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PanContinental Resources
FALCON® Airborne Gravity Gradiometer Survey
Montcalm Township, Ontario

Project Number: 802494

Logistics and Processing Report

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1 INTRODUCTION

CGG conducted a high-sensitivity aeromagnetic and **FALCON®** Airborne Gravity Gradiometer (AGG) survey over the Montcalm Township survey area under contract with PanContinental Resources.

1.1 Survey Location

The Montcalm Township survey area is centred on longitude 82° 08' W, latitude 48º 38' N (see the location map in *Figure 1*).

The production flights took place during August 2018 with the first production flight taking place on August 30th and the final flight taking place on September 3rd. To complete the survey area coverage a total of five production flights were flown, for a combined total of 249 line kilometres of data acquired.

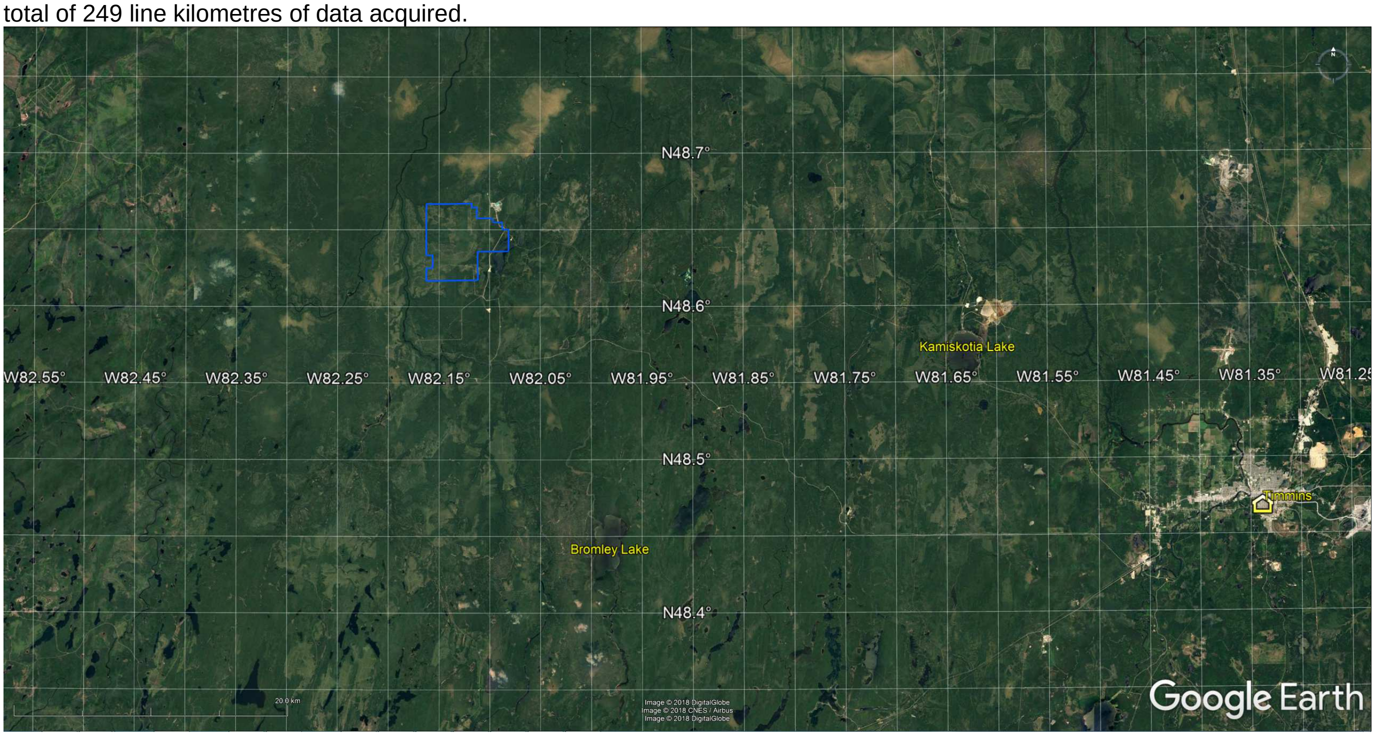

Figure 1: Montcalm Township – Survey Area Location

1.2 General Disclaimer

It is CGG's understanding that the data and report provided to the client are to be used for the purpose agreed between the parties. That purpose was a significant factor in determining the scope and level of the Services being offered to the Client. Should the purpose for which the data and report are used change, the data and report may no longer be valid or appropriate and any further use of, or reliance upon, the data and report in those circumstances by the Client without CGG's review and advice shall be at the Client's own and sole risk.

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2 SUMMARY OF SURVEY PARAMETERS

2.1 Survey Area Specifications

Total Kilometres (km)	249
Clearance Method	Drape
Minimum Drape Height (m)	80
Traverse Line Direction (deg.)	090 / 270
Traverse Line Spacing (m)	100

Table 1: Montcalm Township Survey Specifications

The survey block is defined by the coordinates in *Table 2*, in UTM Zone 17N projection, referenced to the WGS84 datum.

Corner Number	Easting	Northing
1	416244	5391034
2	414409	5391059
3	414349	5387356
4	414809	5387342
5	414797	5386420
6	414338	5386423
7	414329	5385958
8	414322	5385502
9	418079	5385502
10	418079	5385957
11	418078	5387559
12	420333	5387561
13	420361	5389118
14	419903	5389128
15	419907	5389654
16	419222	5389664
17	419220	5389979
18	418050	5389961
19	418081	5390761
20	417704	5390745
21	417702	5391058

Table 2: Montcalm Township – Survey Boundary Coordinates

2.2 Data Recording

The following parameters were recorded during the course of the survey:

- **FALCON® AGG data:** recorded at different intervals.
- **Airborne total magnetic field:** recorded with a 0.1 s sampling rate.

- **Terrain clearance:** provided by the radar altimeter at intervals of 0.1 s.
- **Airborne GPS positional data** (latitude, longitude, height, time and raw range from each satellite being tracked): recorded at intervals of 1 s.
- **Time markers:** in digital data.
- **Ground total magnetic field:** recorded with a 1 s sampling rate.
- **Ground based GPS positional data** (latitude, longitude, height, time and raw range from each satellite being tracked): recorded at intervals of 1 s.
- **Ground surface below aircraft:** mapped by the laser scanner system, scanning at 36 times per second, recording 276 returns per scan (when within range of the instrument and in the absence of thick vegetation).

2.3 Project Safety Plan, HSE Summary

A Job Safety Plan and Job Safety Analysis was prepared and implemented in accordance with the CGG Occupational Safety and Health Management System.

3 FIELD OPERATIONS

3.1 Operations

The survey was based out of Timmins, Ontario. The survey aircraft was operated from Timmins Airport using aircraft fuel available on site. A temporary office was set up in Timmins where all survey operations were run and the post-flight data verification was performed.

3.2 Base Stations

A dual frequency GPS base station was set up at Timmins Airport in order to correct the raw GPS data collected in the aircraft. A secondary GPS base station was available but was not required.

3.2.1 GPS Base Station

Location:	Timmins Airport
Date:	August 24th, 2018
Latitude:	48º 34' 06.9298" N
Longitude:	81º 22' 10.7929" W
Height:	257 m ellipsoidal

3.2.2 Magnetometer Base Station (CF1)

Location:	Timmins Airport
Date:	August 24th, 2018
Used for flights:	6 to 11
Base:	55942.5 nT

3.3 Field Personnel

The following technical personnel participated in field operations:

Crew Leader:	D. Patzer
Pilots:	D. Wiens and T. Sweeney
Technicians:	D. Patzer
Project Manager:	D. Beattie
Final QC and Processing:	J. Mohammed-Nour, A. Zlojutro and A. Carbone

Table 3: Field Personnel

4 QUALITY CONTROL RESULTS

4.1 Survey Acquisition Issues

During the course of the survey there were no data quality issues with:

- AGG instrumentation
- Magnetic and GPS base stations
- Airborne magnetometer system
- Data acquisition systems
- Radar altimeter
- Laser scanner

