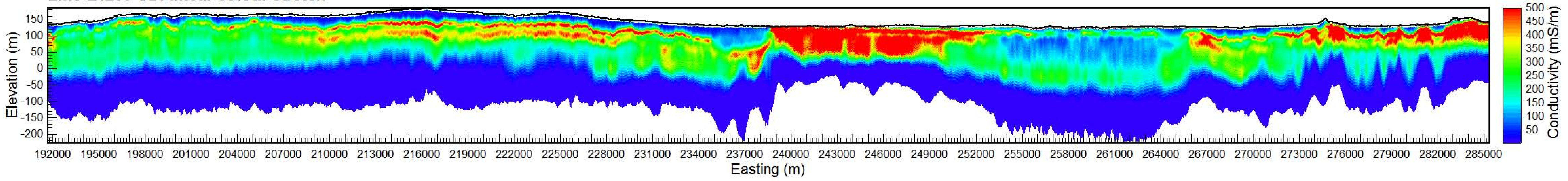
Line L1250 Windowed amplitude data



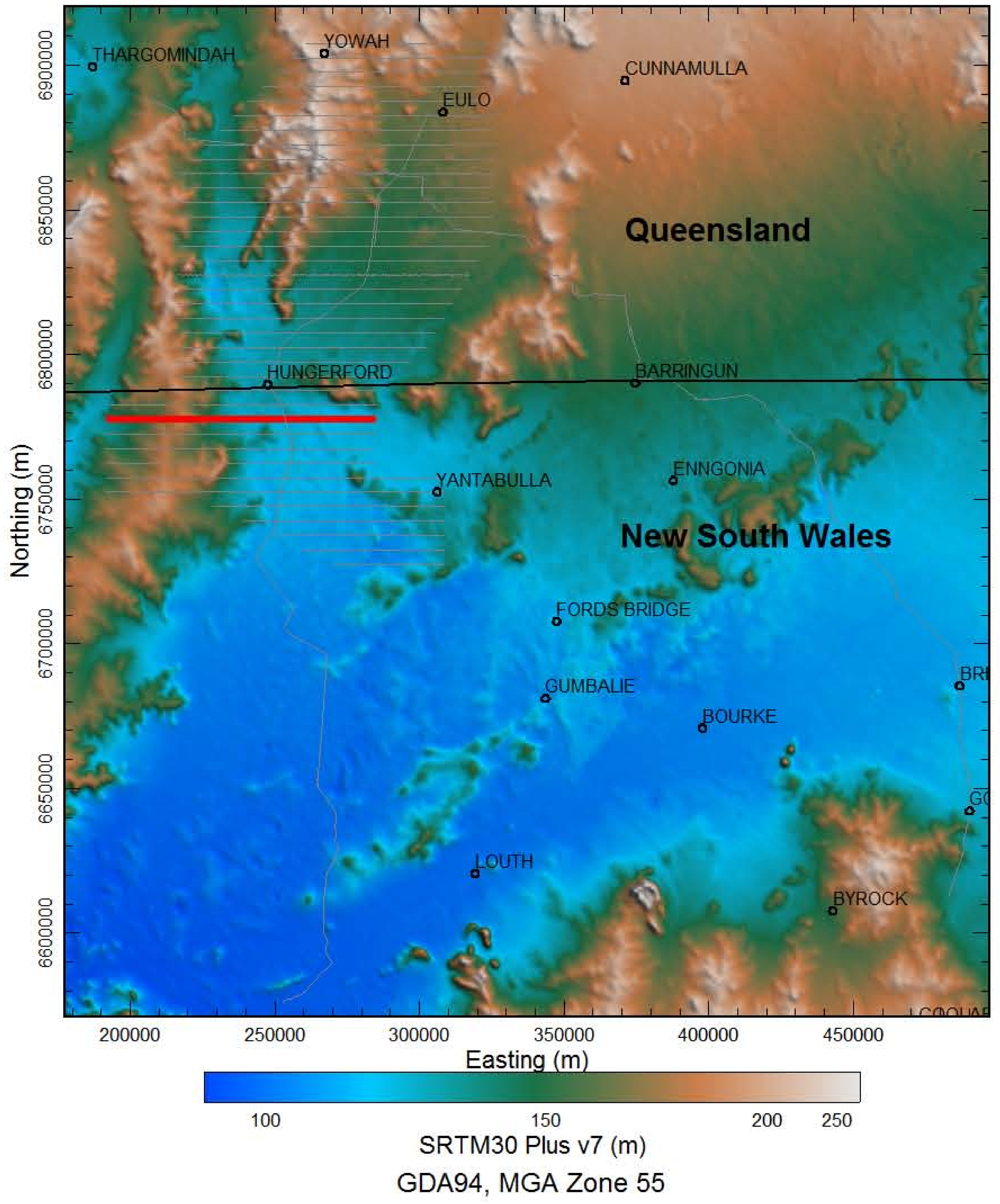
Line L1250 CDI logarithmic colour stretch



Line L1250 CDI linear colour stretch



FLIGHT PATH



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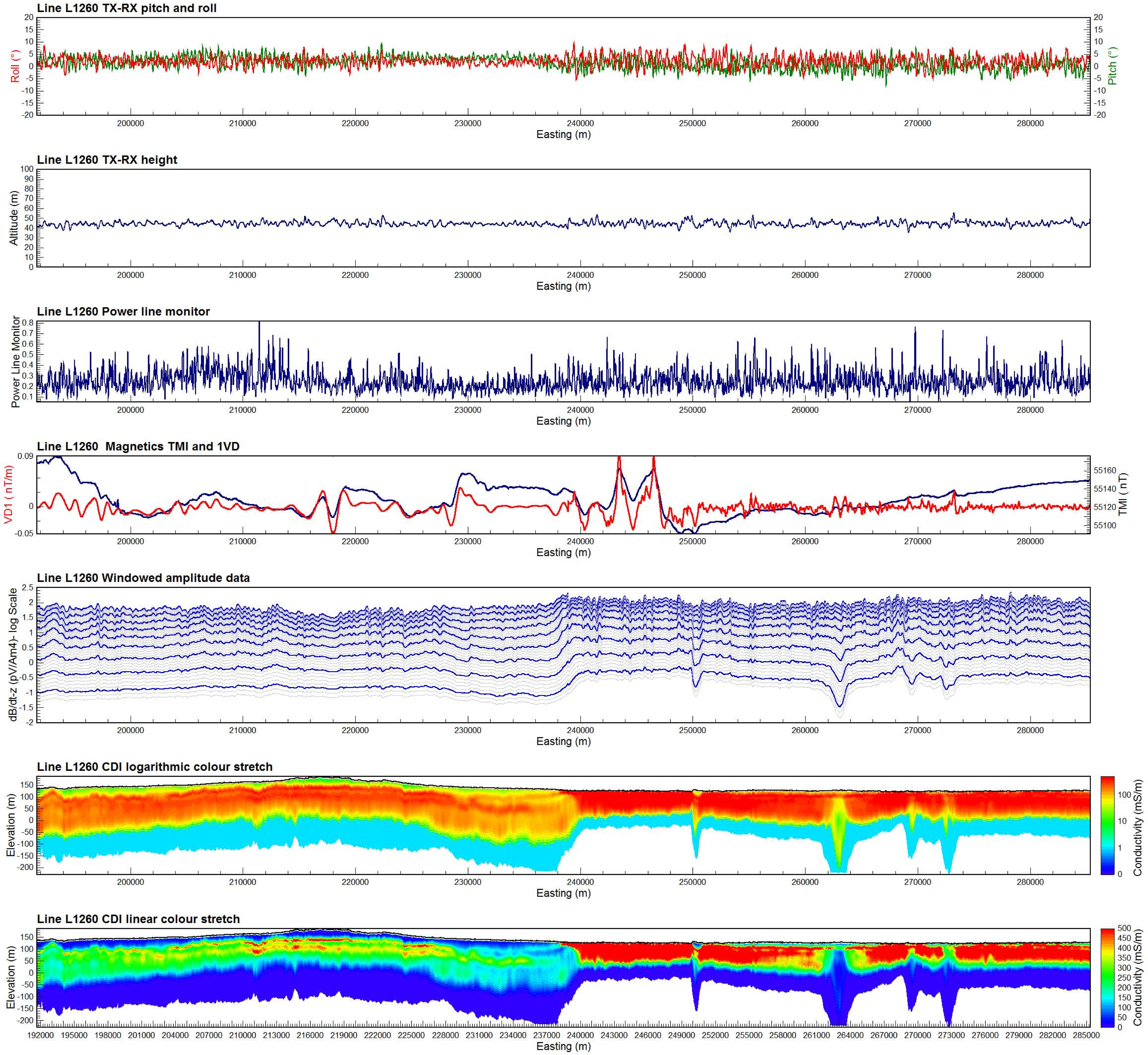
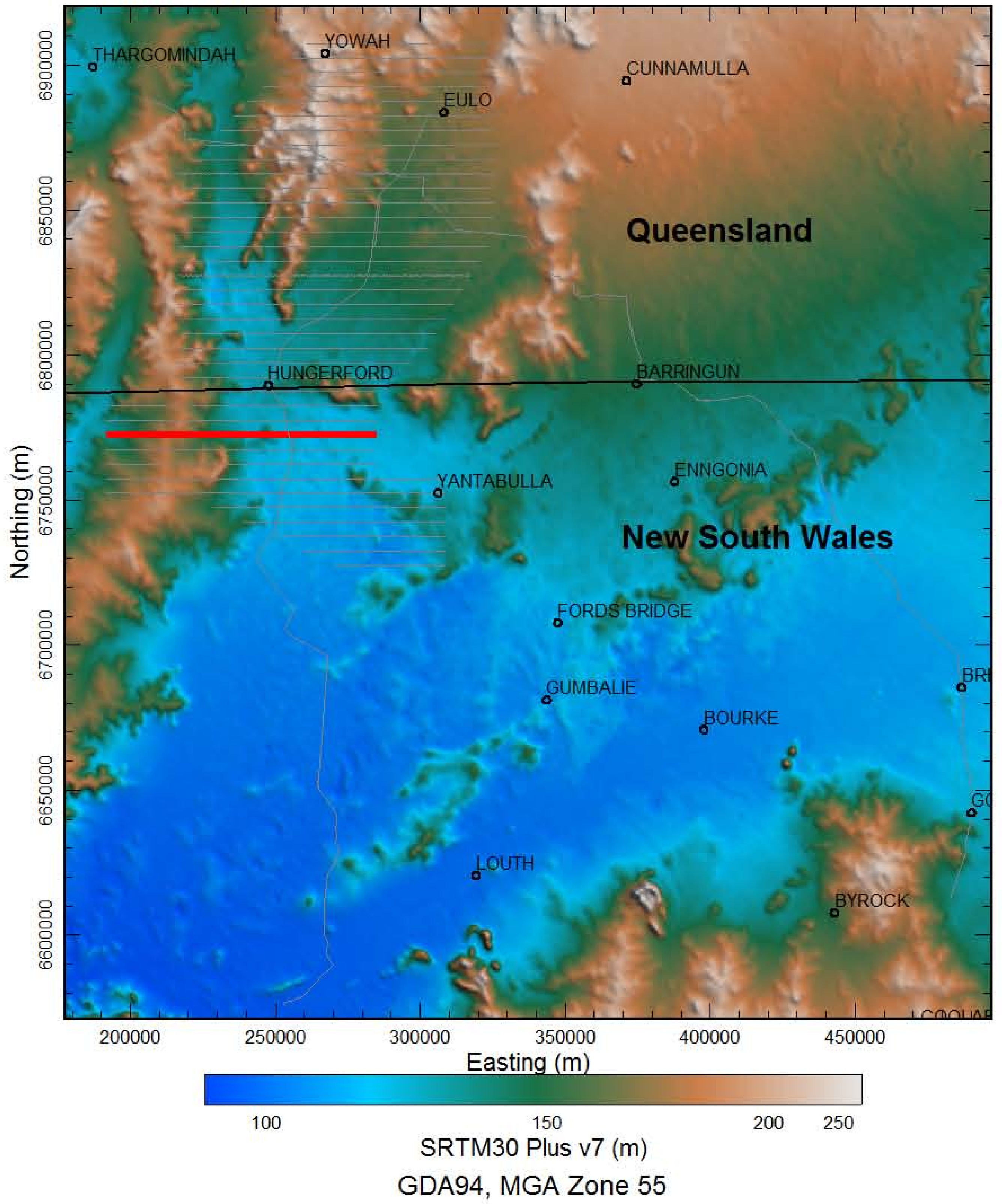


FLIGHT PATH



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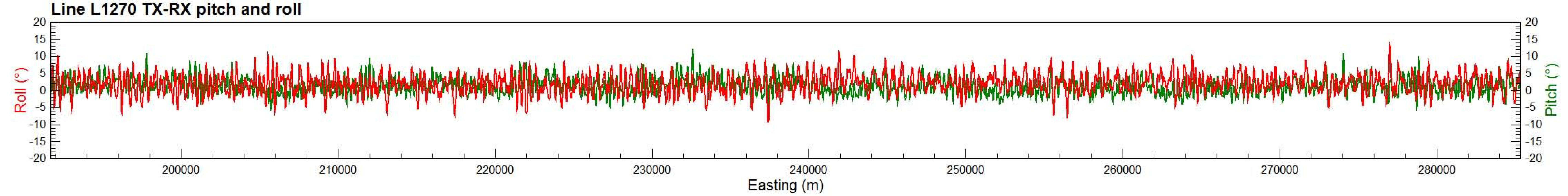
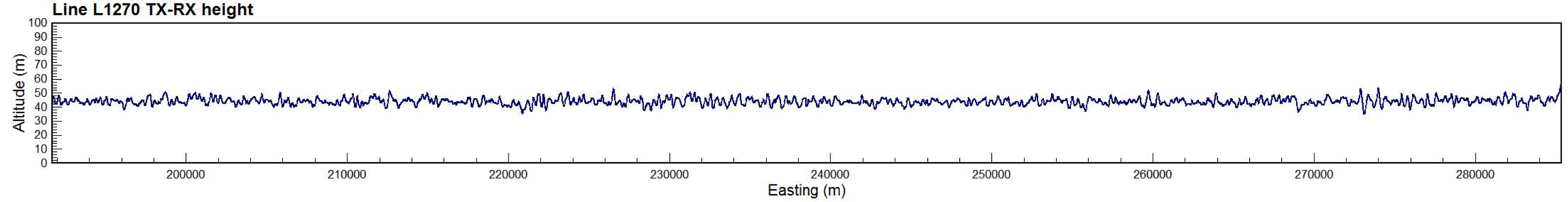
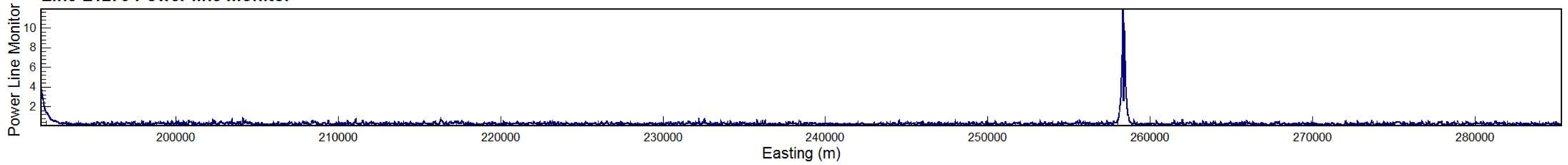
Line L1270 TX-RX pitch and roll



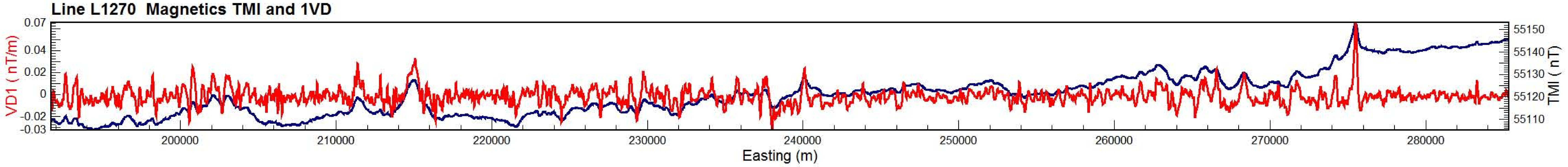
Line L1270 TX-RX height



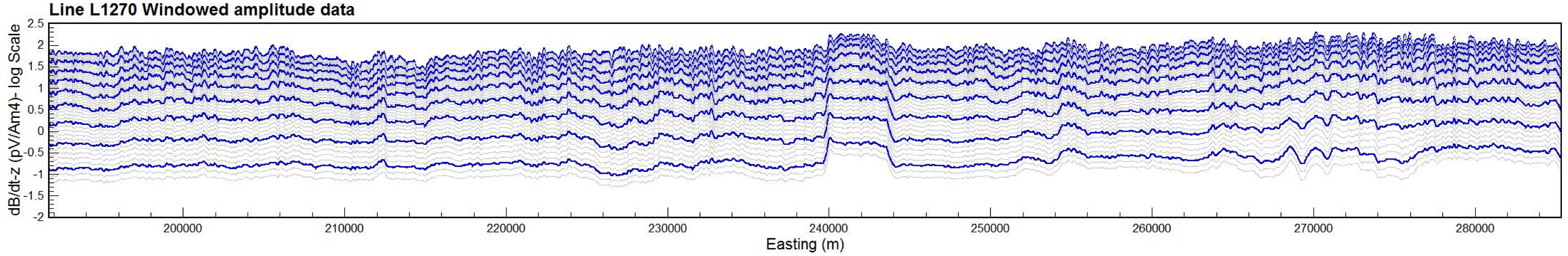
Line L1270 Power line monitor



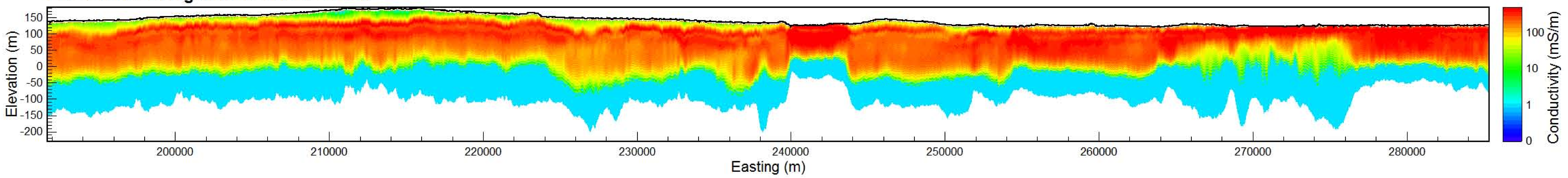
Line L1270 Magnetics TMI and 1VD



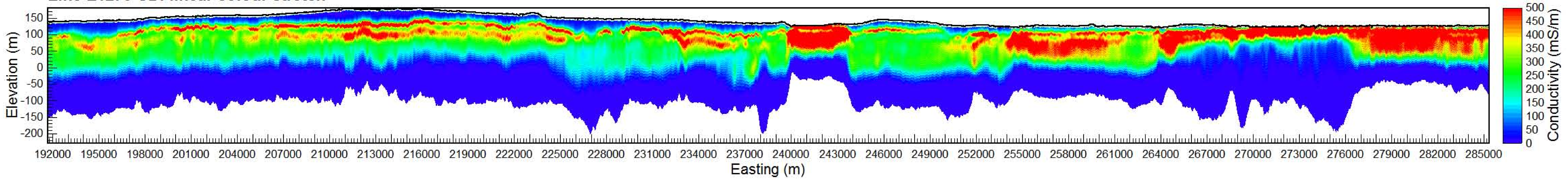
Line L1270 Windowed amplitude data



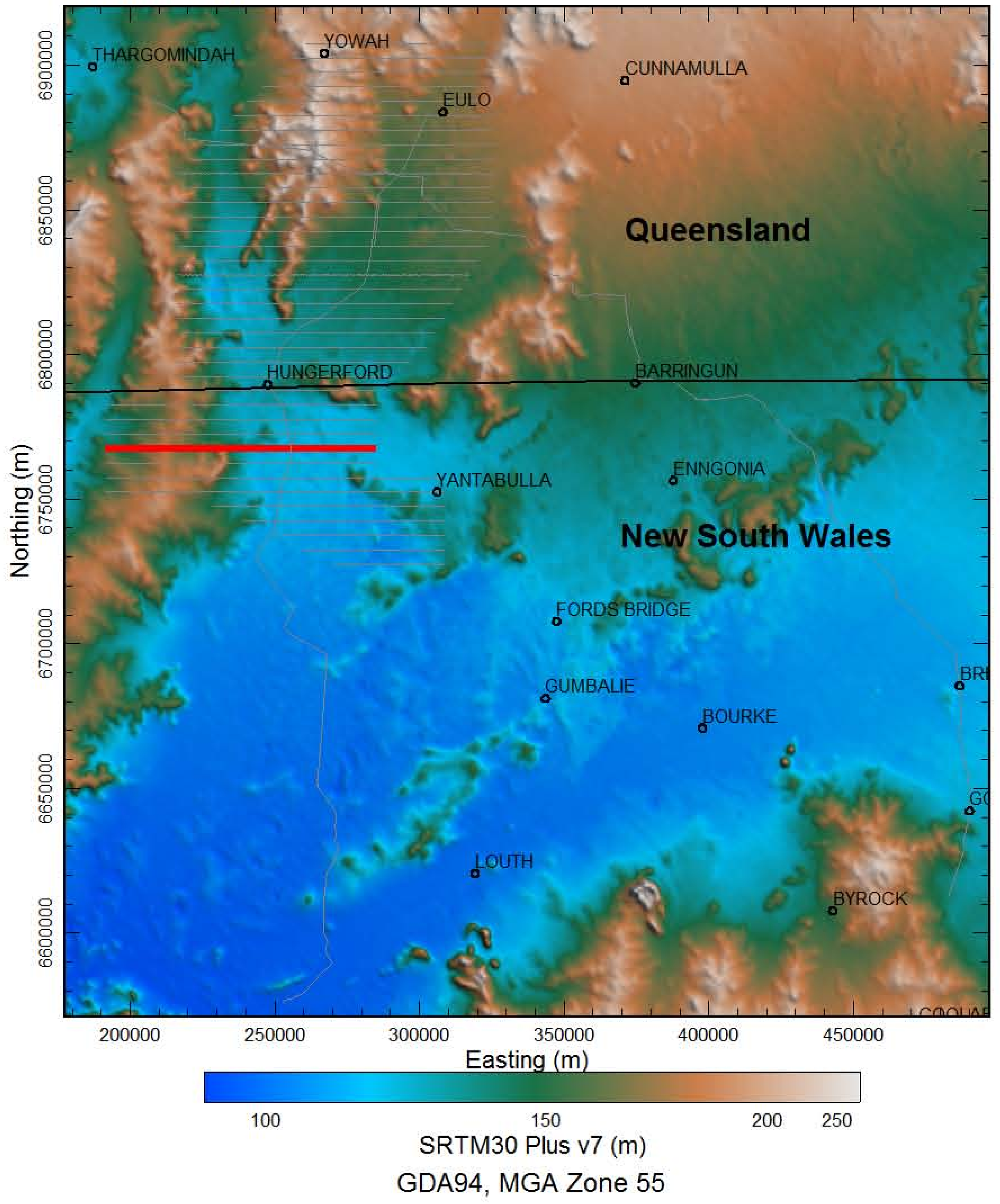
Line L1270 CDI logarithmic colour stretch



Line L1270 CDI linear colour stretch



FLIGHT PATH



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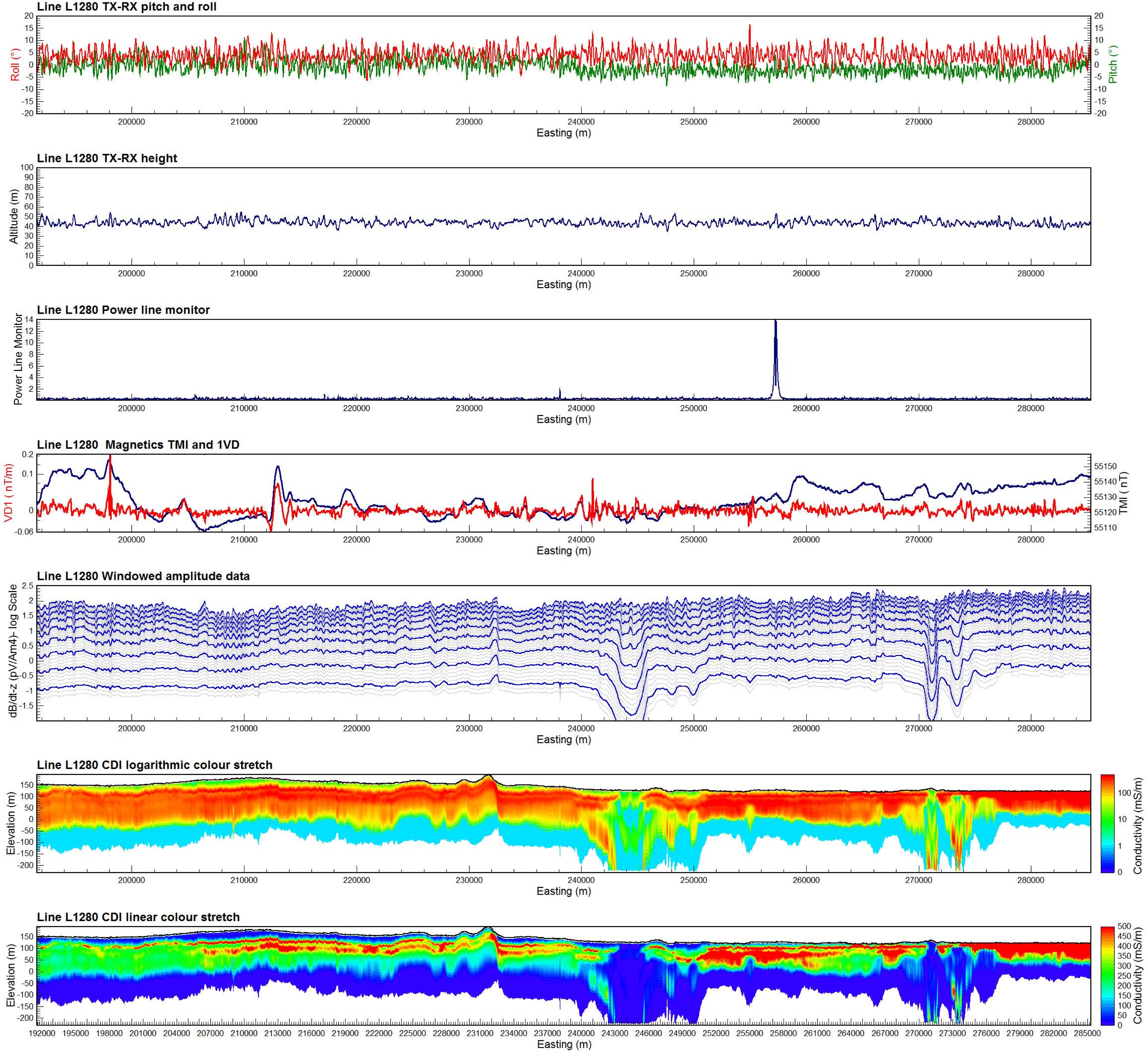
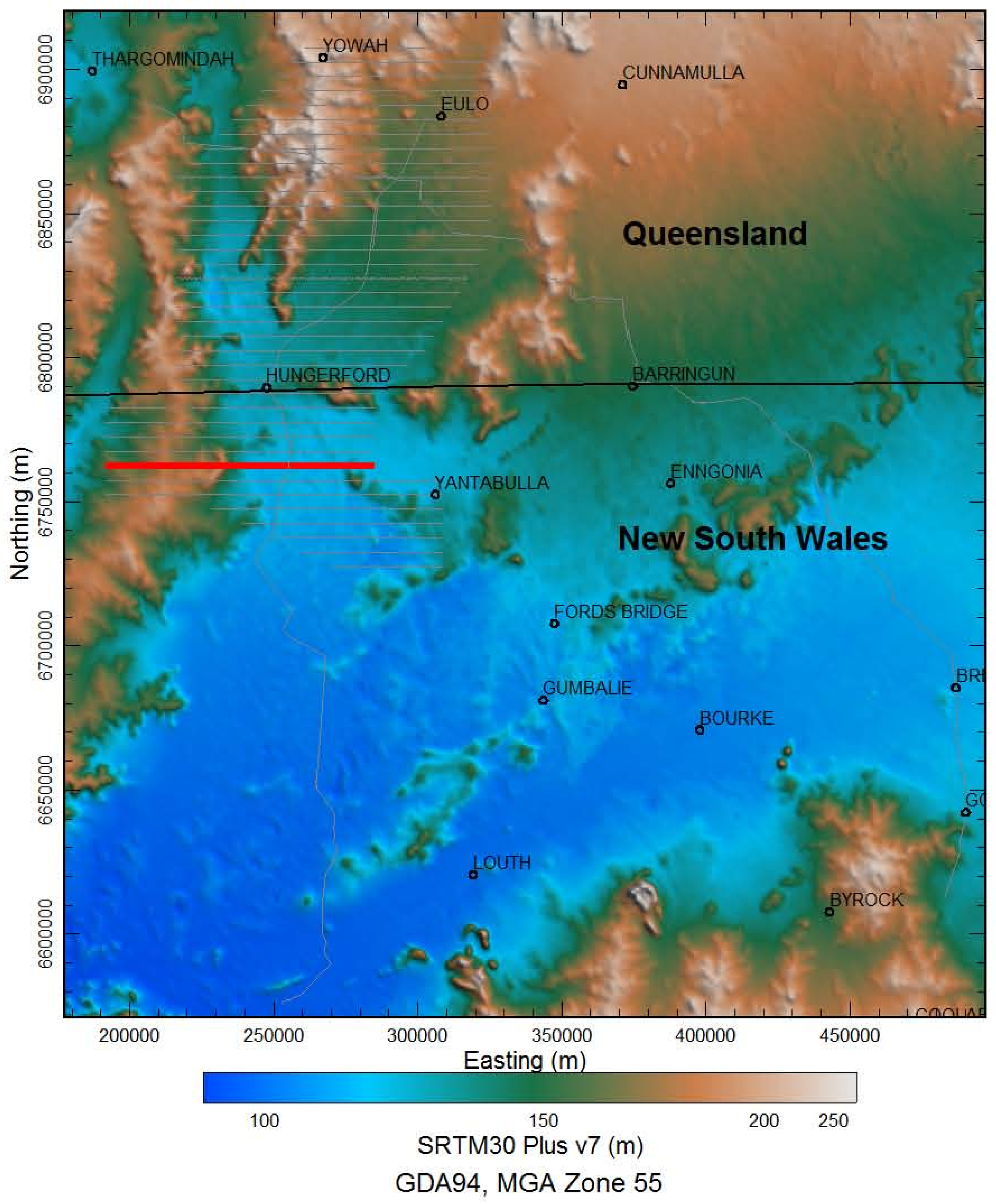
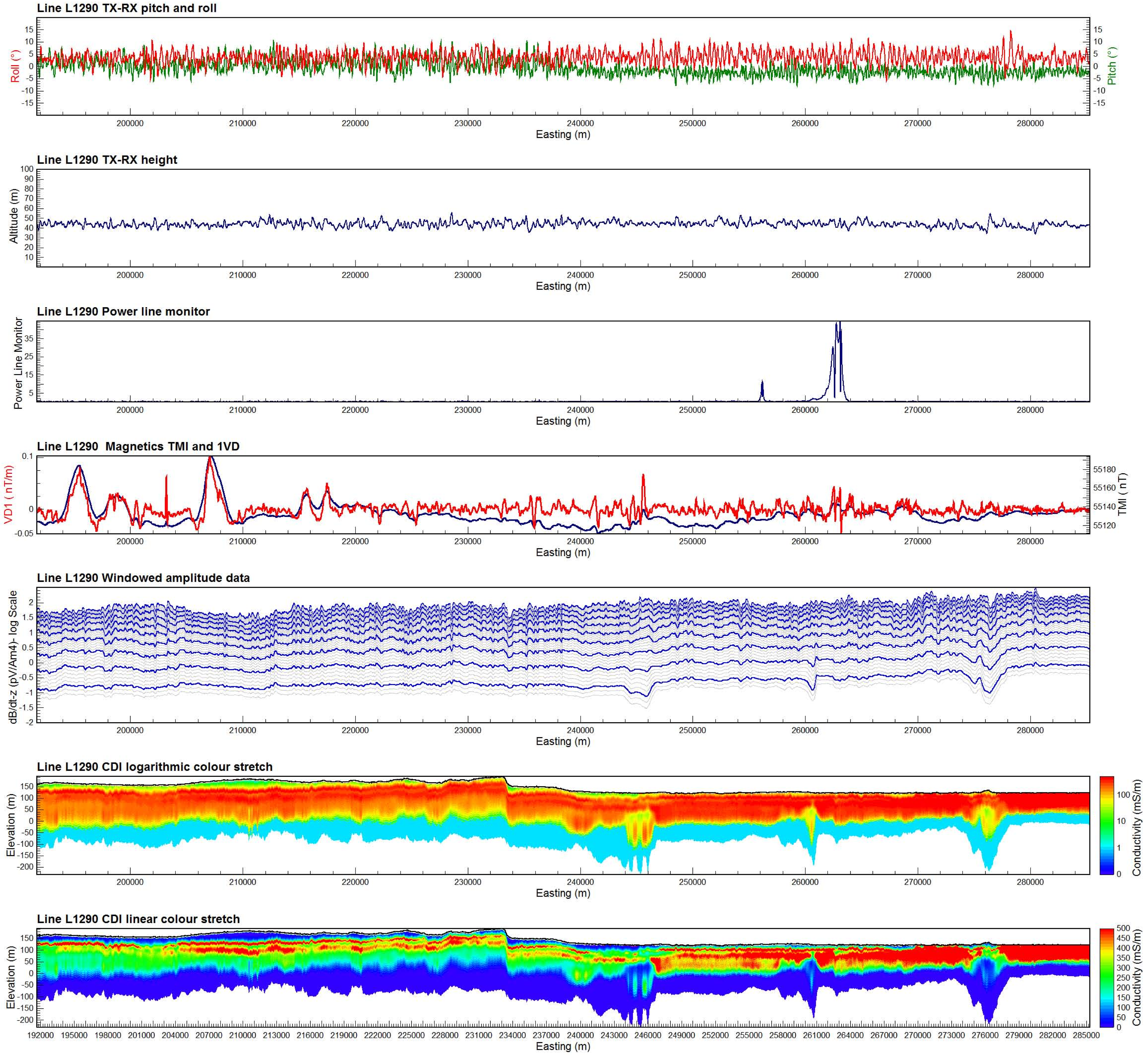


FLIGHT PATH





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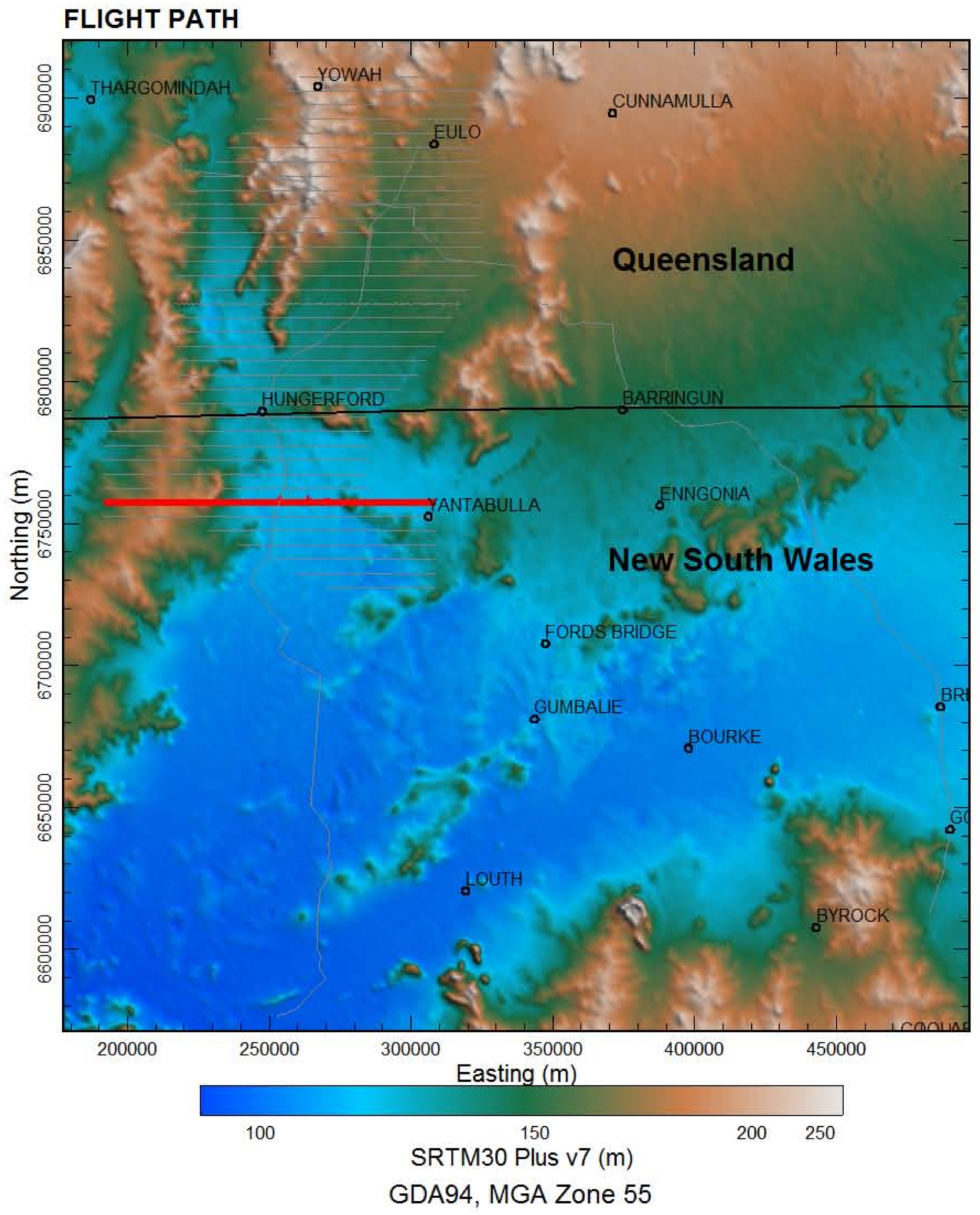

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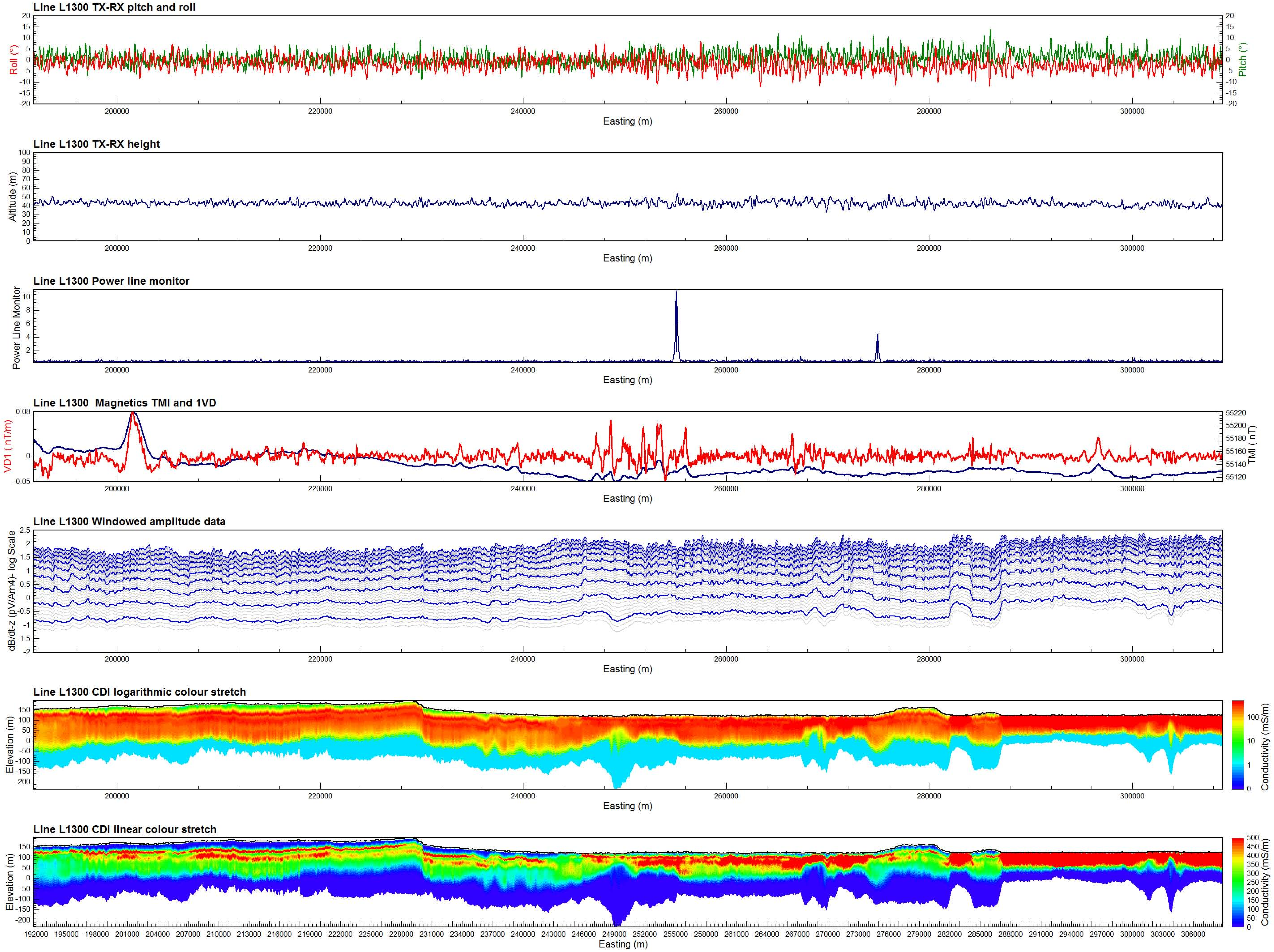
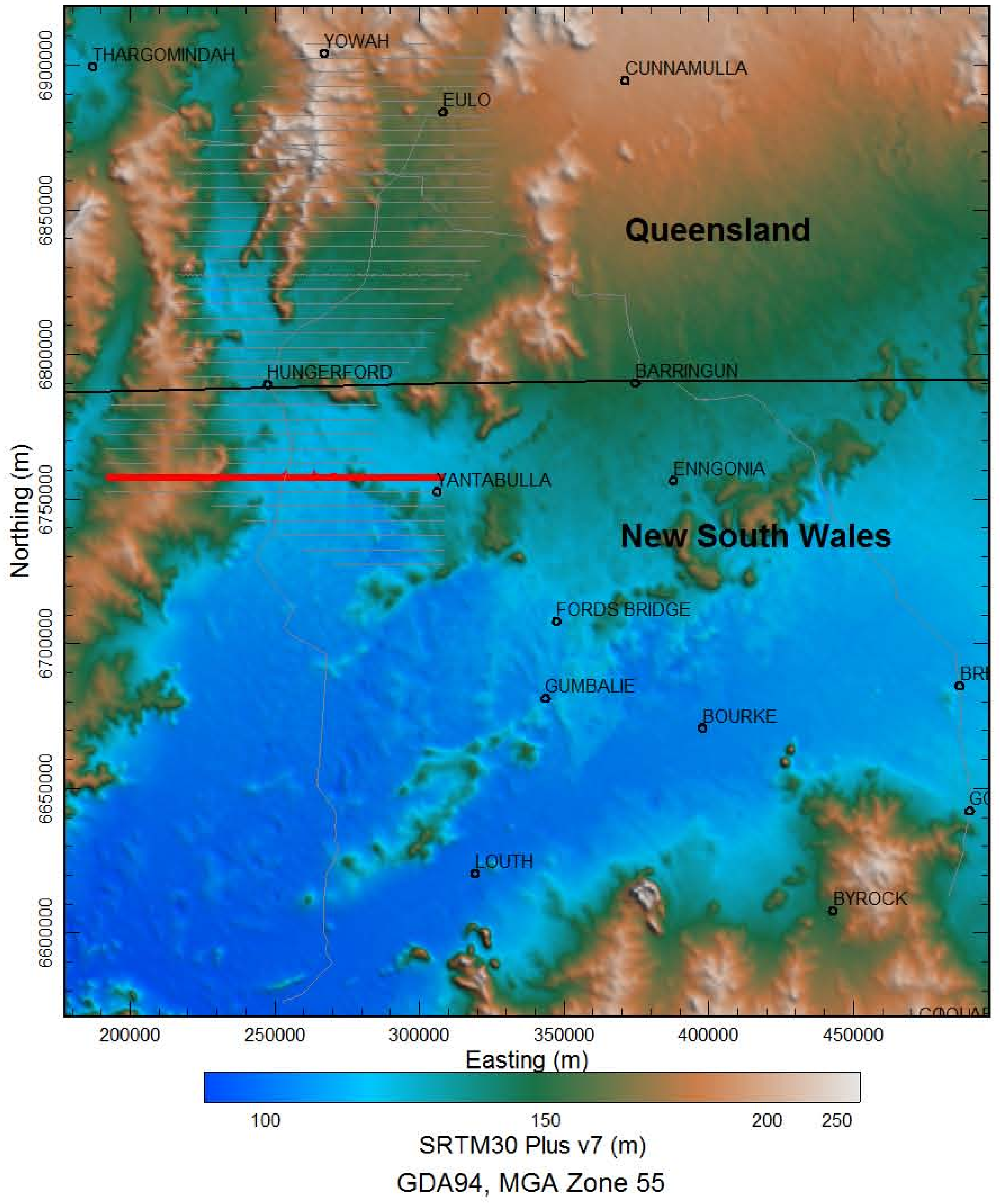