4.2 Flight Path Map

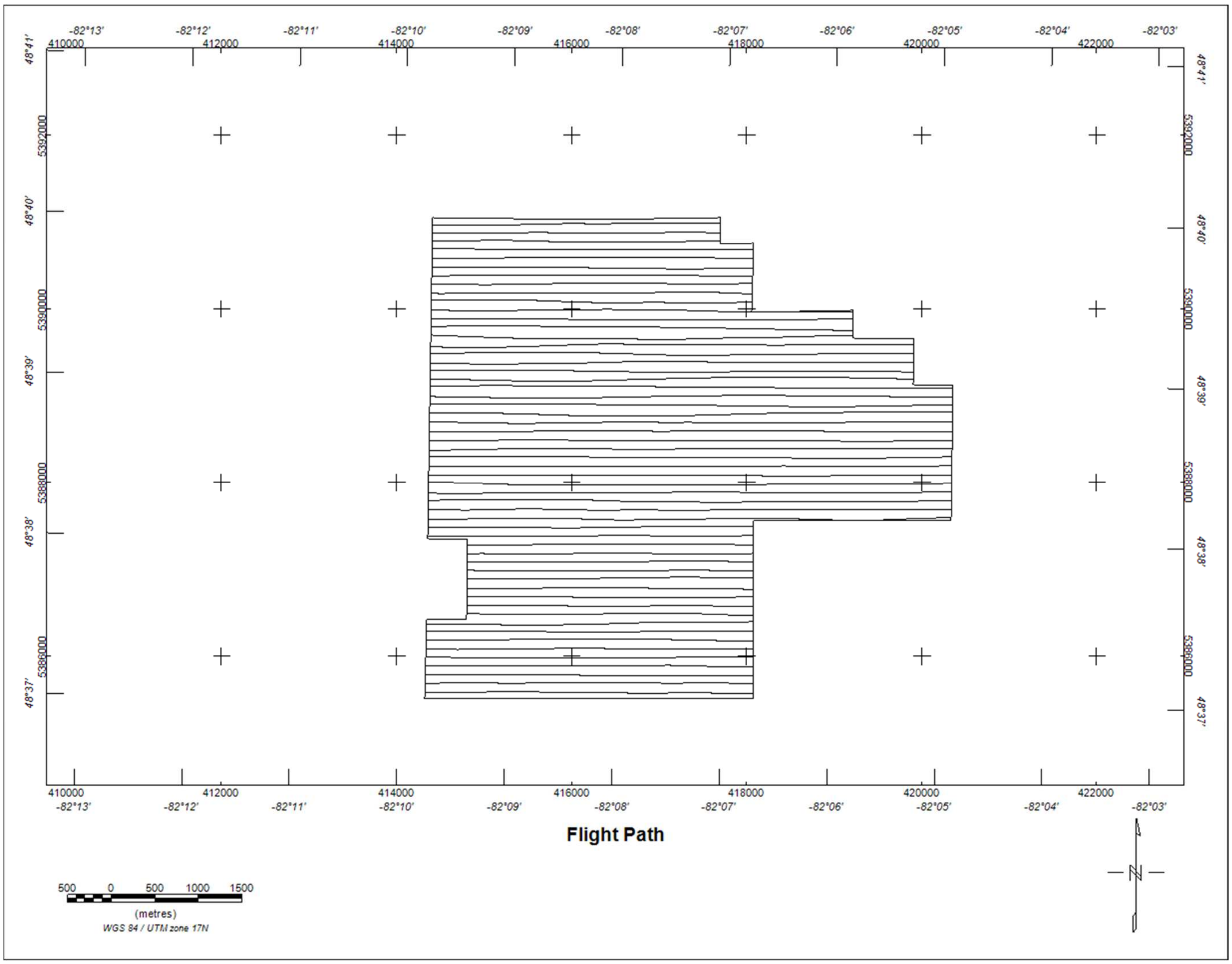

Figure 2: Montcalm Township – Flight Path map

4.3 Turbulence

The mean turbulence recorded in the Montcalm Township survey area was 60.3 milli g (where g = 9.80665 m/sec/sec). Turbulence was variable, ranging from very low to high. The typical pattern for a given flight was for turbulence to commence at a very low level and then increase throughout the flight. The turbulence pattern across the survey area is shown in *Figure 3*.

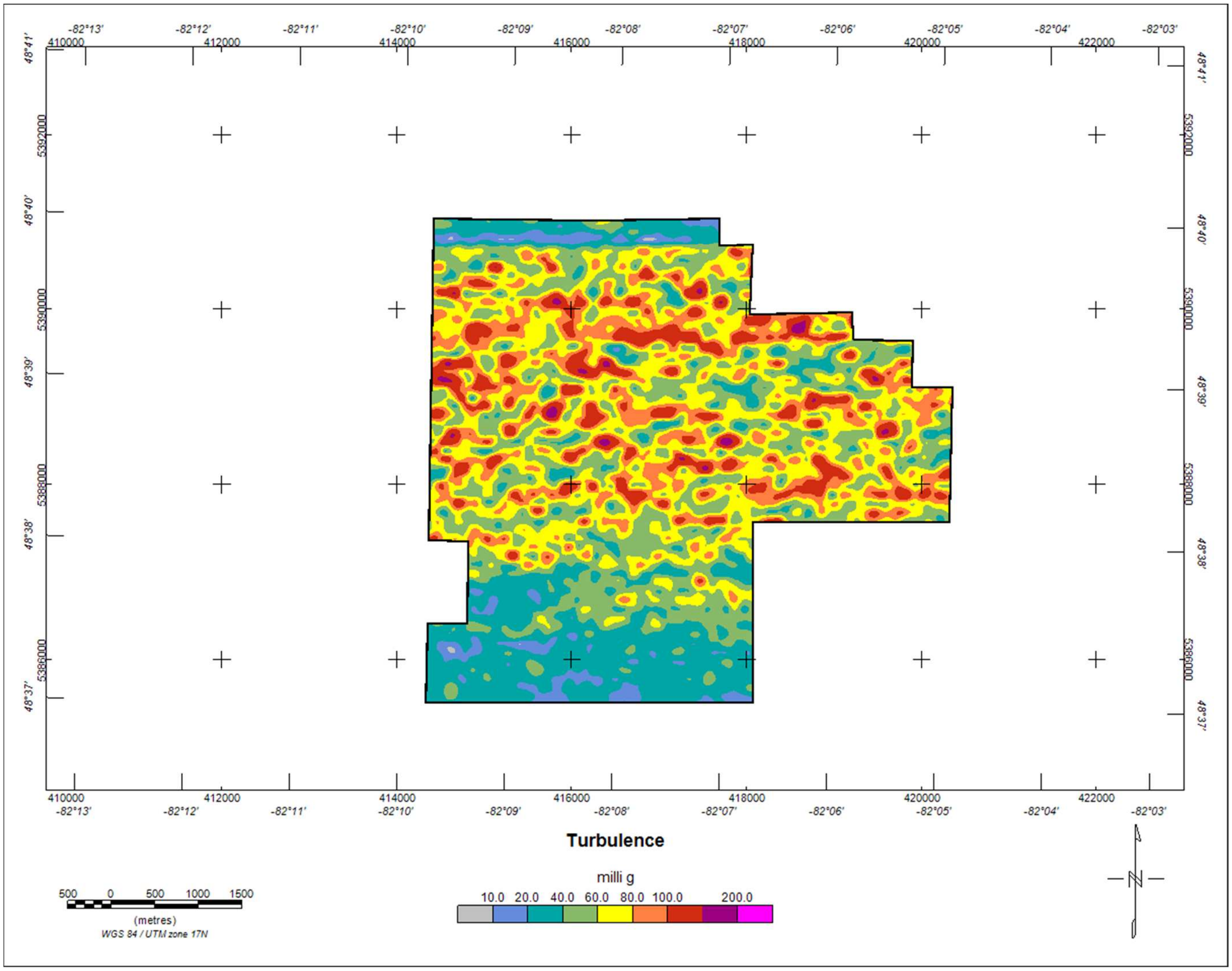

Figure 3: Montcalm Township – Turbulence (millig where g = 9.80665 m/sec/sec)

4.4 AGG System Noise

The system noise is defined to be the standard deviation of half the difference between the A & B complements, for each of the NE and UV curvature components. The results for this survey were very good with values of 3.48 E and 3.14 E for NE and UV respectively.

Figure 4 and *Figure 5* provide a representation of the variation in this standard deviation for each component. This is achieved by gridding a rolling measurement of standard deviation along each line using a window length of 100 data points.

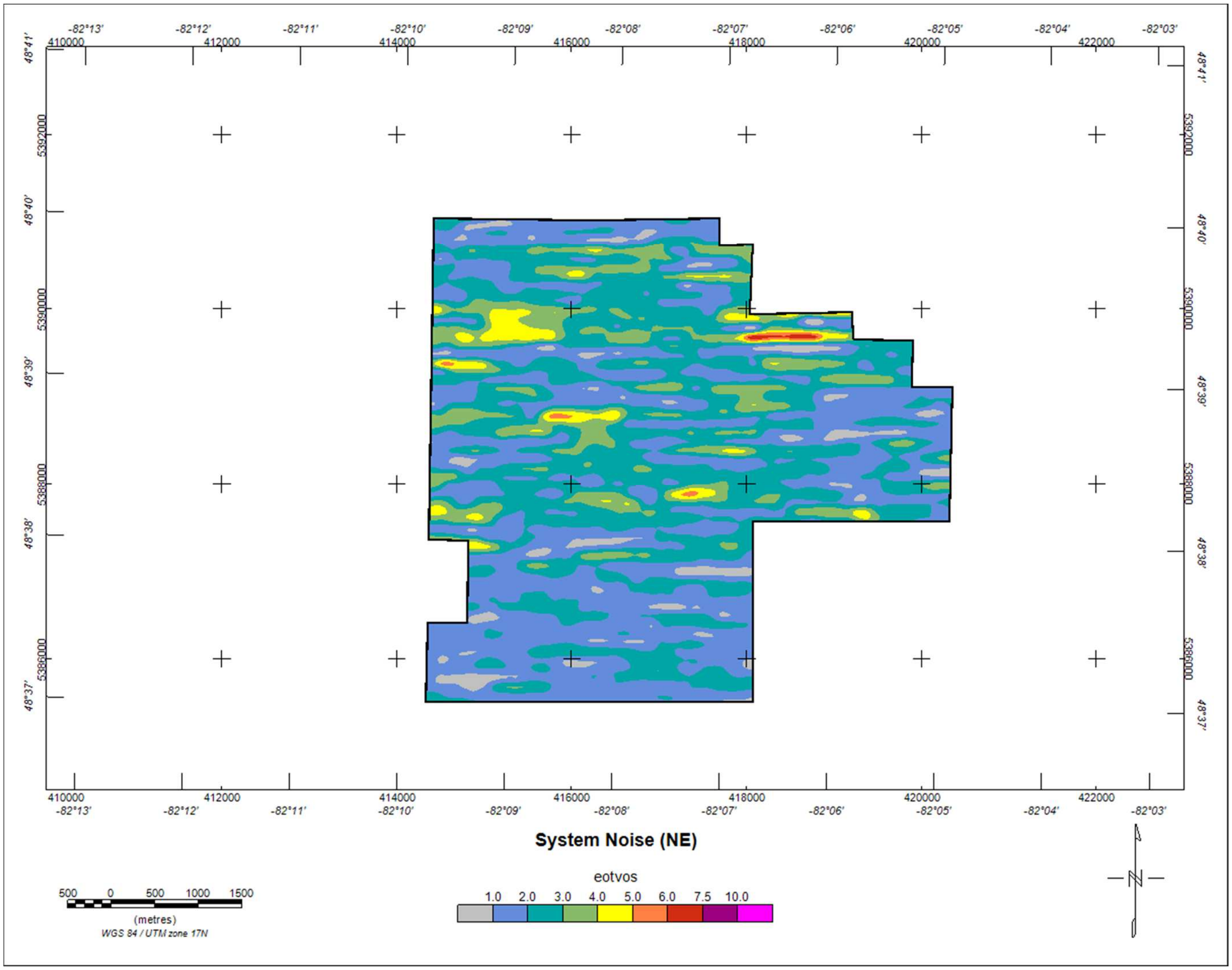

Figure 4: Montcalm Township – System Noise NE (eotvos)

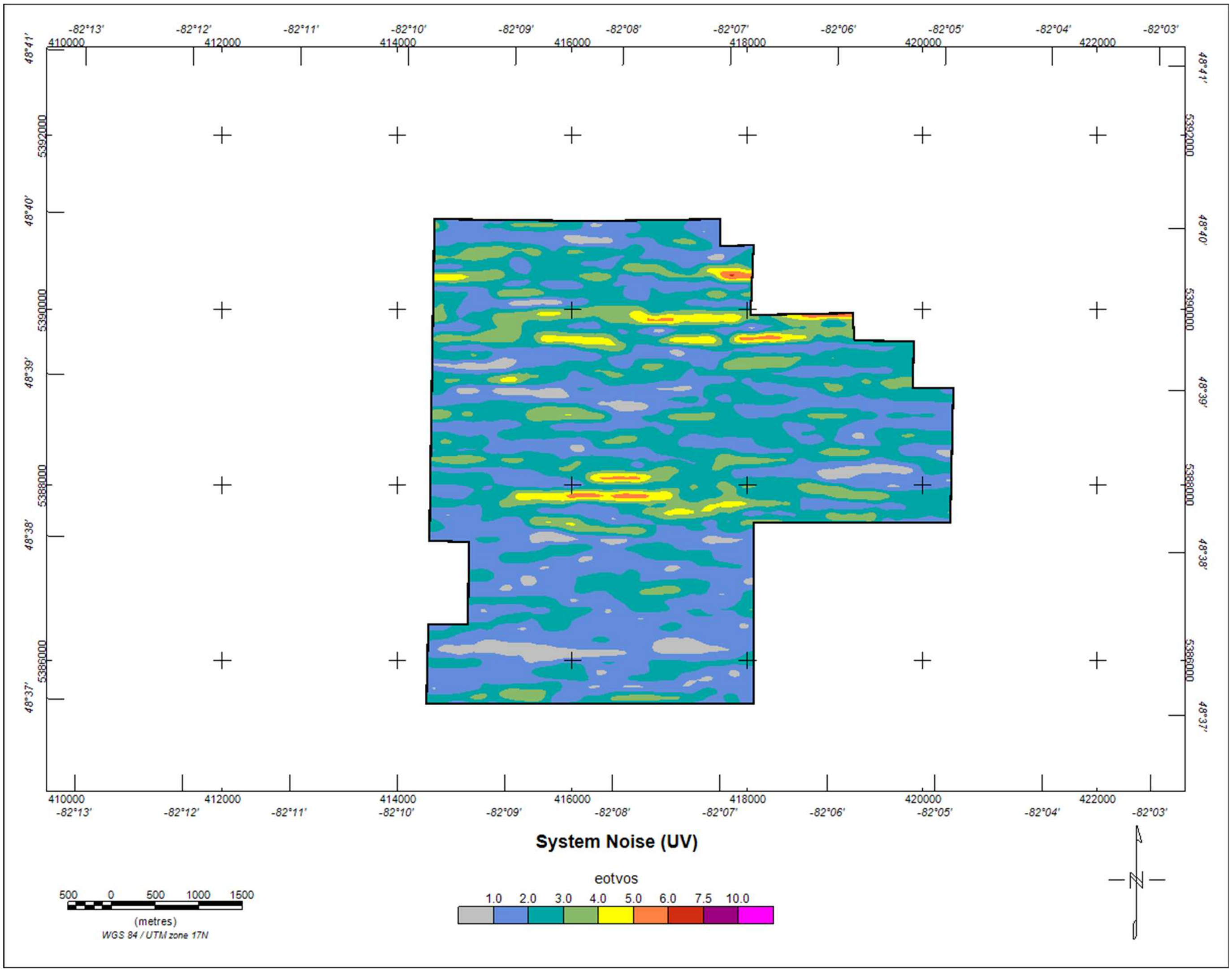

Figure 5: Montcalm Township – System Noise UV (eotvos)

4.5 Digital Terrain Model

Laser scanner range data were combined with GPS position and height data (adjusted from height above the WGS84 ellipsoid to height above the geoid by applying the Earth Gravitational Model 1996 (EGM96)). The output of this process is a "swath" of terrain elevations extending either side of the aircraft flight path. Width and sample density of this swath varies with aircraft height. Typical values are 100 to 150 metres and 5 to 10 metres respectively.

Because terrain correction of AGG data requires knowledge of the terrain at distances up to at least 10 km from the data location, laser scanner data collected only along the survey line path must be supplemented by data from another source. For this purpose, Shuttle Radar Topography Mission (SRTM) v3 (one arc second resolution) data are used.

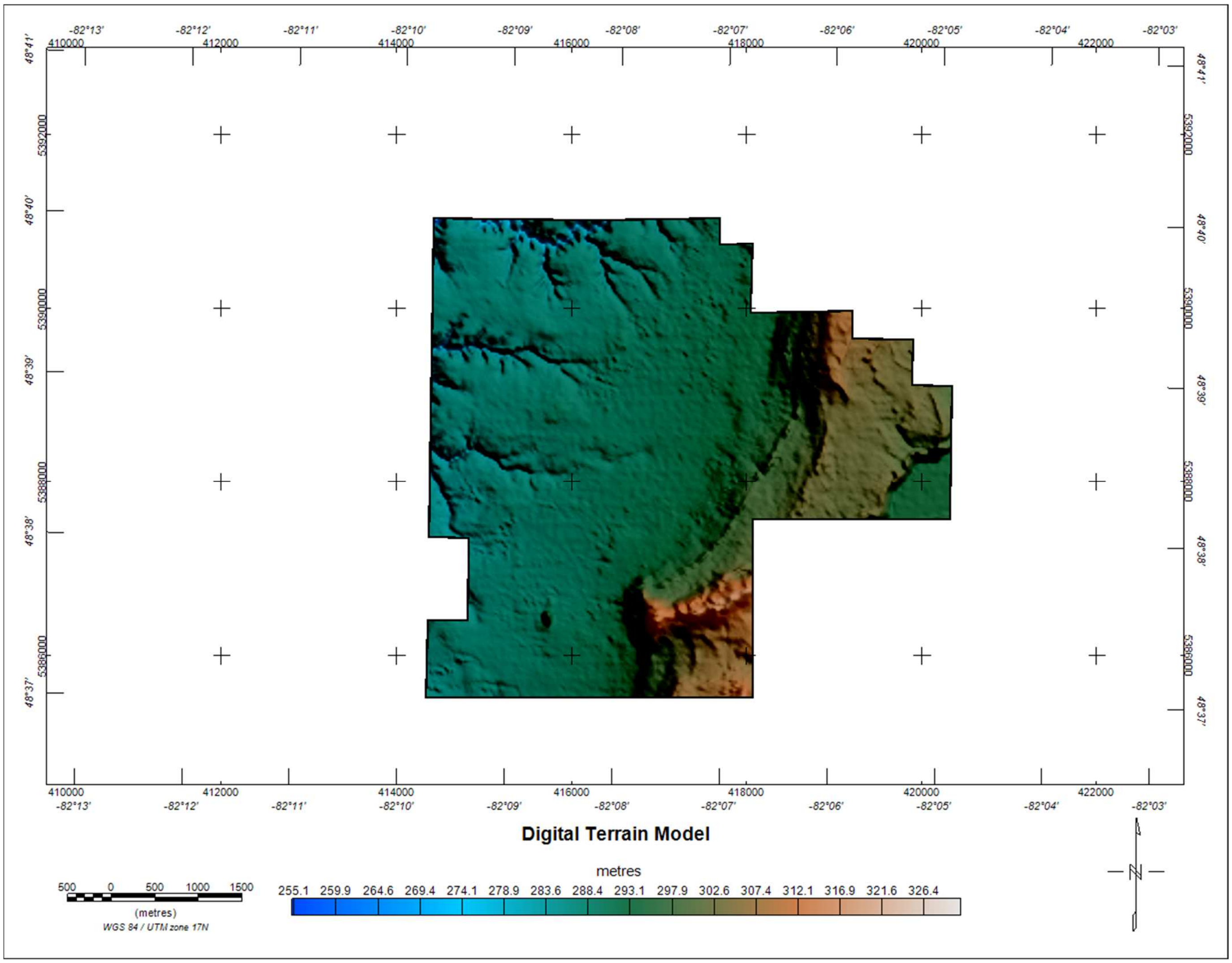

Figure 6: Montcalm Township – Final Digital Terrain Model (metres, referenced to the EGM96 geoid)

4.6 Terrain Clearance

Terrain clearance for the Montcalm Township survey averaged slightly above the nominal clearance of 80 m having a mean value of 84.0 m across the survey area. The terrain clearance, as derived from laser scanner data, is shown in *Figure 7*.