FLIGHT PATH



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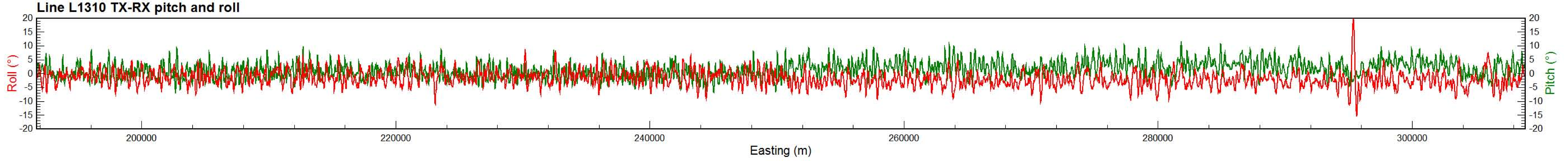
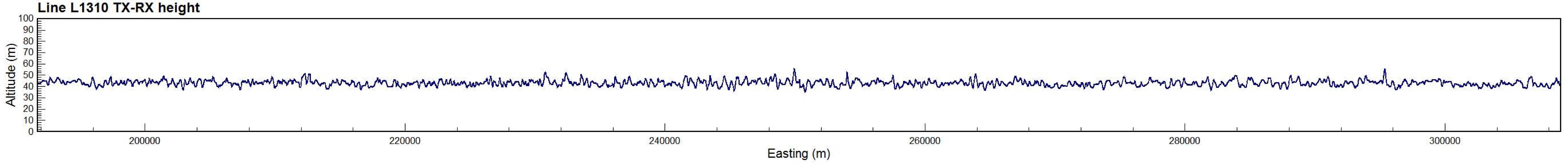
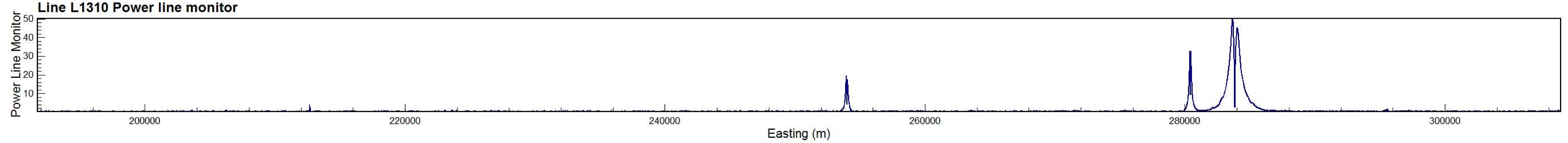
Line L1310 TX-RX pitch and roll



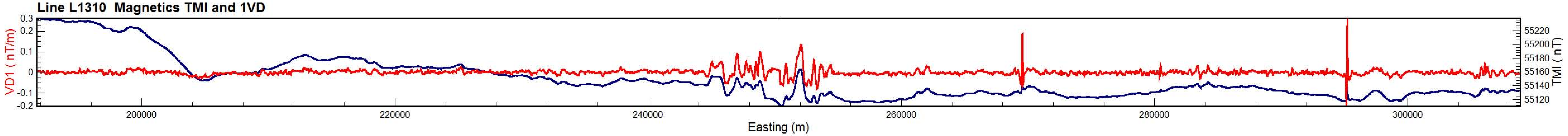
Line L1310 TX-RX height



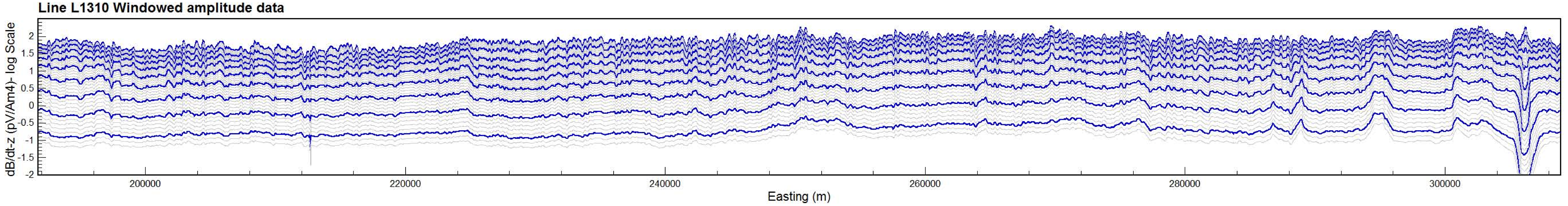
Line L1310 Power line monitor



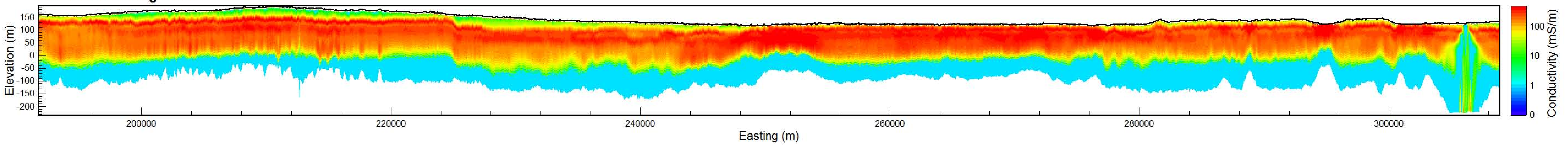
Line L1310 Magnetics TMI and 1VD



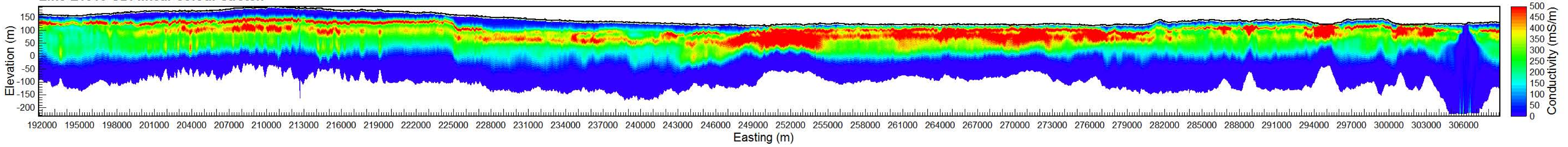
Line L1310 Windowed amplitude data



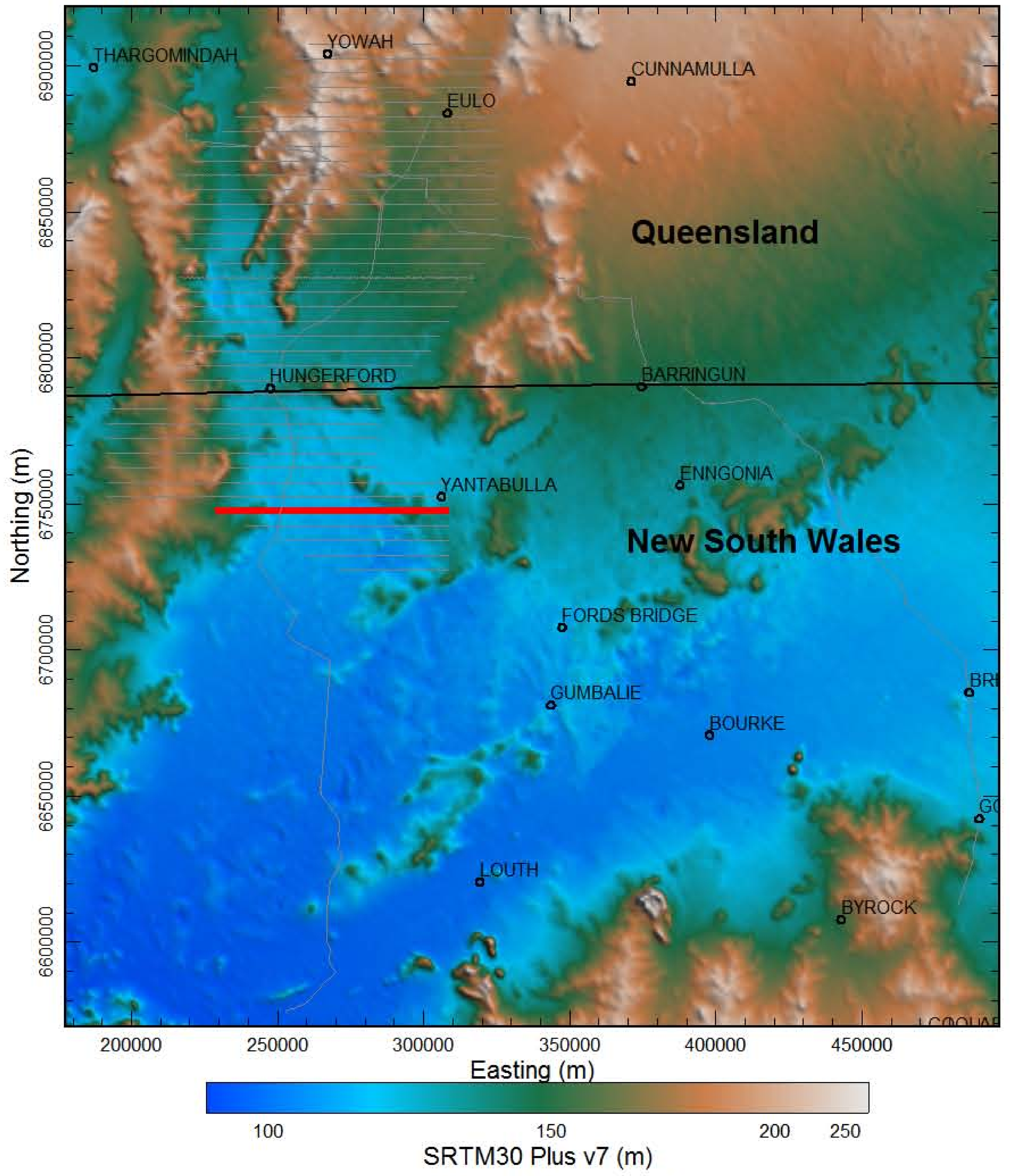
Line L1310 CDI logarithmic colour stretch



Line L1310 CDI linear colour stretch



FLIGHT PATH



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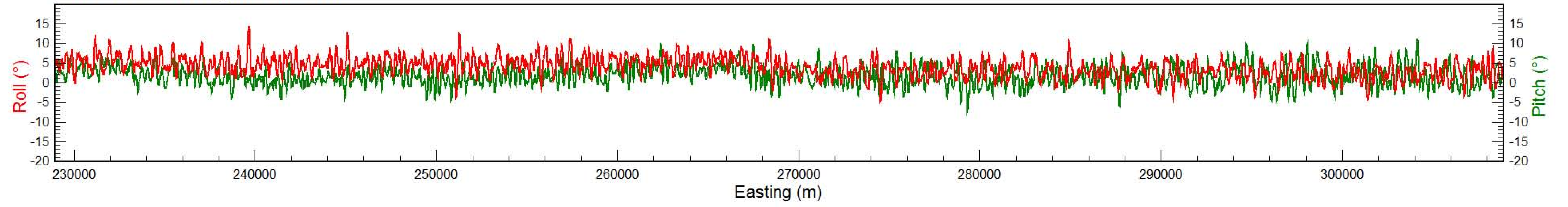
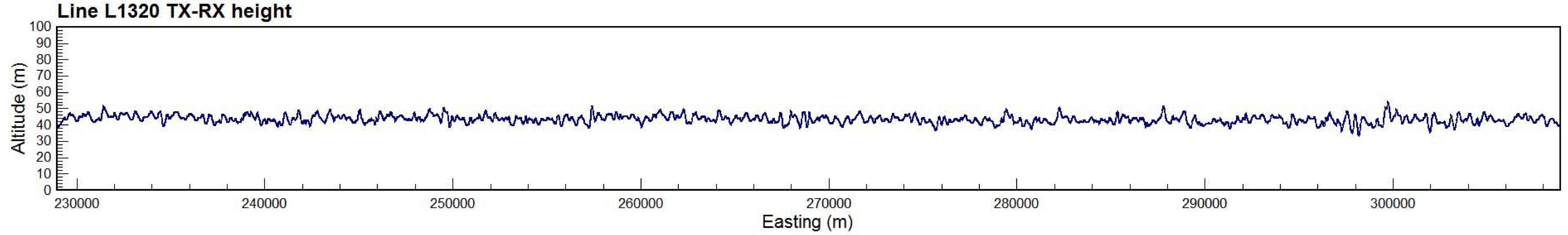
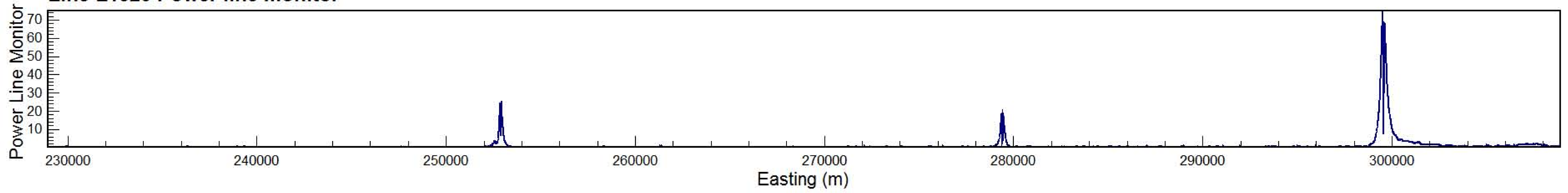
Line L1320 TX-RX pitch and roll



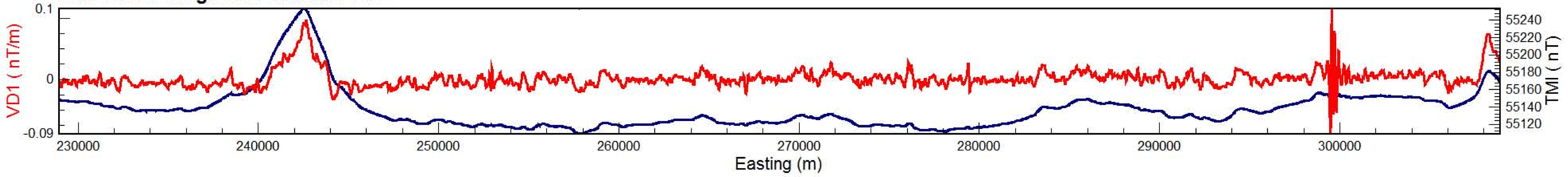
Line L1320 TX-RX height



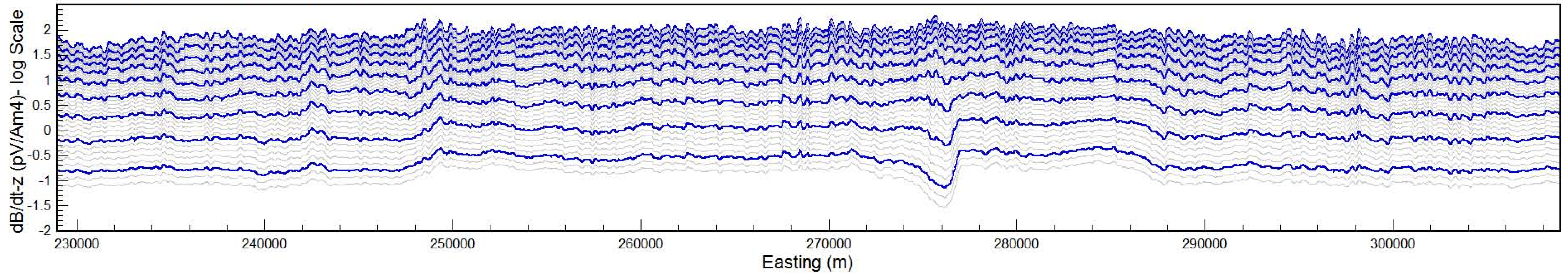
Line L1320 Power line monitor



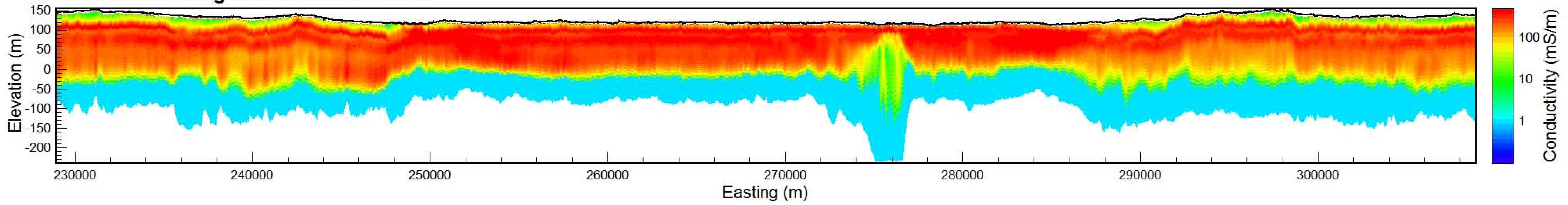
Line L1320 Magnetics TMI and 1VD



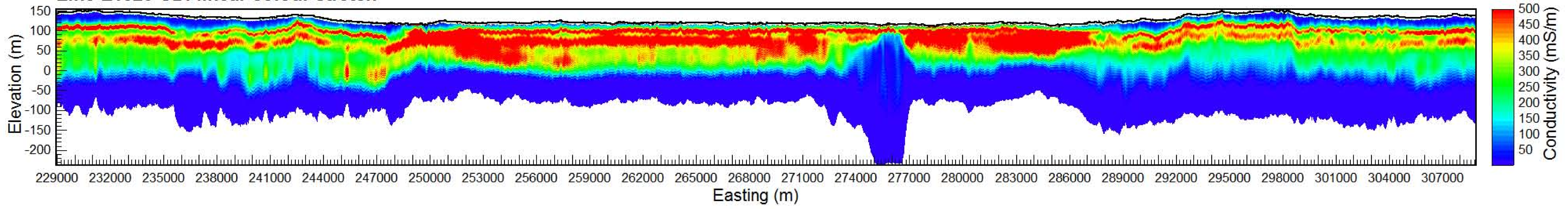
Line L1320 Windowed amplitude data



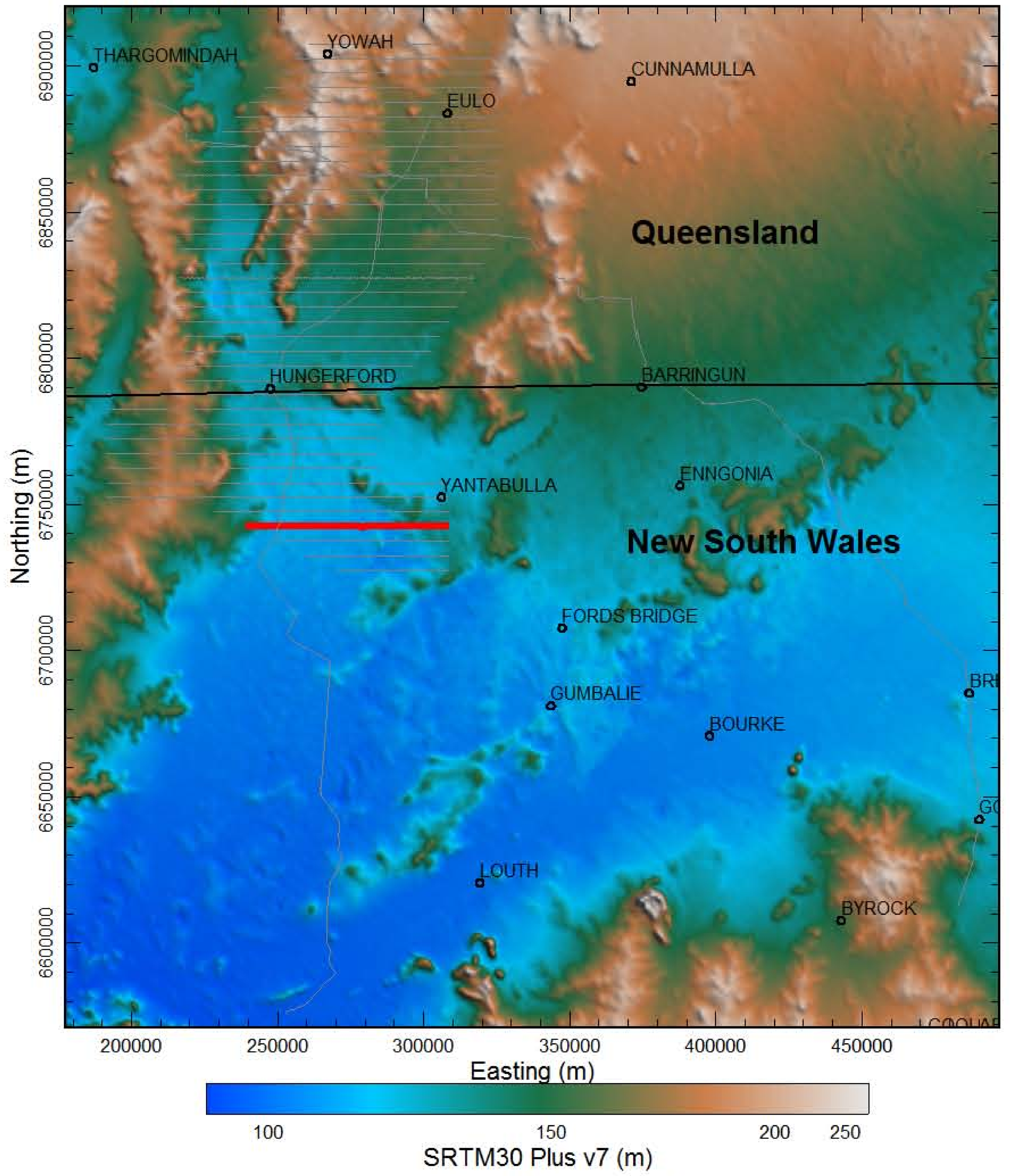
Line L1320 CDI logarithmic colour stretch



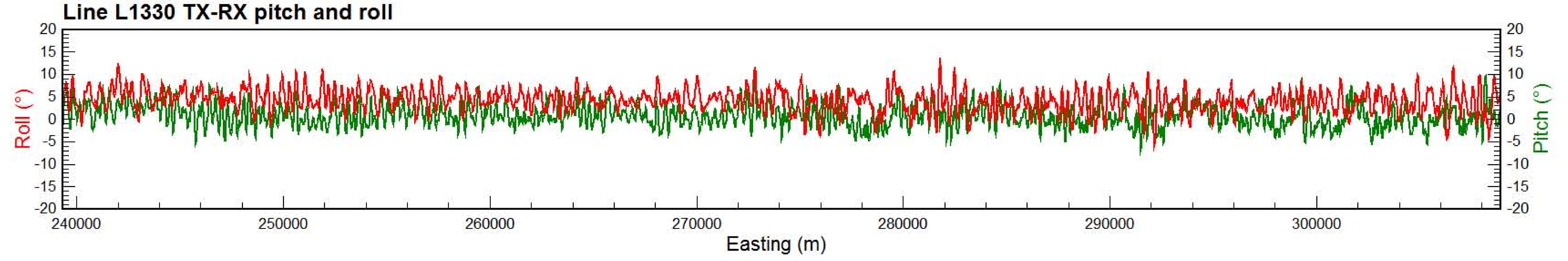
Line L1320 CDI linear colour stretch



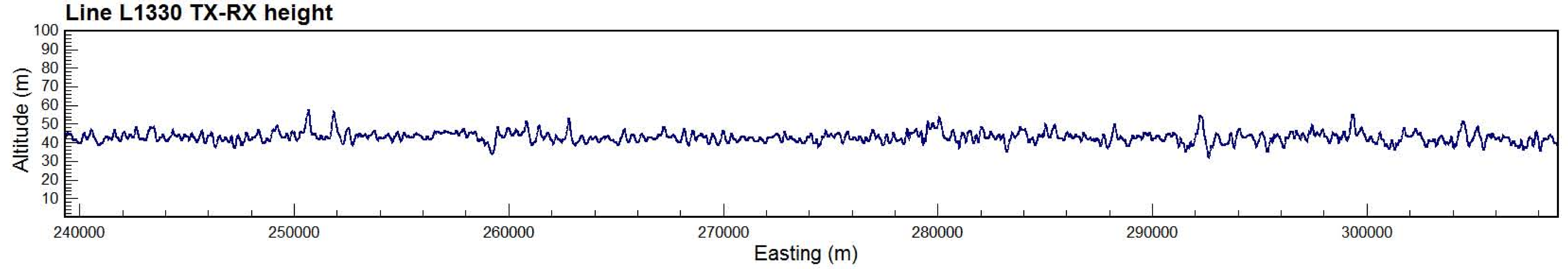
FLIGHT PATH



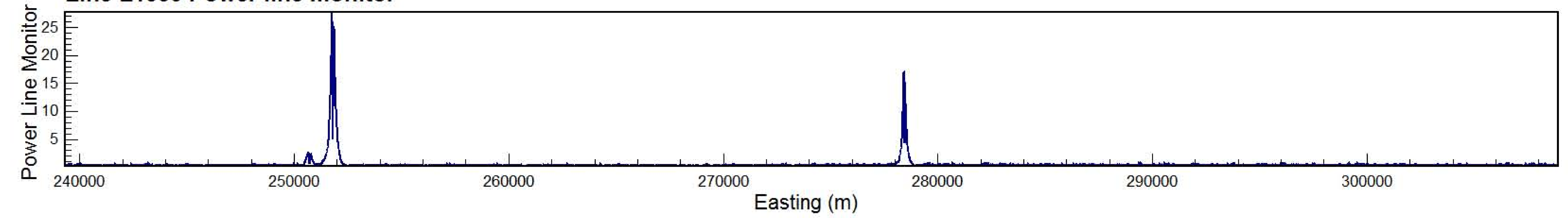
Line L1330 TX-RX pitch and roll



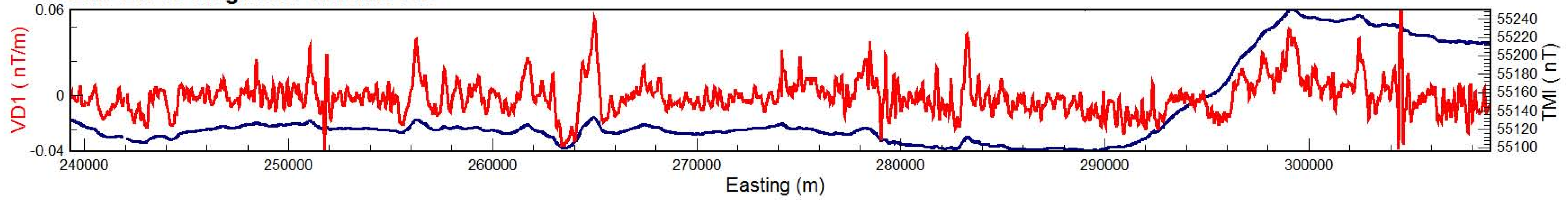
Line L1330 TX-RX height



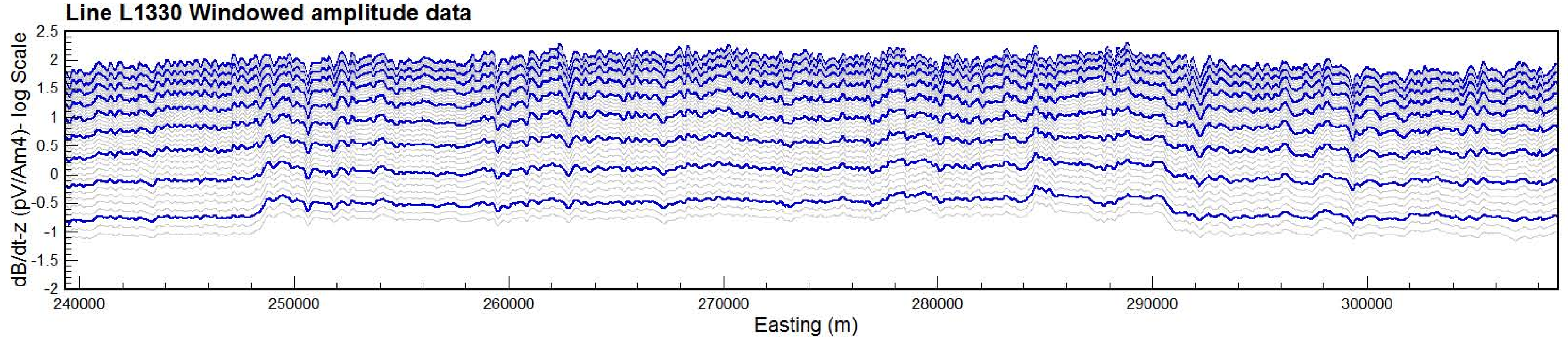
Line L1330 Power line monitor



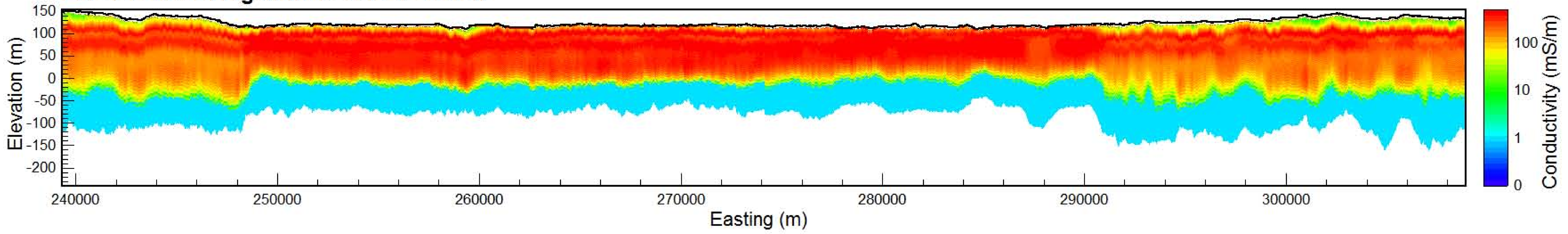
Line L1330 Magnetics TMI and 1VD



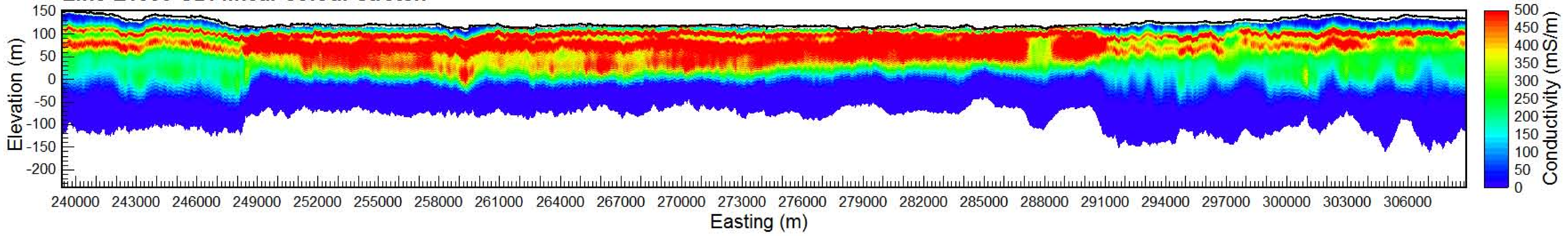
Line L1330 Windowed amplitude data



Line L1330 CDI logarithmic colour stretch



Line L1330 CDI linear colour stretch



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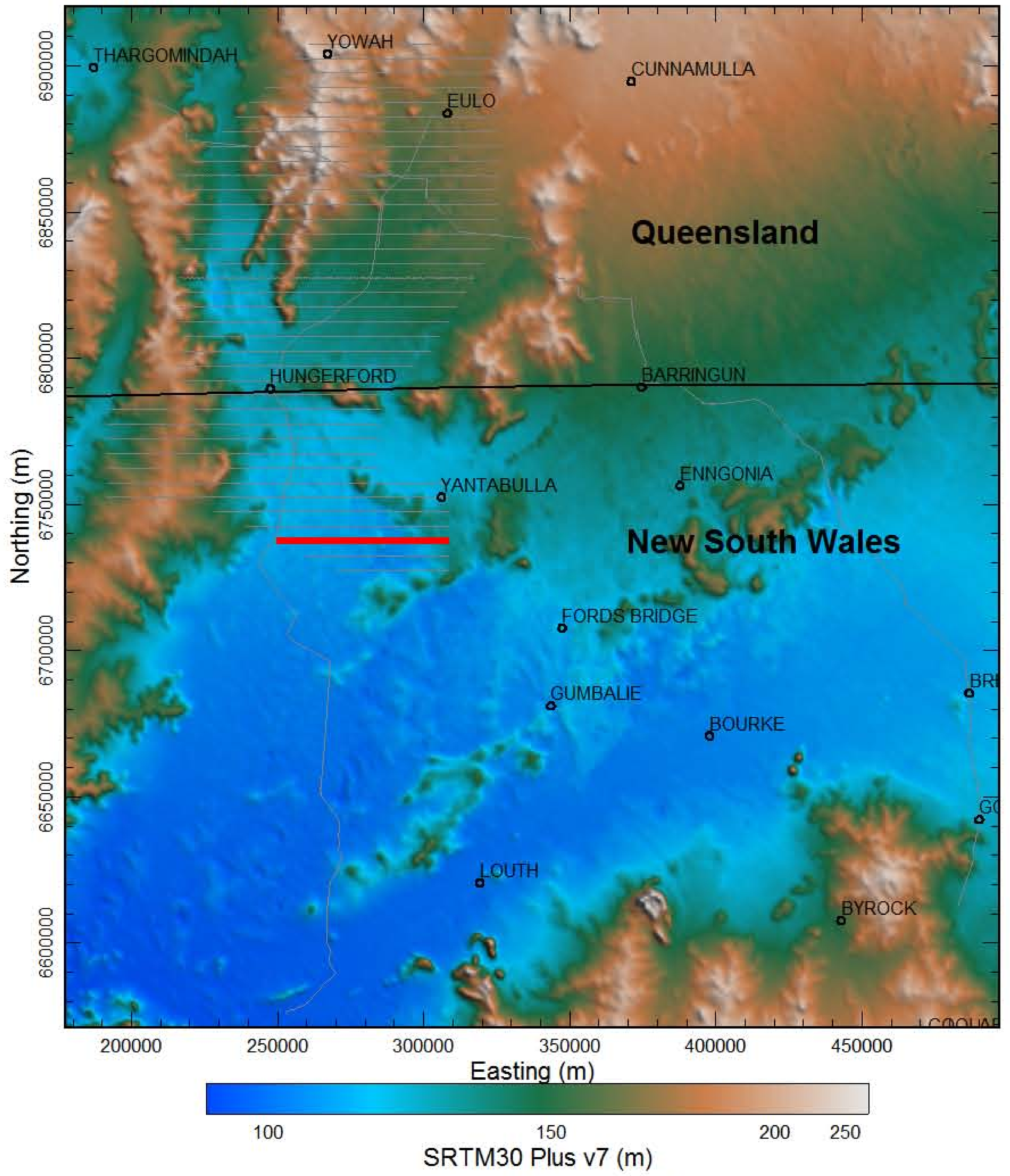
FLIGHT PATH



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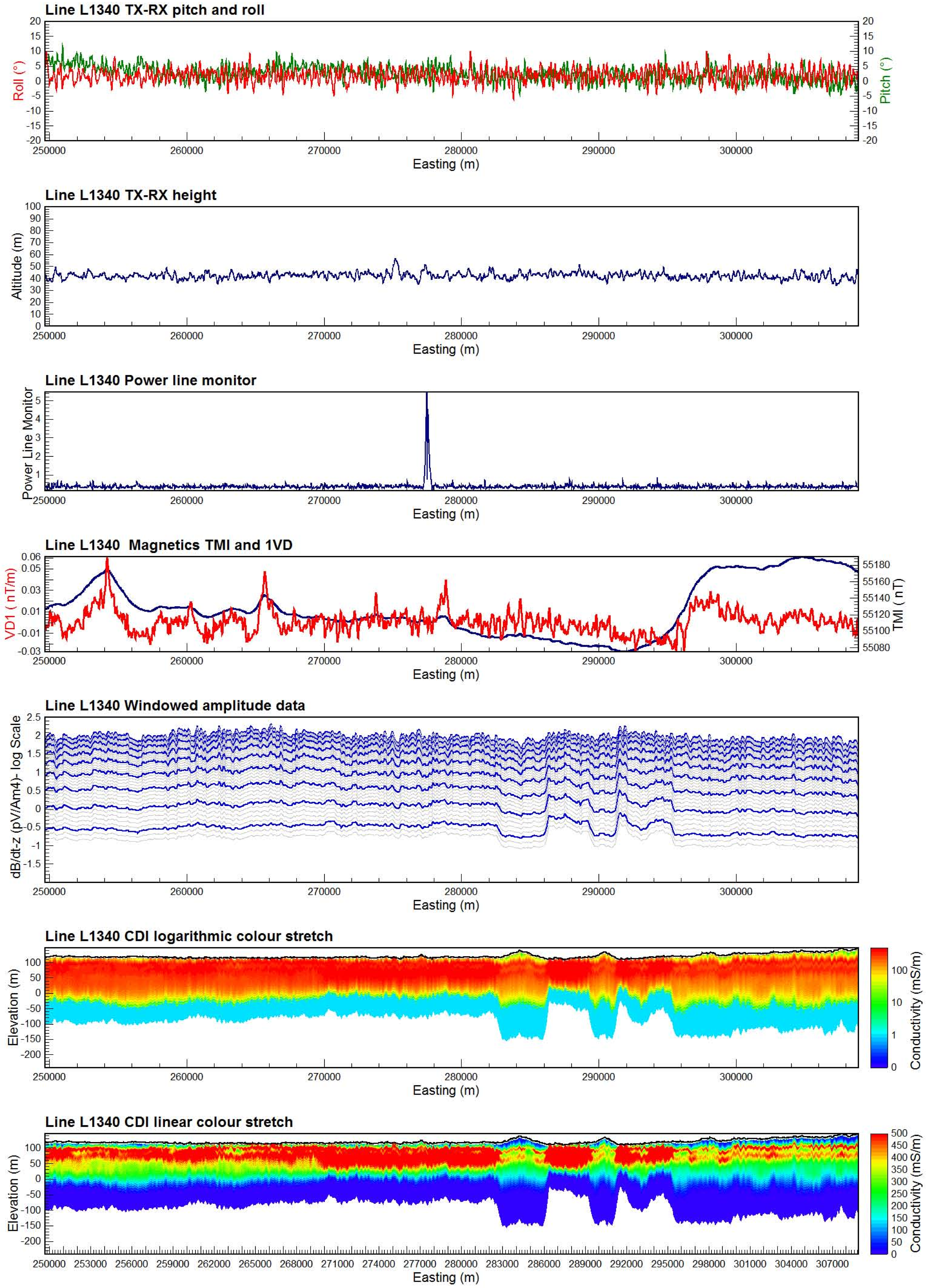
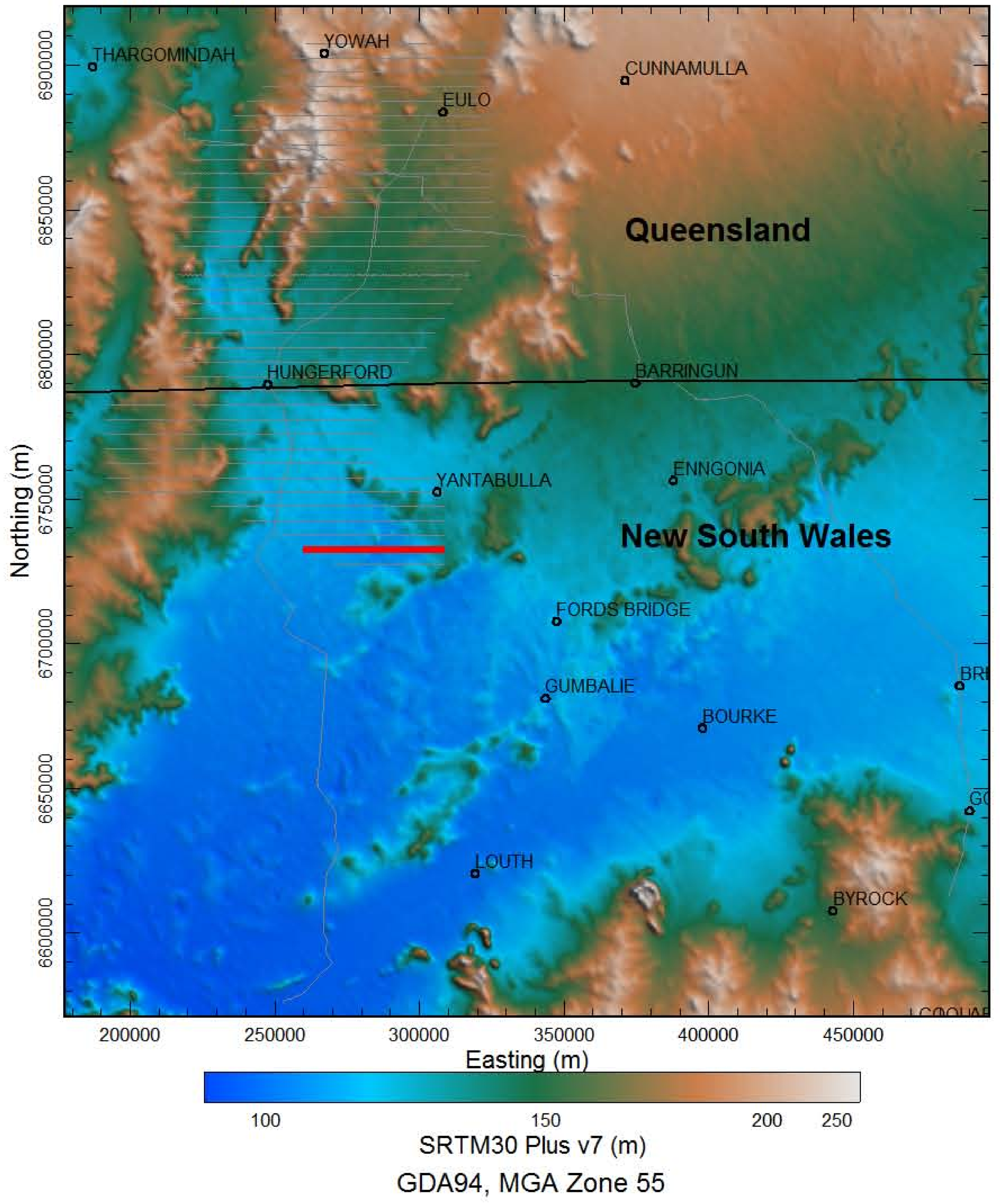


FLIGHT PATH



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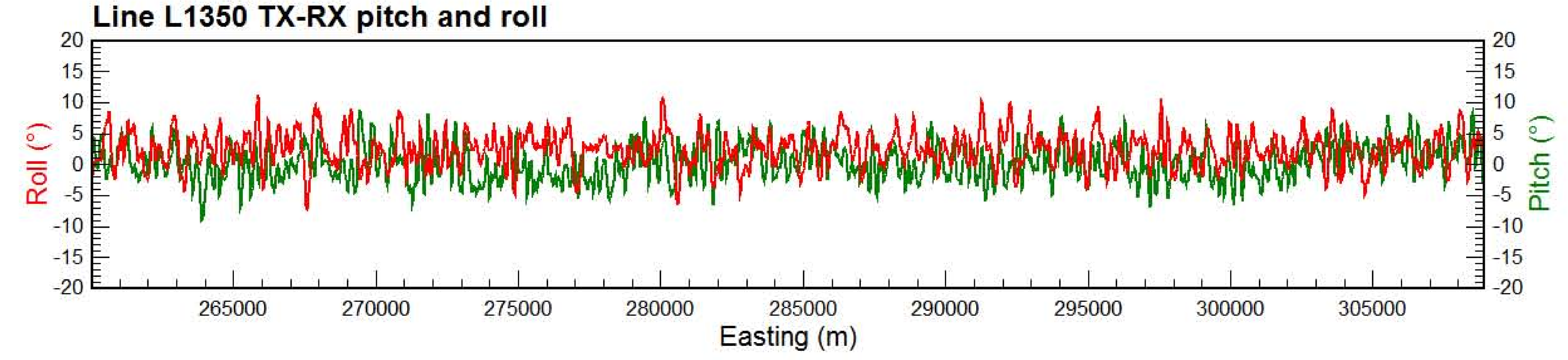
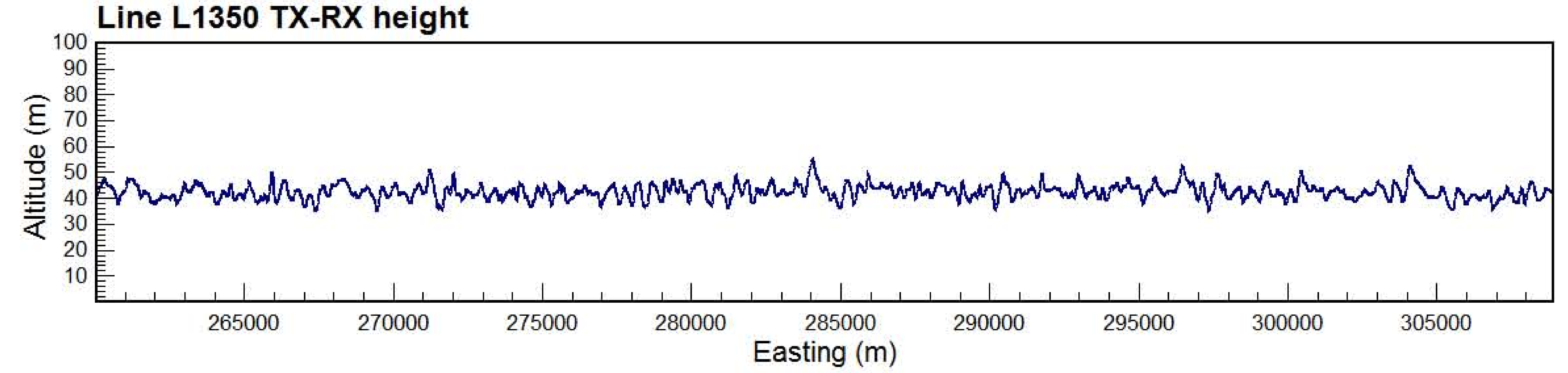
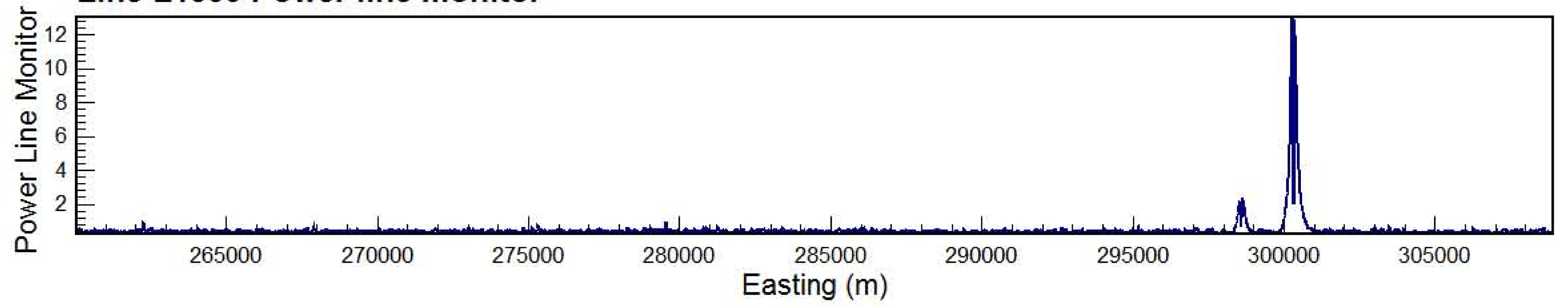
Line L1350 TX-RX pitch and roll



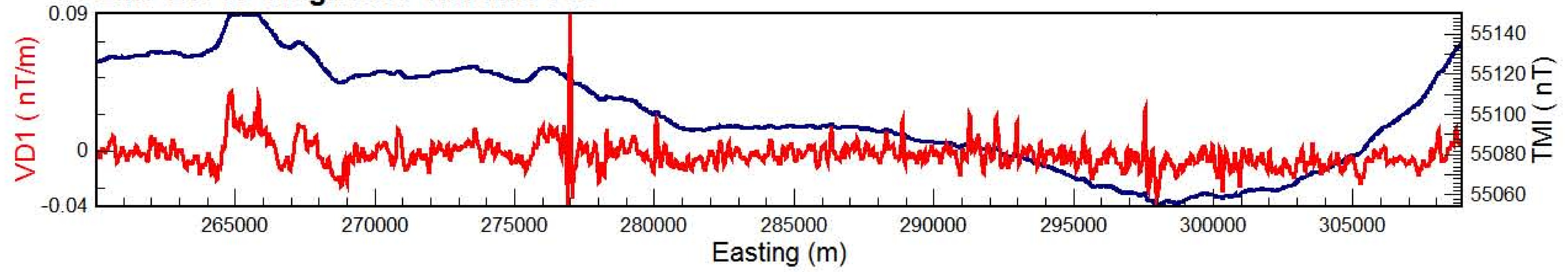
Line L1350 TX-RX height



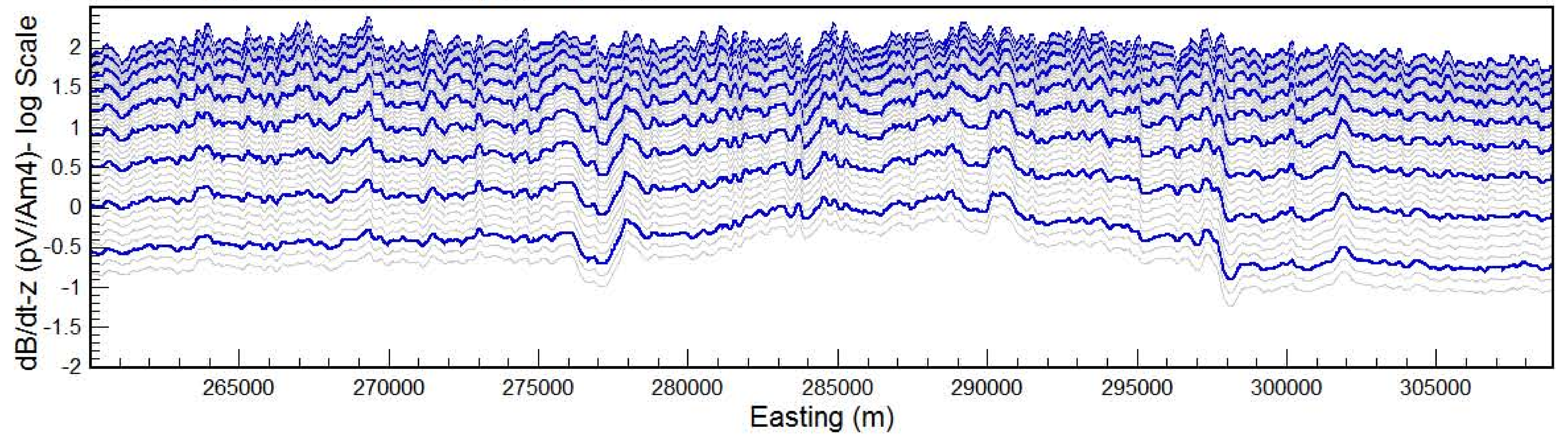
Line L1350 Power line monitor



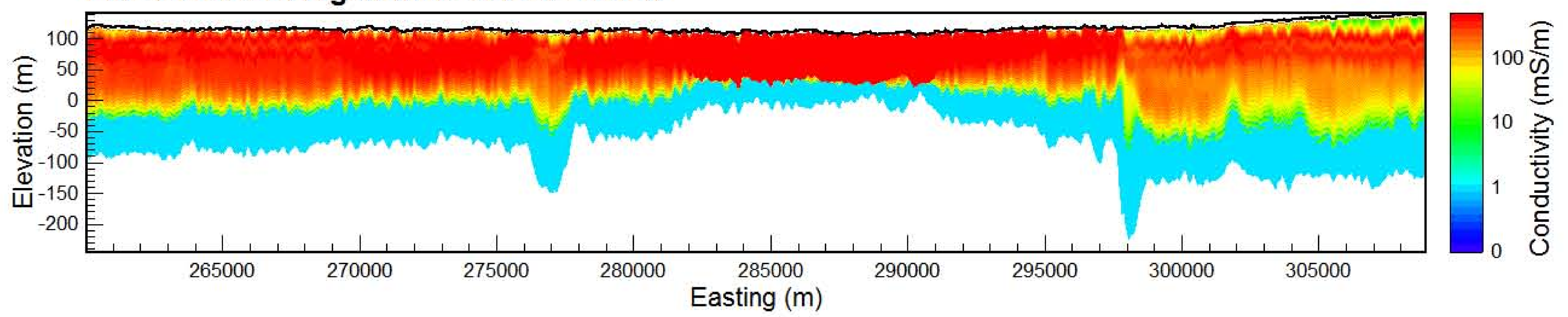
Line L1350 Magnetics TMI and 1VD



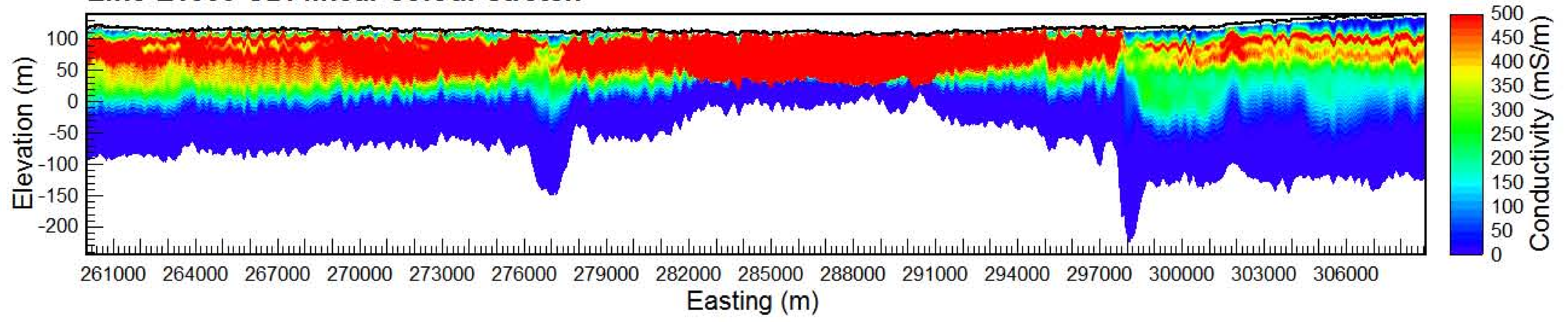
Line L1350 Windowed amplitude data



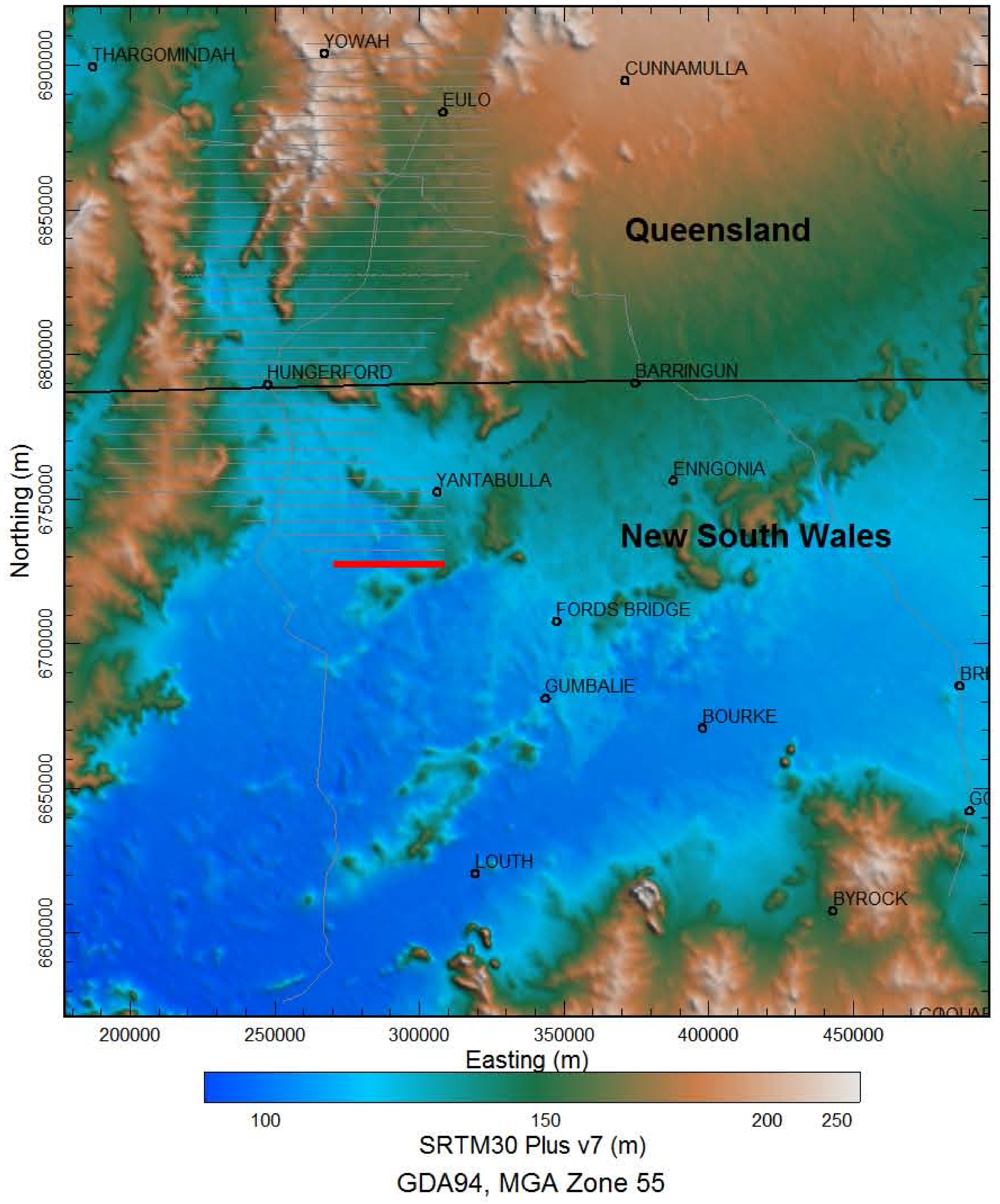
Line L1350 CDI logarithmic colour stretch



Line L1350 CDI linear colour stretch



FLIGHT PATH



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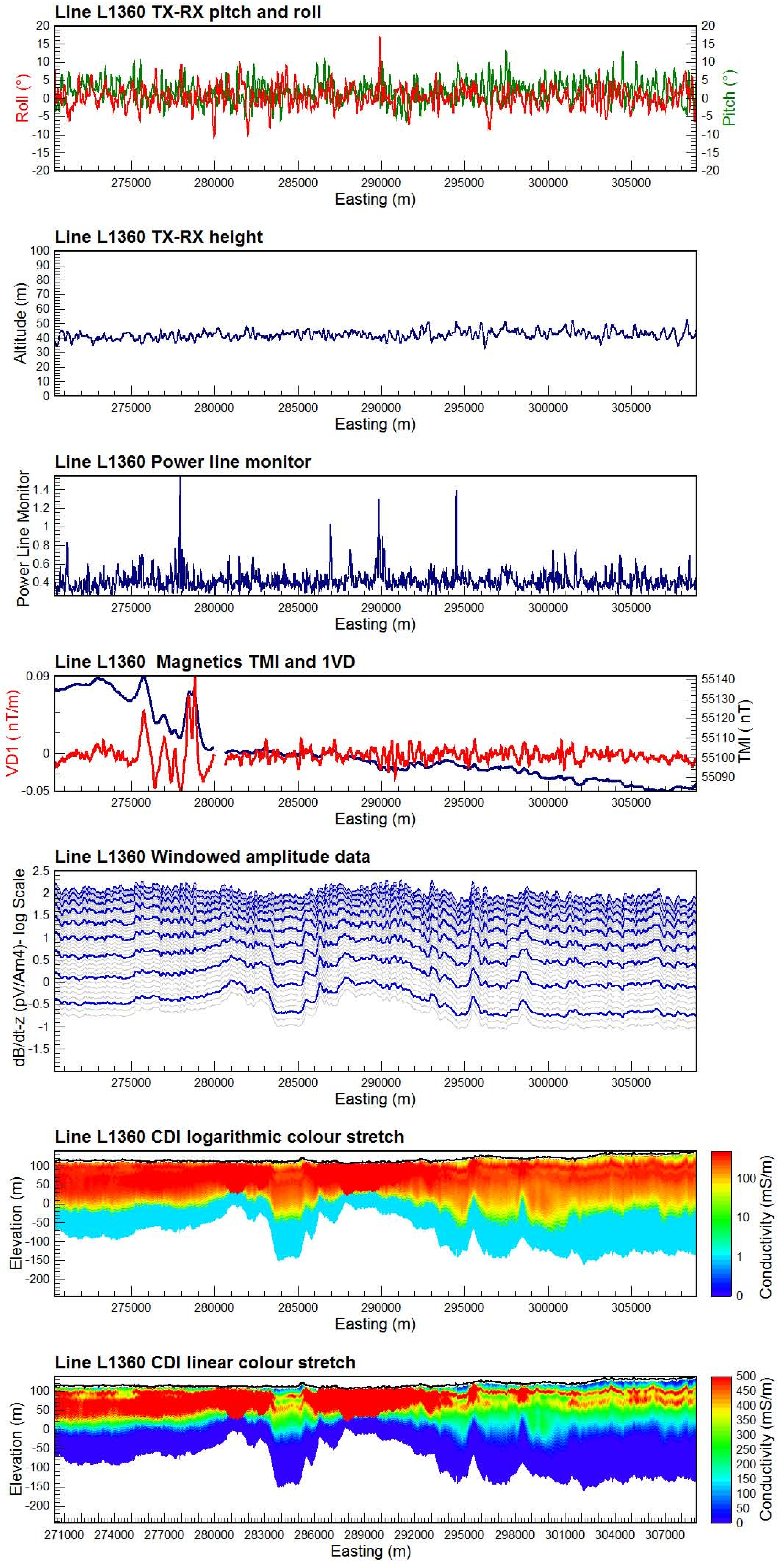
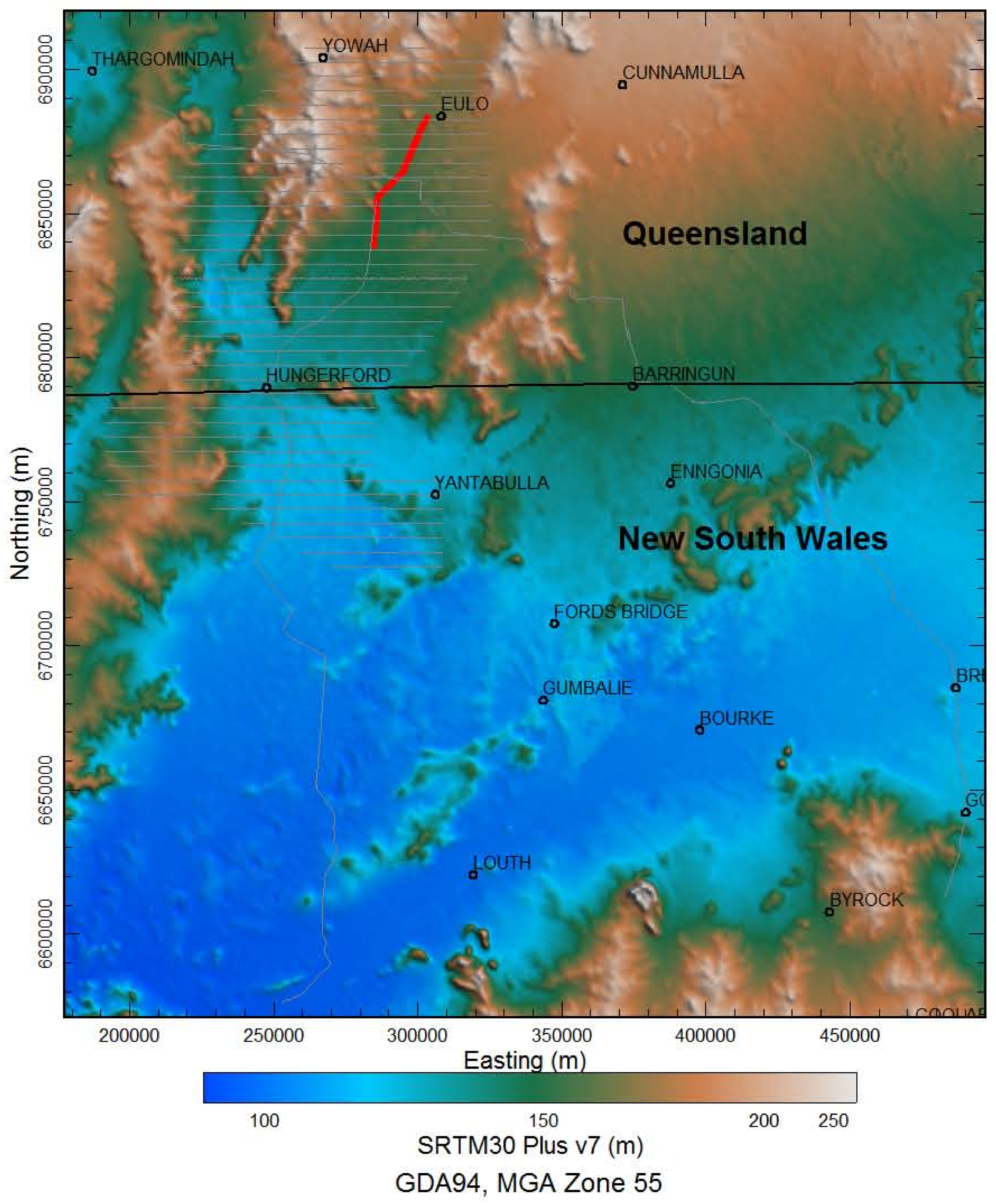


FLIGHT PATH



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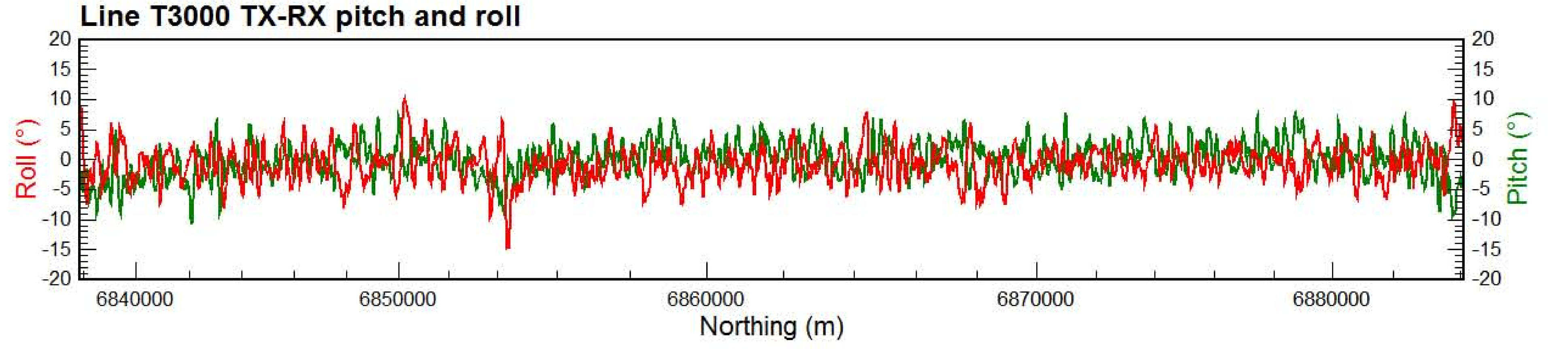
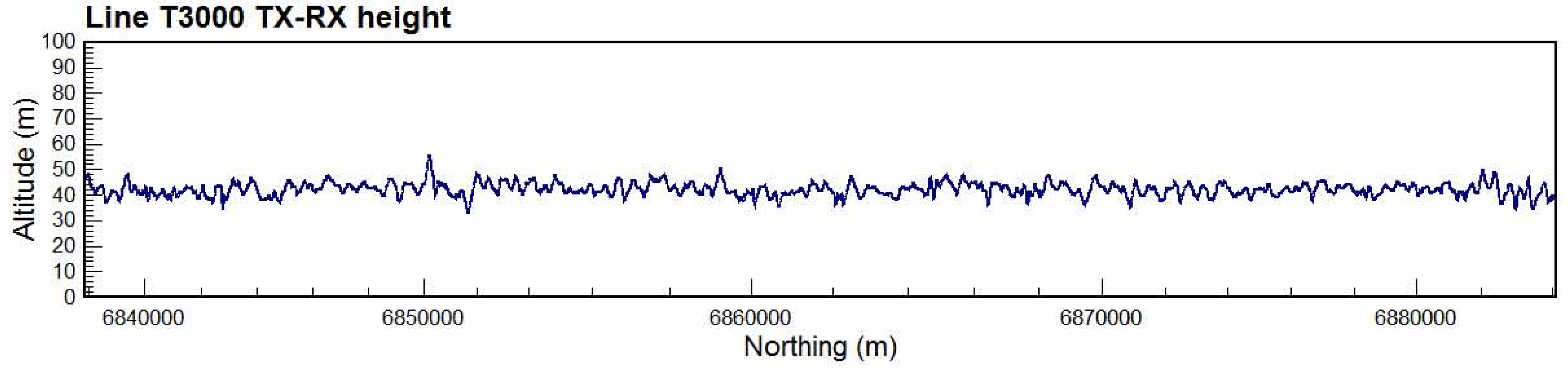
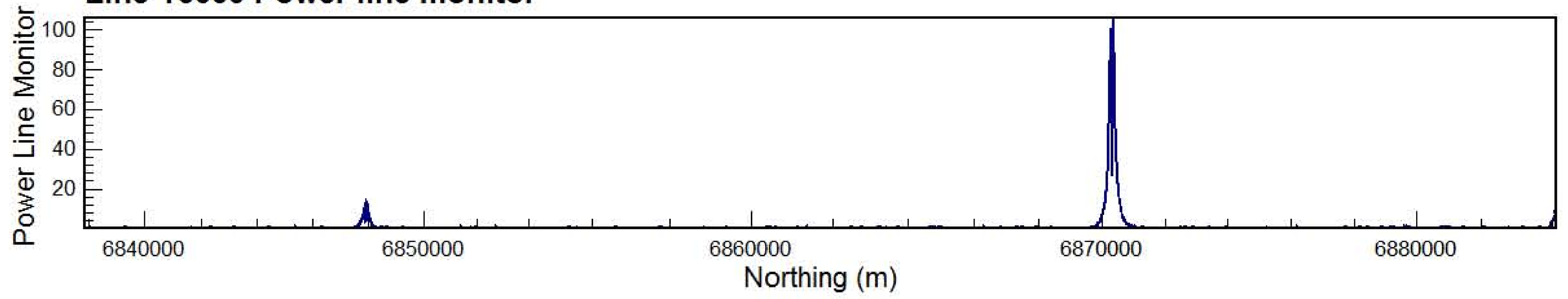
Line T3000 TX-RX pitch and roll



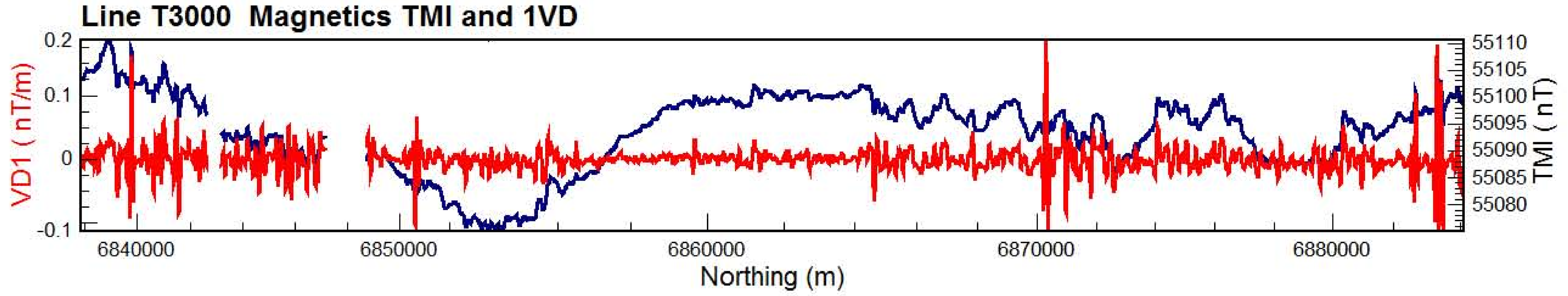
Line T3000 TX-RX height



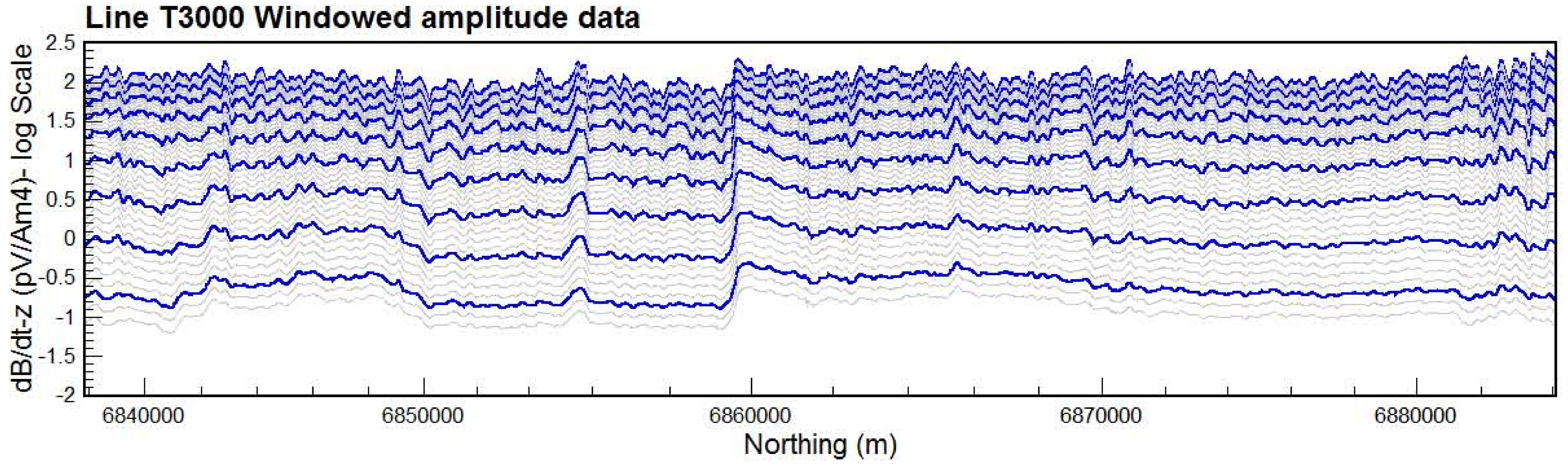
Line T3000 Power line monitor



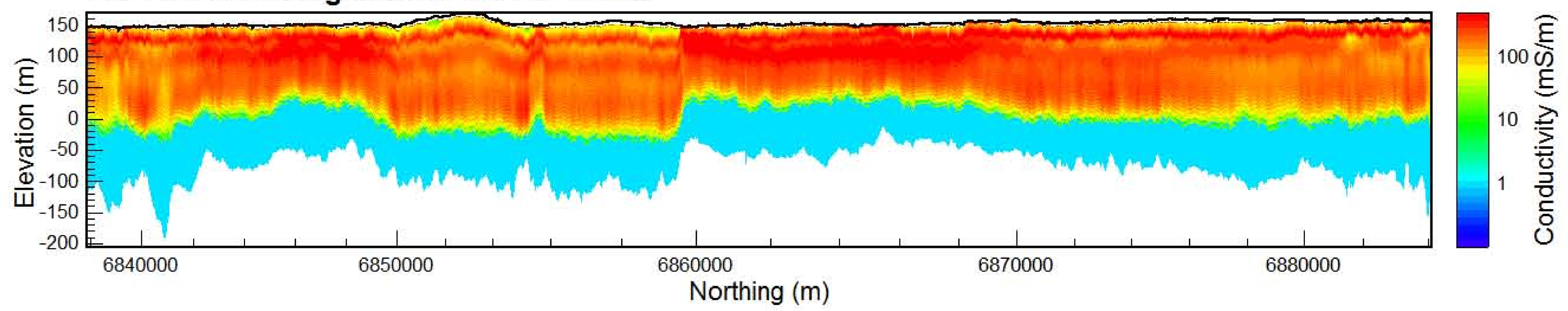
Line T3000 Magnetics TMI and 1VD



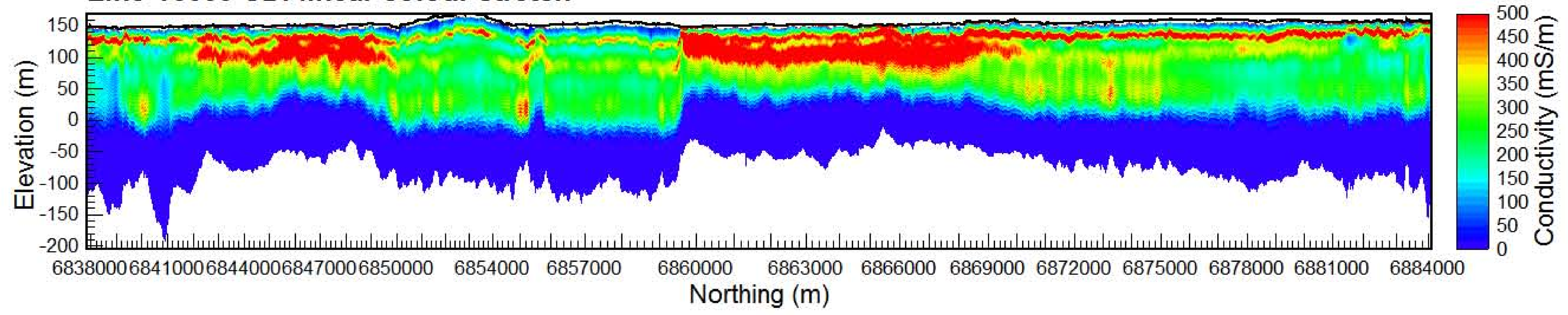
Line T3000 Windowed amplitude data



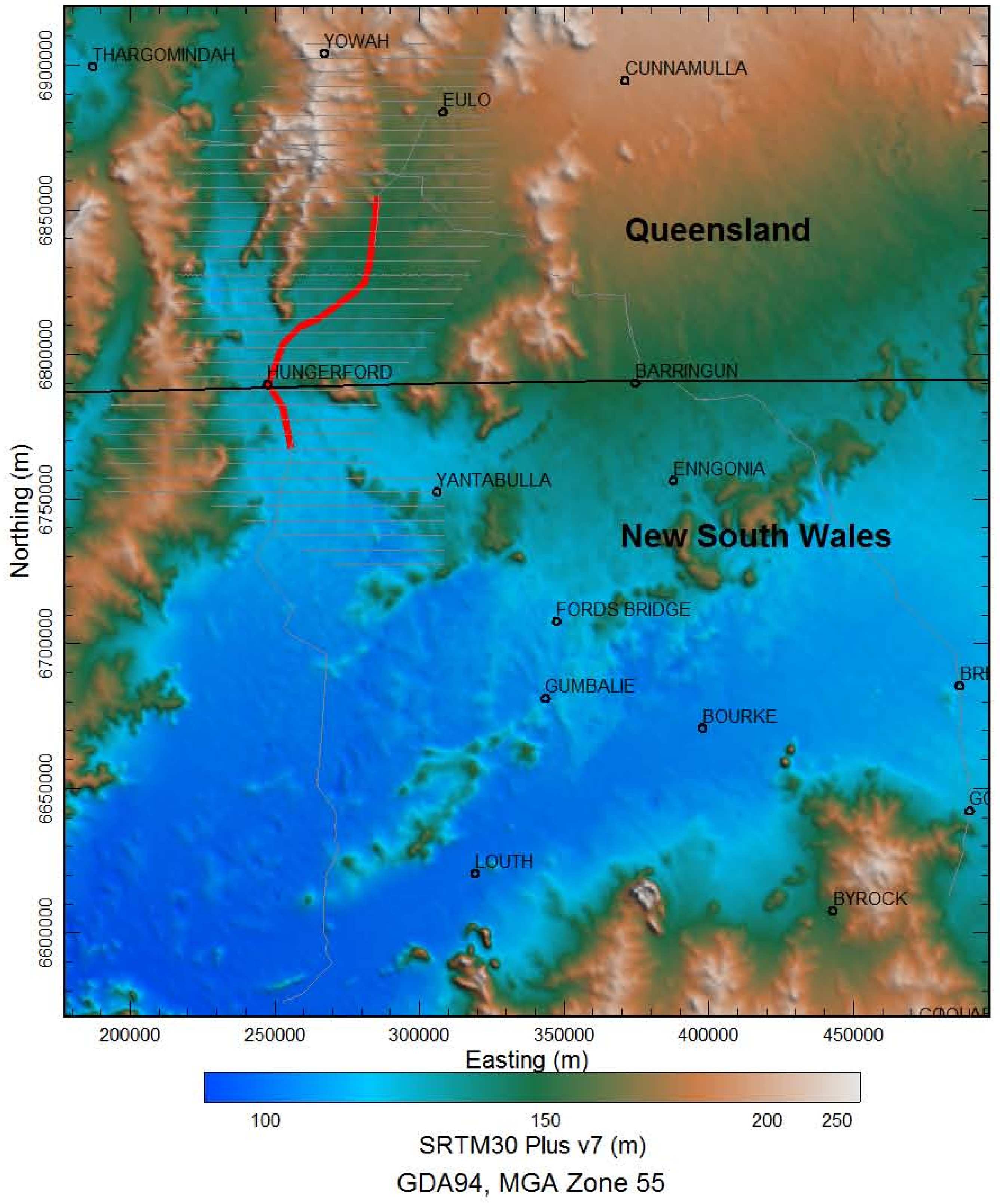
Line T3000 CDI logarithmic colour stretch



Line T3000 CDI linear colour stretch



FLIGHT PATH



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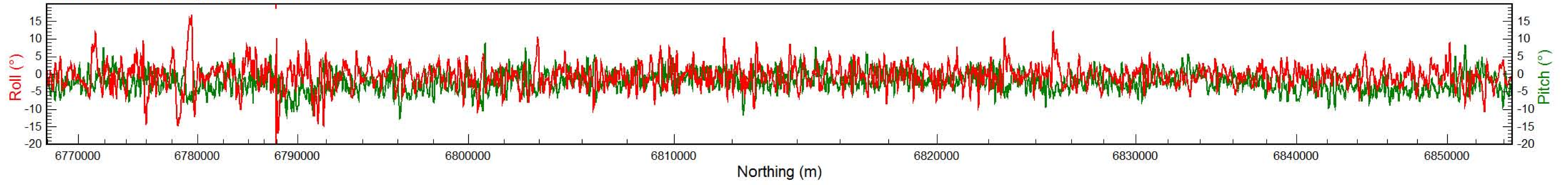
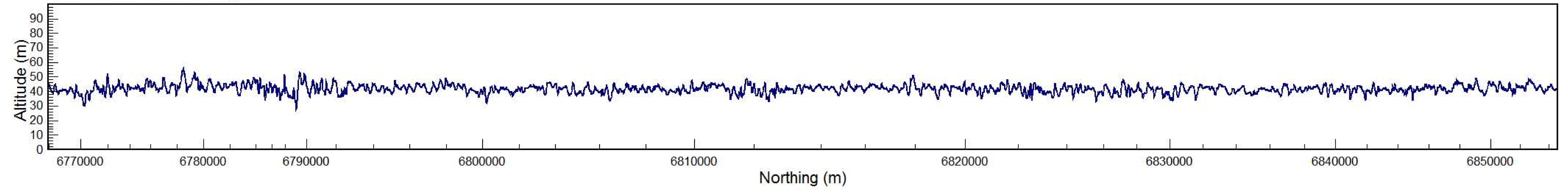
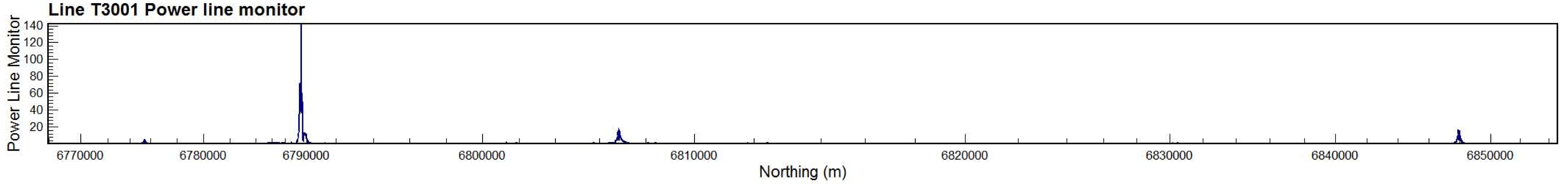
Line T3001 TX-RX pitch and roll