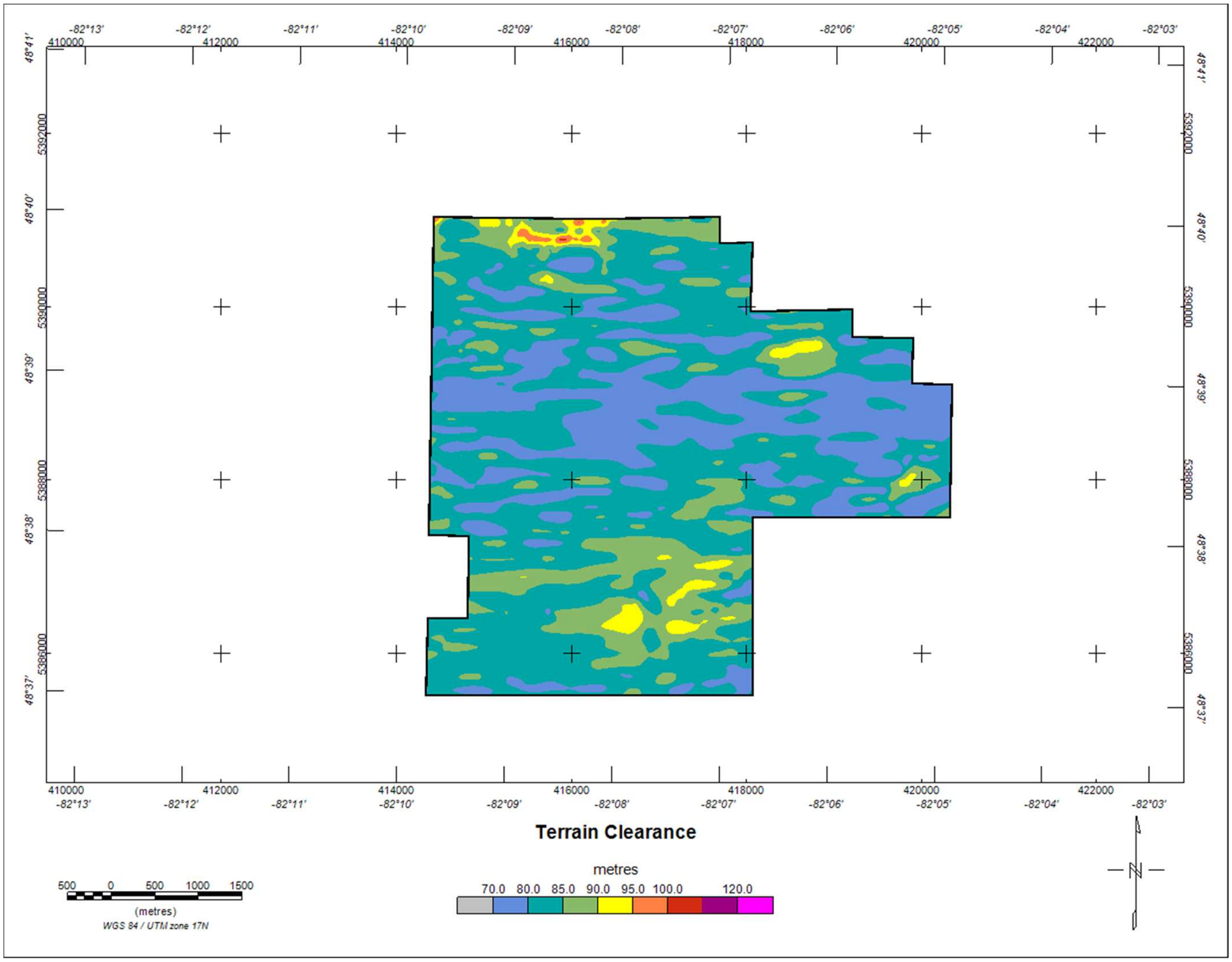

Figure 7: Montcalm Township – Terrain clearance derived from laser scanner data (metres)

5 FALCON® AIRBORNE GRAVITY GRADIENT (AGG) RESULTS

5.1 Processing Summary

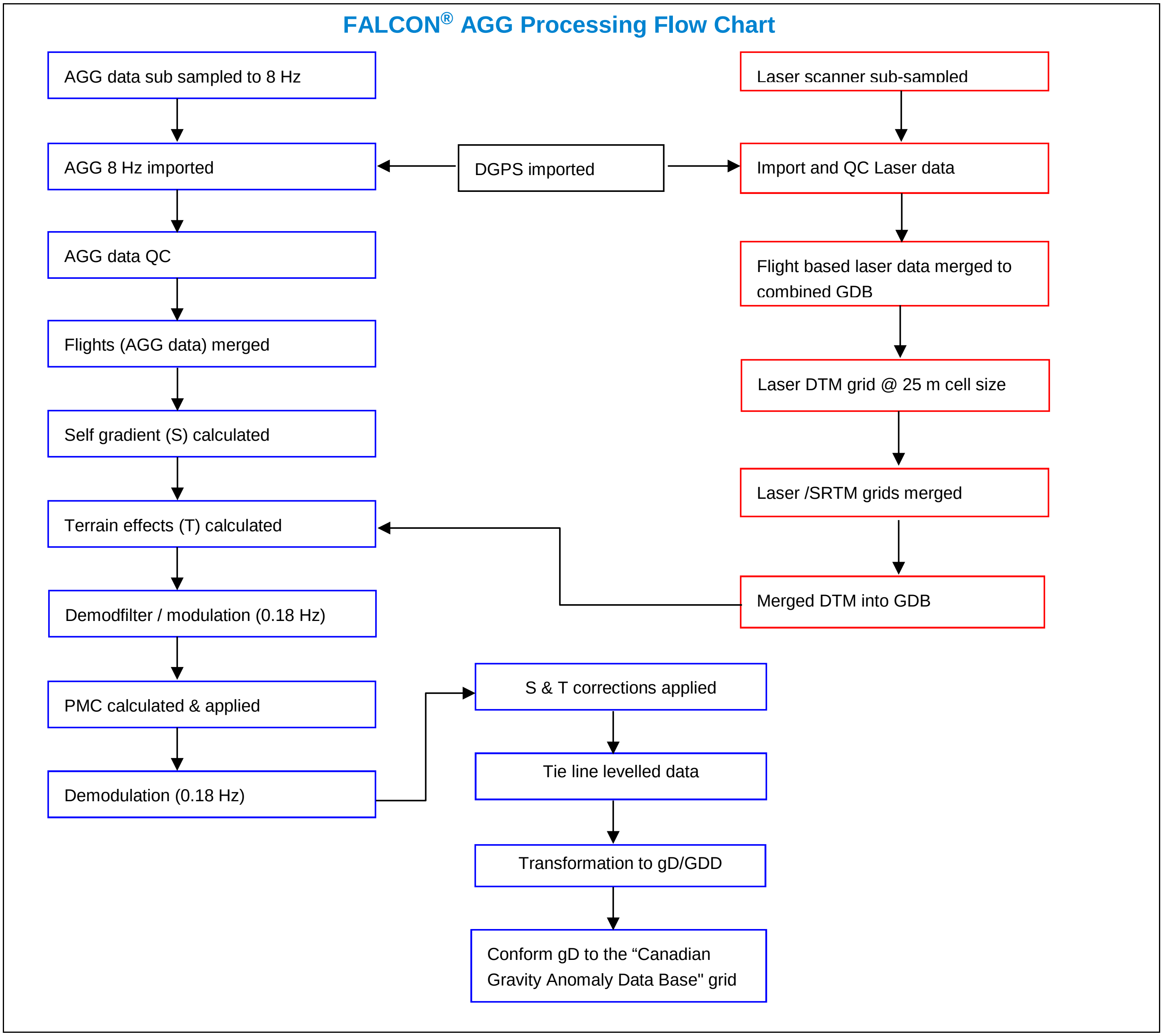

Figure 8: FALCON® AGG Data Processing

5.2 FALCON® Airborne Gravity Gradiometer Data

Figure 8 summarises the steps involved in processing the AGG data obtained from the survey.

The **FALCON®** Airborne Gravity Gradiometer data were digitally recorded by the ADAS on removable hard drives. The raw data were then copied to the field processing laptop, backed up twice onto hard disk media and transferred by Secure File Transfer to the CGG Perth data processing centre.

Preliminary processing and QC of the **FALCON®** AGG data were completed on-site and at the Perth data processing centre using CGG's AGG QC software. Further QC and final **FALCON®** AGG data processing were performed at the Perth data processing centre.

5.3 Radar Altimeter Data

The terrain clearance measured by the radar altimeter in metres was recorded at 10 Hz. The data were plotted and inspected for quality.

5.4 Laser Scanner Data

Laser scanner returns were recorded at a rate of 36 scans per second with each scan returning 276 data points. Each return was converted to ground surface elevation by combining scanner range and angle data with aircraft position and attitude data. Computed elevations were then sub sampled by first dividing each scan into ten segments and combining five adjacent scans per segment, then using a special algorithm to select the optimum return within each data "bin" thus formed. Sub-sampled laser scanner data were edited to remove spikes prior to gridding.

5.5 Positional Data

Differential GPS processing was applied to compute accurate aircraft positions once per second. Waypoint's GrafNav GPS processing software calculated DGPS positions using raw range data obtained from receivers in the aircraft and at a fixed ground base station.

The GPS ground station position was determined by sending several hours of collected data to an online GPS processing service to obtain a differentially corrected computed position. The service selected was AUSPOS, which is provided by Geoscience Australia. The GPS data were processed and quality controlled using the WGS84 datum.

Parameters for the WGS84 datum are:

Ellipsoid: WGS84

Semi-major axis: 6378137.0 m

1/flattening: 298.257

All processing was performed using WGS84/UTM Zone 17N coordinates. Final line data and final grid data were supplied in this projection.