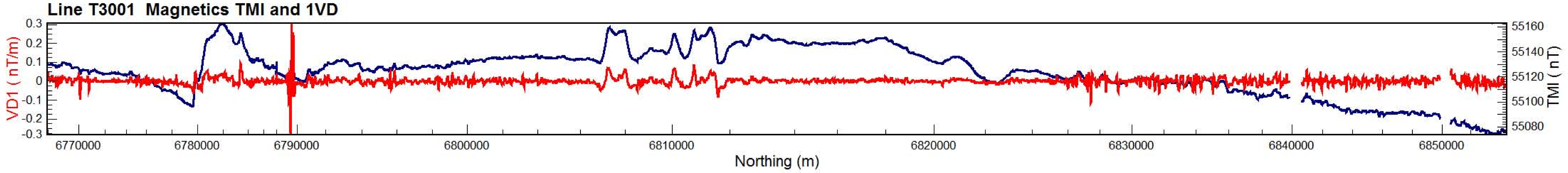
Line T3001 TX-RX height



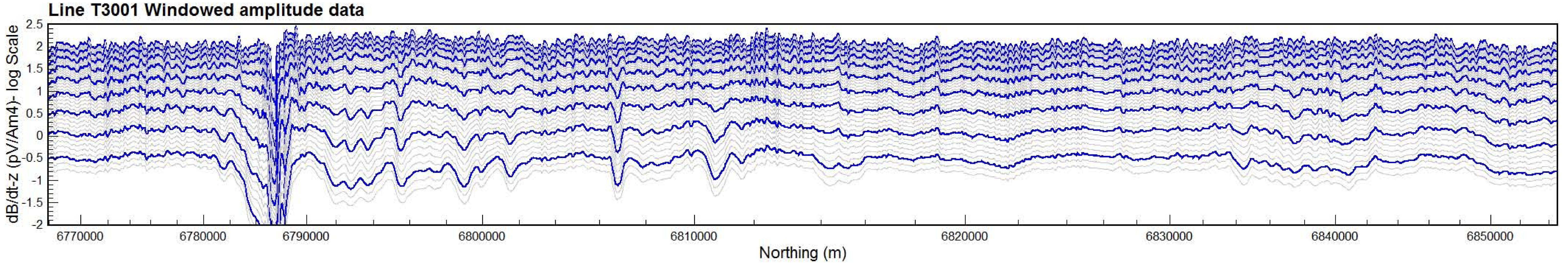
Line T3001 Power line monitor



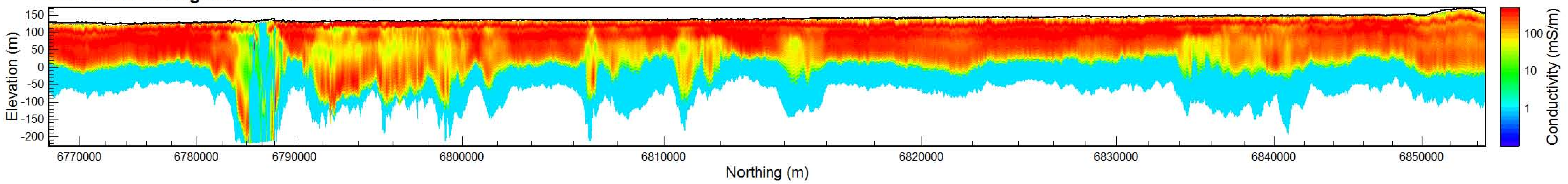
Line T3001 Magnetics TMI and 1VD



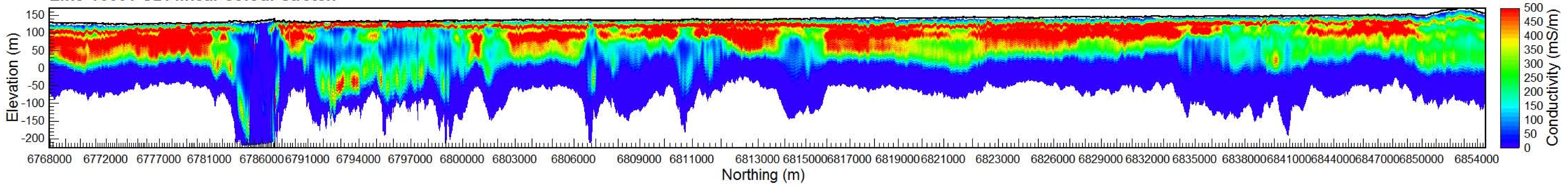
Line T3001 Windowed amplitude data



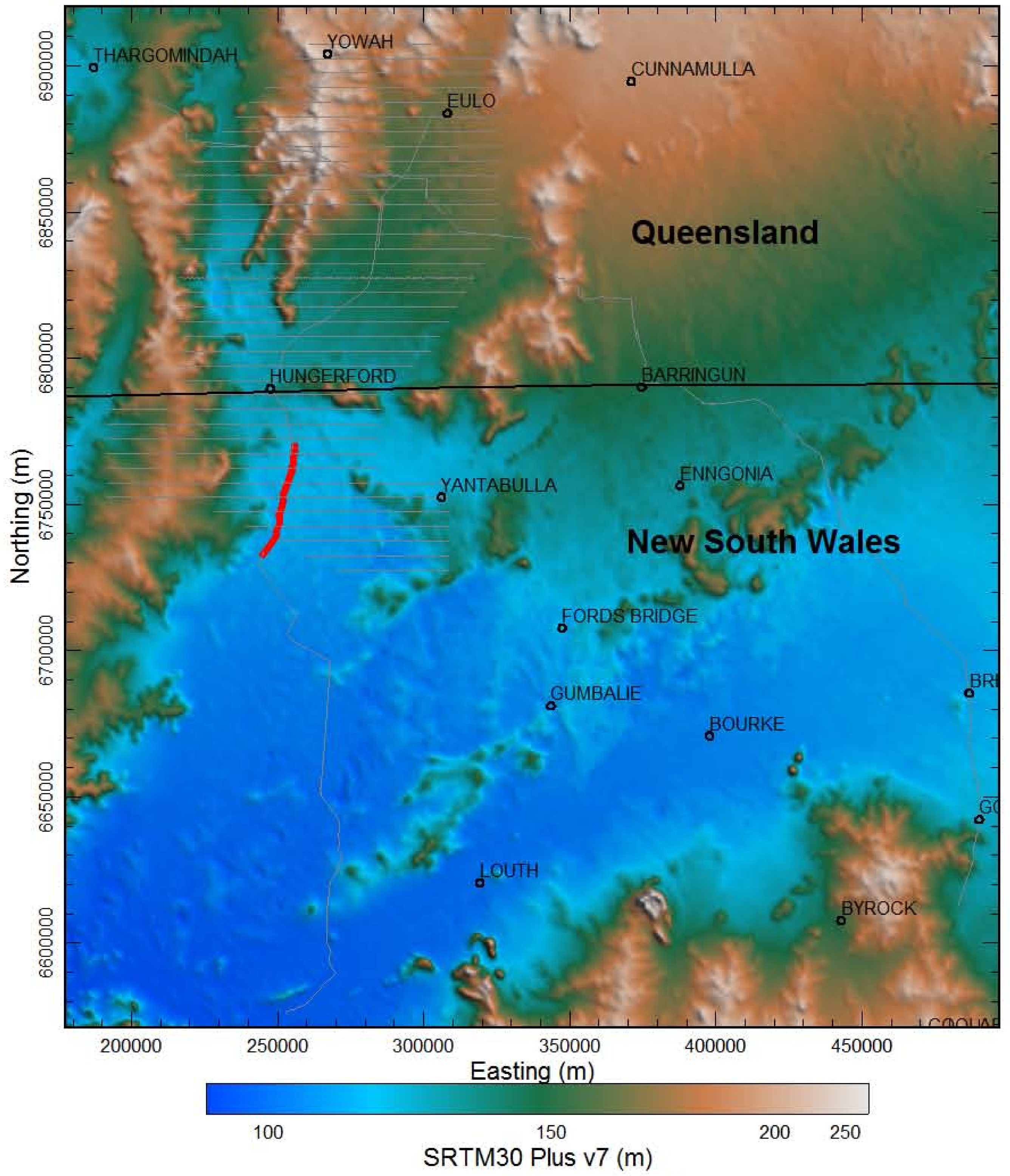
Line T3001 CDI logarithmic colour stretch



Line T3001 CDI linear colour stretch



FLIGHT PATH



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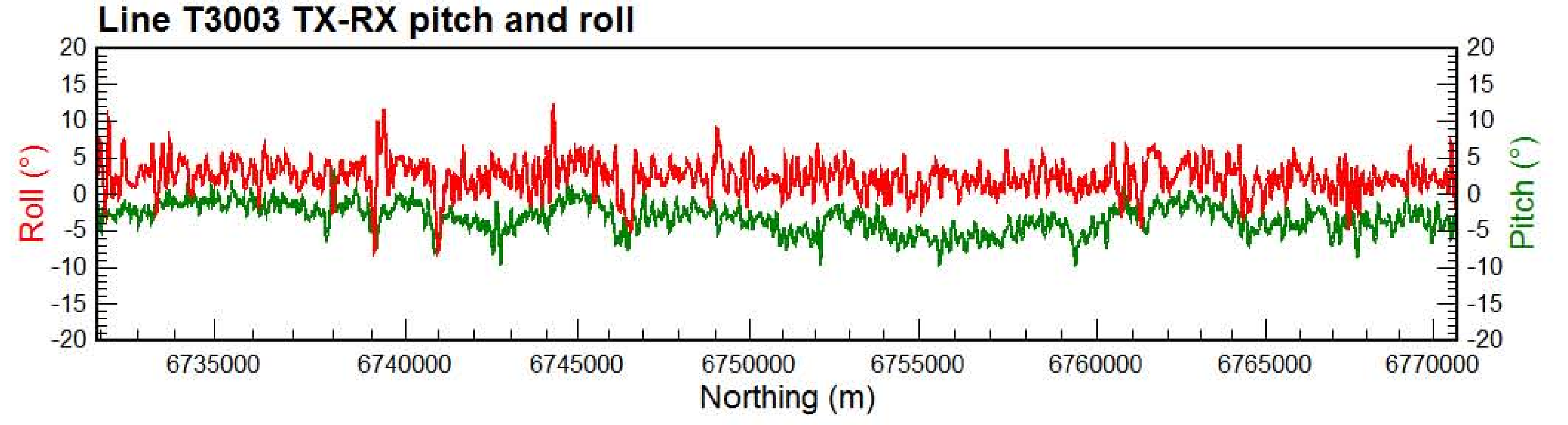
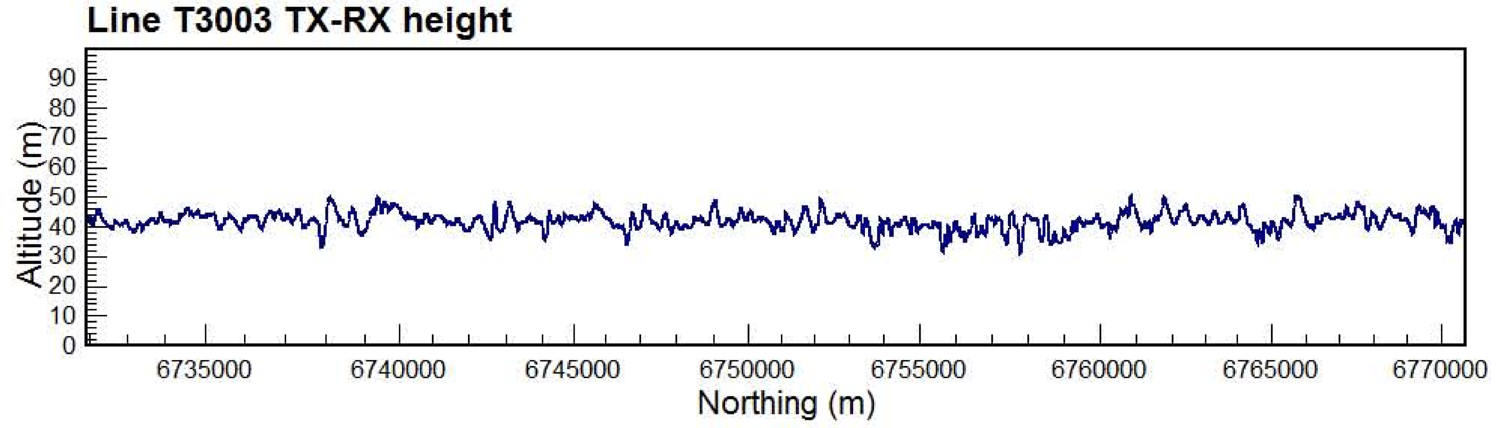
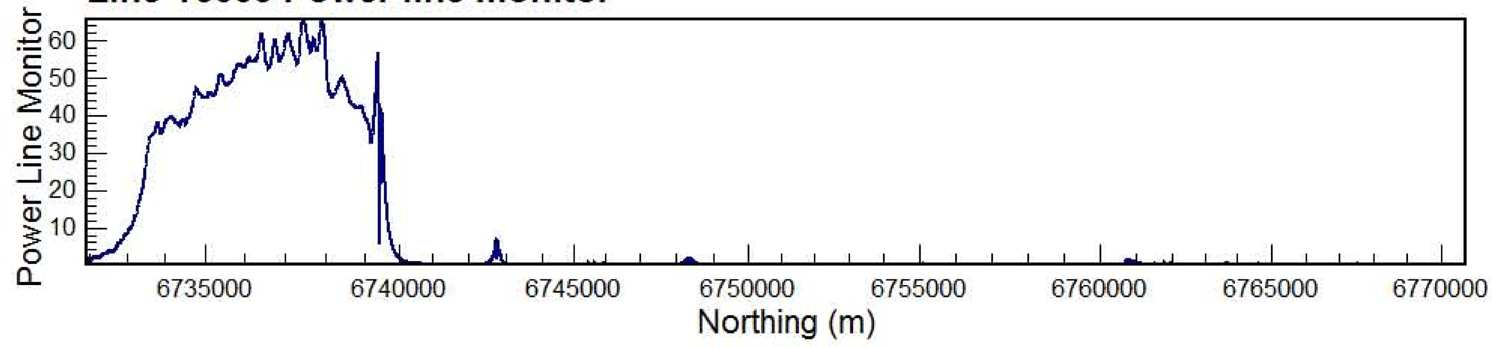
Line T3003 TX-RX pitch and roll



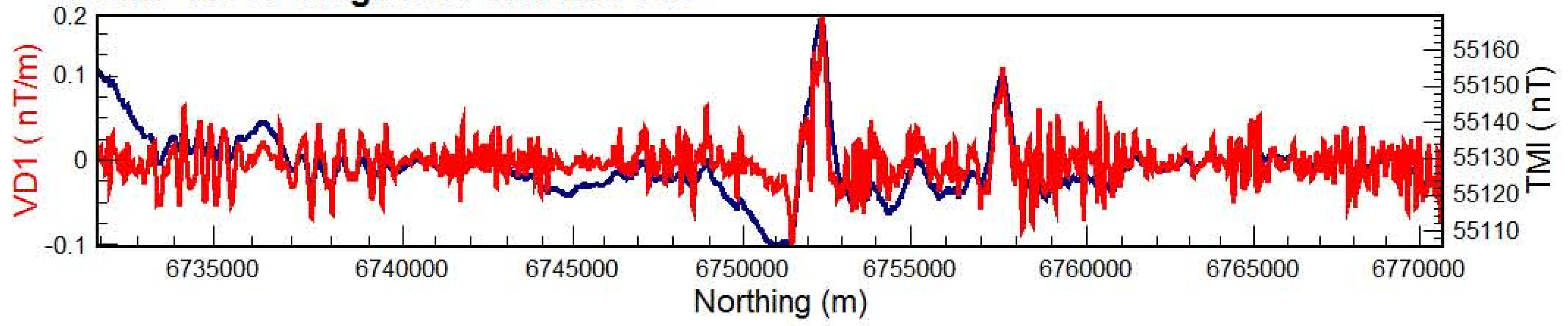
Line T3003 TX-RX height



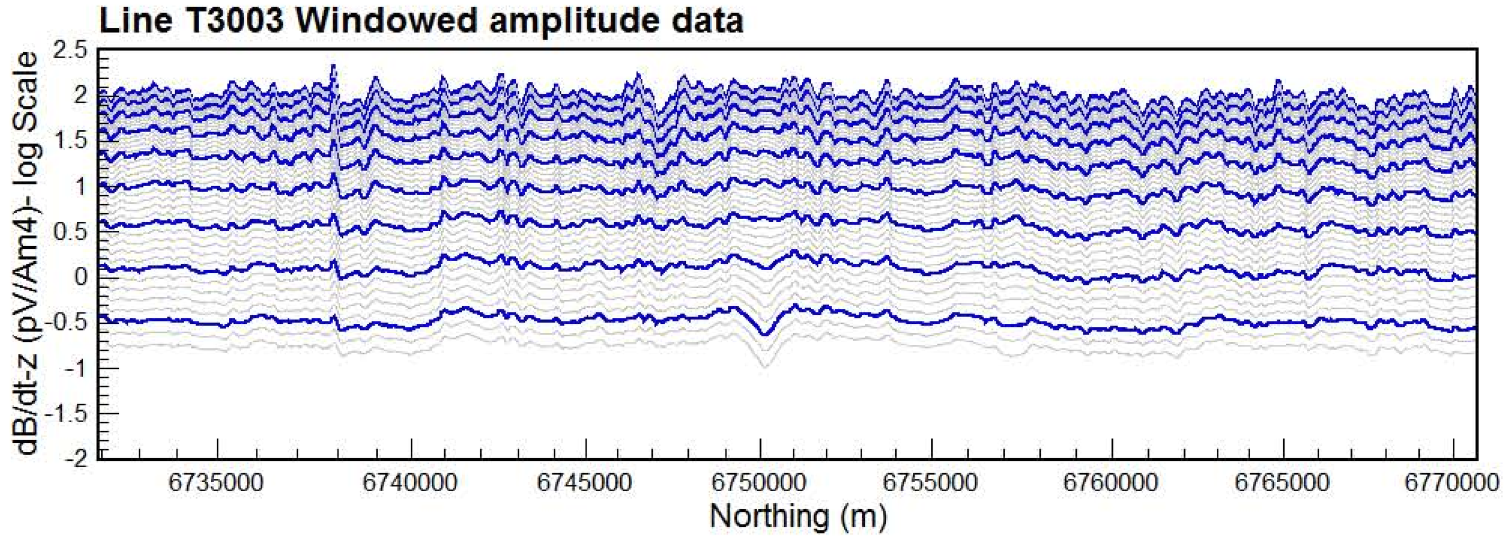
Line T3003 Power line monitor



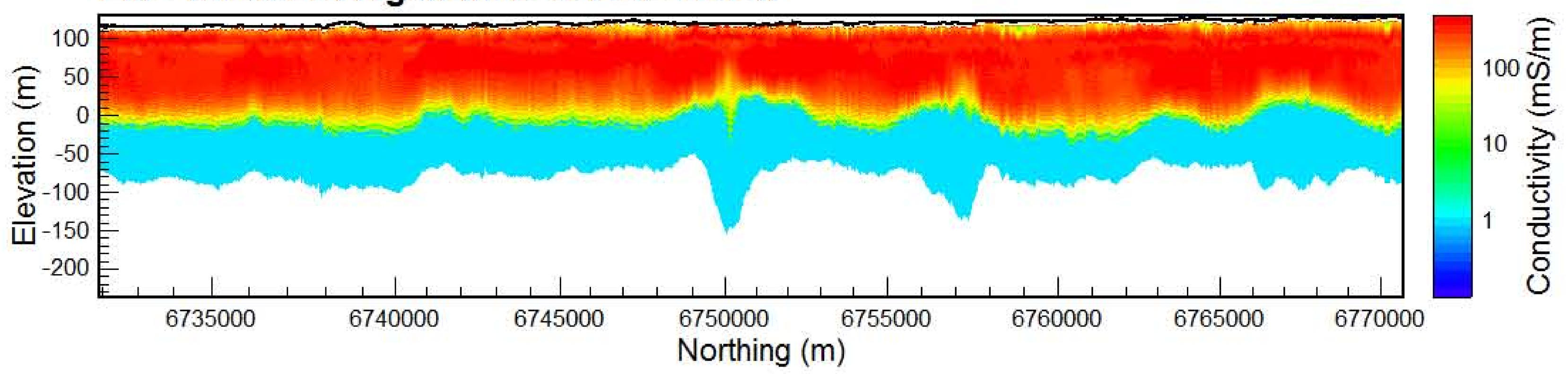
Line T3003 Magnetics TMI and 1VD



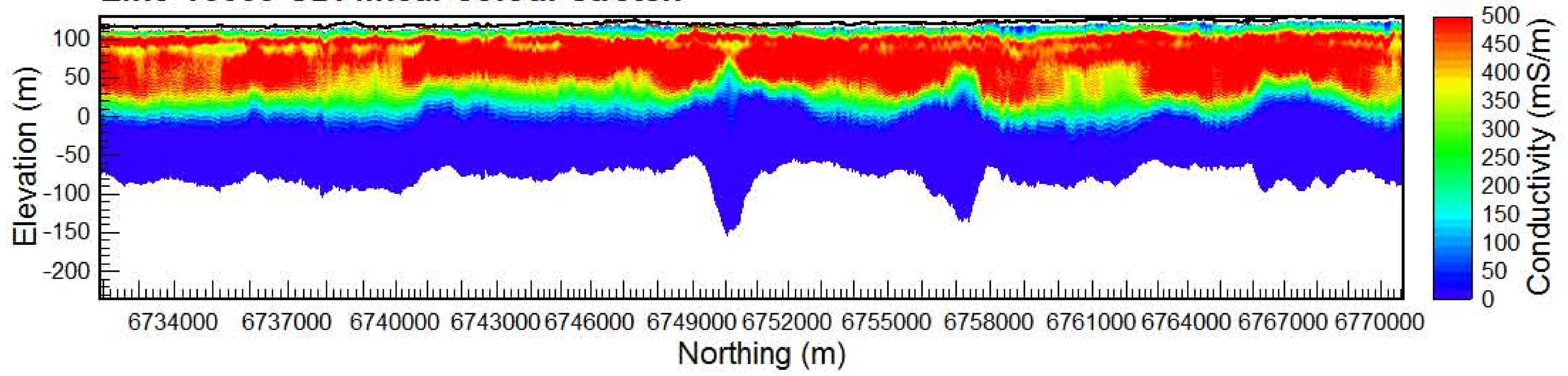
Line T3003 Windowed amplitude data



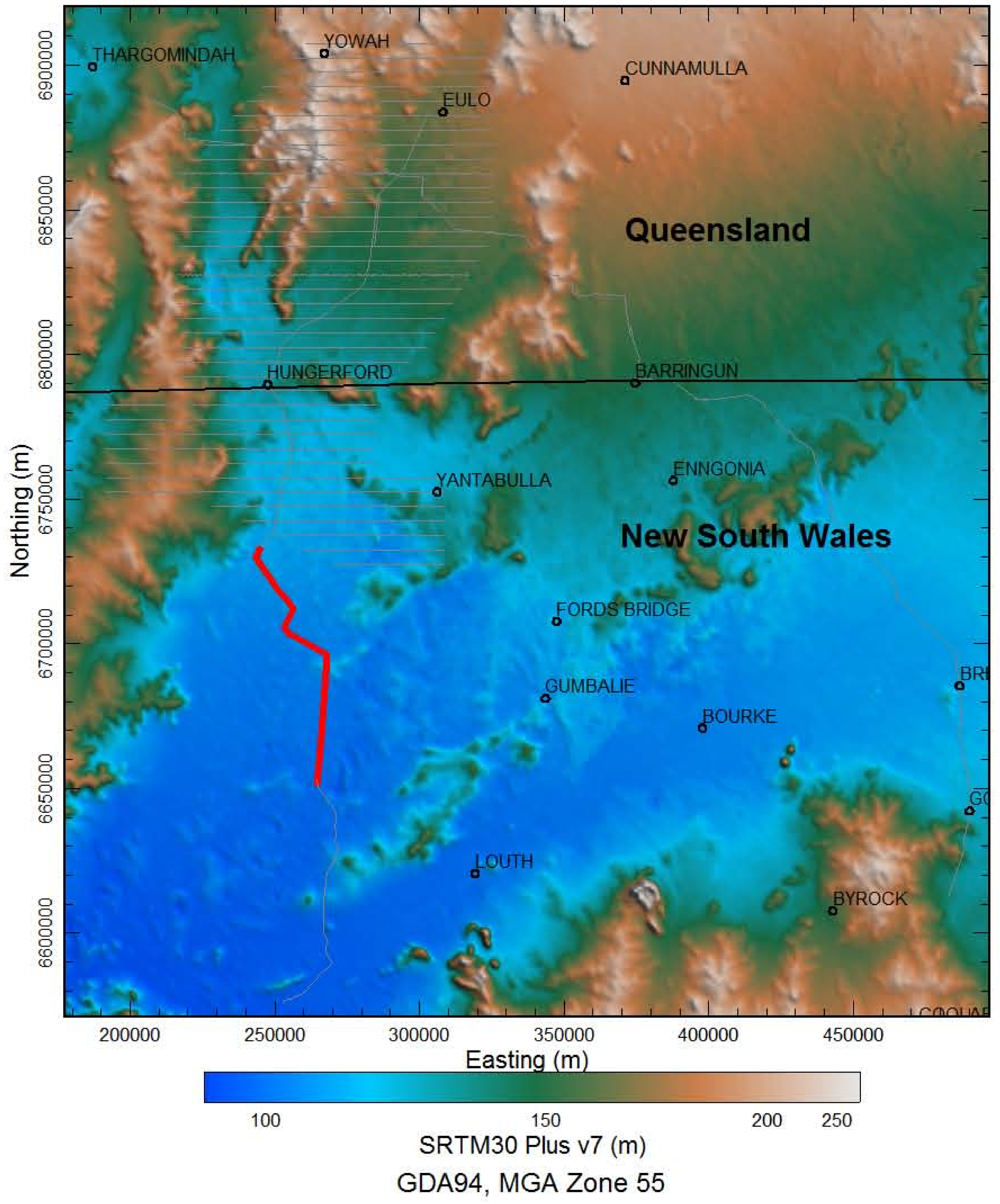
Line T3003 CDI logarithmic colour stretch



Line T3003 CDI linear colour stretch



FLIGHT PATH



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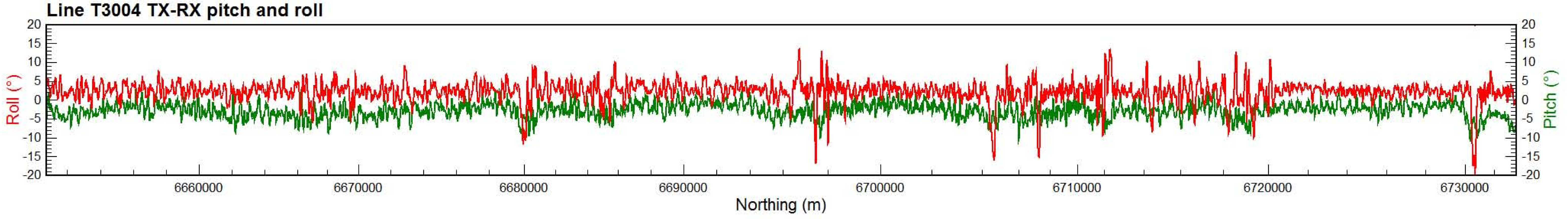
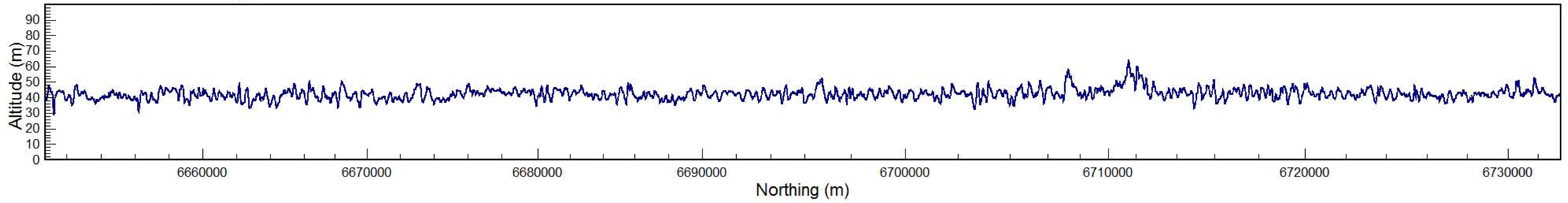
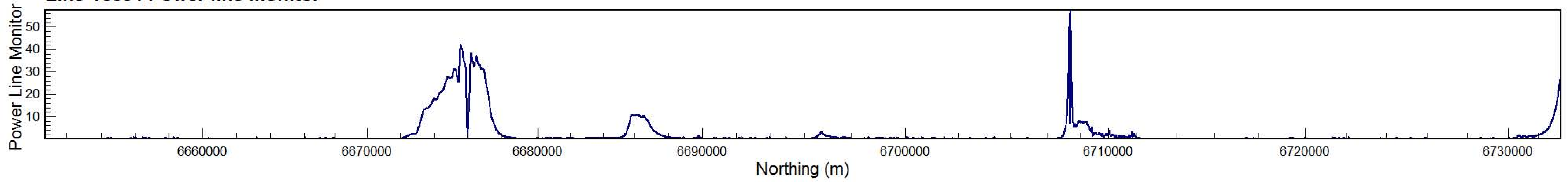
Line T3004 TX-RX pitch and roll



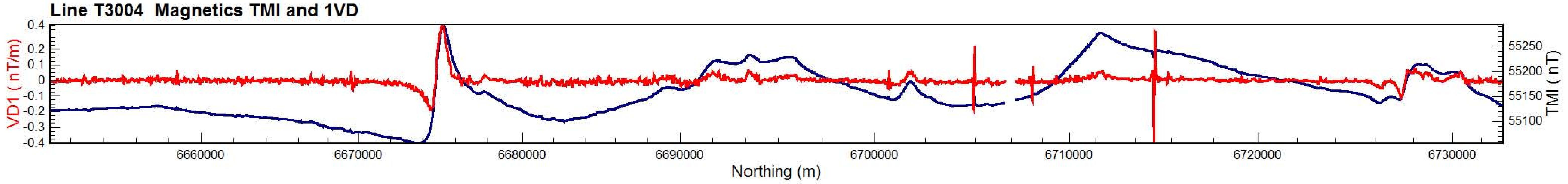
Line T3004 TX-RX height



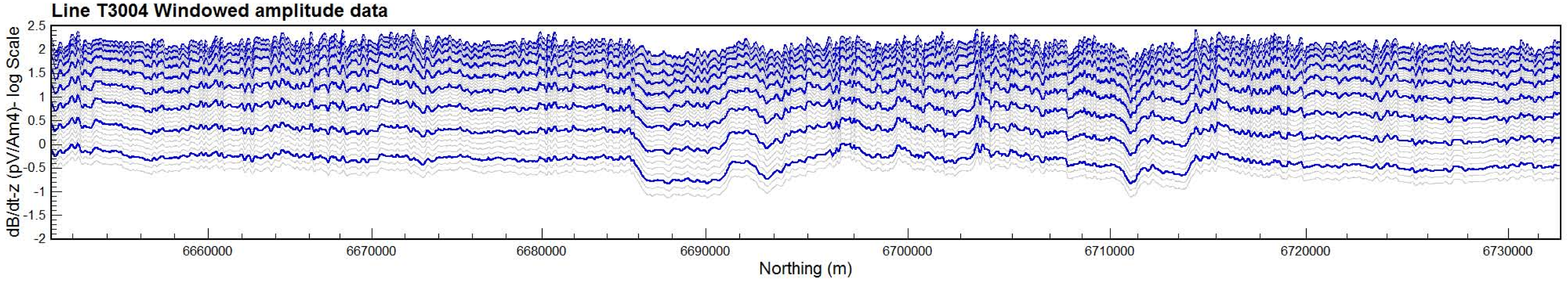
Line T3004 Power line monitor



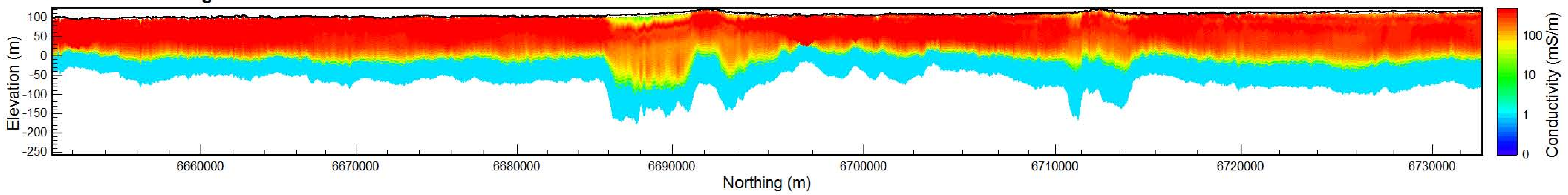
Line T3004 Magnetics TMI and 1VD



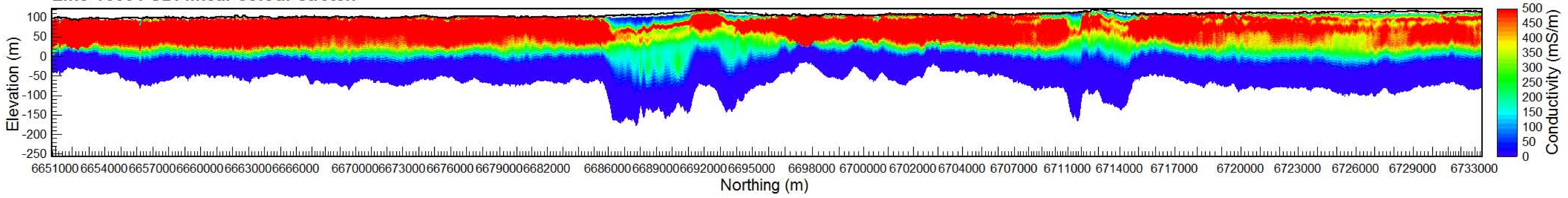
Line T3004 Windowed amplitude data



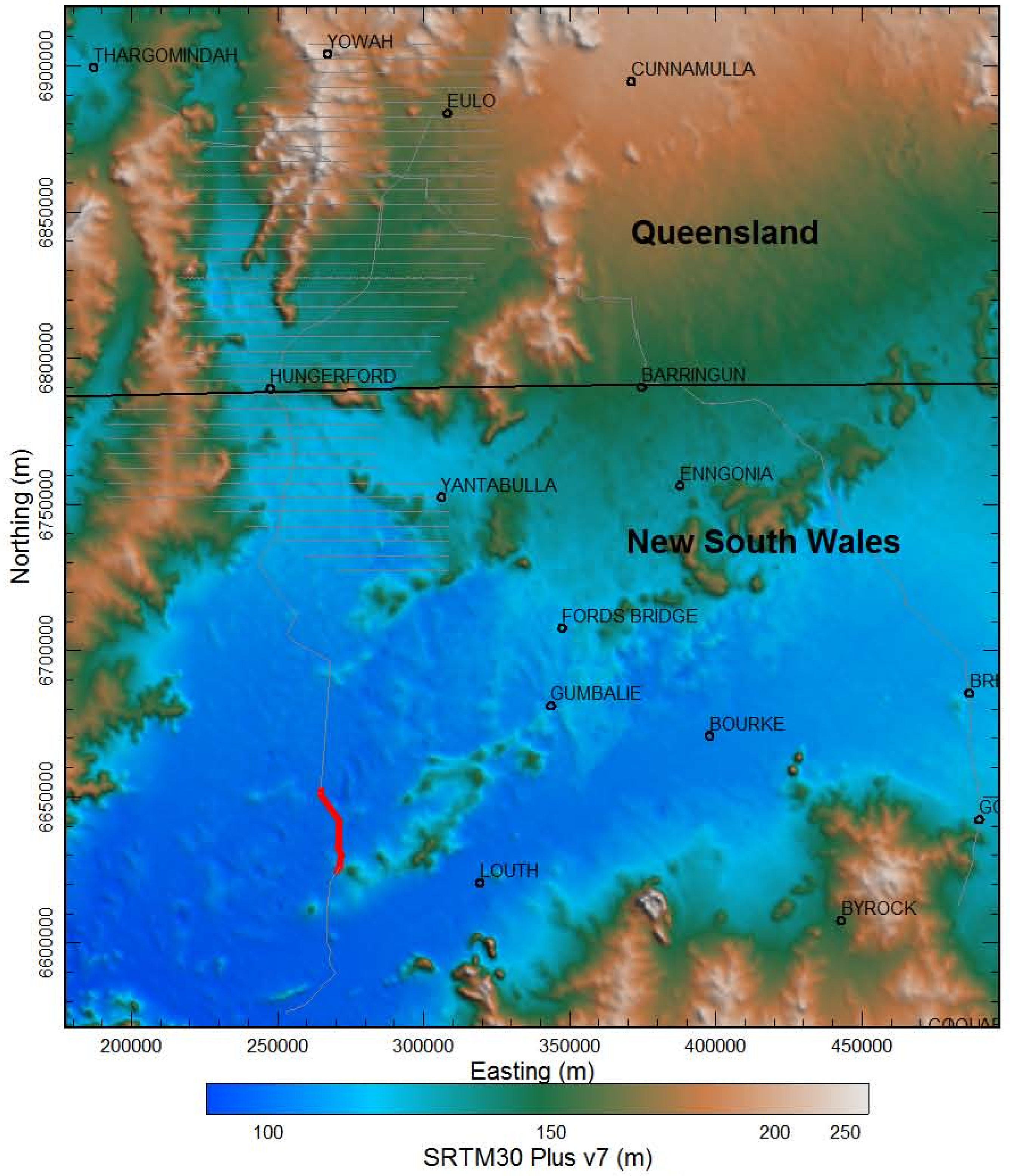
Line T3004 CDI logarithmic colour stretch



Line T3004 CDI linear colour stretch



FLIGHT PATH



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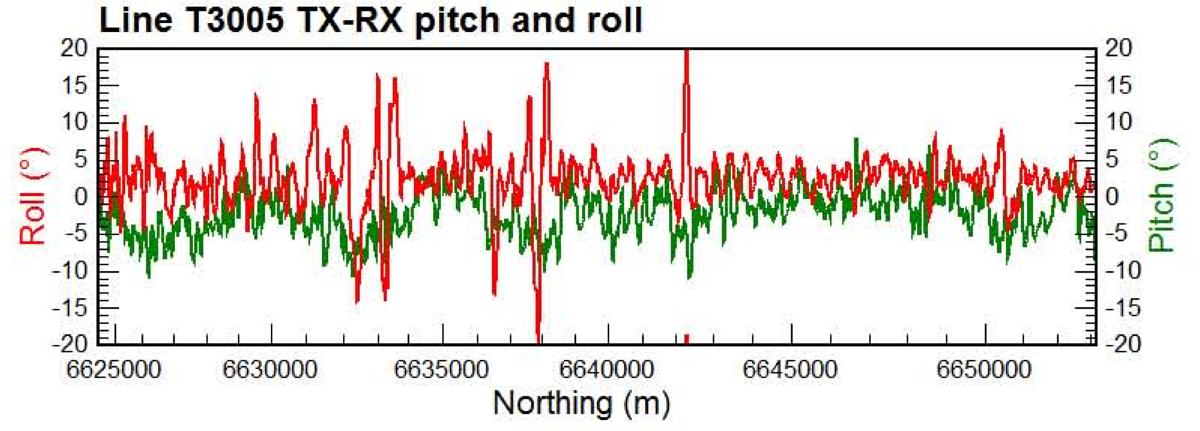
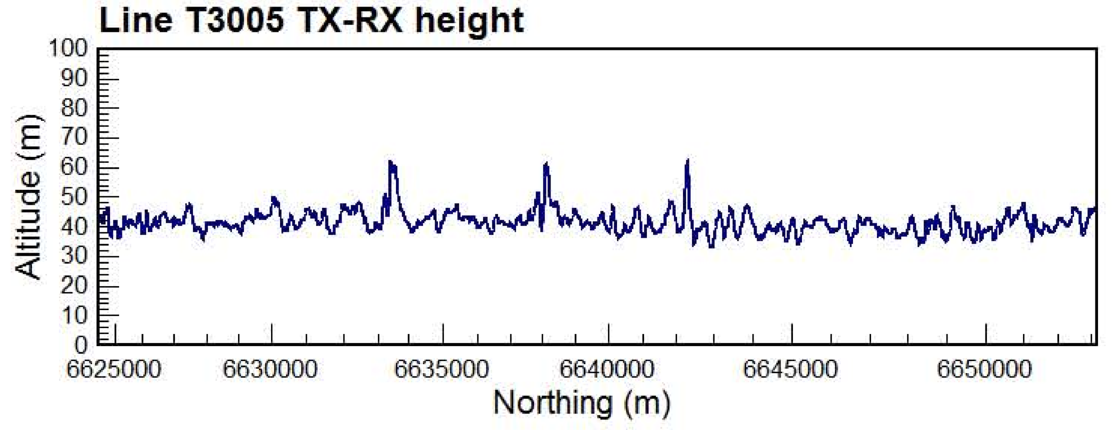
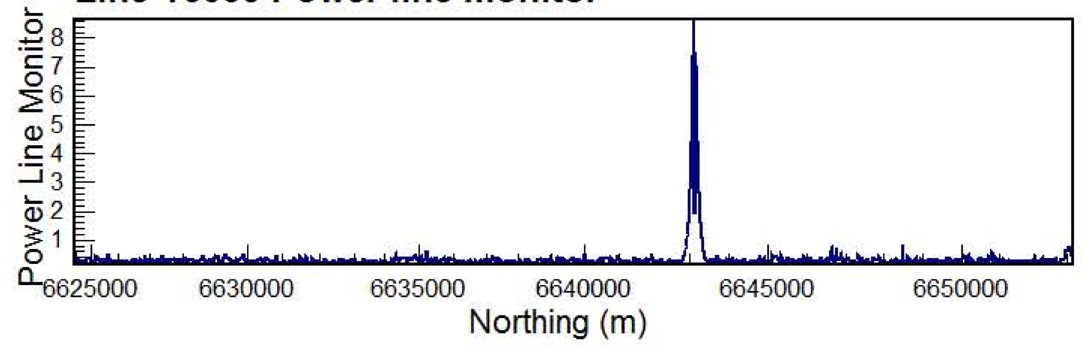
Line T3005 TX-RX pitch and roll



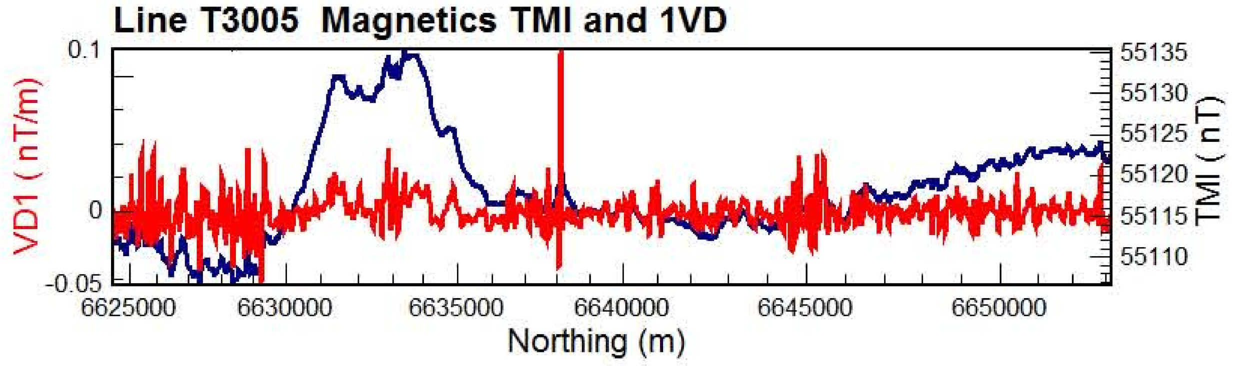
Line T3005 TX-RX height



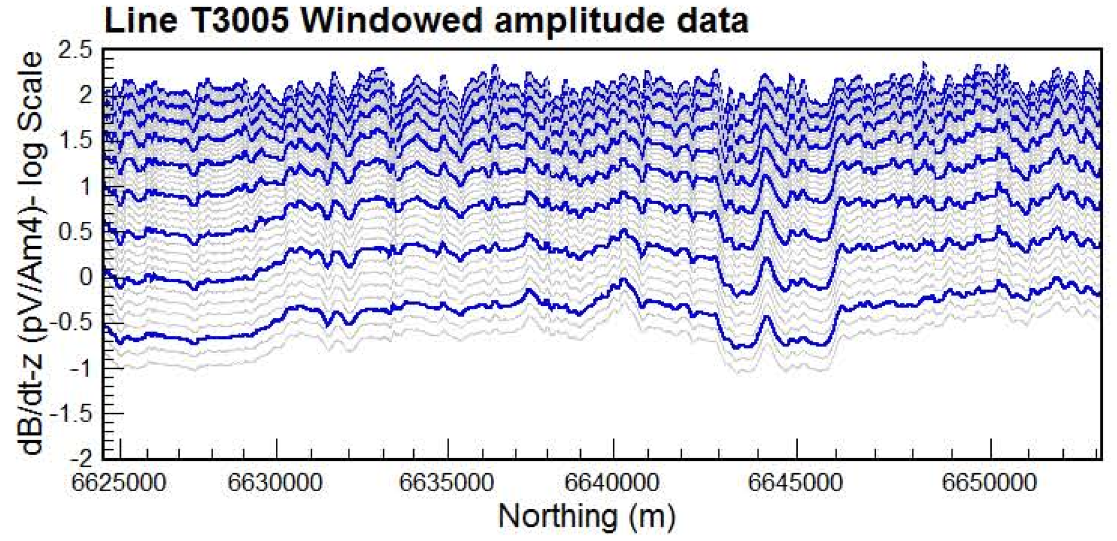
Line T3005 Power line monitor



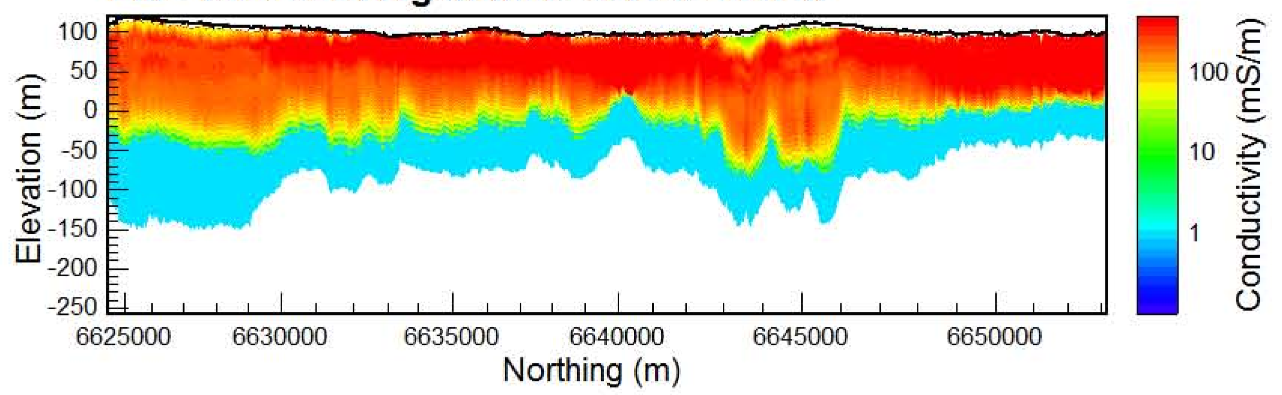
Line T3005 Magnetics TMI and 1VD



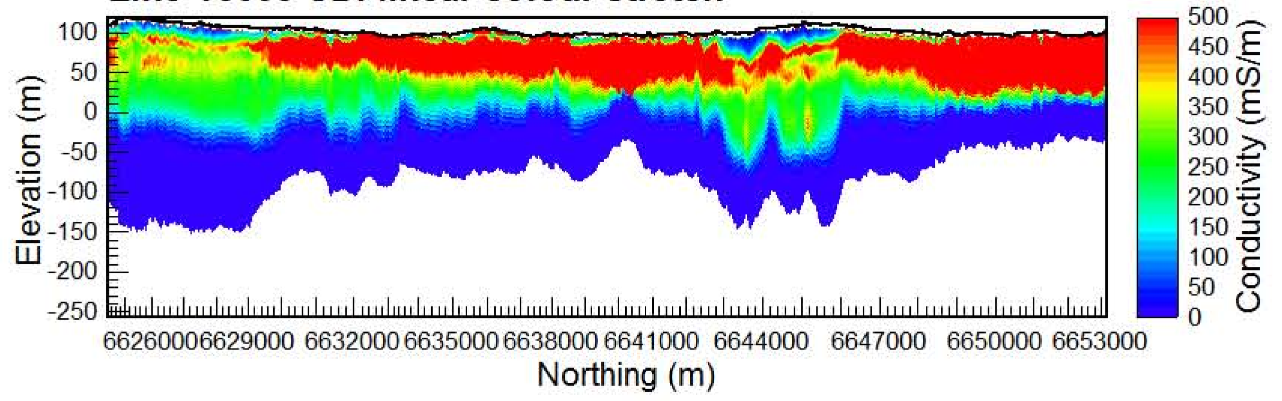
Line T3005 Windowed amplitude data



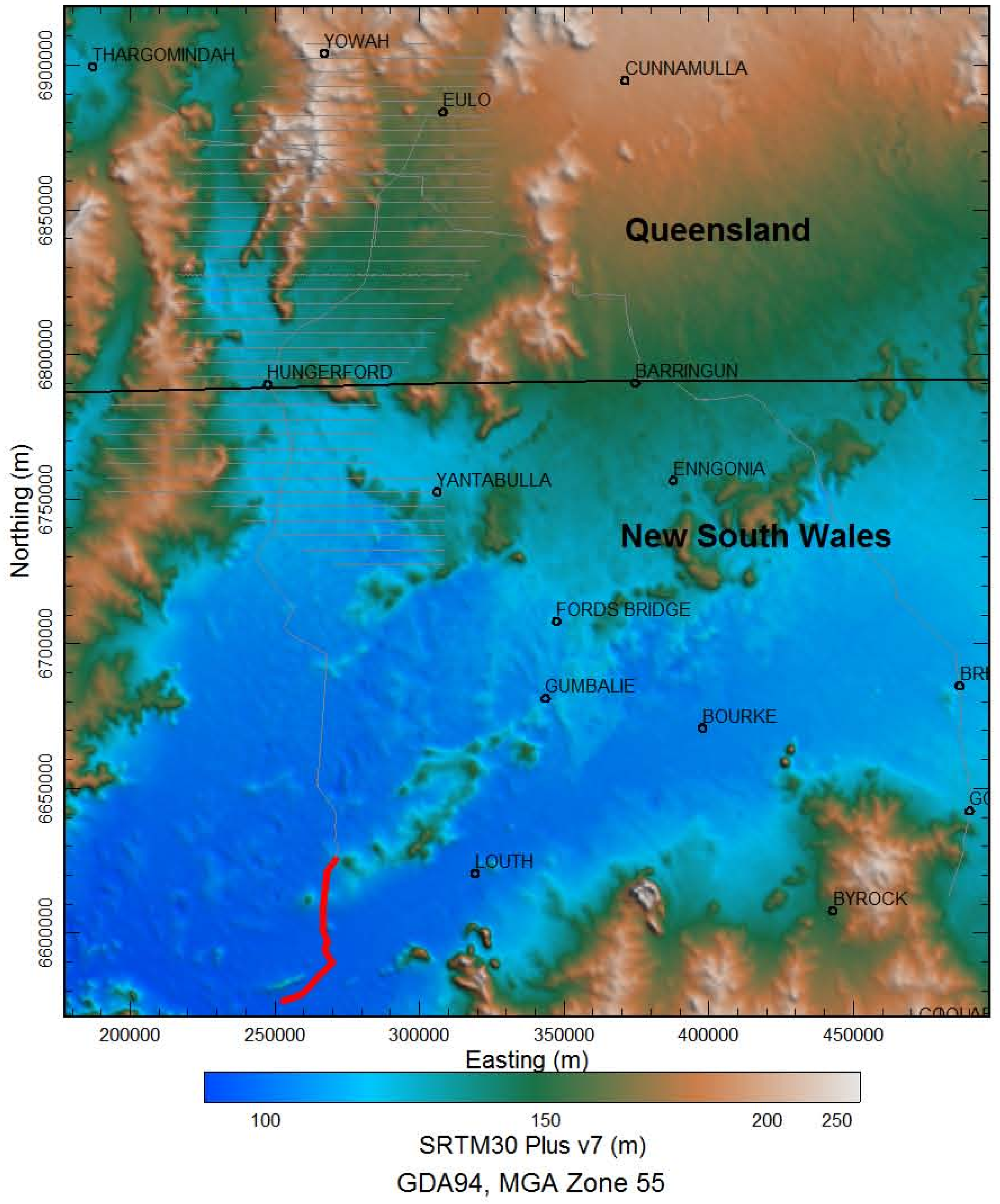
Line T3005 CDI logarithmic colour stretch



Line T3005 CDI linear colour stretch



FLIGHT PATH



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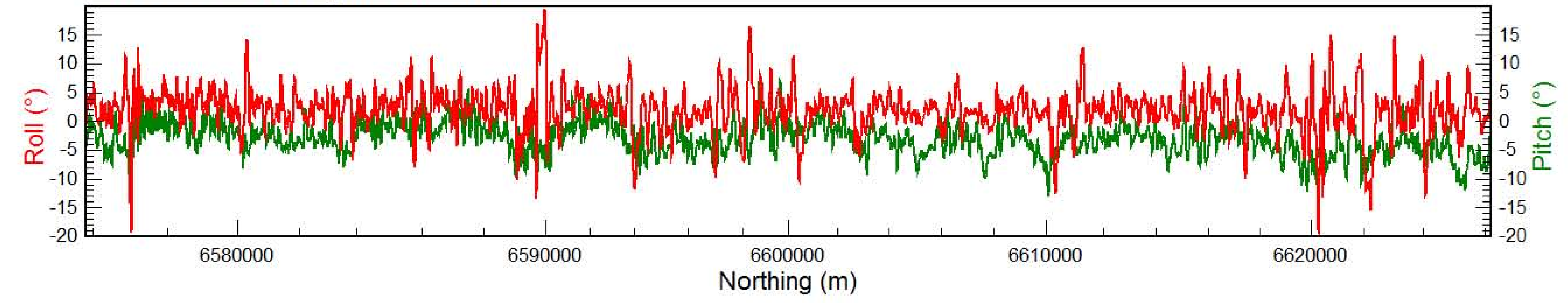
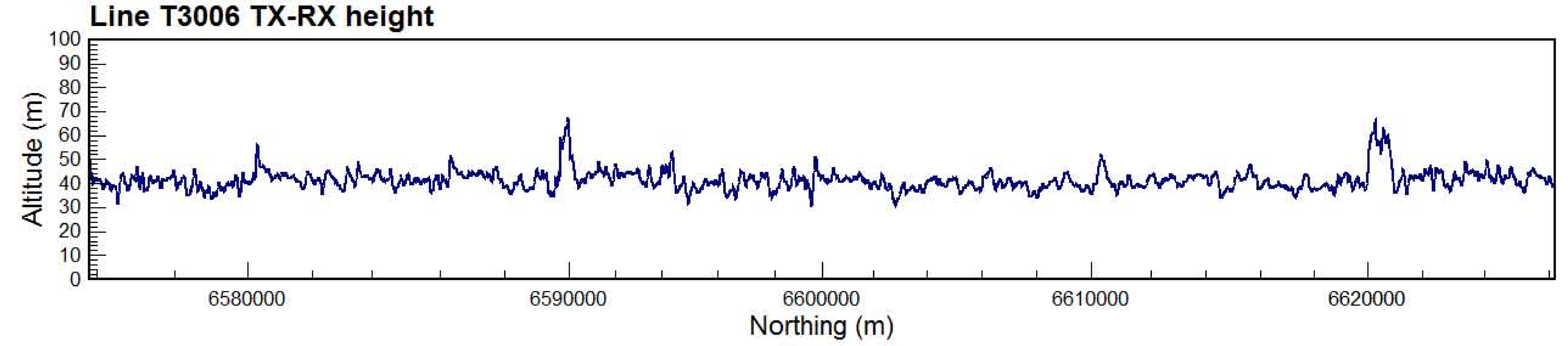
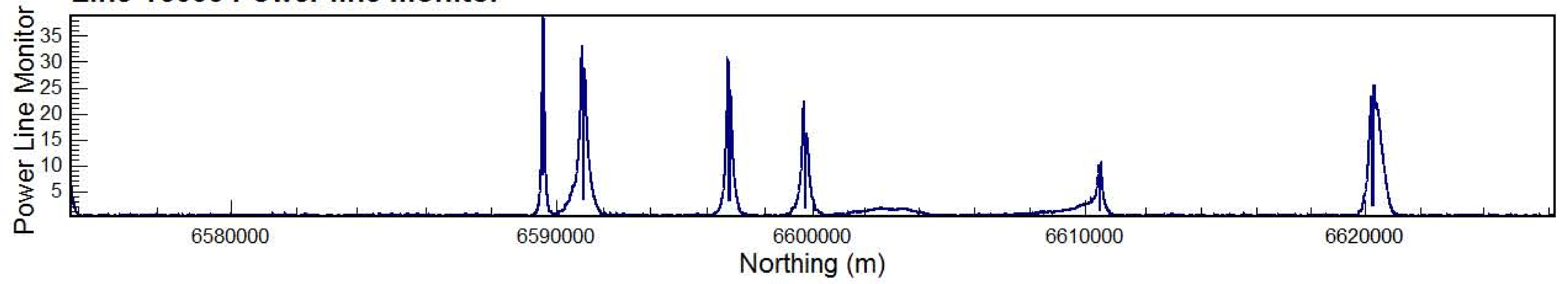
Line T3006 TX-RX pitch and roll



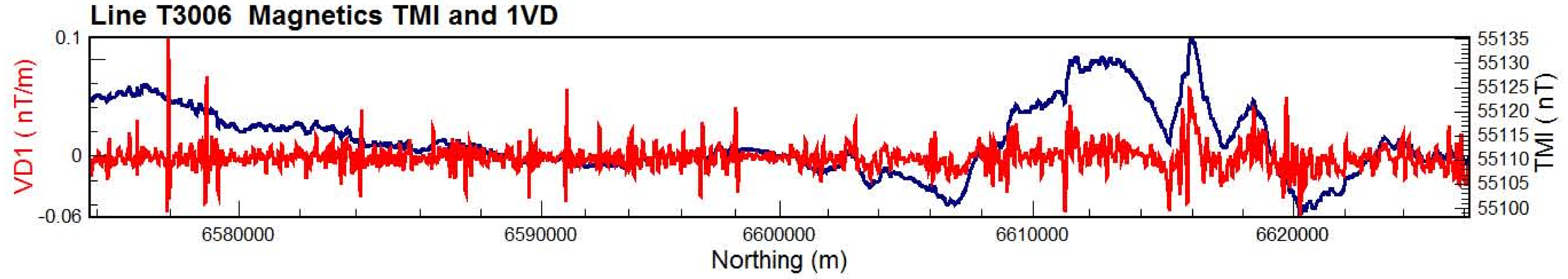
Line T3006 TX-RX height



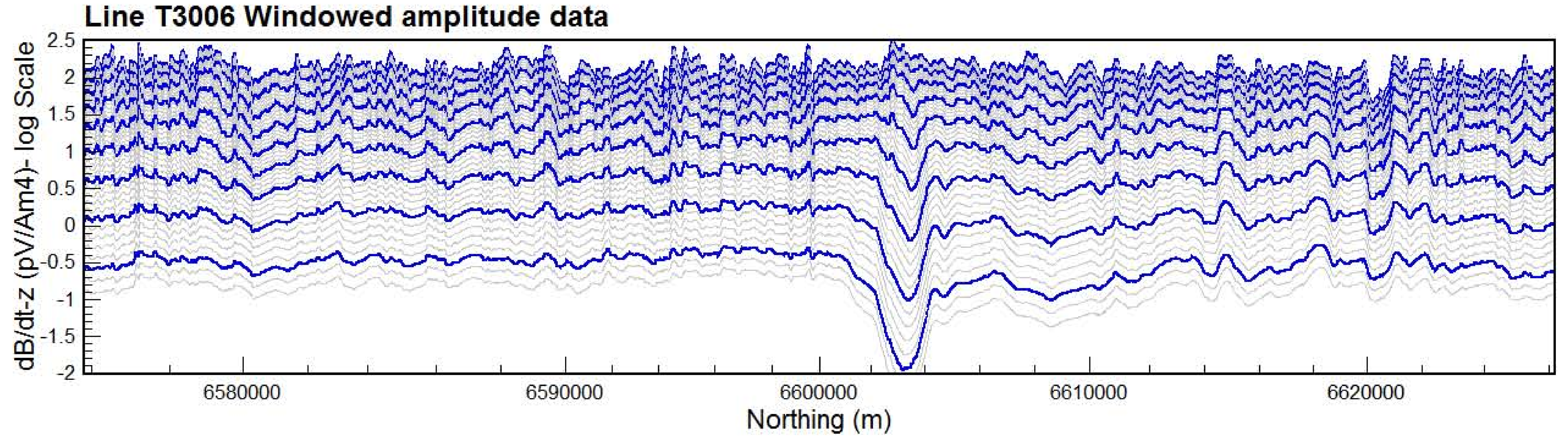
Line T3006 Power line monitor



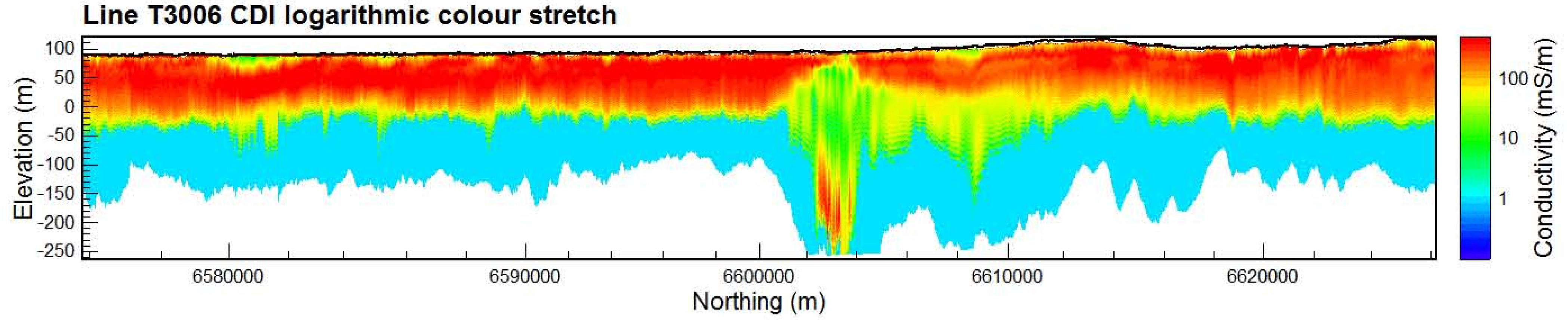
Line T3006 Magnetics TMI and 1VD



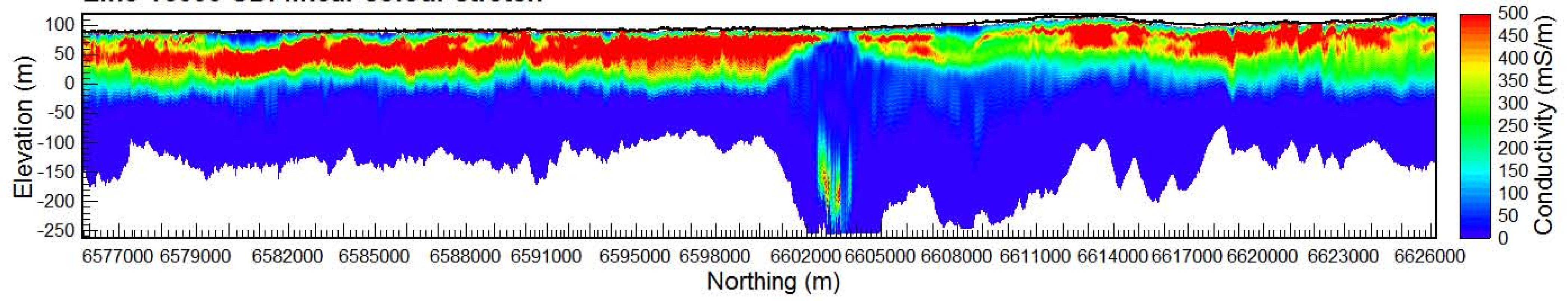
Line T3006 Windowed amplitude data



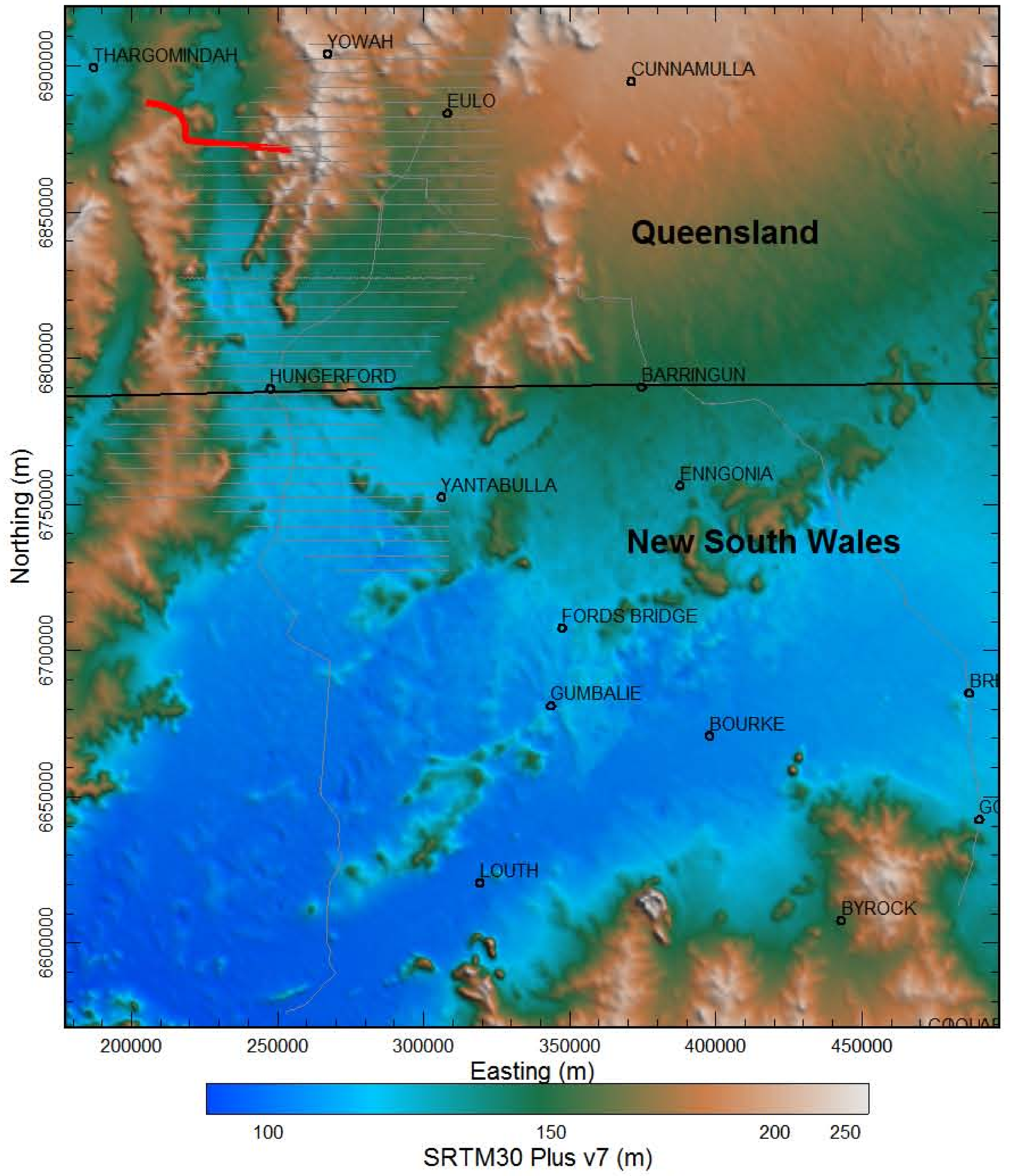
Line T3006 CDI logarithmic colour stretch



Line T3006 CDI linear colour stretch



FLIGHT PATH



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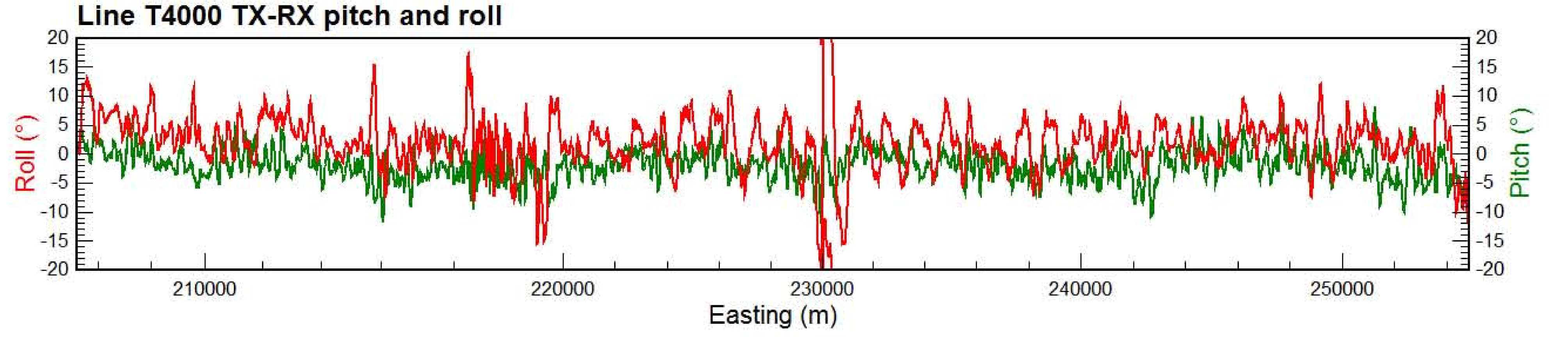
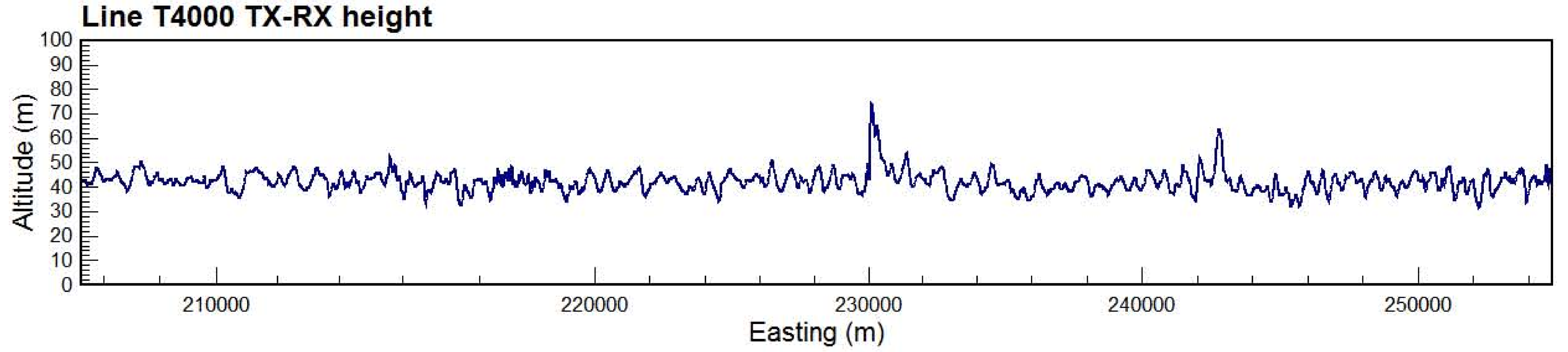
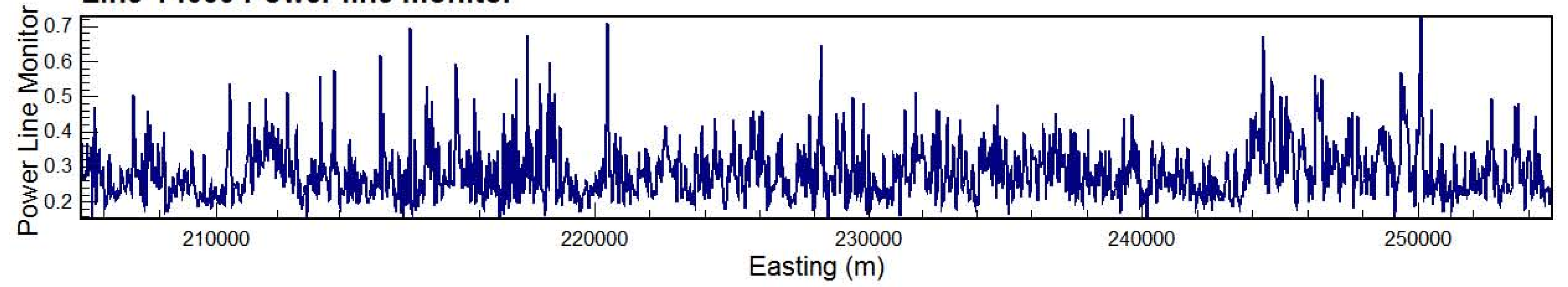
Line T4000 TX-RX pitch and roll



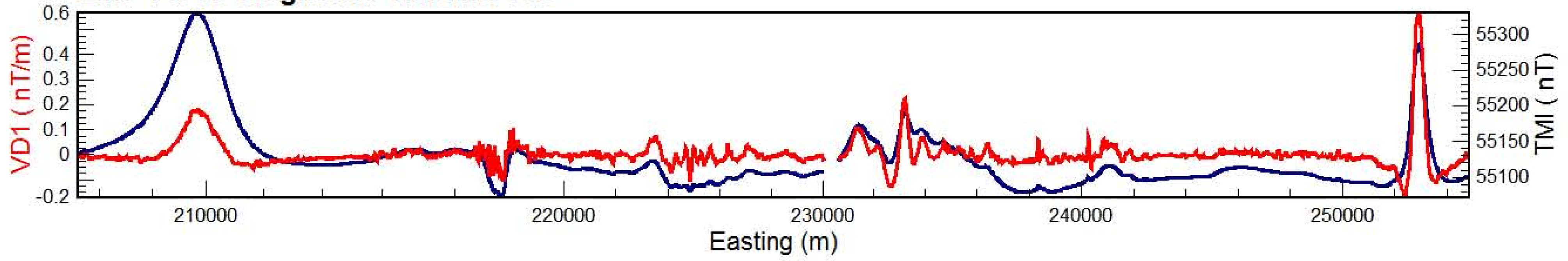
Line T4000 TX-RX height



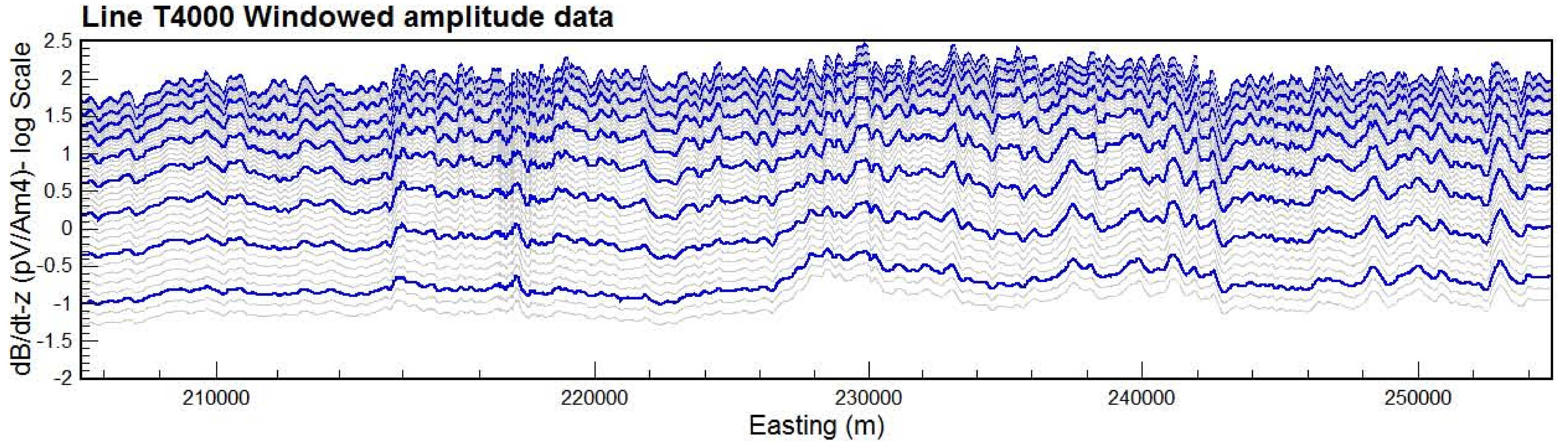
Line T4000 Power line monitor



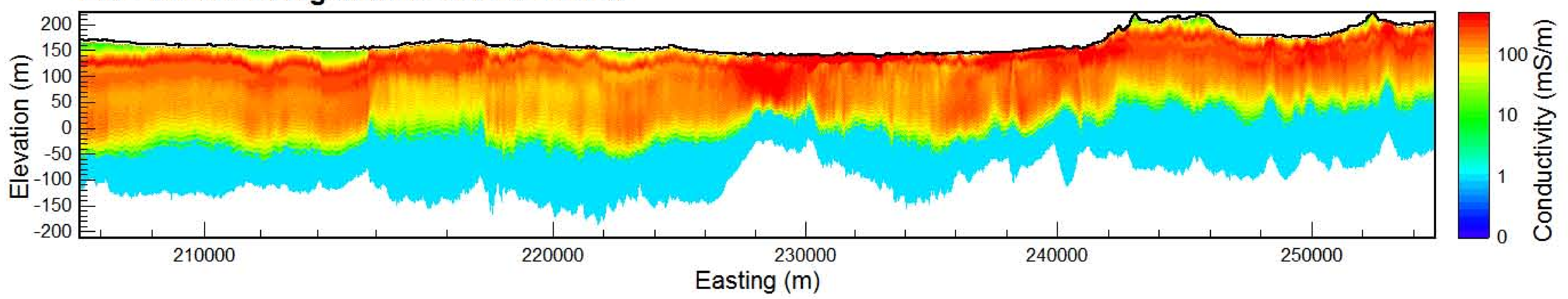
Line T4000 Magnetics TMI and 1VD



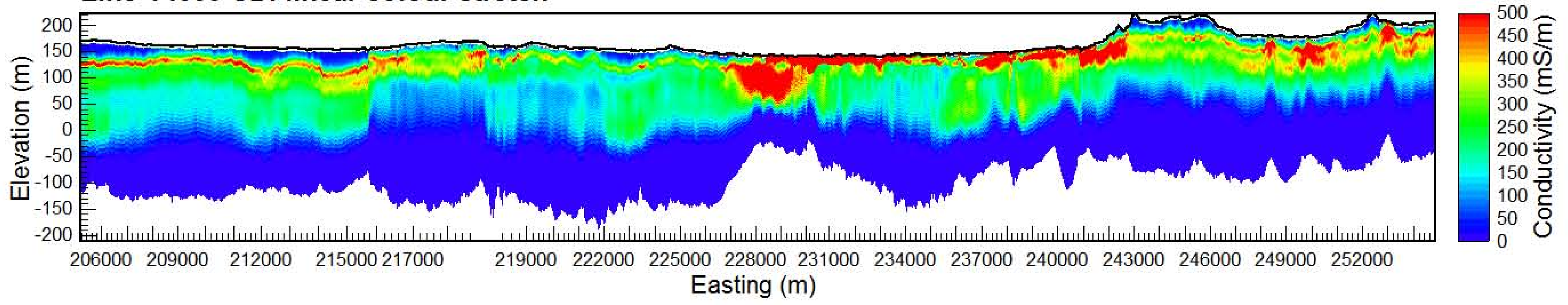
Line T4000 Windowed amplitude data



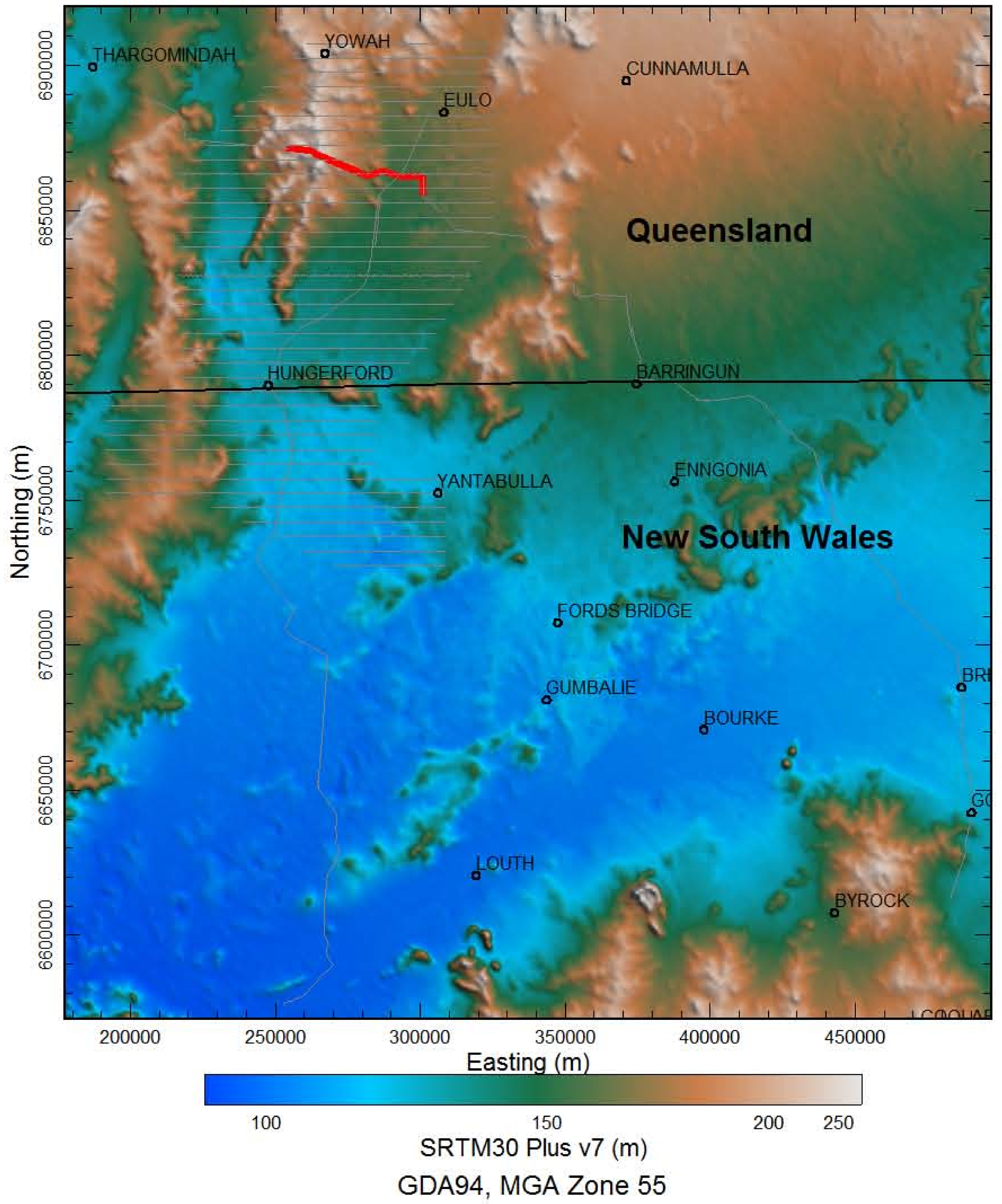
Line T4000 CDI logarithmic colour stretch



Line T4000 CDI linear colour stretch



FLIGHT PATH



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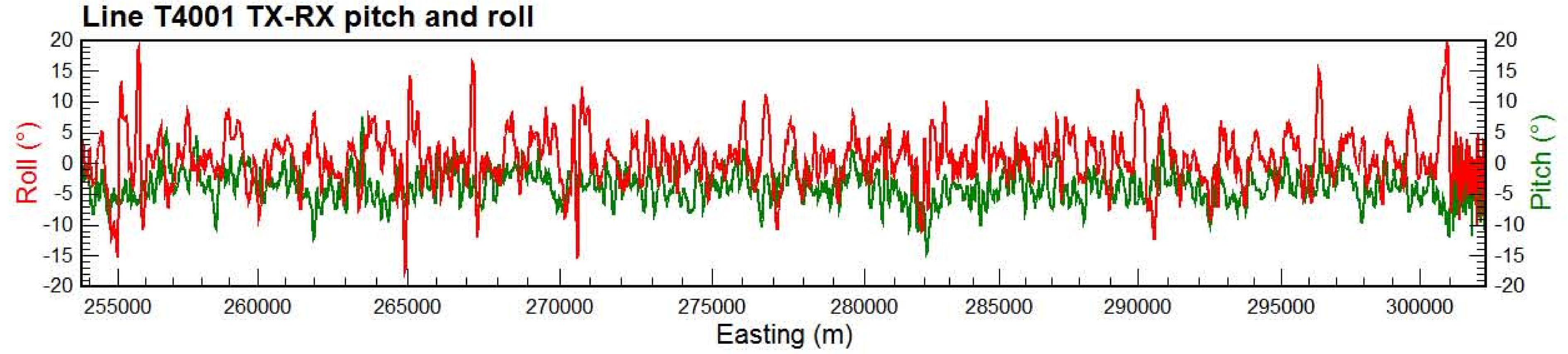
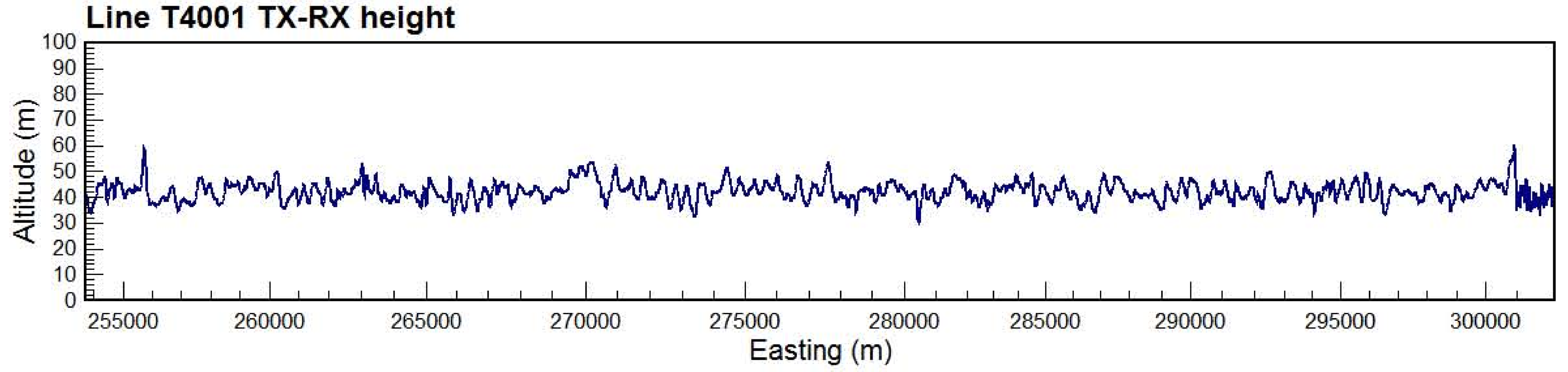
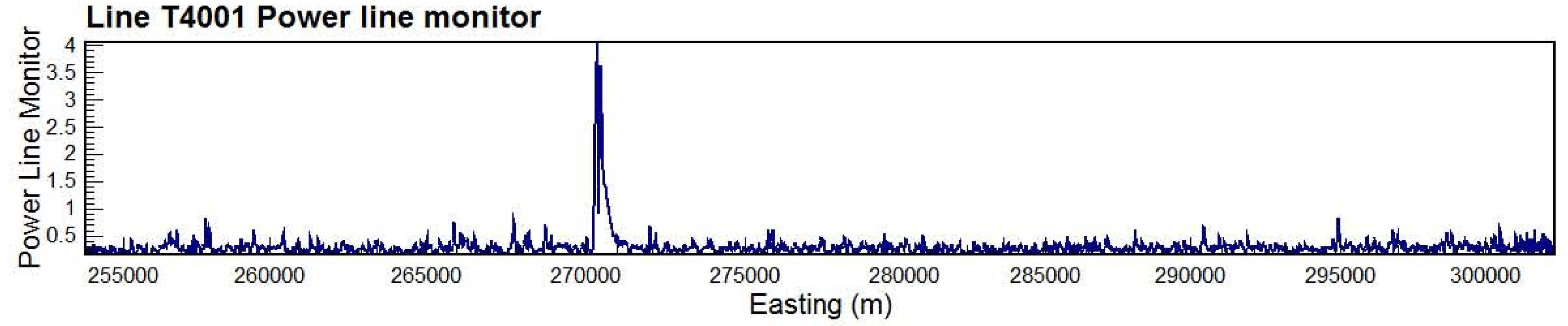
Line T4001 TX-RX pitch and roll