5.6 Terrain Correction

Terrain corrections were derived from the digital terrain model grid for every data point in the survey. A terrain density of 1.00 g/cm^3 was used to compute the terrain correction channels, which were then multiplied by the chosen correction density before being subtracted from the data.

In the absence of any knowledge of the local geology, the standard correction density of 2.67 g/cm^3 was selected. Typically 2.67 g/cm^3 will work well for most terrain types but may lead to over correction or under correction in some areas.

5.7 FALCON® Airborne Gravity Gradient Data - G_{DD} & g_D

The transformation into G_{DD} and g_D was accomplished using the Method of Equivalent Sources.

The equivalent source transformation utilises a smooth model inversion to calculate the density of a surface of sources followed by a forward calculation to produce g_D and G_{DD}. It was possible to closely match the short to medium wavelength characteristics of the Fourier results by placing the sources at a depth of 100 metres.

5.7.1 Drape Surfaces

The equivalent source process uses a smoothed surface onto which the output data are projected. This surface is a smoothed version of the actual flying surface.

The equivalent source (density 2.67 g/cm³) G_{DD} and g_D maps are shown in *Figure 9* and *Figure 10* respectively.

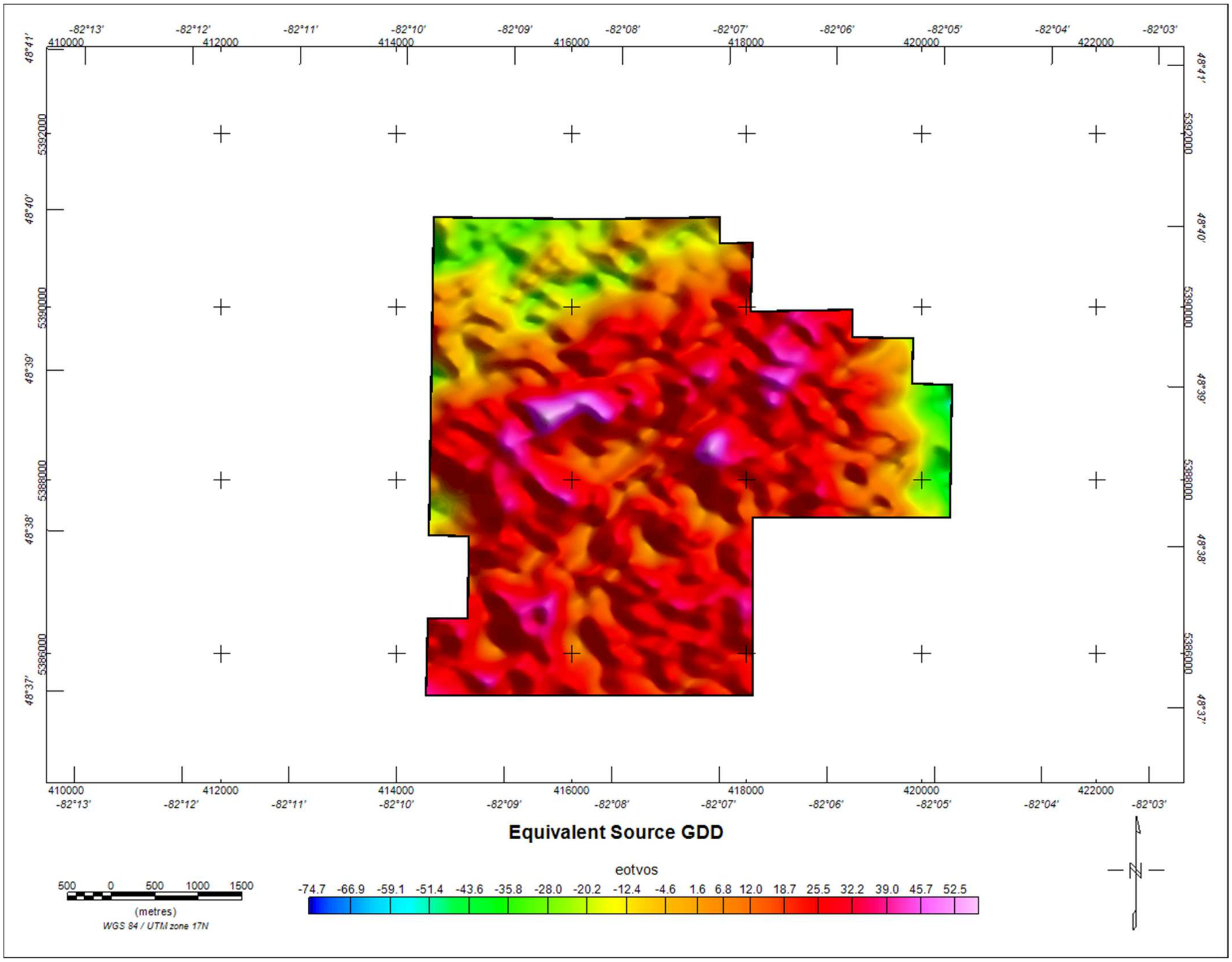

Figure 9: Montcalm Township – Vertical Gravity Gradient (GDD) from equivalent source processing (eotvos)

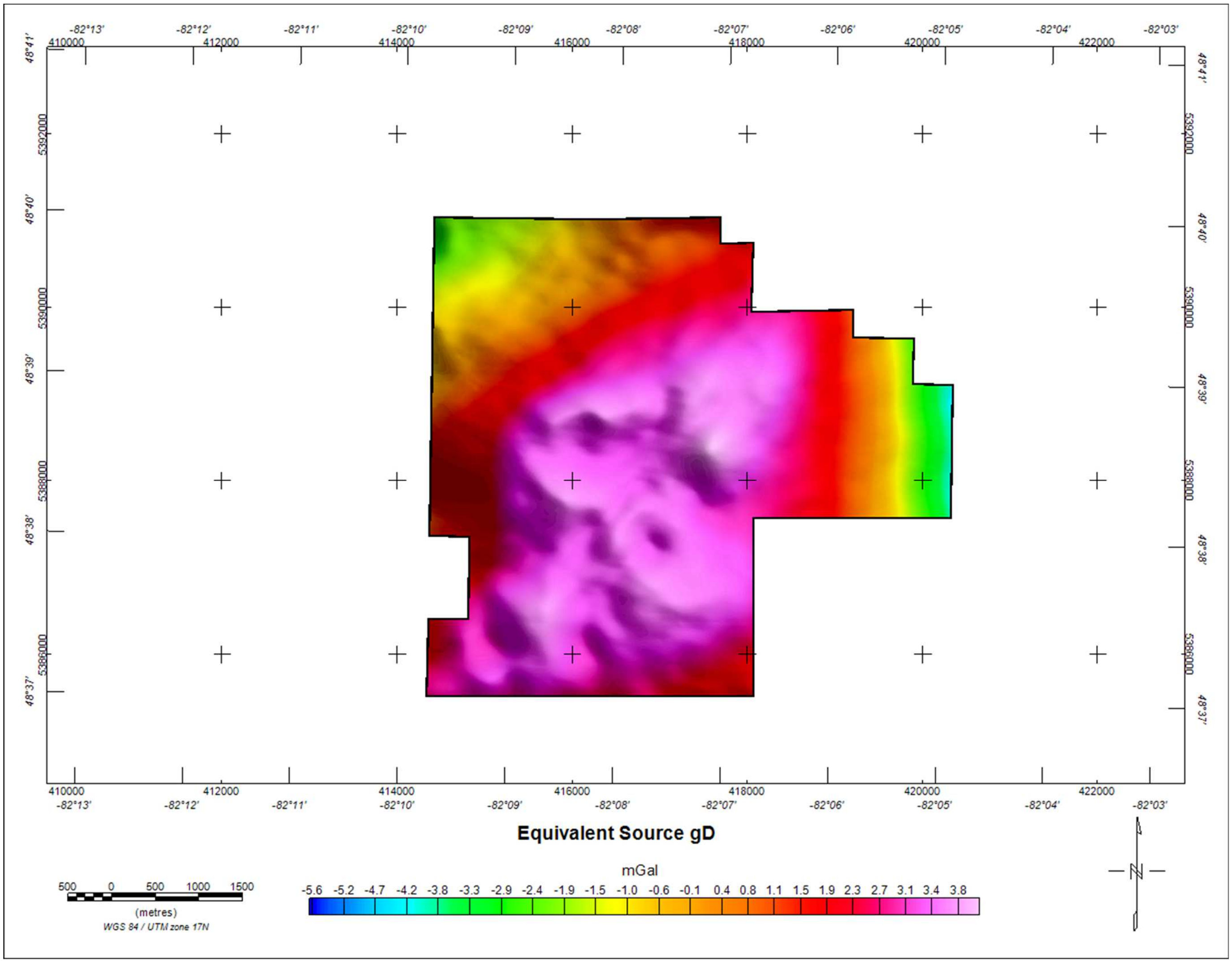

Figure 10: Montcalm Township – Vertical Gravity (gD) from equivalent source processing (mGal)