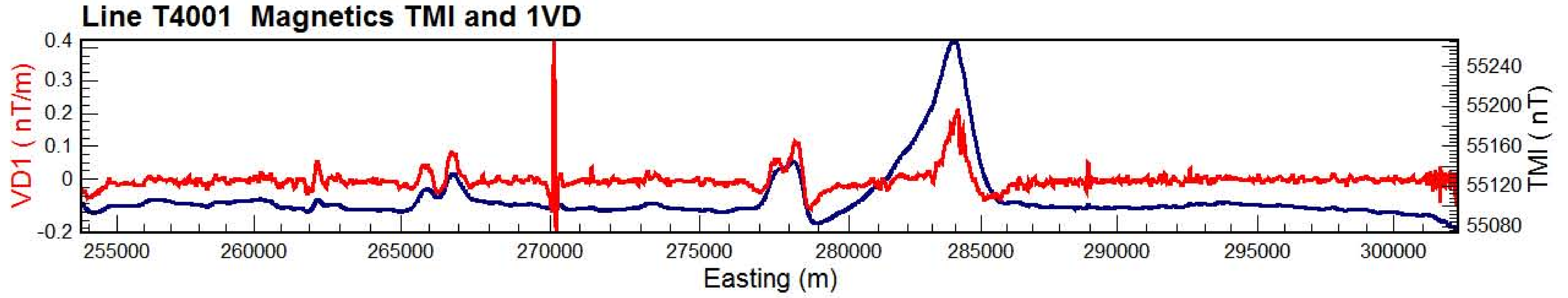
Line T4001 TX-RX height



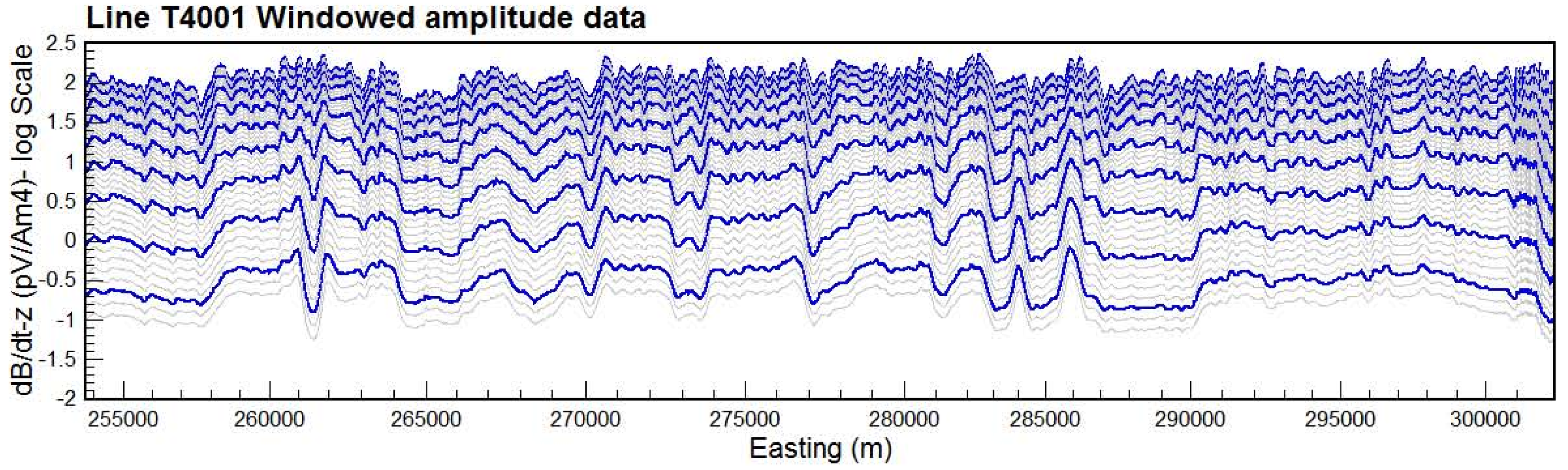
Line T4001 Power line monitor



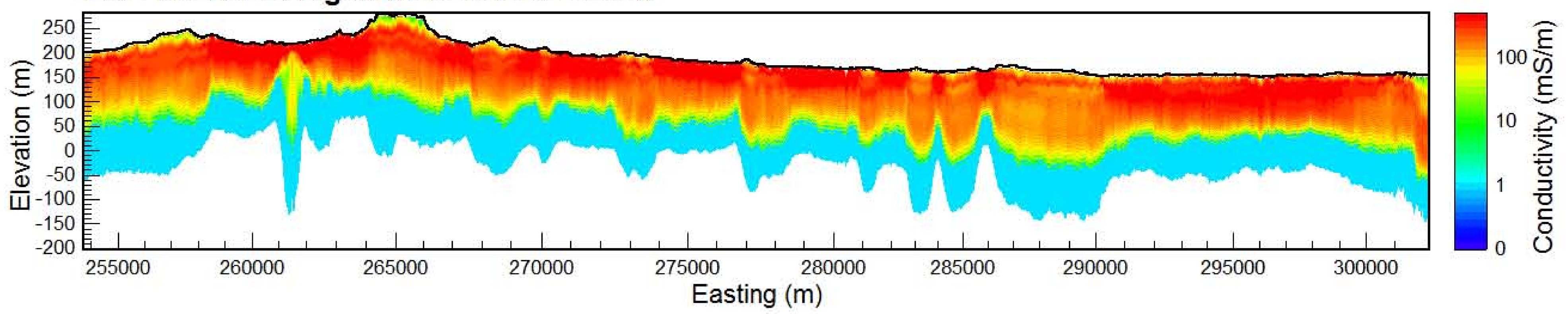
Line T4001 Magnetics TMI and 1VD



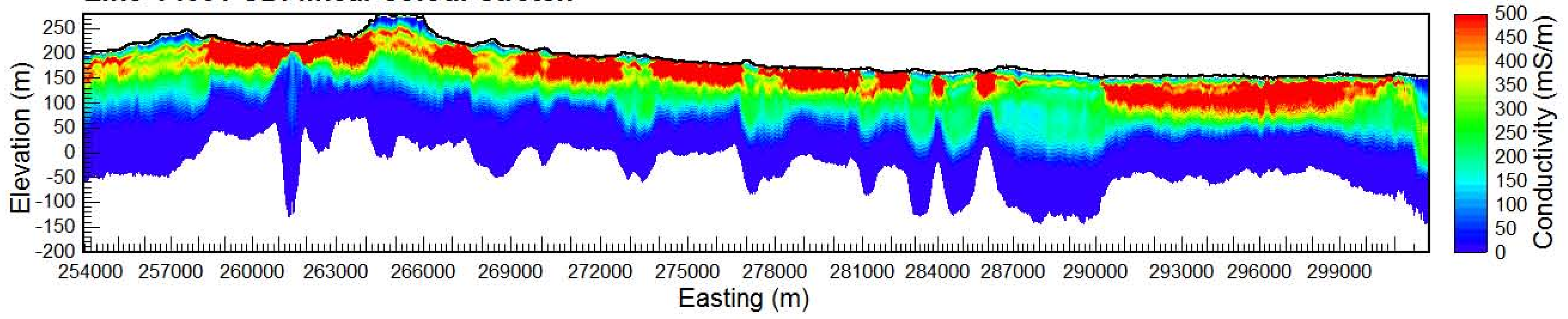
Line T4001 Windowed amplitude data



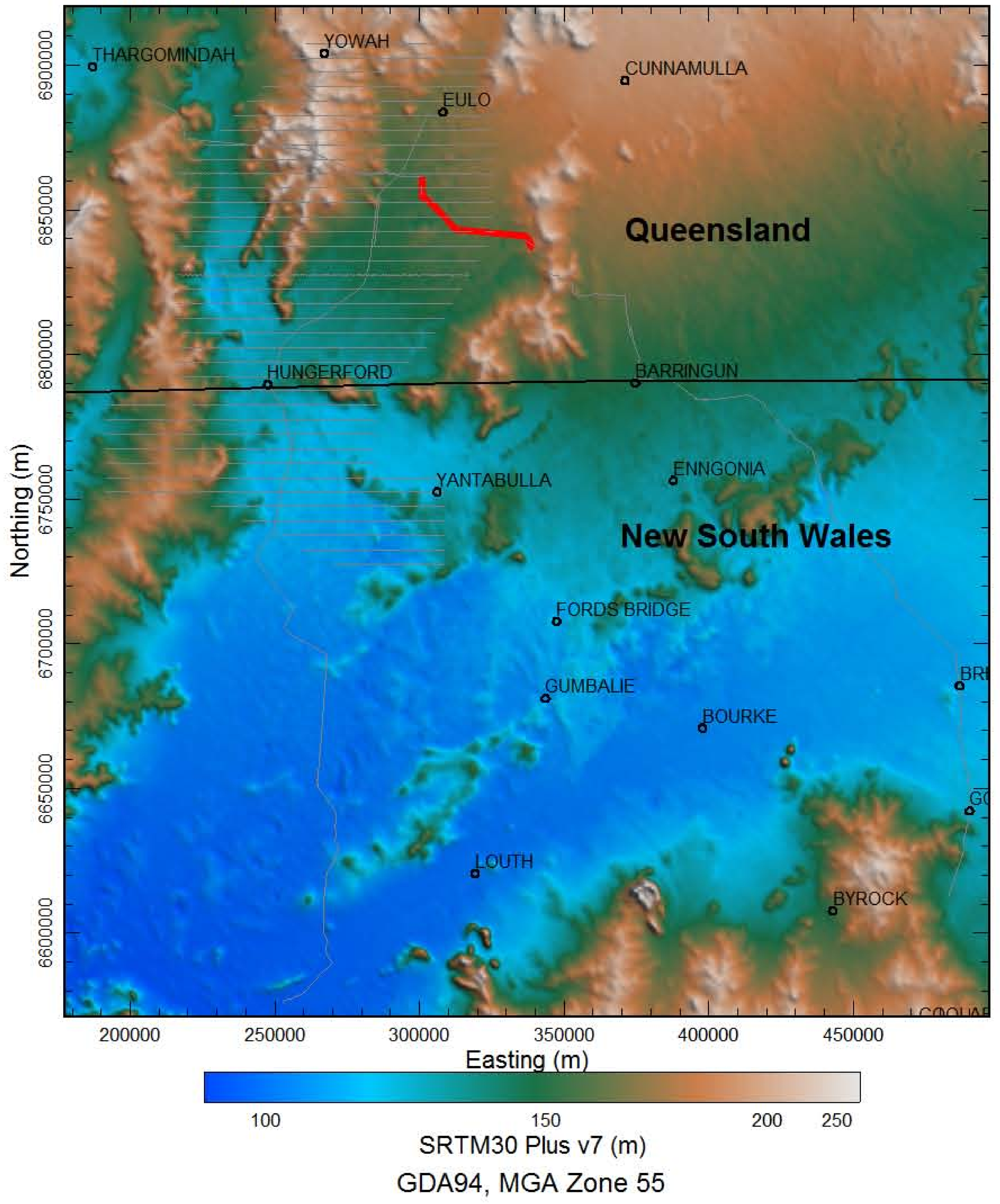
Line T4001 CDI logarithmic colour stretch



Line T4001 CDI linear colour stretch



FLIGHT PATH



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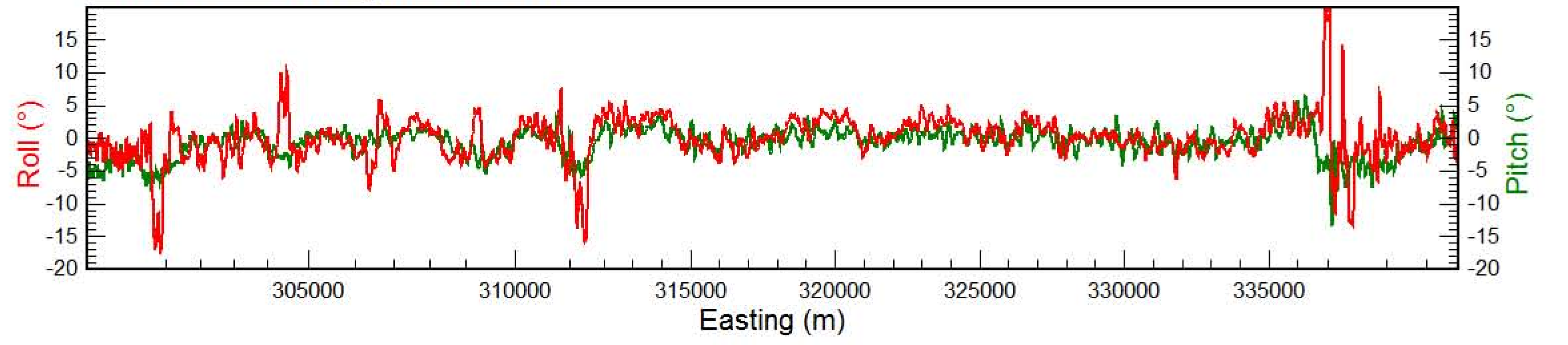
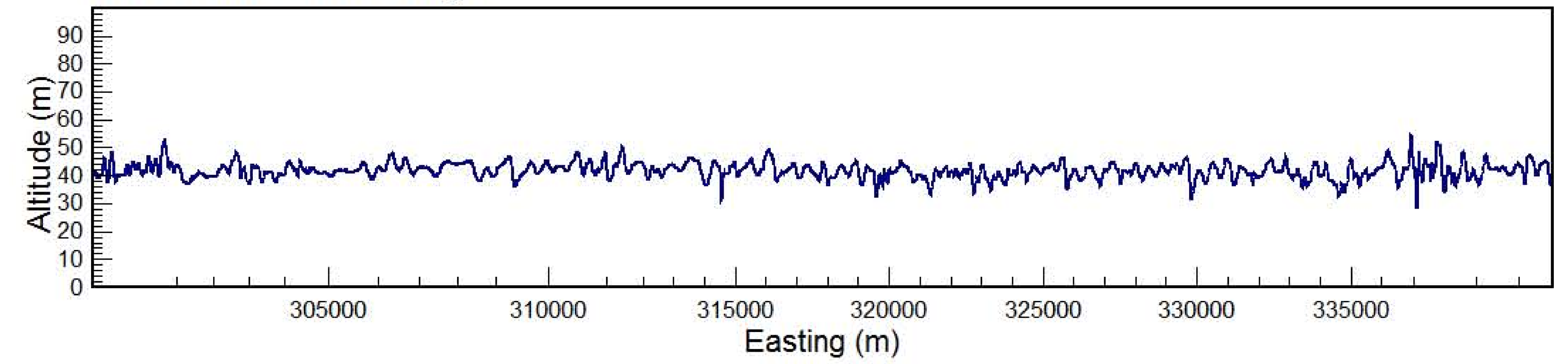
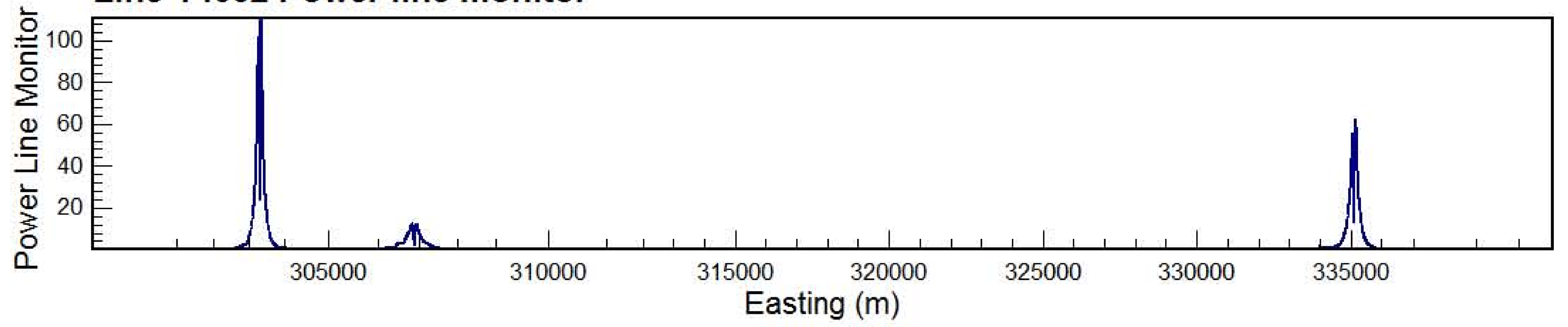
Line T4002 TX-RX pitch and roll



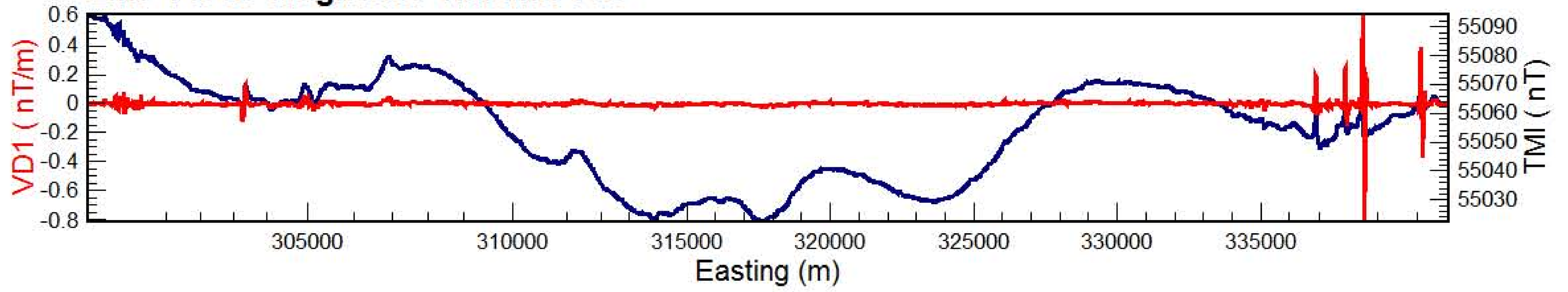
Line T4002 TX-RX height



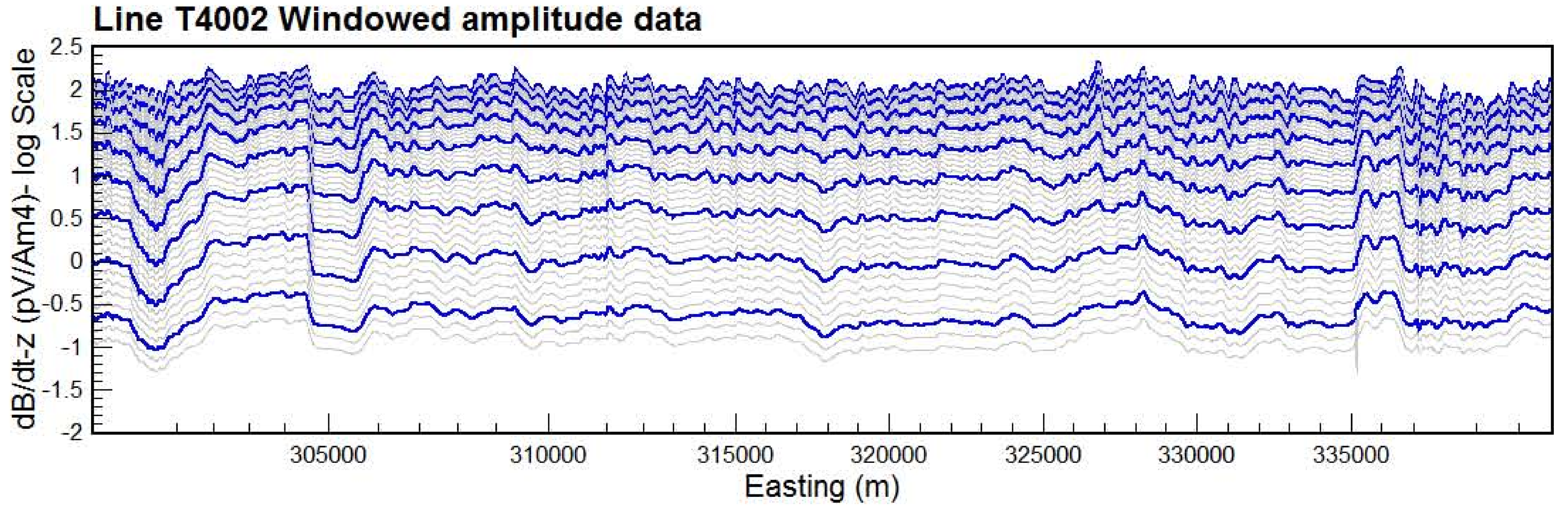
Line T4002 Power line monitor



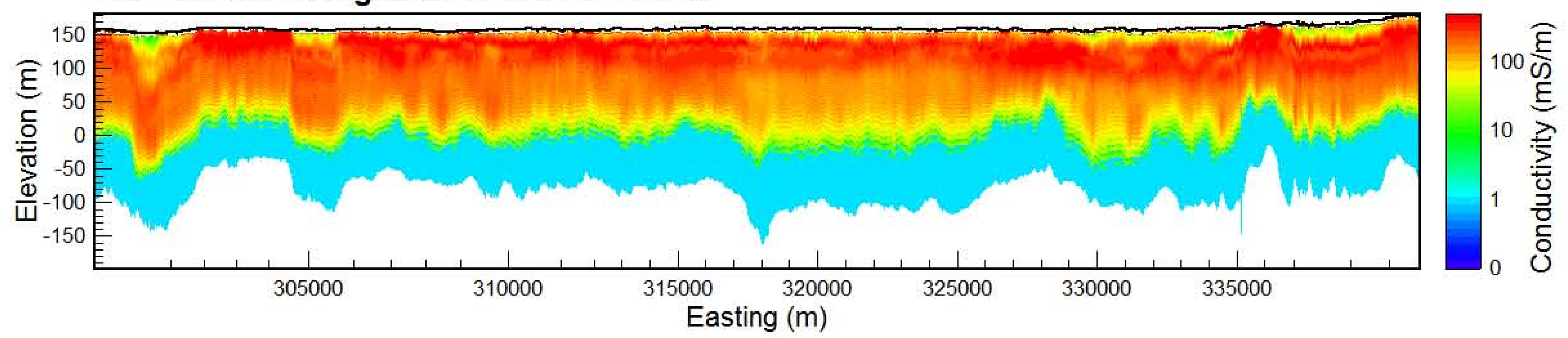
Line T4002 Magnetics TMI and 1VD



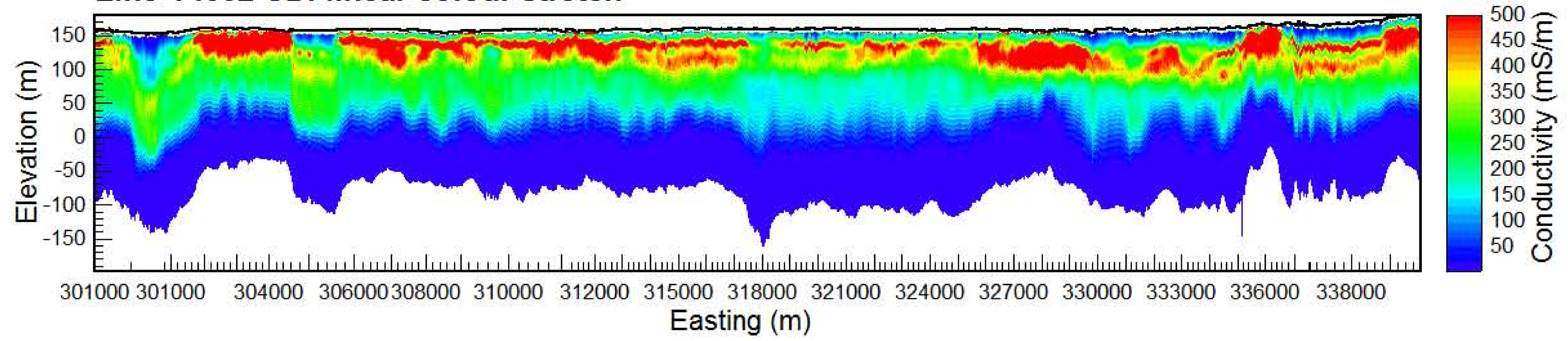
Line T4002 Windowed amplitude data



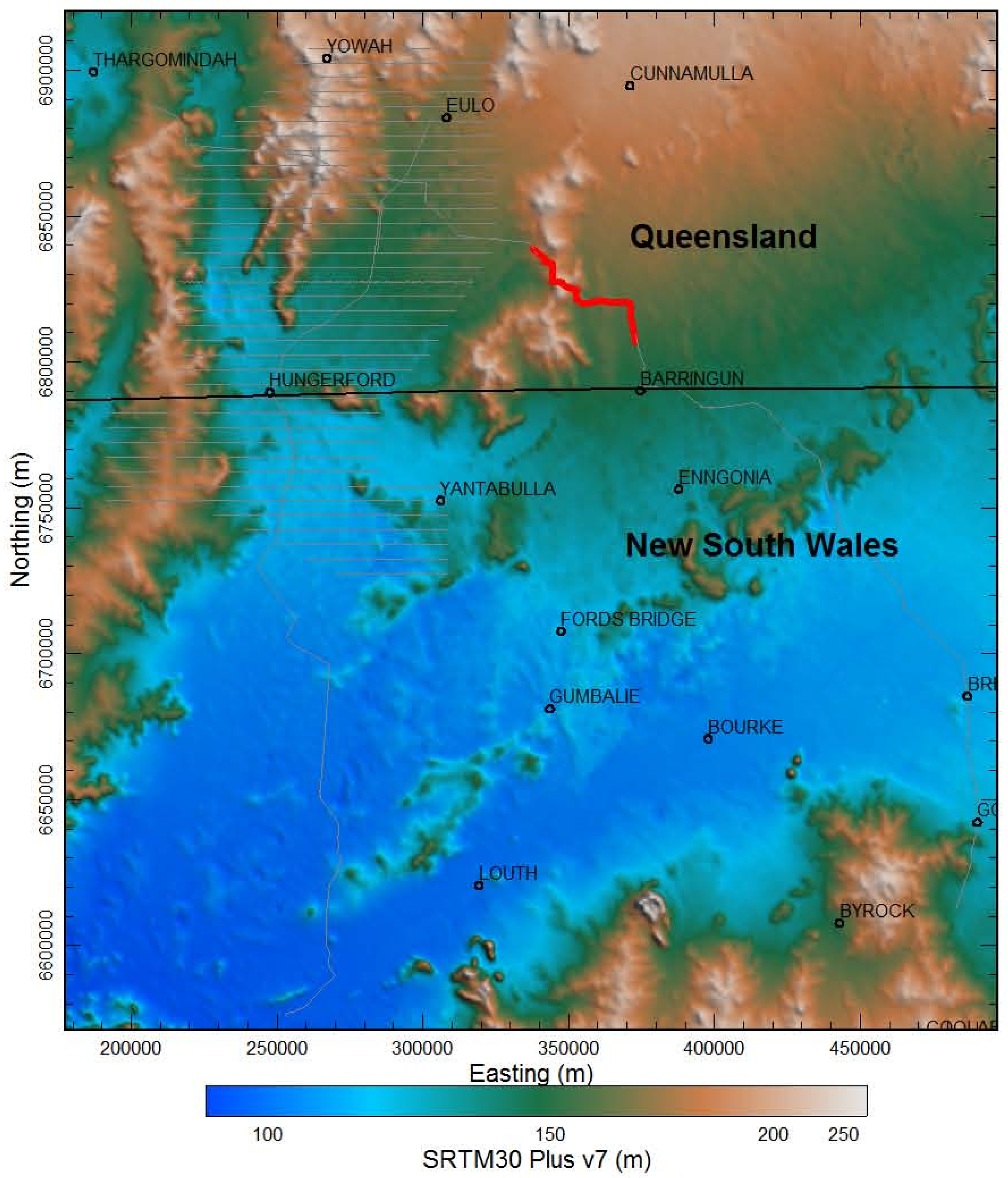
Line T4002 CDI logarithmic colour stretch



Line T4002 CDI linear colour stretch



FLIGHT PATH



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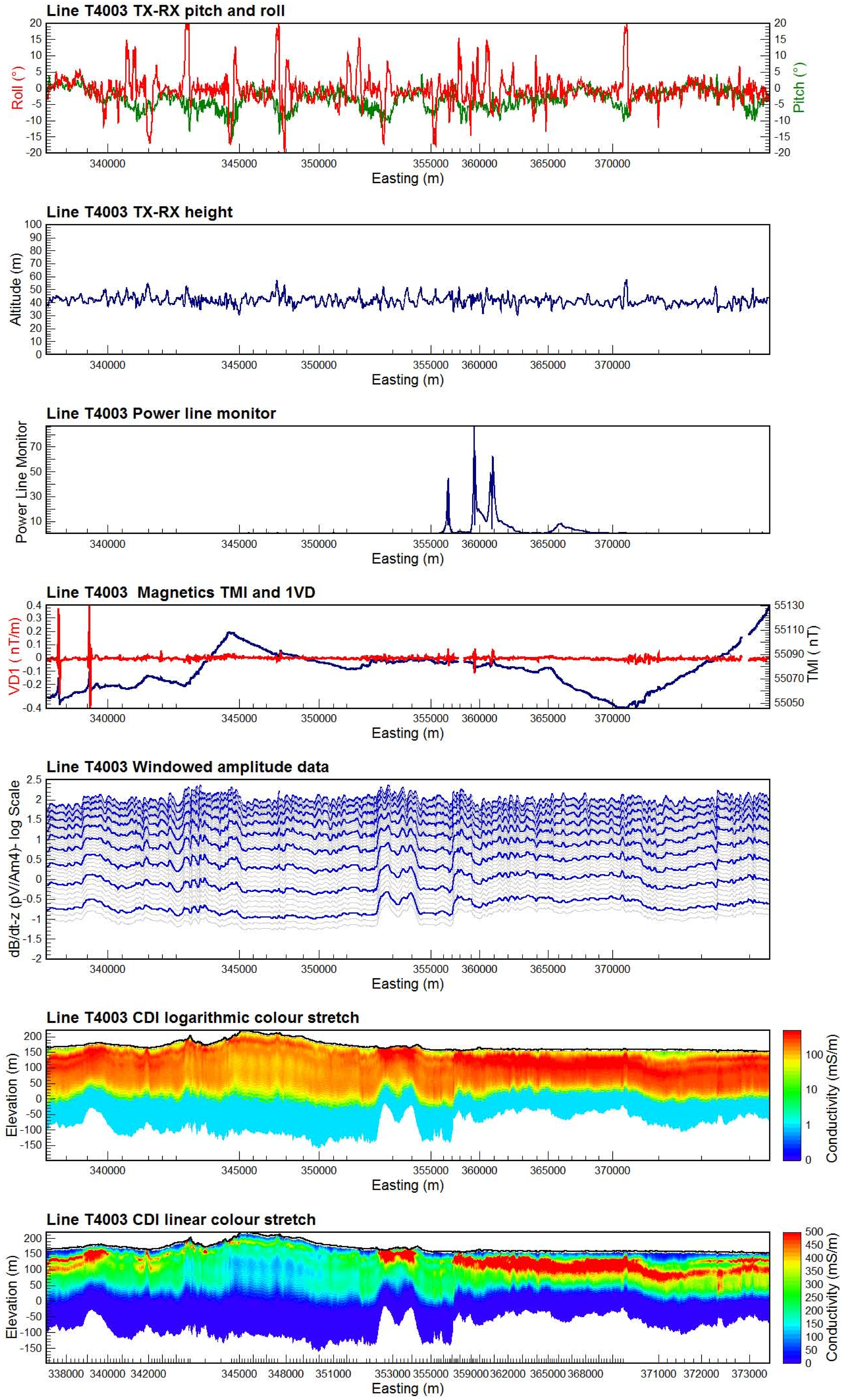
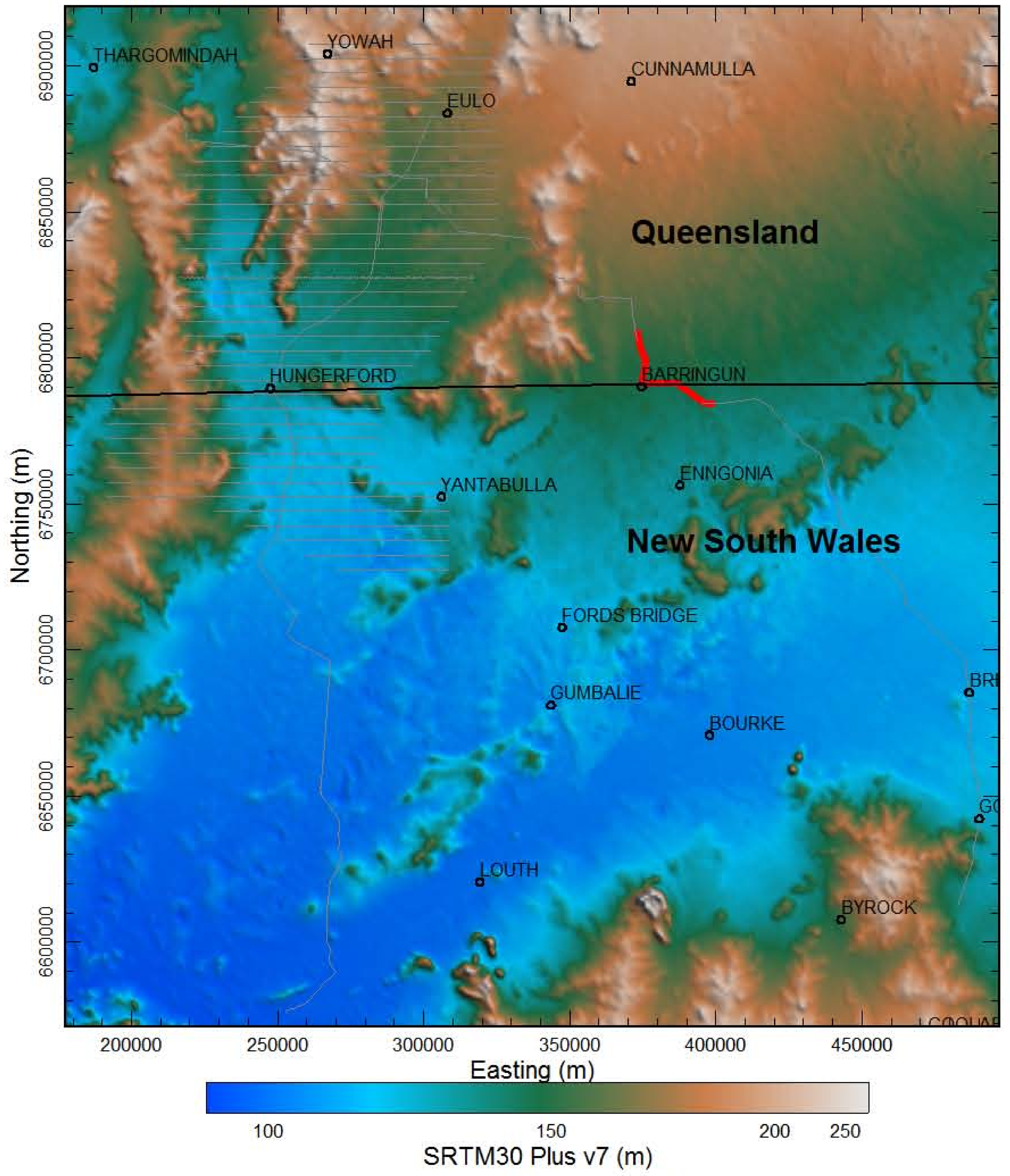


FLIGHT PATH



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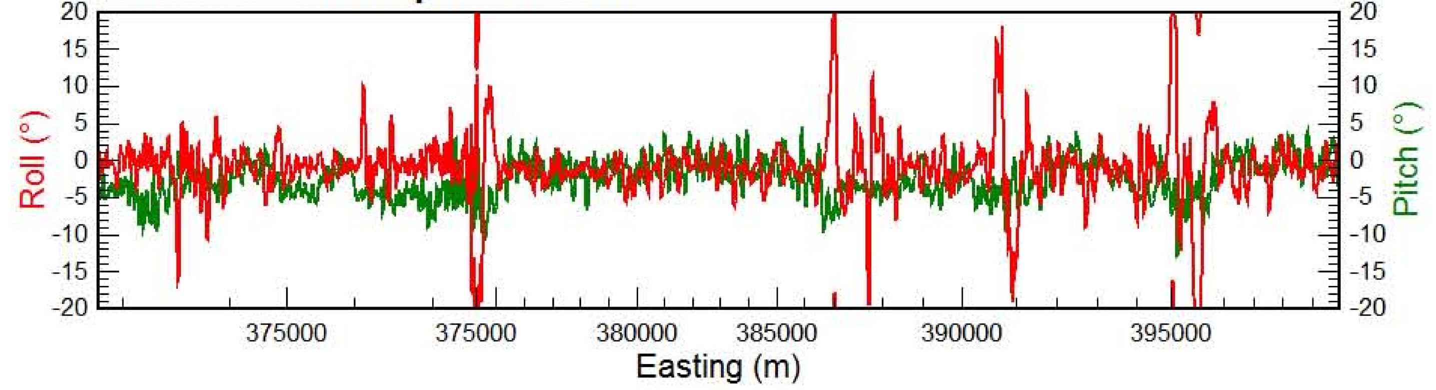
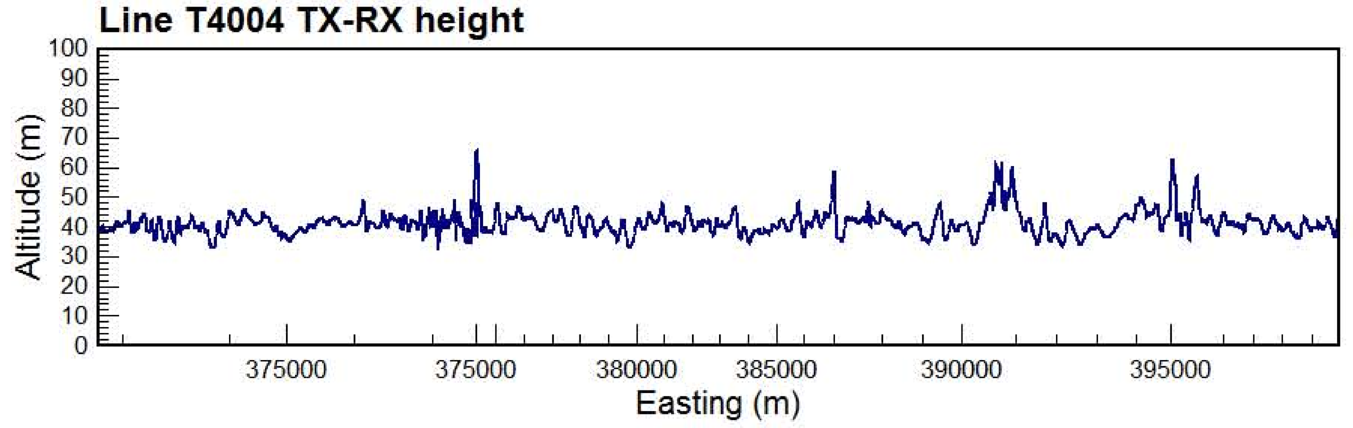
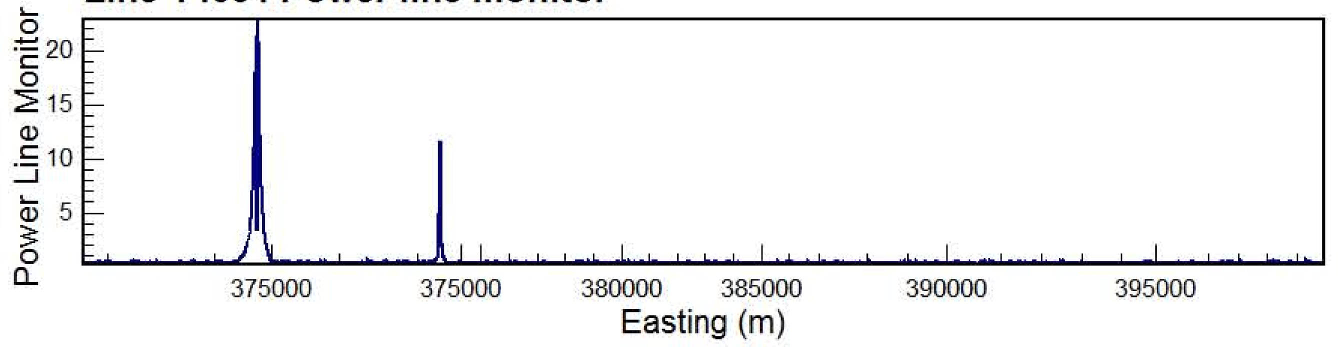
Line T4004 TX-RX pitch and roll



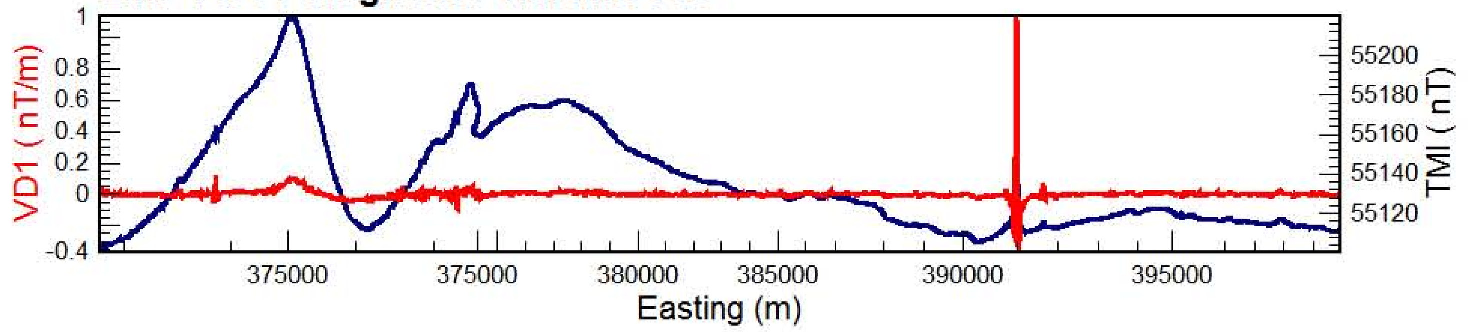
Line T4004 TX-RX height



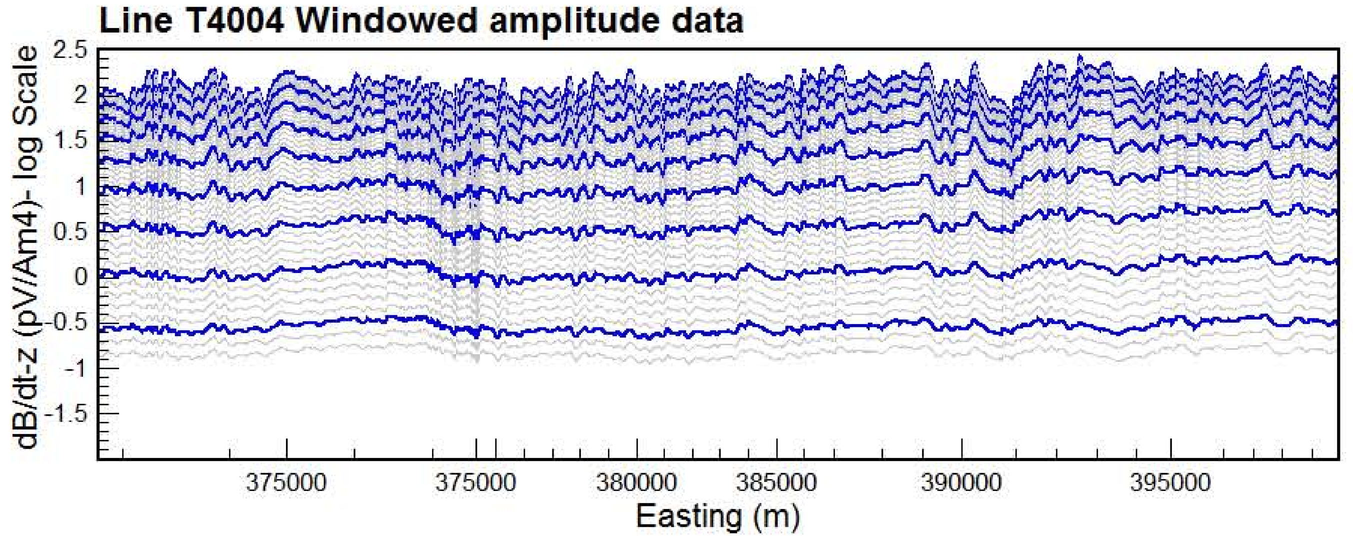
Line T4004 Power line monitor



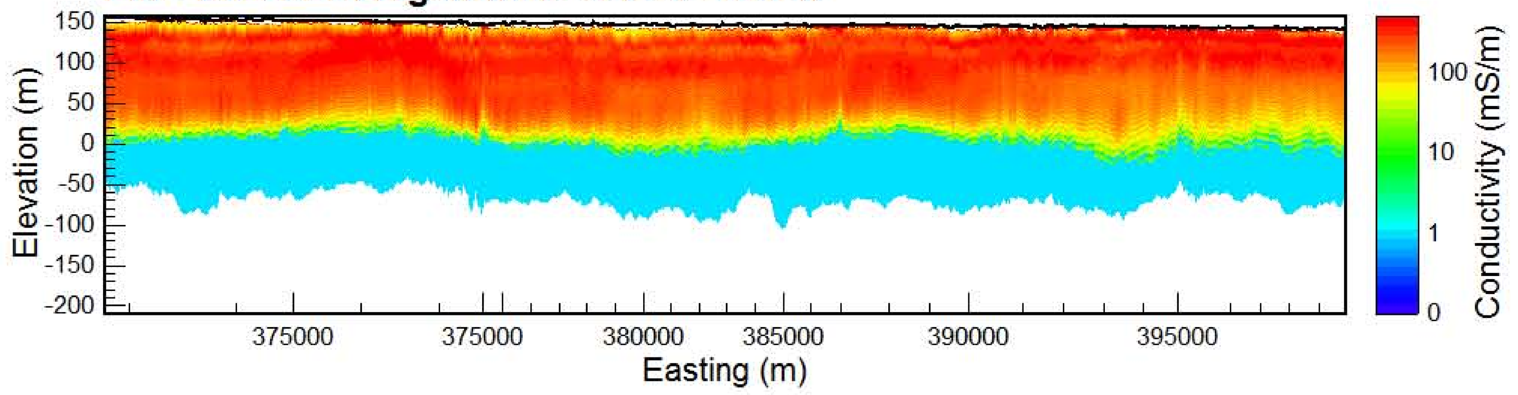
Line T4004 Magnetics TMI and 1VD



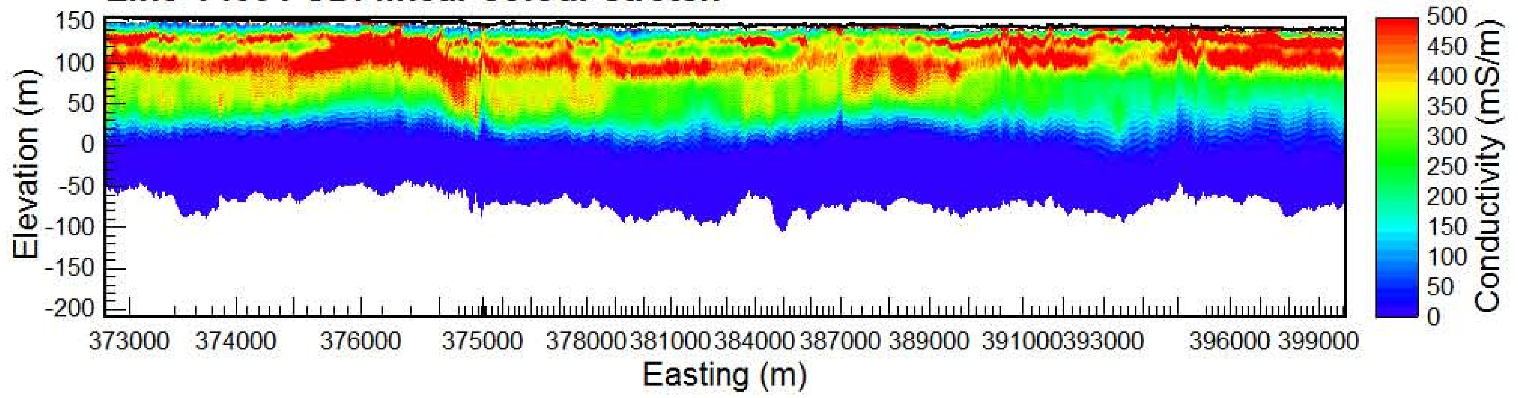
Line T4004 Windowed amplitude data



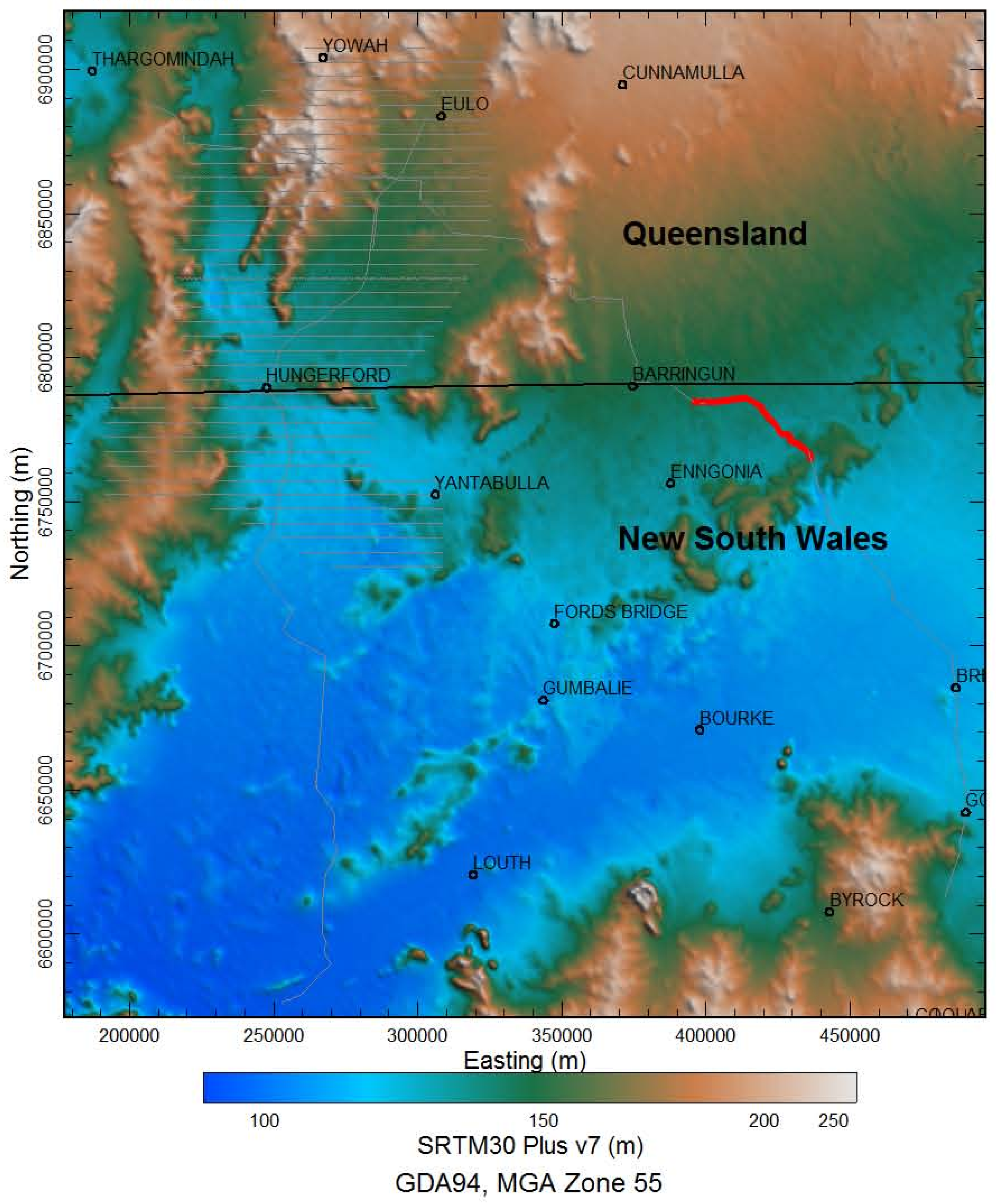
Line T4004 CDI logarithmic colour stretch



Line T4004 CDI linear colour stretch



FLIGHT PATH



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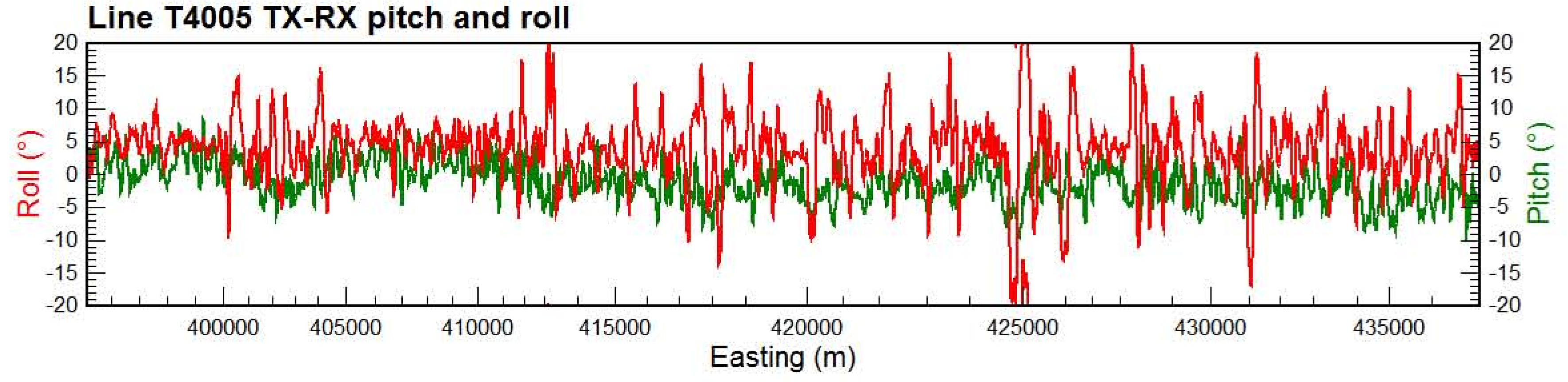
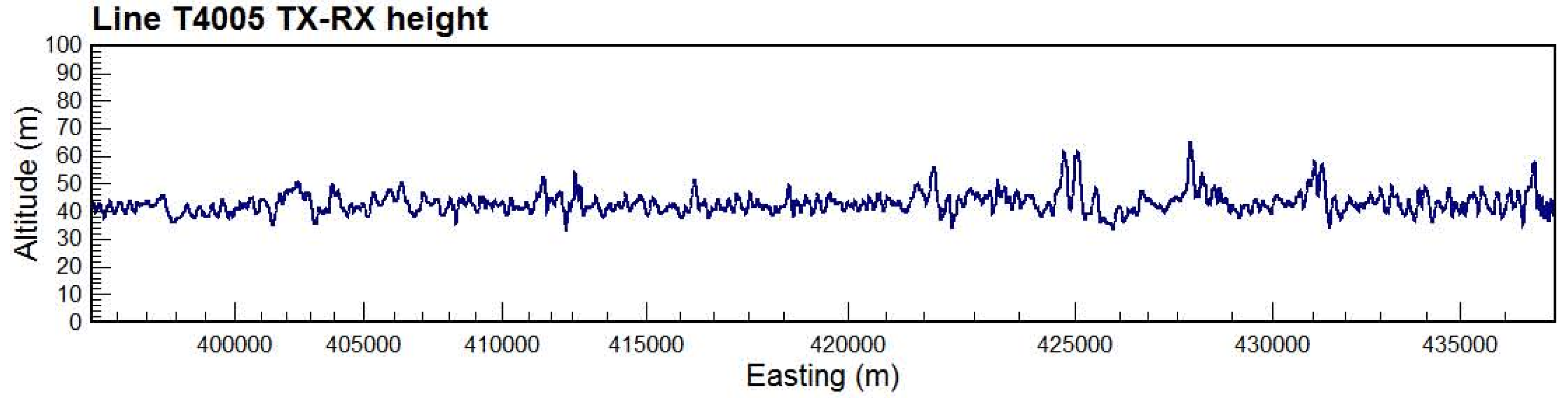
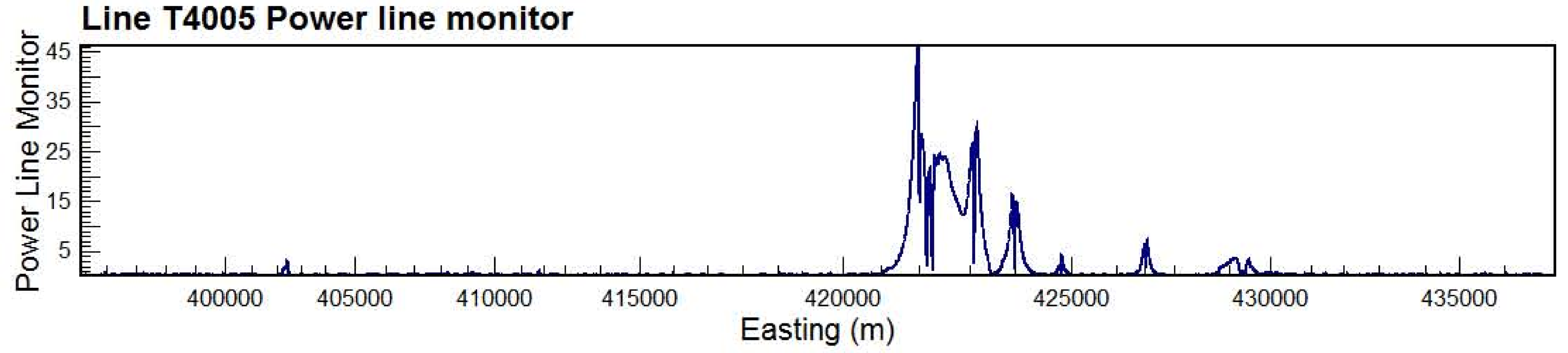
Line T4005 TX-RX pitch and roll



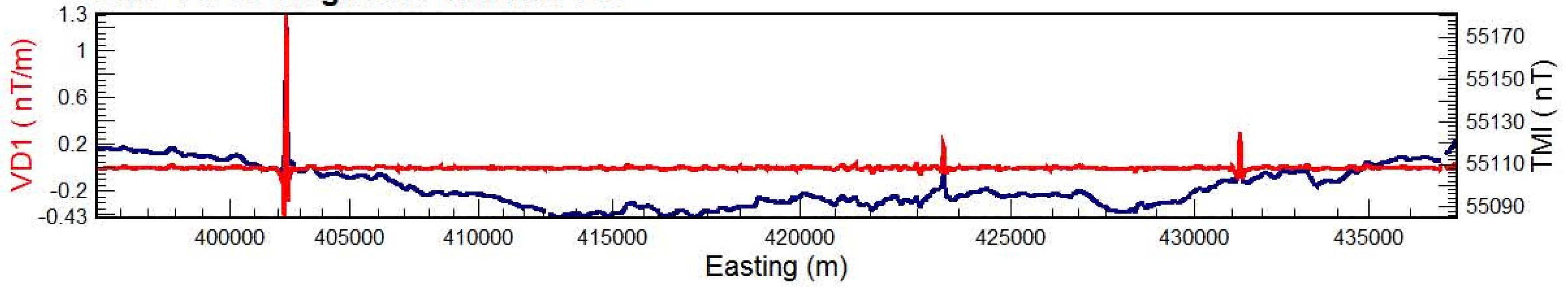
Line T4005 TX-RX height



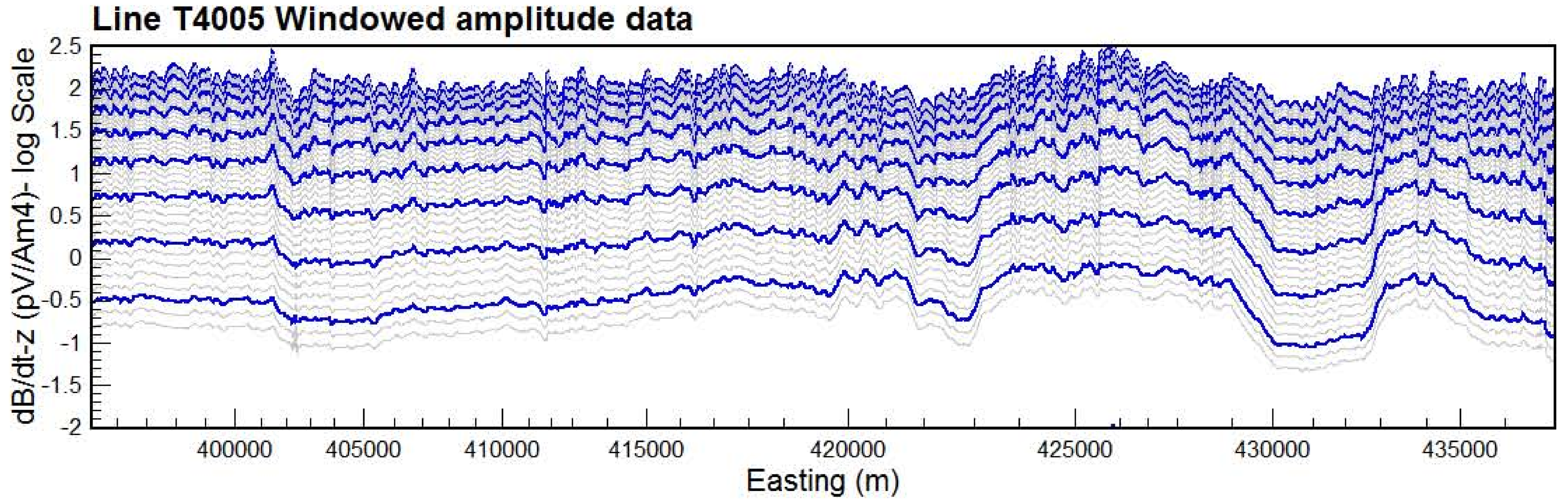
Line T4005 Power line monitor



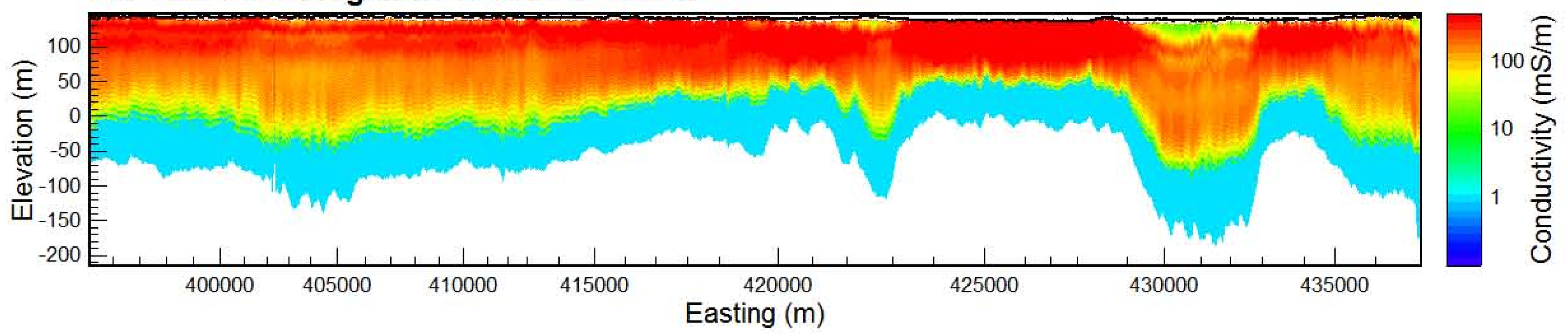
Line T4005 Magnetics TMI and 1VD



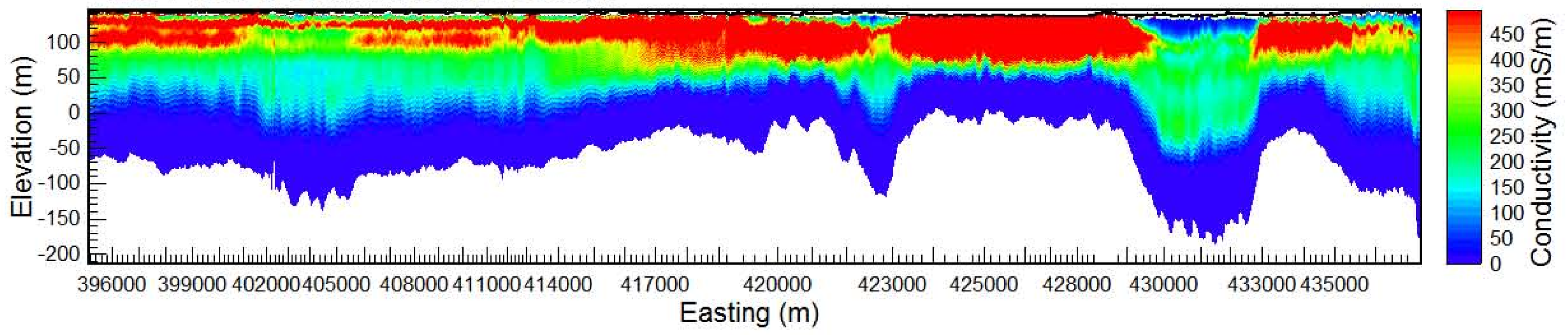
Line T4005 Windowed amplitude data

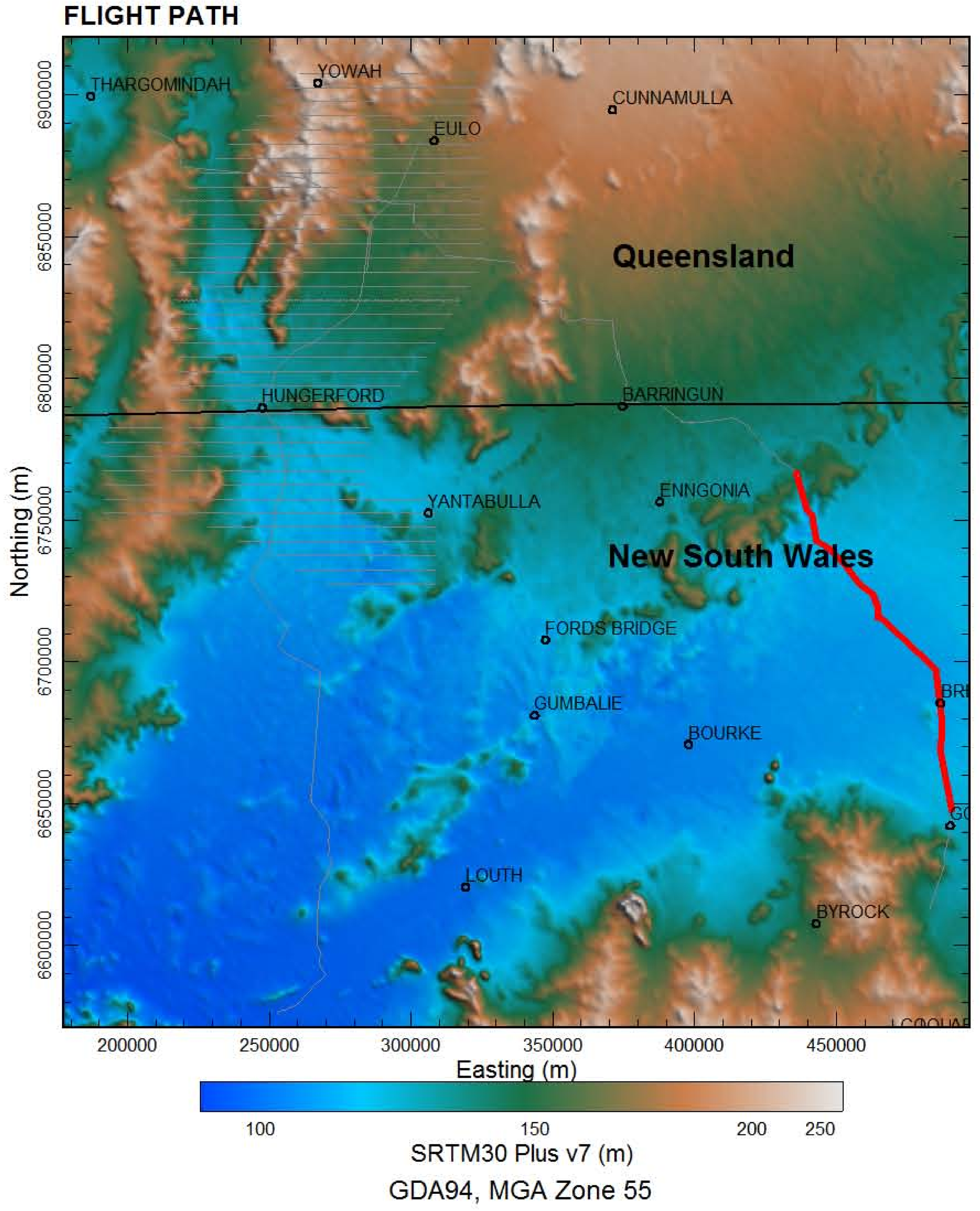


Line T4005 CDI logarithmic colour stretch



Line T4005 CDI linear colour stretch





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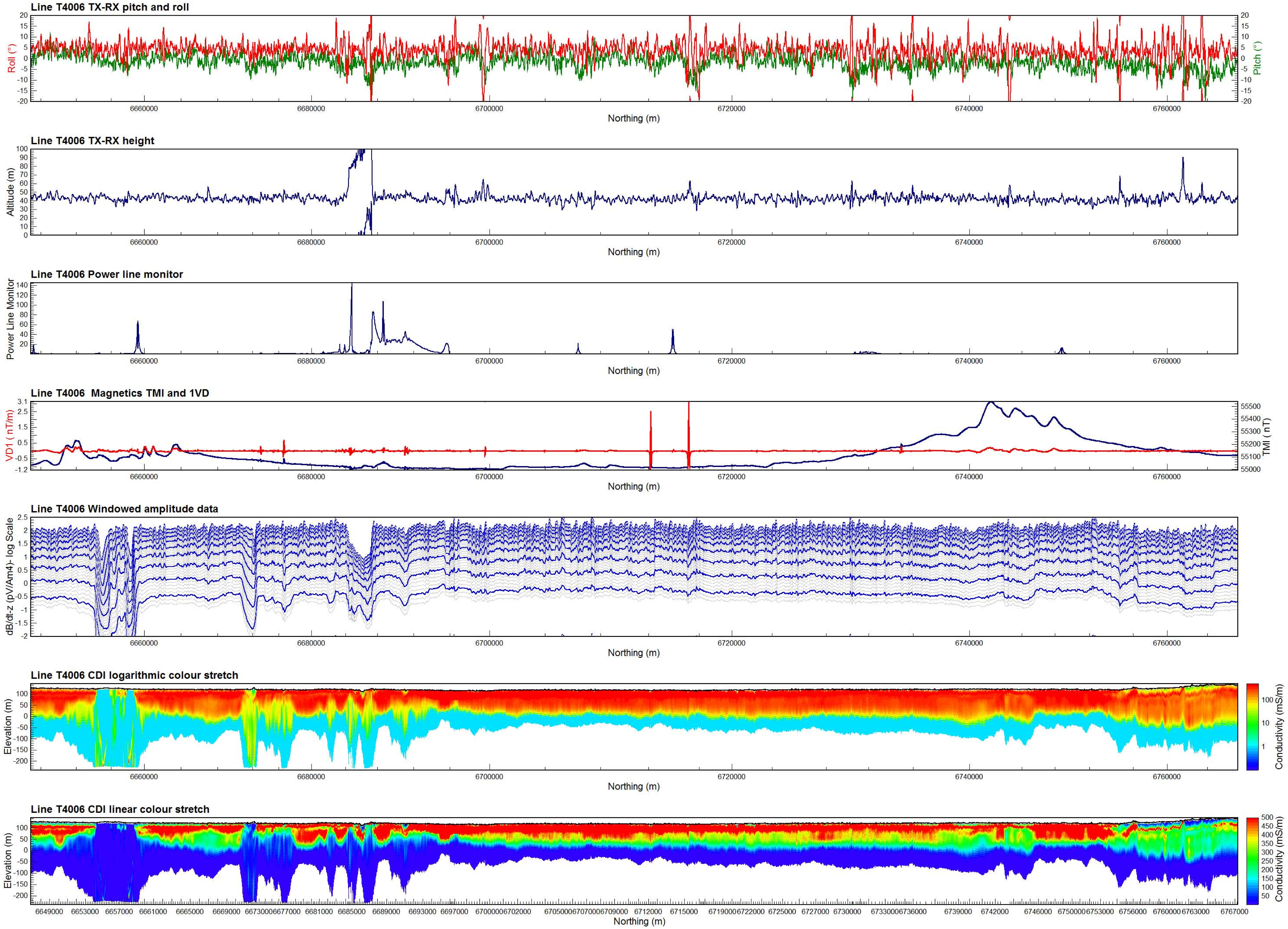
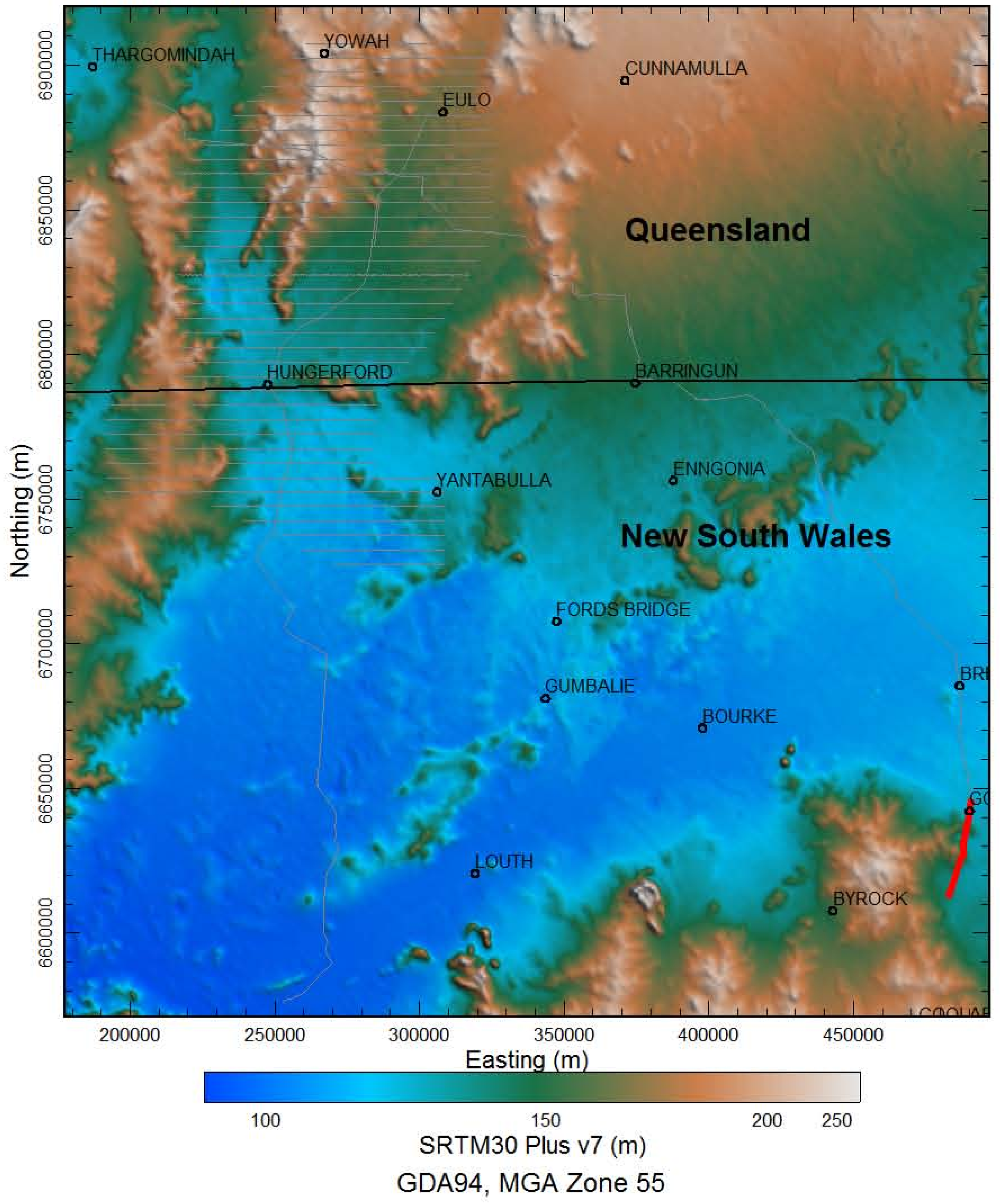


FLIGHT PATH



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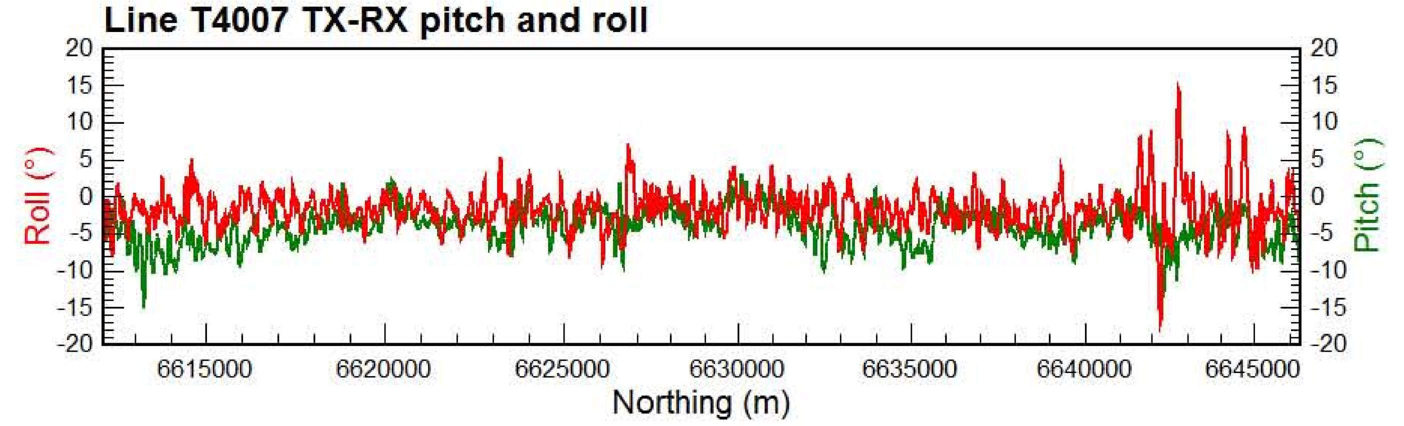
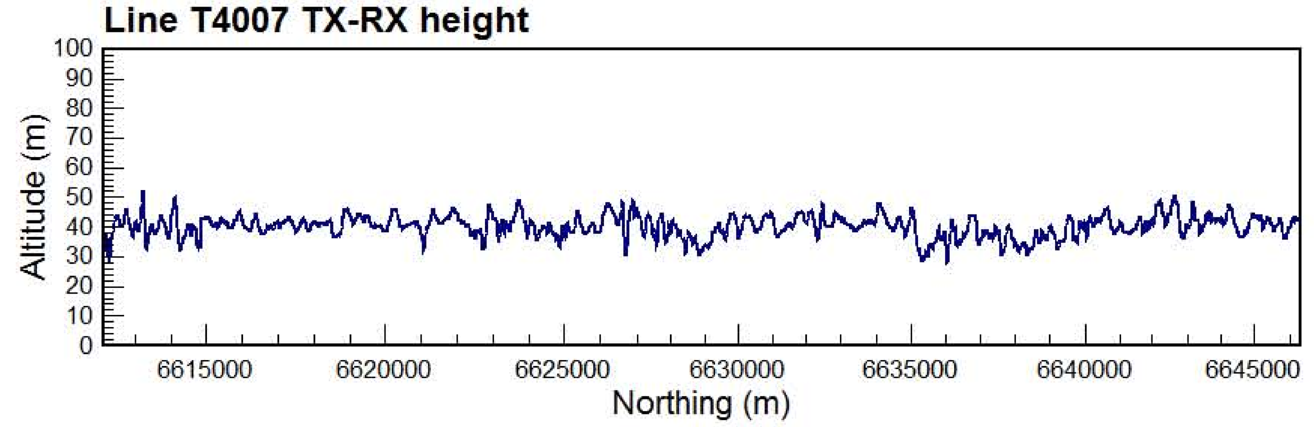
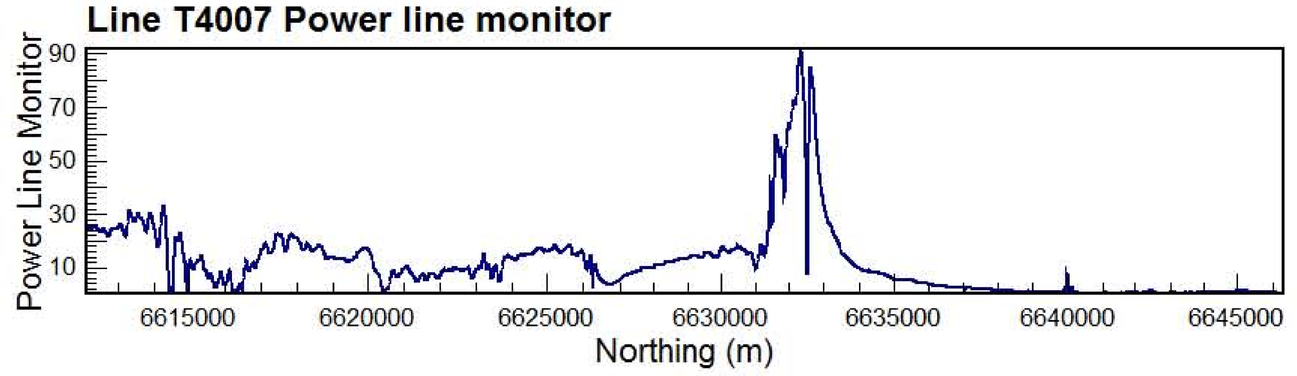
Line T4007 TX-RX pitch and roll



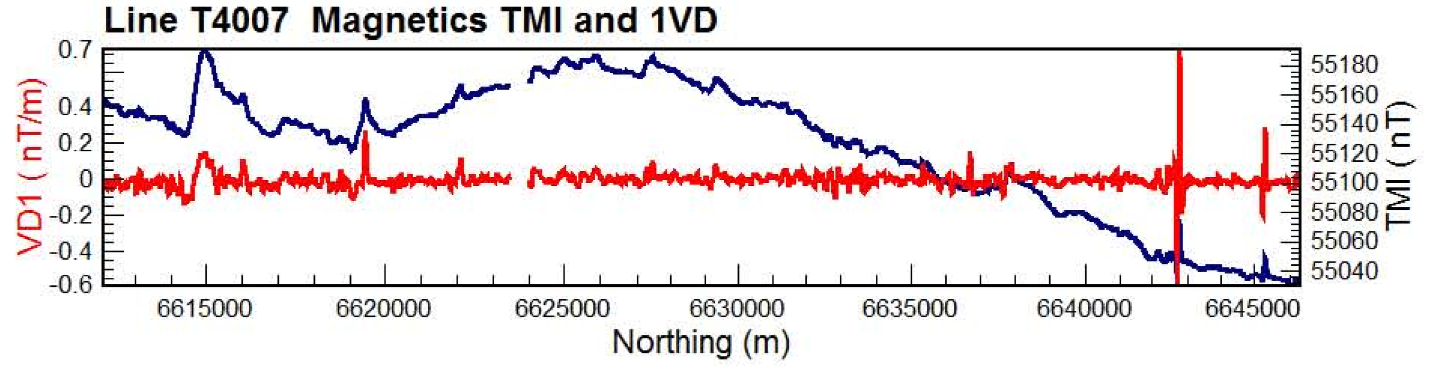
Line T4007 TX-RX height



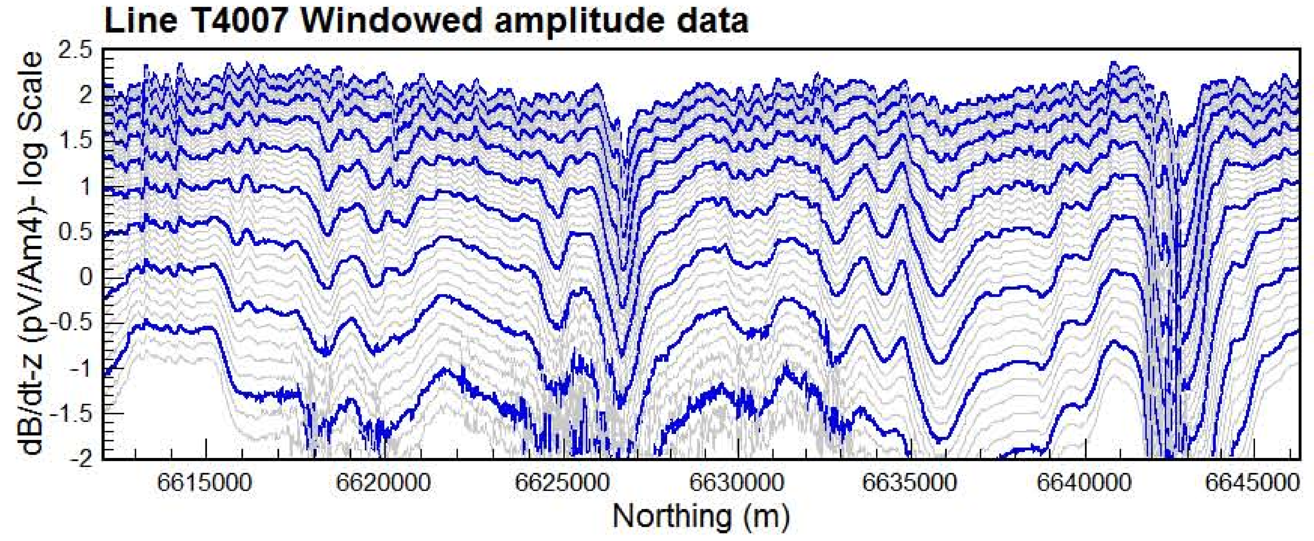
Line T4007 Power line monitor



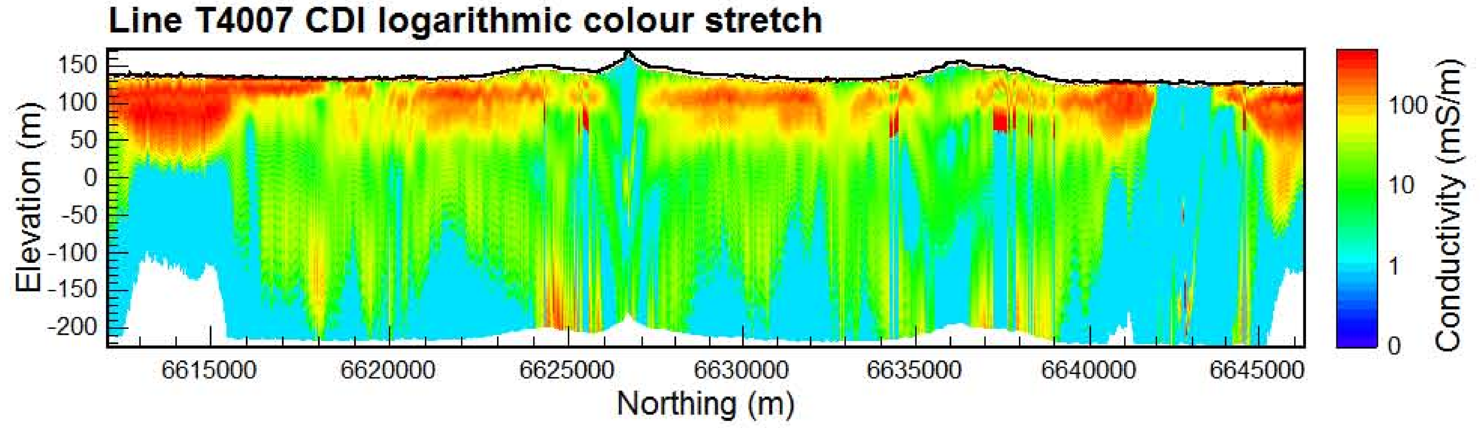
Line T4007 Magnetics TMI and 1VD



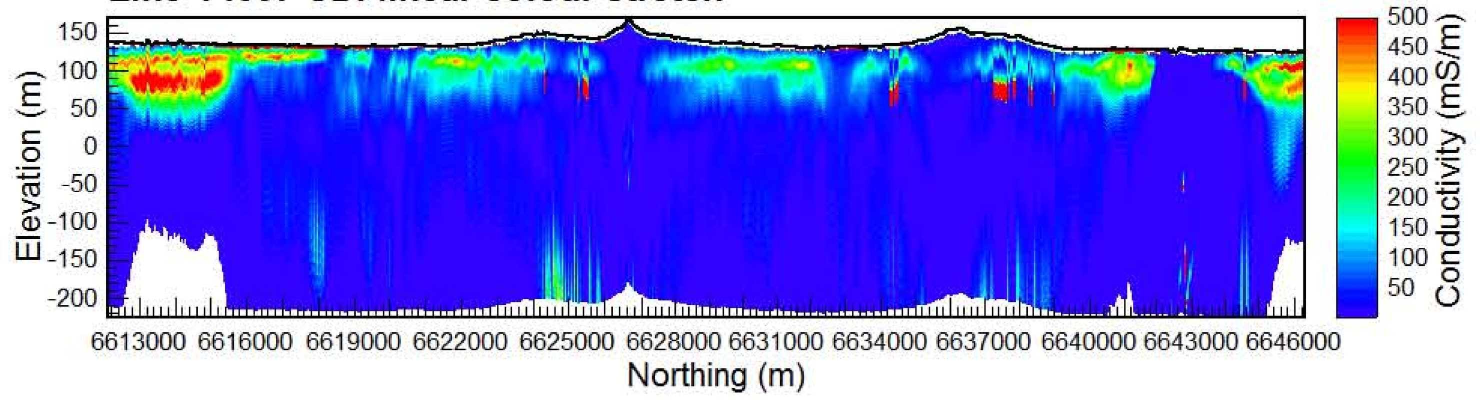
Line T4007 Windowed amplitude data



Line T4007 CDI logarithmic colour stretch



Line T4007 CDI linear colour stretch



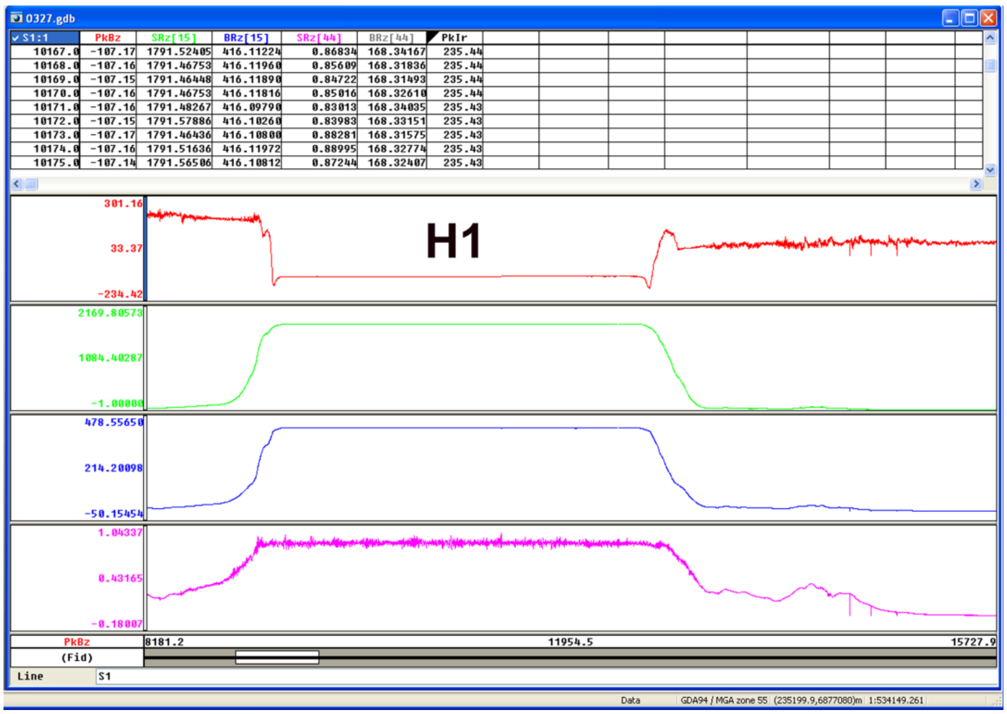
APPENDIX F

TEST SITES AND CALIBRATIONS

PLATE / ALUMINUM TEST

When the aluminum plate is horizontal with respect to the loop, measured signal will show positive response, indicating a proper polarity (see H1 in figure below).

Figure below present the plate/aluminum test results performed on March 27th, 2014.