6 AEROMAGNETIC RESULTS

6.1 Processing Summary

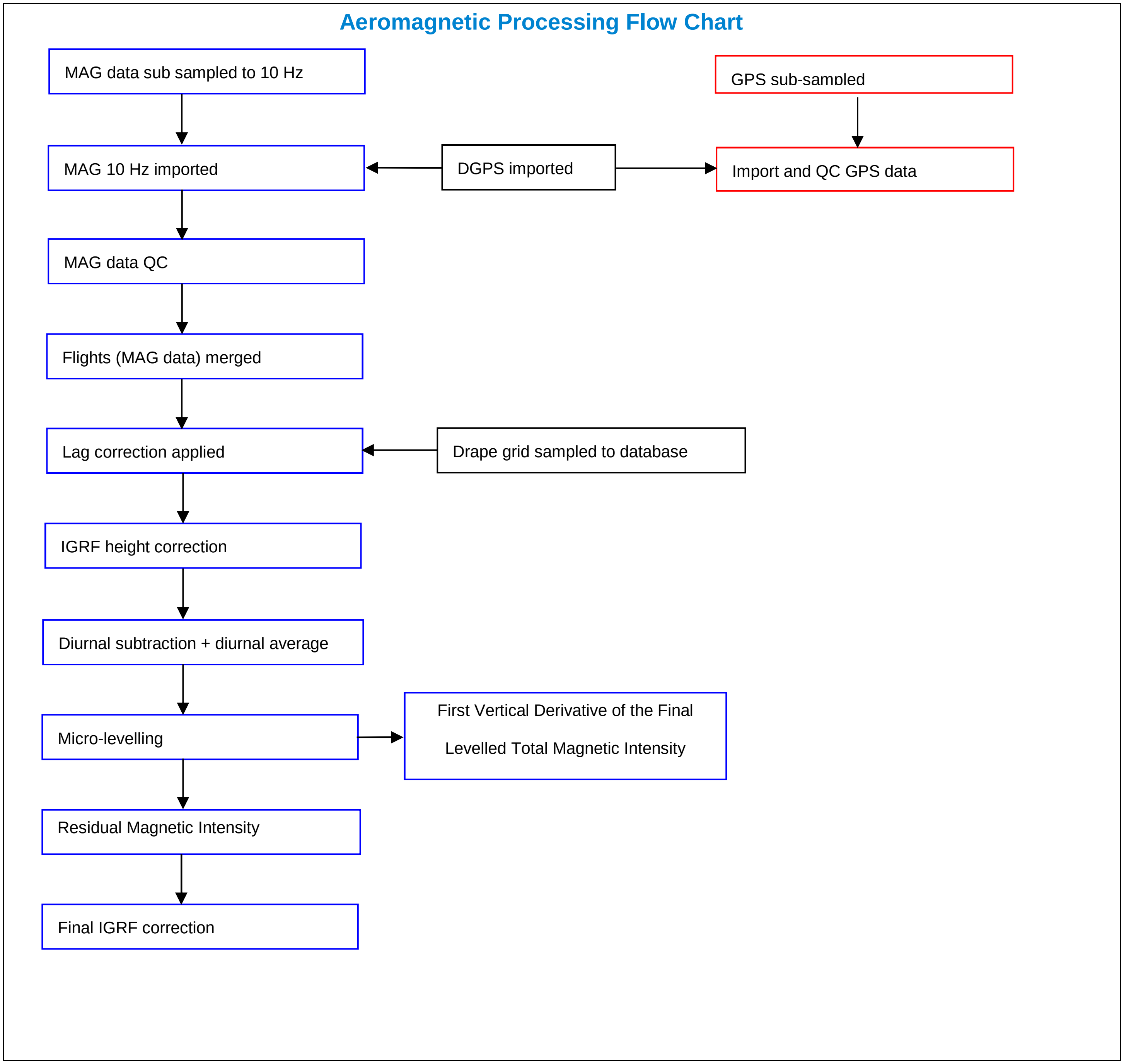

Figure 11: Aeromagnetic Data Processing

6.2 Aeromagnetic Data

Figure 11 summarises the steps involved in processing the aeromagnetic data obtained from the survey.

The aeromagnetic data were digitally recorded by the FASDAS on removable hard drives. The raw data were then copied onto the field processing laptop, backed up twice onto hard drive media and sent via FTP to CGG's secure server.

Preliminary QC of the aeromagnetic data was completed on-site using CGG's proprietary ATLAS software. Further QC and aeromagnetic data processing were performed by the office based data processor.

6.3 Radar Altimeter Data

Refer to section *5.3* for radar altimeter data.

6.4 Positional Data

Refer to section *5.5* for positional data processing.

6.5 Lag Correction

All aeromagnetic data were lagged prior to final processing. A lag of 0.50 seconds was applied.

6.6 IGRF Height Correction

The IGRF was calculated using the drape height and using the GPS height to produce a height corrected total magnetic intensity. A final IGRF correction was applied during a later step.

6.7 Diurnal Subtraction

The base station magnetics (diurnal) were filtered using a long wavelength filter to retain wavelengths longer than 71 seconds. This value was subtracted from the height corrected total magnetic intensity. Next, based upon the average magnetic value calculated from running the base station for 24 hours, a base value of 55942.5 nT was added back to the magnetics. This produced the diurnally corrected total magnetic intensity.

6.8 Micro-levelling

At this stage the total magnetic intensity data were micro-levelled using CGG's proprietary ATLAS software.

6.9 Total Magnetic Intensity

The total magnetic intensity had a minimum value of 55605 nT and a maximum value of 56427 nT across the survey area presented in *Figure 12.*

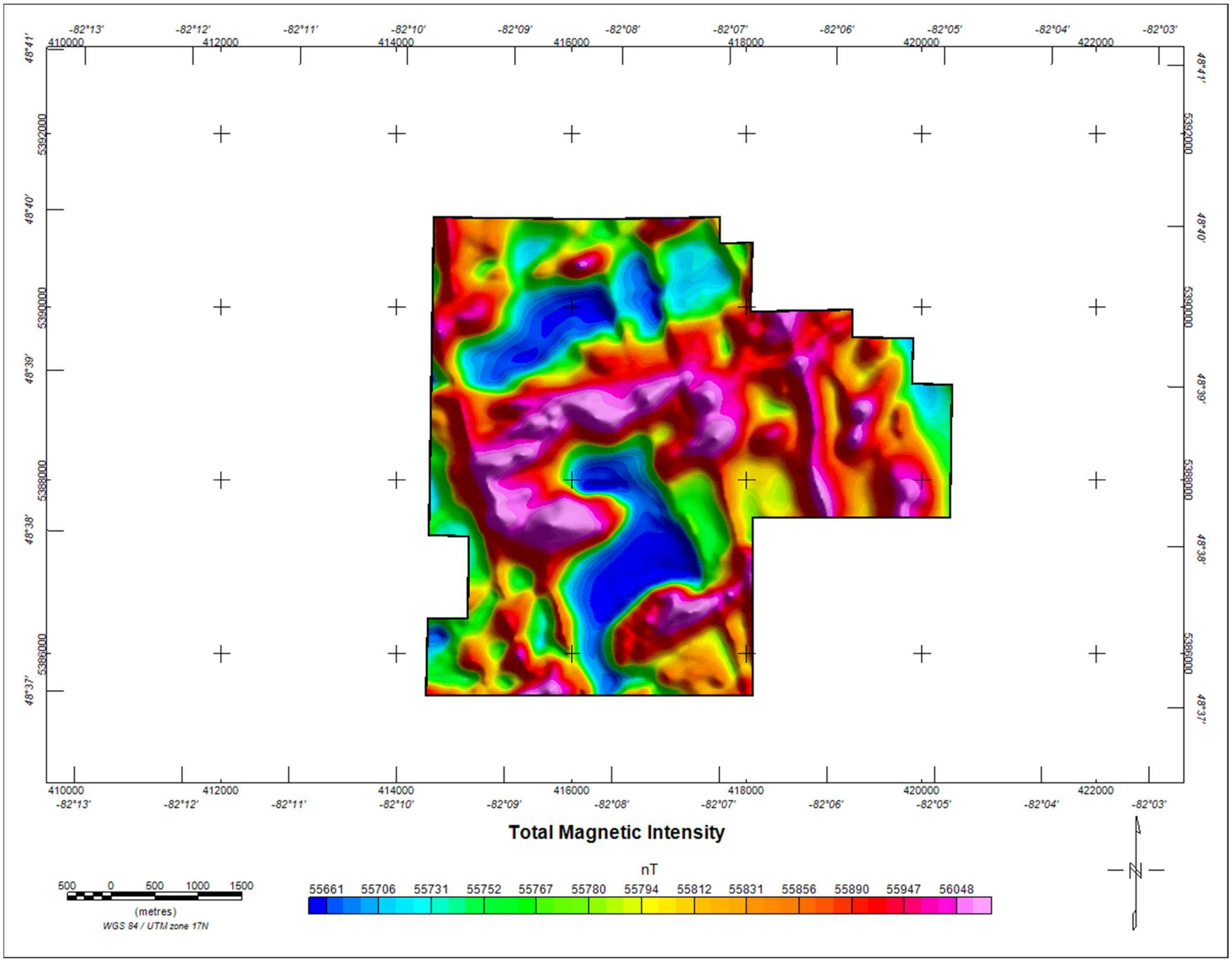

Figure 12: Montcalm Township – Total Magnetic Intensity (nT)

6.10 First Vertical Derivative of the Total Magnetic Intensity

The first vertical derivative of the total magnetic intensity had a minimum value of -2.348 nT/m and a maximum value of 5.719 nT/m across the survey area presented in *Figure 13*.