REPEAT LINES
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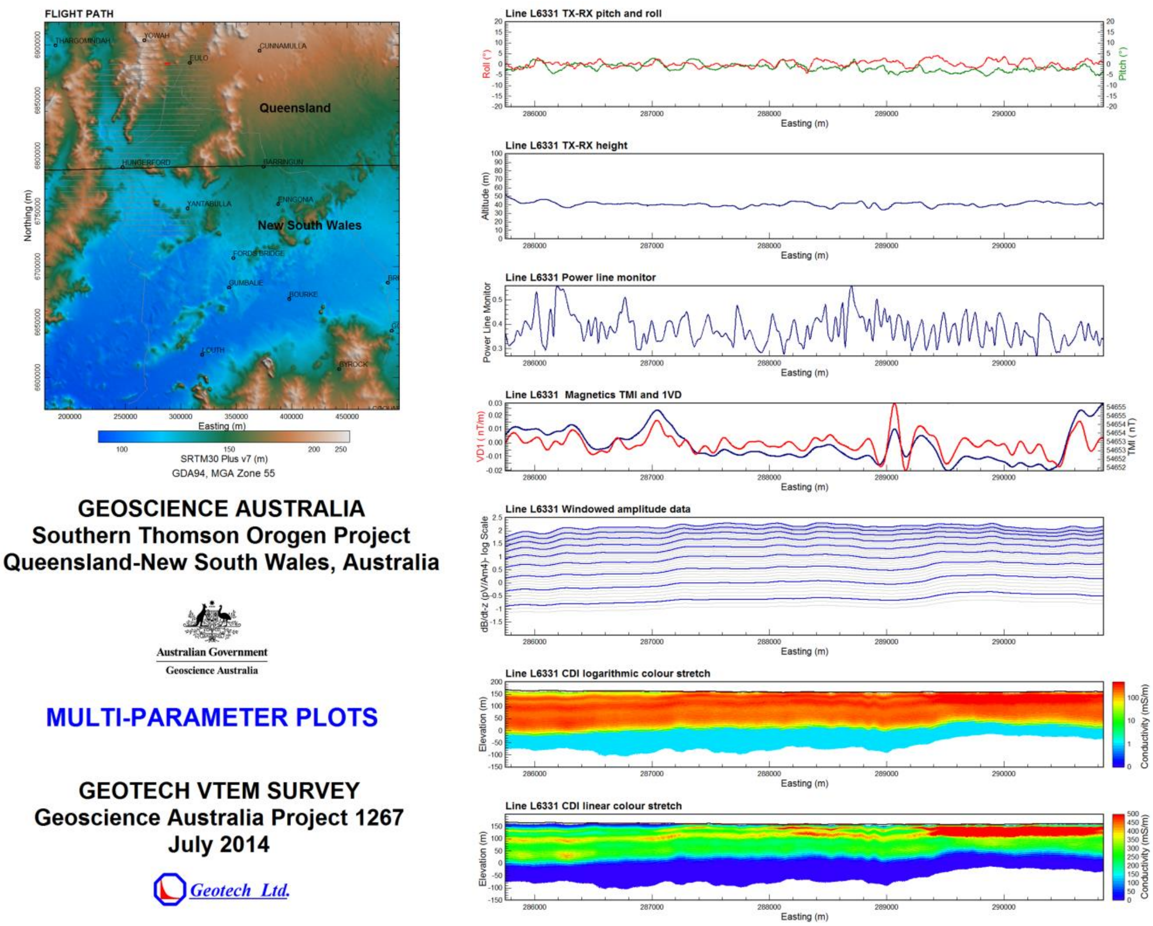

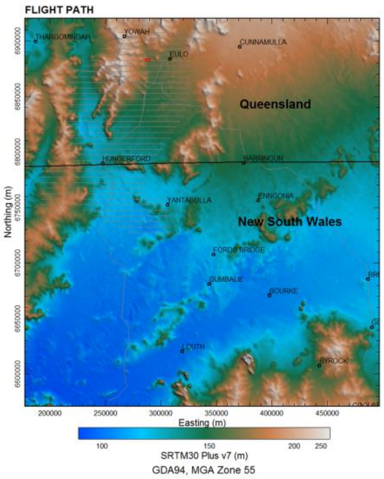

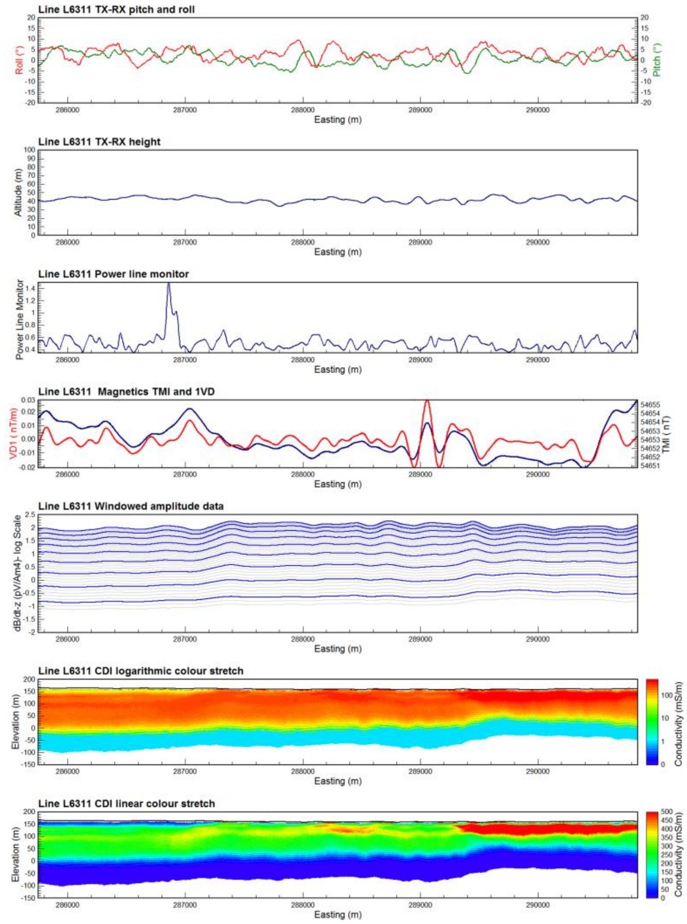

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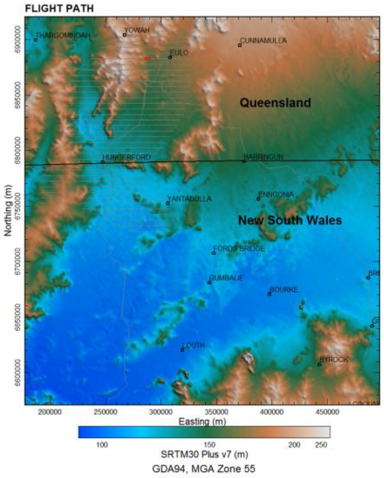
FLIGHT PATH



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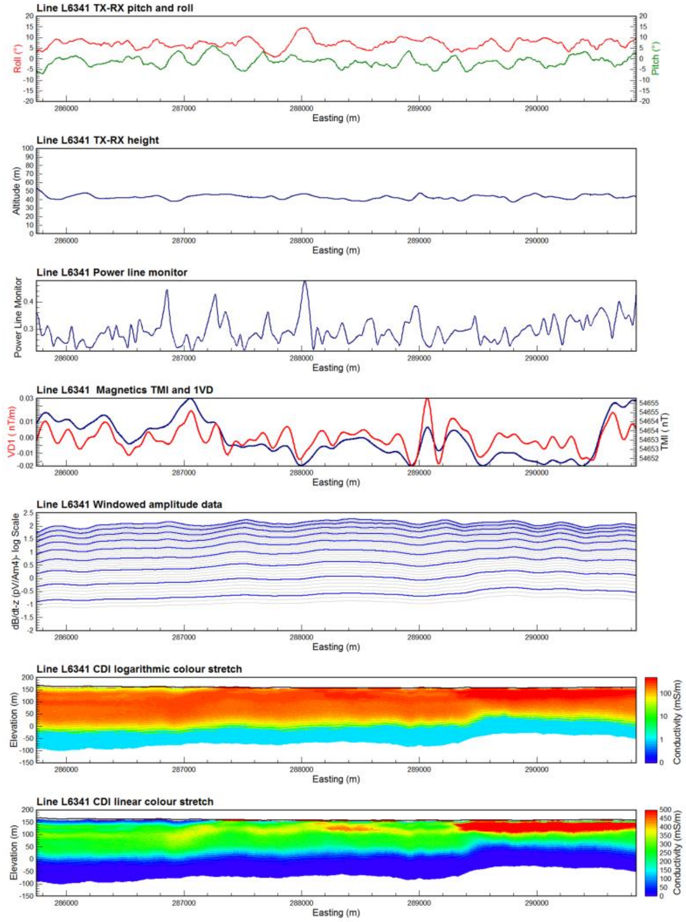

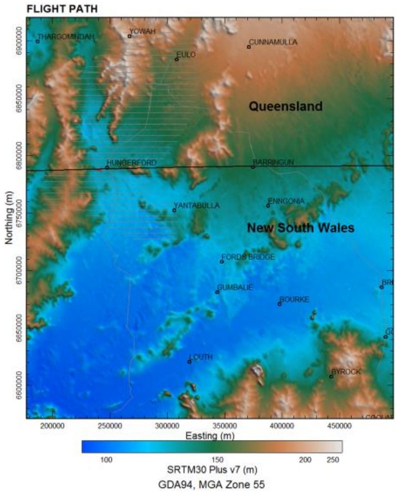

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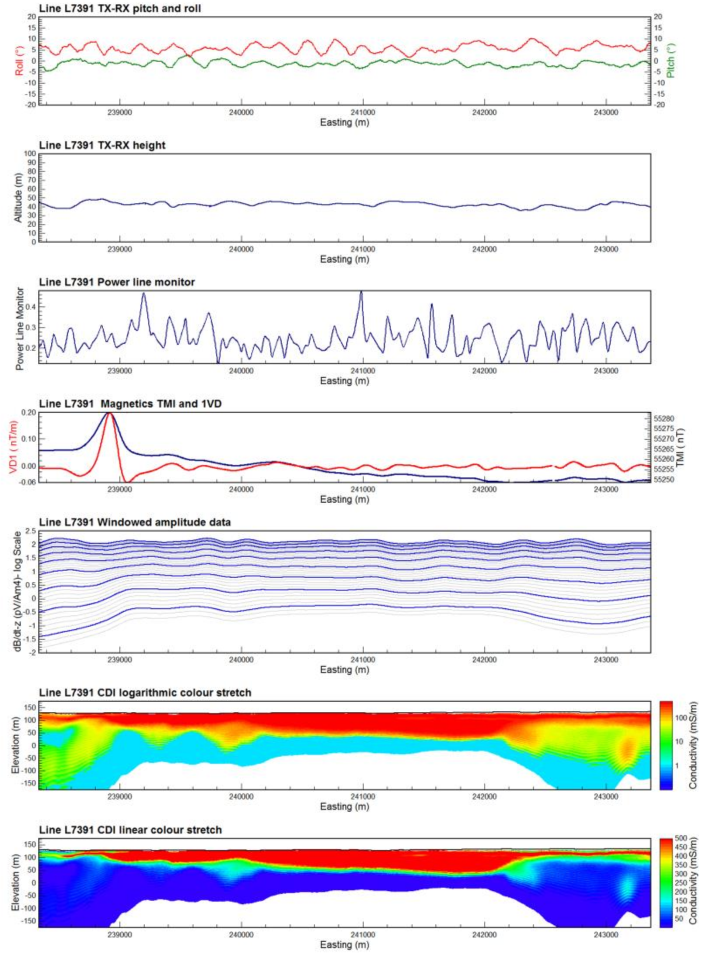

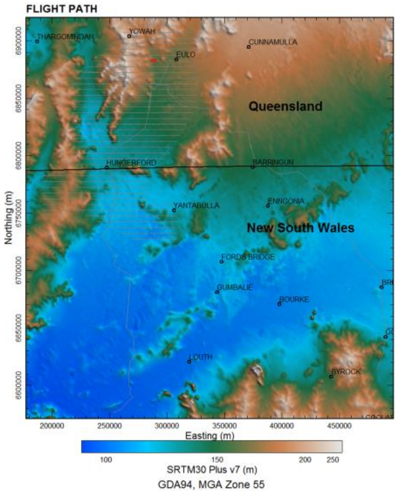

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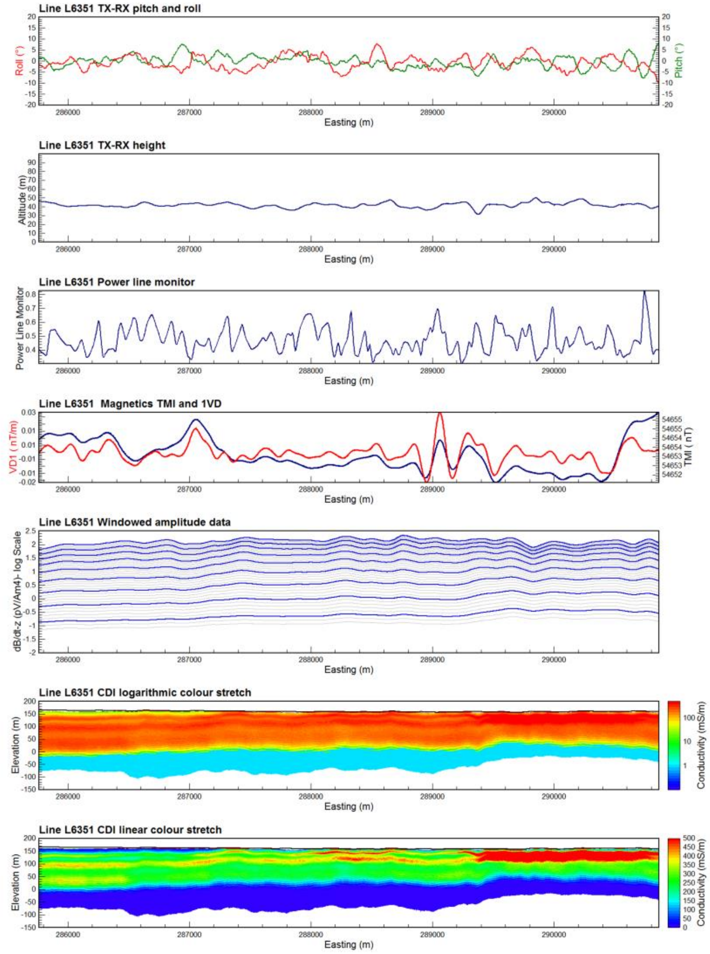

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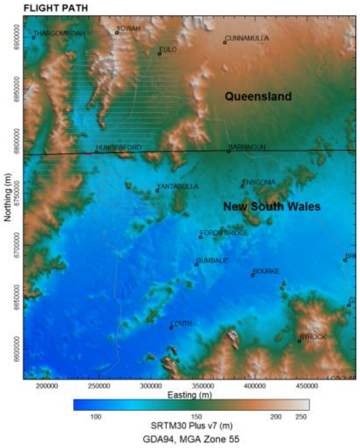

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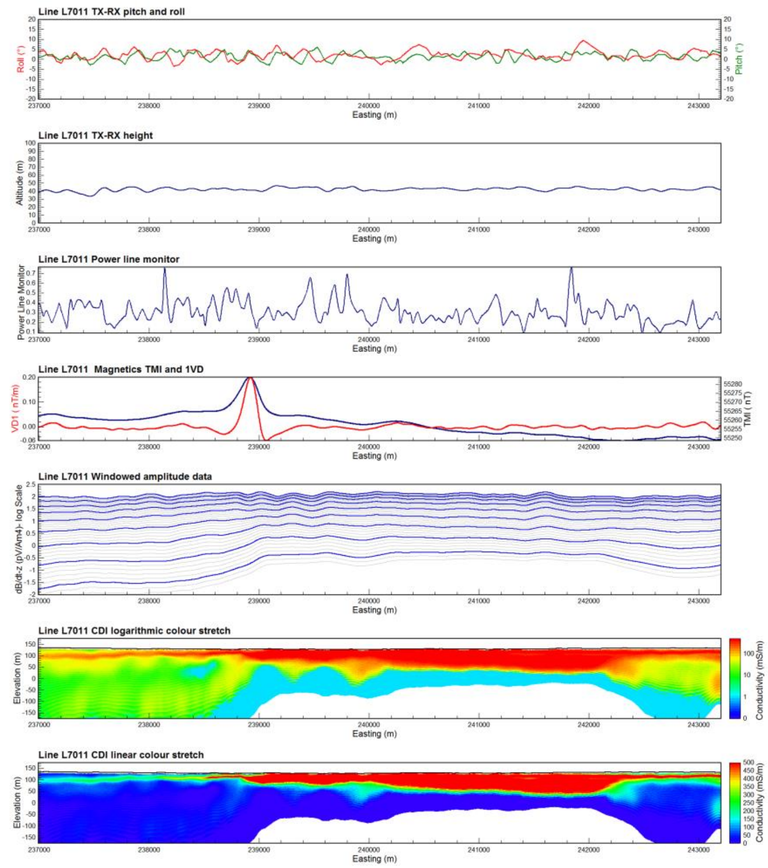

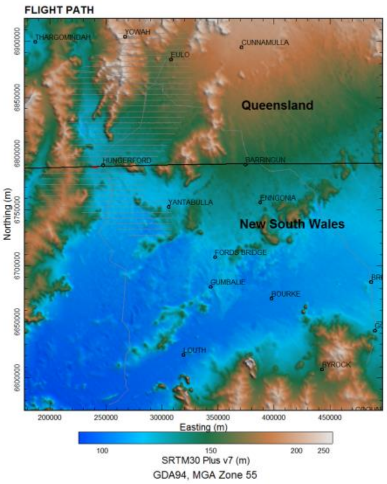

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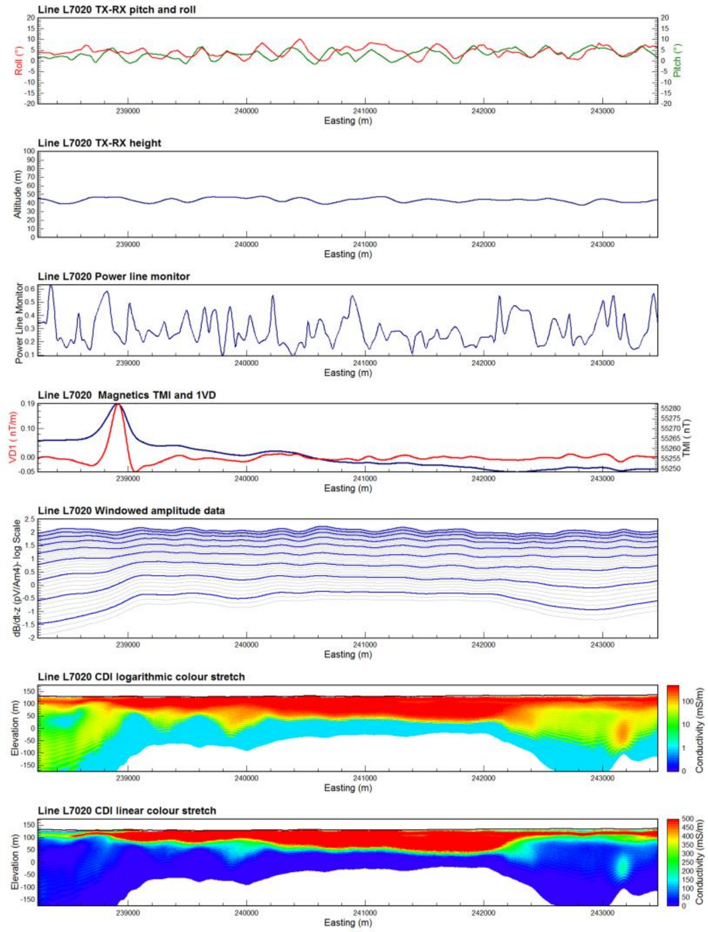

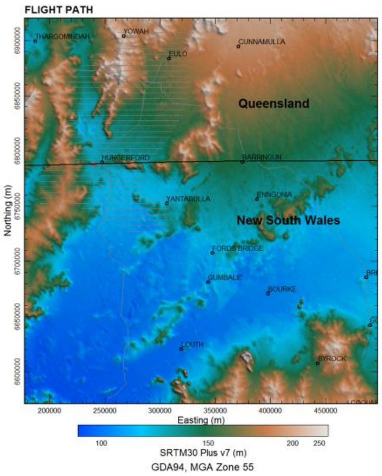

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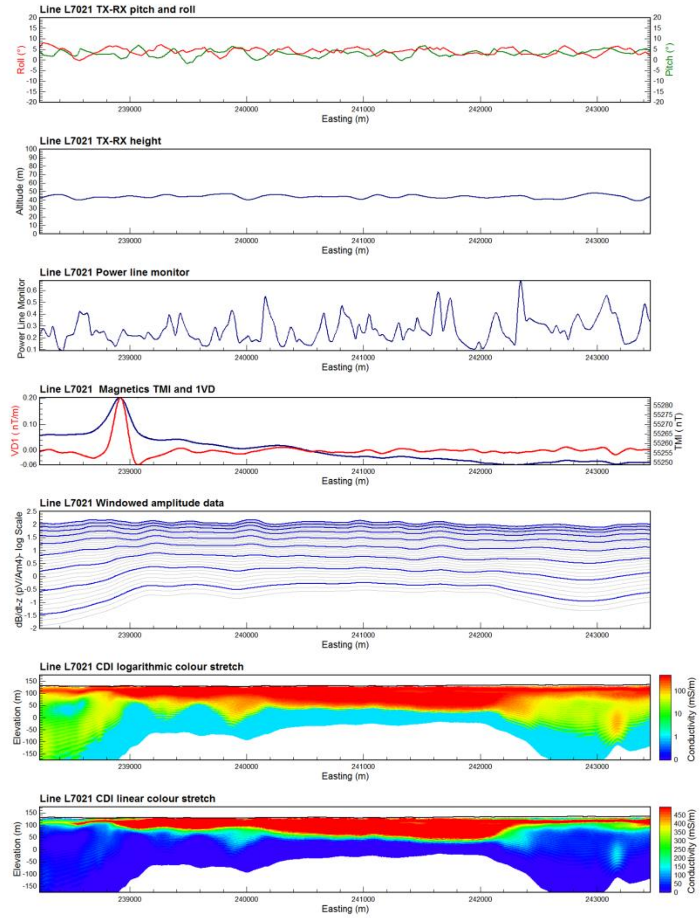

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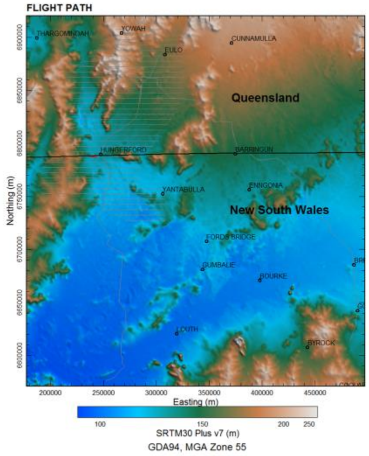

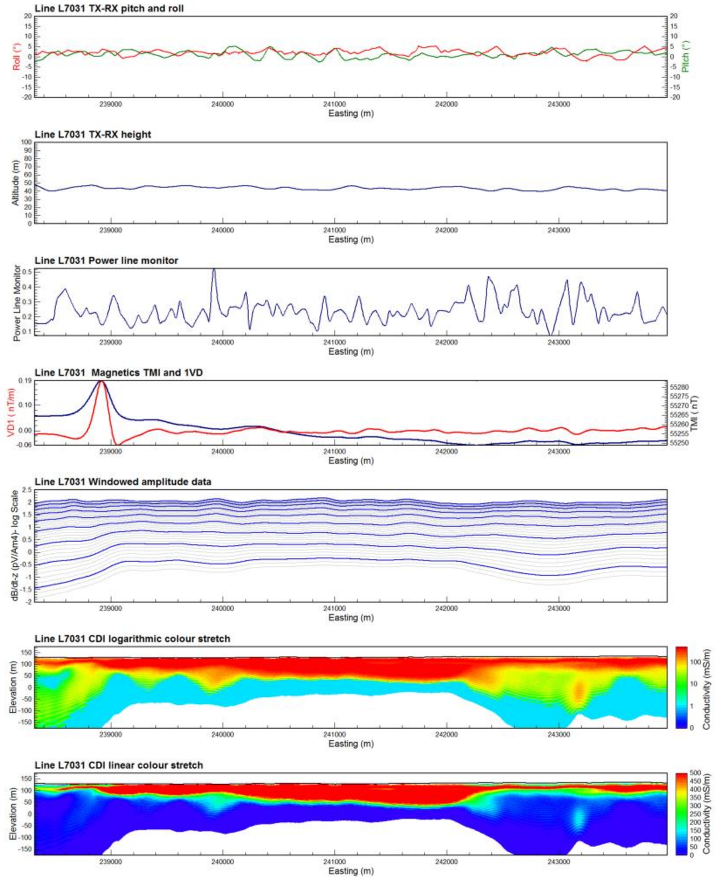

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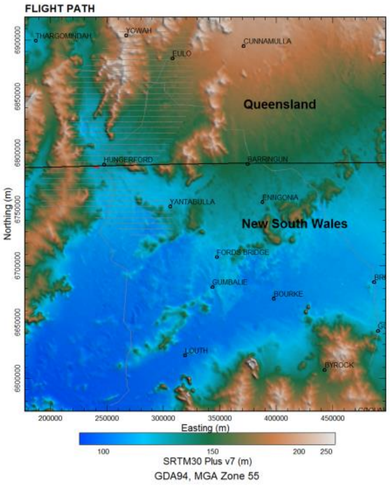

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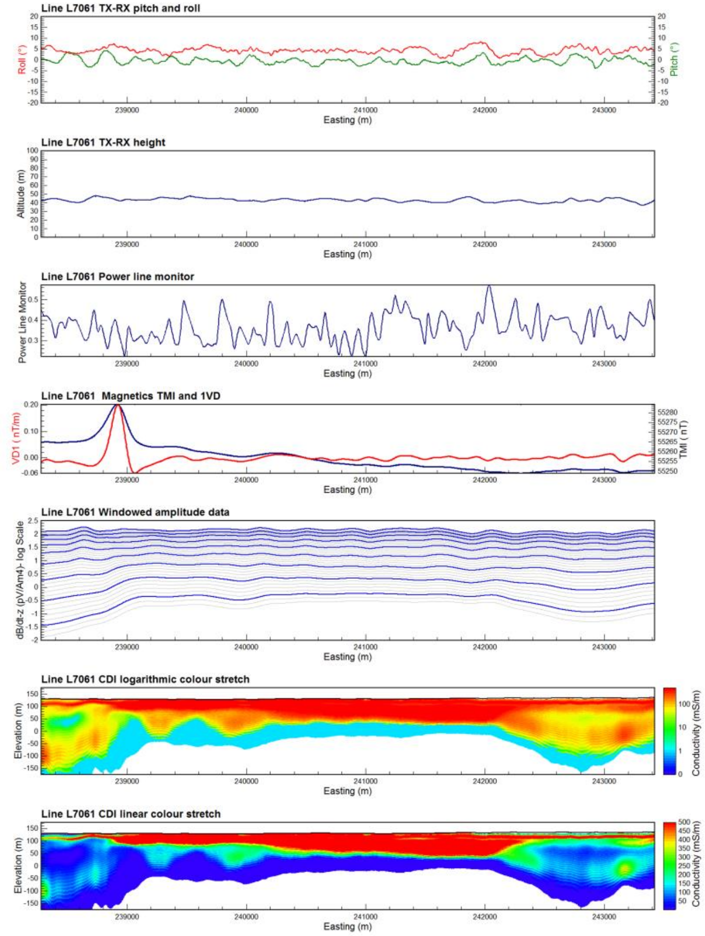

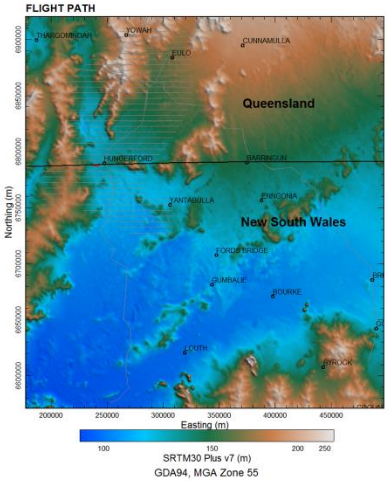

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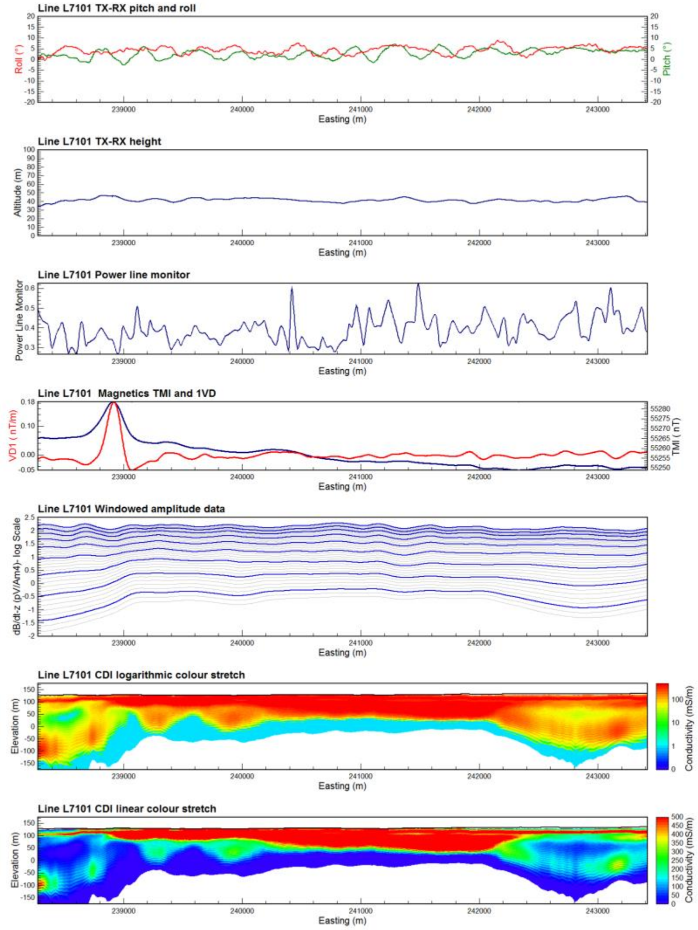

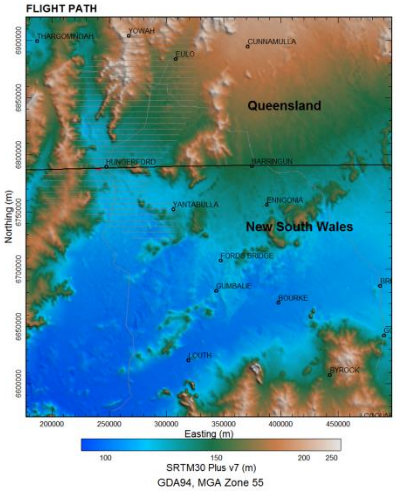

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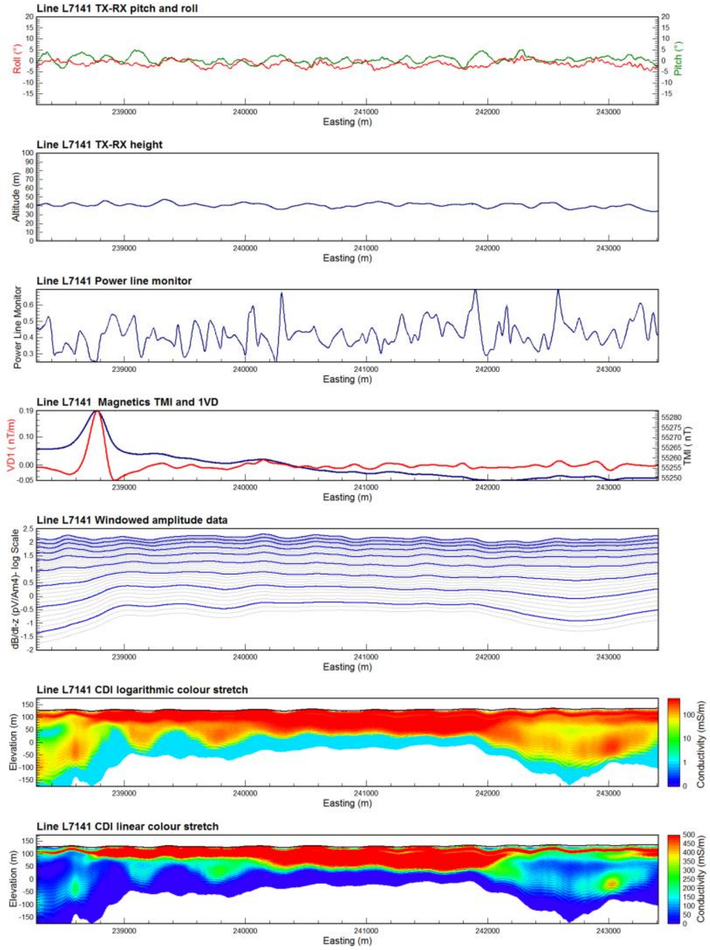

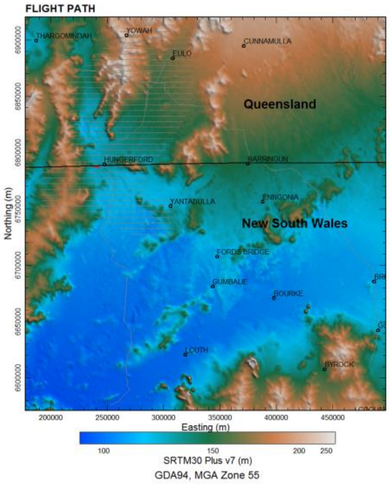

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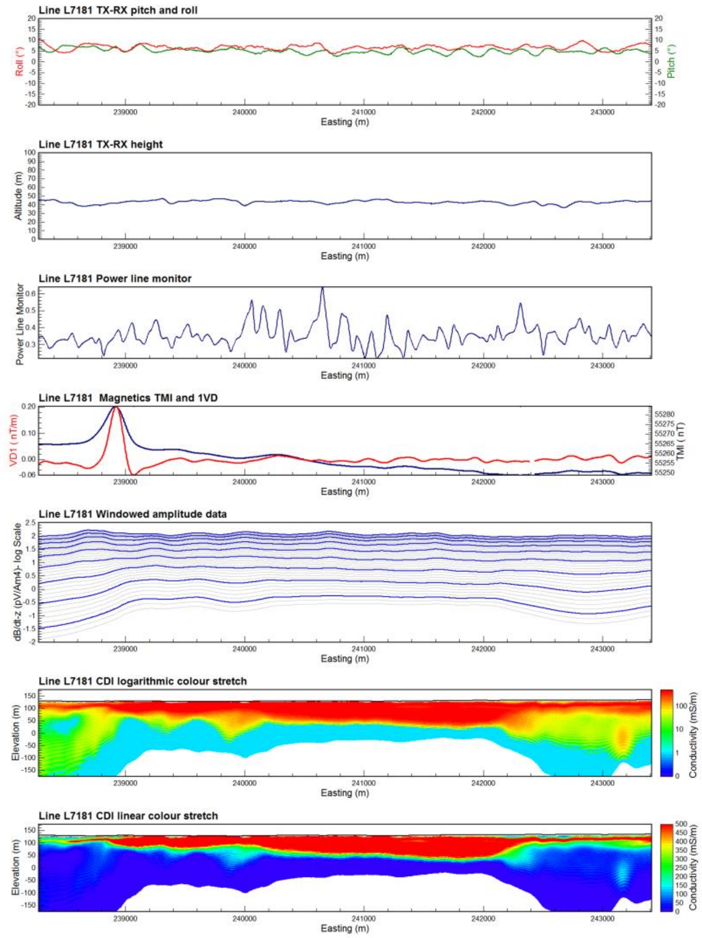

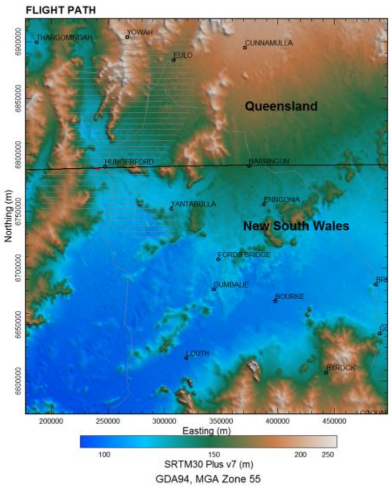

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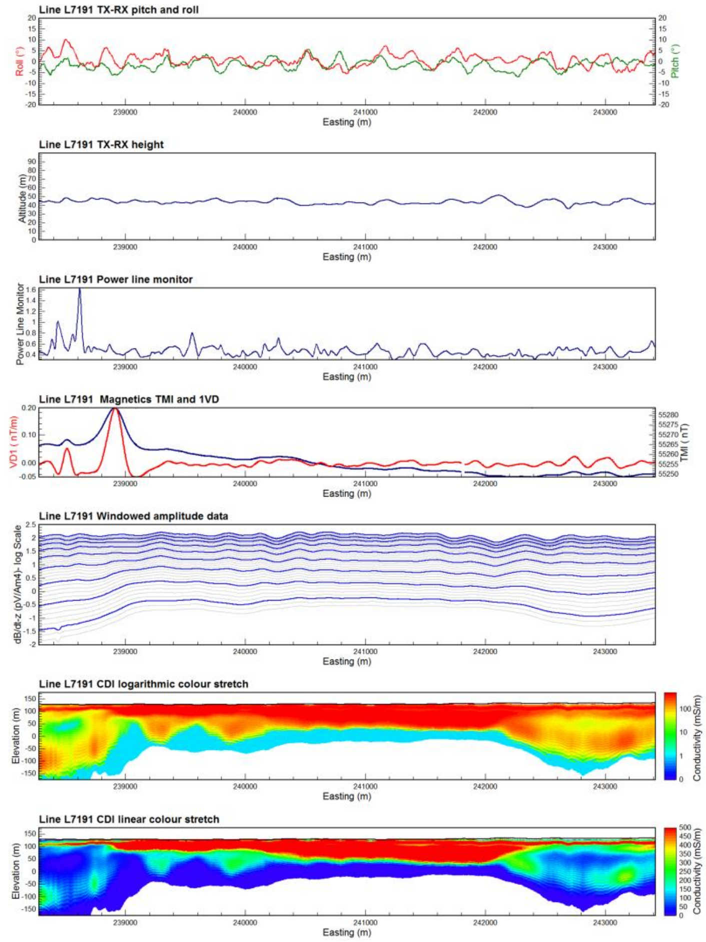

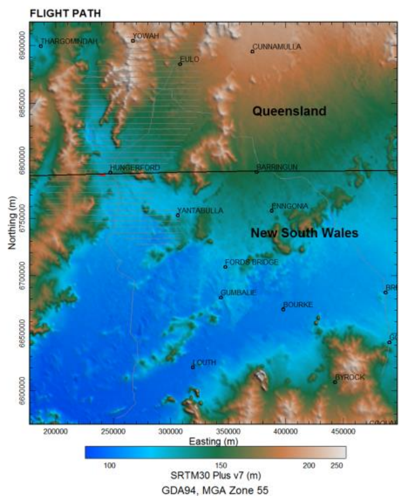

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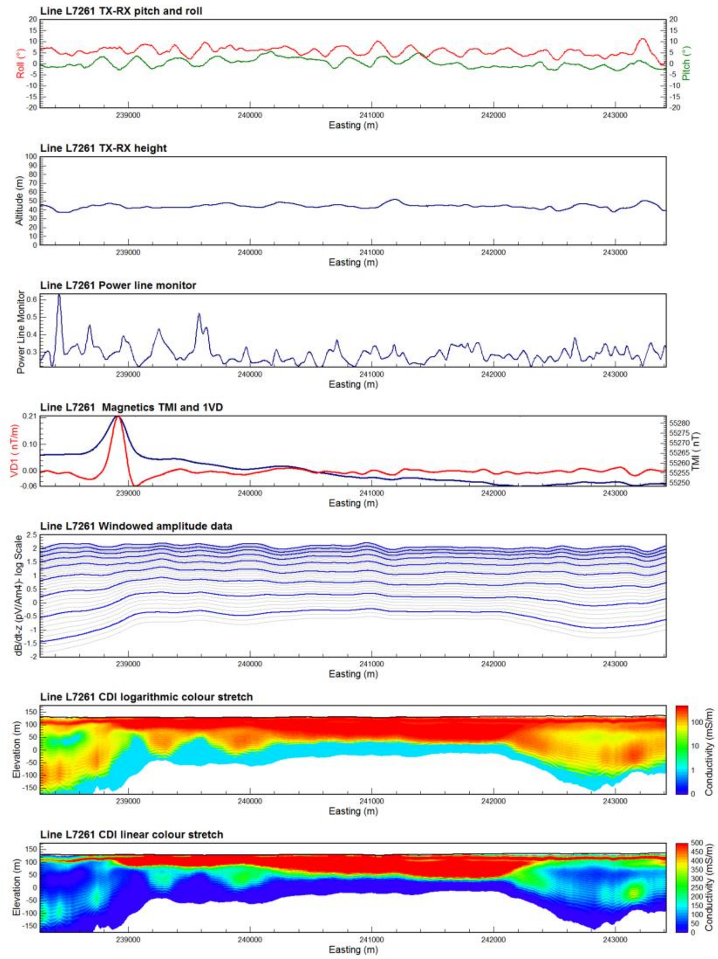
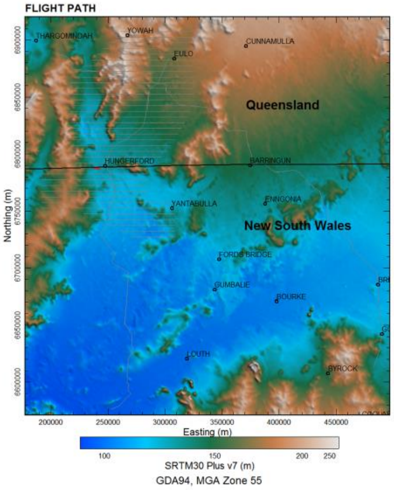
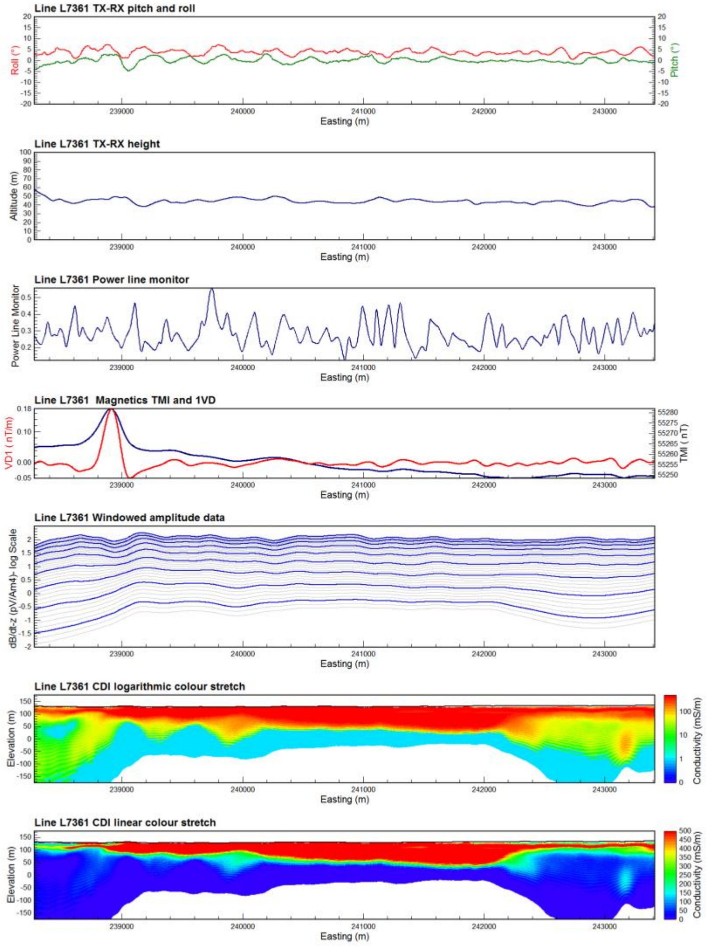


FLIGHT PATH





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RADAR AND LASER ALTIMETER CALIBRATION TESTS

Test Date: March 27, 2014 Hungerford Airport
Ground Elevation at test site is 144 metres.

Database Line	**Helicopter GPS Height** (m)	**Radar Altimeter** (m)	**Magnetic Gradiometer GPS Height** (m)	**Laser Altimeter** (m)
10060	208	61	182	40.6
10075	222	76	196	56.6
10090	240	93	215	73.7
10115	261	116	236	95.5
10130	279	133	255	114.3