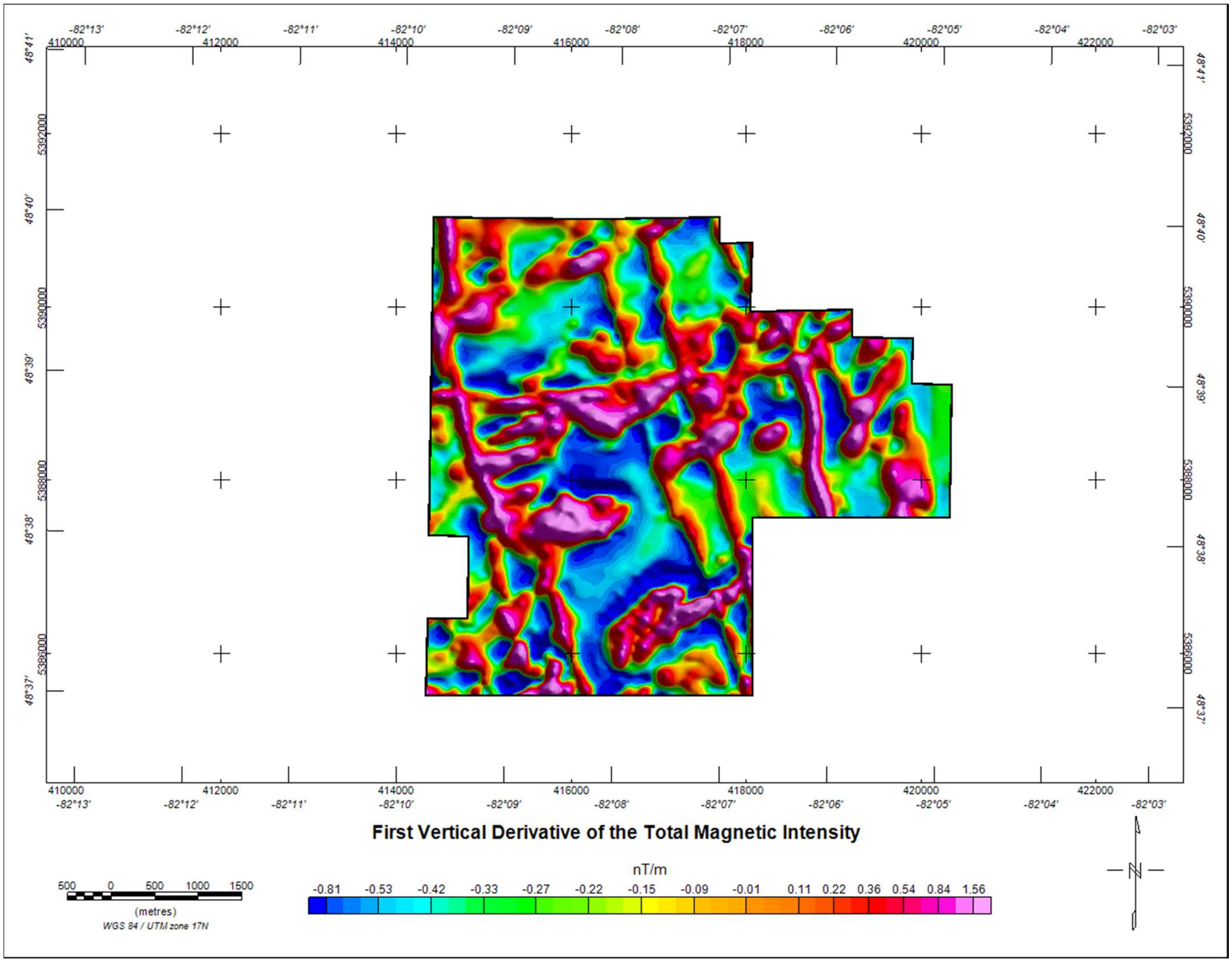

Figure 13: Montcalm Township – First Vertical Derivative of the Total Magnetic Intensity (nT/m)

6.11 Final IGRF Correction

The levelled total magnetic intensity was then IGRF corrected using the 2010 model, 2018/08/31 as the removal date and a constant elevation of 376.6 m above the WGS84 ellipsoid. The output from this correction is the residual magnetic intensity.

7 APPENDIX I - SURVEY EQUIPMENT

7.1 Survey Aircraft

A CGG Basler BT67 turbo prop, Canadian registration C-GGSU, was used to fly the survey area. The following instrumentation was used for this survey.

7.2 FALCON® Airborne Gravity Gradiometer

FALCON® AGG System (Galileo)

The **FALCON®** AGG System is based on current state-of-the-art airborne gravity gradiometer technology and has been optimized for airborne broad band geophysical exploration. The system is capable of supporting surveying activities in areas ranging from 1,000 ft below sea level to 13,000 ft above sea level with aircraft speeds from 30 to 130 knots. The FALCON® AGG data streams were digitally recorded at different rates on removable drives installed in the FALCON® AGG electronics rack.

7.3 Airborne Data Acquisition Systems

Digital Acquisition System (FASDAS)

The FASDAS is a data acquisition system executing propriety software for the acquisition and recording of location, magnetic and ancillary data. Data are presented both numerically and graphically in real time on the VGA display providing on-line quality control capability.

The FASDAS is also used for real time navigation. A pre-programmed flight plan containing boundary coordinates, line start and end coordinates, the altitude values calculated for a theoretical drape surface, line spacing and cross track definitions is loaded into the computer prior to each flight. The WGS84 latitude and longitude and altitude received from the real-time corrected, dual frequency Novatel OEMV L1/L2-Band Positioning receiver, is transformed to the local coordinate system for cross track and distance to go values. This information, together with ground heading and speed, is displayed to the pilot numerically and graphically on a two line LCD display. It is also presented on the operator LCD screen in conjunction with a pictorial representation of the survey area, survey lines and ongoing flight path.

FALCON® AGG Data Acquisition System (ADAS)

The FASDAS provides control and data display for the FALCON® AGG system. Data are displayed in real time for the operator and warnings displayed should system parameters deviate from tolerance specifications. All FALCON® AGG and laser scanner data are recorded to a removable hard drive.

7.4 Aerial and Ground Magnetometers

The airborne Caesium magnetometer was a **Scintrex CS-3** having a noise envelope of 0.1 nT.

The ground magnetometer was a **Scintrex CS-3** Caesium sensor sampling at 1 Hz.

7.5 Real-Time Differential GPS

The **Novatel OEMV-3G** positioning receiver provides real-time differential GPS for the on-board navigation system. The differential data set was relayed via a geo-synchronous satellite to the aircraft where the receiver optimized the corrections for the current location.

7.6 GPS Base Station Receiver

The **Novatel OEM4 L1/L2** GPS receiver is a 12 channel dual frequency GPS receiver. It provides raw range information of all satellites in view sampled every second and recorded on a computer laptop. These data are post-processed with the rover data to provide differential GPS (DGPS) corrections for the flight path.

7.7 Altimeters

King KRA405B Radar Altimeter

The radar altimeter has a resolution of 1 m, an accuracy of 3 ft or +/-3% at 0-500 ft and +/-5% at 500-2500 ft, a range of 0-2,500 ft and a measurement rate of 10 Hz.

Vaisala PMB100 Barometric Pressure Sensor

The barometric pressure is measured with an on board pressure **module (Vaisal PMB100) with a suitable** pneumatic connection to a Pitot-static system.

7.8 Laser Scanner

Riegl LMS-Q240I-80

The laser scanner is designed for high speed line scanning applications. The system is based upon the principle of time-of-flight measurement of short laser pulses in the infrared wavelength region and the angular deflection of the laser beam is obtained by a rotating polygon mirror wheel. The measurement range is up to 650 m with a minimum range of 2 m and an accuracy of 20 mm. The laser beam is eye safe, the laser wavelength is 0.9 µm, the scan angle range is +/- 40° and the scan speed is 36 scans/s.

7.9 Data Processing Hardware and Software

The following equipment and software were used:

Hardware

- One 2.0 GHz (or higher) laptop computer
- External USB hard drive reader for ADAS removable drives
- Two External USB hard drives for data backup
- All-In-One printer, copier, scanner

Software

- Oasis Montaj data processing and imaging software
- GrafNav Differential GPS processing software
- CGG - Atlas data processing software
- CGG - DiAGG processing software

8 APPENDIX II - SYSTEM TESTS

8.1 Instrumentation Lag

Due to the relative position of the magnetometer, altimeters and GPS antenna on the aircraft and to processing/recording time lags, raw readings from each data stream vary in position. To correct for this and to align selected anomaly features on lines flown in opposite directions, the magnetic and altimeter data are ‘parallaxed’ with respect to the position information. The lags were applied to the data during processing.

8.2 Radar Altimeter Calibration

The radar altimeter is checked for accuracy and linearity every 12 months, or when any change in a key system component requires this procedure to be carried out. This calibration allows the radar altimeter data to be compared and assessed with the other height data (GPS, barometric and laser) to confirm the accuracy of the radar altimeter over its operating range. The calibration is performed by flying a number of 30 second lines at preselected terrain clearances over an area of flat terrain and using the results of the radar altimeter, differentially corrected GPS heights in mean sea level (MSL) and laser scanner were used to derive slope and offset information.

8.3 FALCON® AGG Noise Measurement

At the commencement of the survey, 20 minutes of data were collected with the aircraft in straight level flight at 3500 ft AGL. These data were assessed in-flight to check the AGG noise levels.

Daily flight debriefs incorporating **FALCON®** AGG performance statistics for each flight line are prepared using output from CGG DiAGG software. These are sent daily to CGG office staff for performance evaluation.

8.4 Daily Calibrations

A set of daily calibrations were performed each survey day as follows:

- Magnetic base station time check
- AGG Quiescent Calibration

8.4.1 Magnetic Base Station Time Check

Prior to each day’s survey all magnetic base stations were synchronised using broadcast GPS time signals.

8.4.2 FALCON® AGG Calibration

A calibration was performed at the beginning of each flight and the results monitored by the operator. The coefficients obtained from each of the calibrations were used in the processing of the data.

9 APPENDIX III - FALCON® AGG DATA & PROCESSING

9.1 Nomenclature

The **FALCON®** airborne gravity gradiometer (AGG) system adopts a North, East, and Down coordinate sign convention and these directions (N, E, and D) are used as subscripts to identify the gravity gradient tensor components (gravity vector derivatives). Lower case is used to identify the components of the gravity field and upper case to identify the gravity gradient tensor components. Thus the parameter usually measured in a normal exploration ground gravity survey is $\mathbf{g_D}$ and the vertical gradient of this component is $\mathbf{G_{DD}}$.

9.2 Units

The vertical component of gravity ($\mathbf{g_D}$) is delivered in the usual units of mGal. The gradient tensor components are delivered in eotvos, which is usually abbreviated to "E". By definition **1 E = 10^{-4} mGal/m.**

9.3 FALCON® Airborne Gravity Gradiometer Surveys

In standard ground gravity surveys, the component measured is "$\mathbf{g_D}$", which is the *vertical component of the acceleration due to gravity*. In airborne gravity systems, since the aircraft is itself accelerating, measurement of "$\mathbf{g_D}$" cannot be made to the same precision and accuracy as on the ground. Airborne gravity gradiometry uses a differential measurement to remove the aircraft motion effects and delivers gravity data of a spatial resolution and sensitivity comparable with ground gravity data.

The **FALCON®** gradiometer instrument acquires two curvature components of the gravity gradient tensor namely $\mathbf{G_{NE}}$ and $\mathbf{G_{UV}}$ where $\mathbf{G_{UV}} = (\mathbf{G_{NN}} – \mathbf{G_{EE}})/2$.

A feature of the **FALCON®** AGG system is that two independent measurements are made of both the NE and UV curvature components. This is achieved by using two sets of accelerometers, referred to as the A complement and the B complement. Each complement consists of four accelerometers. The measured gradients from these complements are referred to as A_{NE} and A_{UV} and B_{NE} and B_{UV}. The $\mathbf{G_{NE}}$ and $\mathbf{G_{UV}}$ gradients are computed by averaging A and B:

$$\boldsymbol{G_{NE}} = \frac{(A_{NE} + B_{NE})}{2}$$

$$\boldsymbol{G_{UV}} = \frac{(A_{UV} + B_{UV})}{2}$$

Since these curvature components cannot easily and intuitively be related to the causative geology, they are transformed into the vertical gravity gradient ($\mathbf{G_{DD}}$), and integrated to derive the vertical component of gravity ($\mathbf{g_D}$). Interpreters display, interpret and model both $\mathbf{G_{DD}}$ and $\mathbf{g_D}$. The directly measured $\mathbf{G_{NE}}$ and $\mathbf{G_{UV}}$ data are appropriate for use in inversion software to generate density models of the earth. The vertical gravity gradient, $\mathbf{G_{DD}}$, is more sensitive to small or shallow sources and has greater spatial resolution than $\mathbf{g_D}$ (similar to the way that the vertical magnetic gradient provides greater spatial resolution and increased sensitivity to shallow sources of the magnetic field). In the integration of $\mathbf{G_{DD}}$ to give $\mathbf{g_D}$, the very long wavelength component, at wavelengths comparable to or greater than the size of the survey area, cannot be fully recovered. Long wavelength gravity are therefore incorporated in the $\mathbf{g_D}$ data from other sources. This might be regional ground, airborne or marine gravity if such data are available. The Danish Technical University global gravity data of 2013 (DTU13) are used as a default if other data are not available.

9.4 Gravity Data Processing

The main elements and sequence of processing of the gravity data are given below. Unless not applicable or specified otherwise, the processing step is applied to each individual complement element (A_{NE}, A_{UV}, B_{NE}, B_{UV}):

1. Dynamic corrections for residual aircraft motion (called Post Mission Compensation or PMC) are calculated and applied.
2. Self-gradient corrections are calculated and applied to reduce the time-varying gradient response from the aircraft and platform.

3. A Digital Terrain Model (DTM) is created from the laser scanner range data, the AGG inertial navigation system rotation data and the DGPS position data.
4. Terrain corrections are calculated and applied.
5. Tie line levelling and micro-levelling (where necessary) are applied.
6. $\mathbf{G_{NE}}$ and $\mathbf{G_{UV}}$ are transformed into the full gravity gradient tensor, including $\mathbf{G_{DD}}$, and into $\mathbf{g_D}$.

9.5 Aircraft Dynamic Corrections

The design and operation of the **FALCON®** AGG results in very considerable reduction of the effects of aircraft acceleration but residual levels are still significant and further reduction is required and must be done in post-processing.

Post-processing correction relies on monitoring the inertial acceleration environment of the gravity gradiometer instrument (GGI) and constructing a model of the response of the GGI to this environment. Parameters of the model are adjusted by regression to match the sensitivity of the GGI during data acquisition. The modelled GGI output in response to the inertial sensitivities is subtracted from the observed output. Application of this technique to the output of the GGI, when it is adequately compensated by its internal mechanisms, reduces the effect of aircraft motion to acceptable levels.

Following these corrections, the gradient data are demodulated and filtered along line using a 6-pole Butterworth low-pass filter with a cut-off frequency of 0.18 Hz.

9.6 Self-gradient Corrections

The GGI is mounted in gimbals controlled by an inertial navigation system which keeps the GGI pointing in a fixed direction whilst the aircraft and gimbals rotate around it. Consequently, the GGI measures a time-varying gravity gradient due to these masses moving around it as the heading and attitude of the aircraft changes during flight. This is called the self-gradient.

Like the aircraft dynamic corrections, the self-gradient is calculated by regression of model parameters against measured data. In this case, the rotations of the gimbals are the input variables of the model. Once calculated, the modelled output is subtracted from the observed output.

9.7 Laser S721canner Processing

The laser scanner measures the range from the aircraft to the ground in a swath of angular width ±40 degrees below the aircraft. The aircraft attitude (roll, pitch and heading) data provided by the AGG inertial navigation system are used to adjust the range data for changes in attitude and the processed differential GPS data are used to reference the range data to located ground elevations referenced to the WGS84 datum (corrected for the EGM96 geoid separation model). Statistical filtering strategies are used to remove anomalous elevations due to foliage or built up environment. The resulting elevations are gridded to form a digital terrain model (DTM).

9.8 Terrain Corrections

An observation point above a hill has excess mass beneath it compared to an observation point above a valley. Since gravity is directly proportional to the product of the masses, uncorrected gravity data have a high correlation with topography.

It is therefore necessary to apply a terrain correction to gravity survey data. For airborne gravity gradiometry at low survey heights, a detailed DTM is required. Typically, immediately below the aircraft, the digital terrain will need to be sampled at a cell size roughly one-third to one-half of the survey height and with a position accuracy of better than 1 metre. For these accuracies, LIDAR data are required and each **FALCON®** survey aircraft comes equipped with LIDAR (laser scanner).

If bathymetric data are used then these form a separate terrain model for which terrain corrections are calculated at a density chosen to suit the water bottom – water interface.

Once the DTM has been merged, the terrain corrections for each of the $\mathbf{G_{NE}}$ and $\mathbf{G_{UV}}$ data streams are calculated. In the calculation of terrain corrections, a density of 1 g/cm^3 is used. The calculated corrections are stored in the database allowing the use of any desired terrain correction density by subtracting the product of desired density and correction from the measured $\mathbf{G_{NE}}$ and $\mathbf{G_{UV}}$ data. The terrain correction density is chosen to be representative of the terrain density over the survey area. Sometimes more than one density is used with input from the client.

Typically, the terrain corrections are calculated over a distance 40 to 60 km from each survey measurement point.

9.9 Tie line Levelling

The terrain- and Self gradient-corrected $\mathbf{G_{NE}}$ and $\mathbf{G_{UV}}$ data are tie line levelled across the entire survey using a least-squares minimisation of differences at survey line intersections. Occasionally some micro-levelling might be performed.

9.10 Transformation into GDD & g_D

The transformation of the measured, corrected and levelled $\mathbf{G_{NE}}$ and $\mathbf{G_{UV}}$ data into gravity and components of the full gravity gradient tensor is accomplished using two methods:

- Fourier domain transformation
- Equivalent source transformation

The input data for the Fourier method are the average **NE** and **UV** components computed from the complement data, as described in section *9.3*. The Fourier method relies on the Fourier transform of Laplace's equation. The application of this transform to the complex function $\mathbf{G_{NE} + i\, G_{UV}}$ provides a stable and accurate calculation of each of the full tensor components and gravity. The Fourier method performs piece-wise upward and downward continuation to work with data collected on a surface that varies from a flat horizontal plane. For stability of the downward continuation, the data are low-pass filtered. The cut-off wavelength of this filter depends on the variations in altitude and the line spacing. It is set to the smallest value that provides stable downward continuation.

In survey areas where the variability of the terrain surface (and hence the flight surface) makes it impossible to obtain Fourier transformation results that are both high resolution and stable, an alternate method can be applied which bypasses the upward and downward continuation steps. The results are calculated at the flight surface. This approach lacks the mathematical rigour of the complete method but allows for greater detail in the output data. It must be noted however that, if the terrain is too extreme, this method may fail to accurately transform the input data. This can be checked by comparing the input GNE and GUV data with the predicted values of the same data after transformation. If they do not match well, the Fourier transformation method cannot be relied upon.

The input data for the equivalent source method are the individual **NE** and **UV** component data from each complement, as referred to in section *9.3*. The equivalent source method relies on a smooth model inversion to calculate the density of a surface of sources and from these sources, a forward calculation provides the $\mathbf{G_{DD}}$ and $\mathbf{g_D}$ data as well as the other gradient tensor components. The effect of the smoothing is similar to but not the same as the application of the low-pass filter in the Fourier domain method. In areas of highly variable terrain, flying low can lead to some instability in the equivalent source method as the computation surface approaches the location of the derived sources. It may be necessary to accept some localised instability in order to optimise the overall result.

The equivalent source procedure defines an array of rectangular (usually square) plates, extending slightly past the survey area in all directions. Each plate is assumed to have uniform (but initially unknown) surface density and to lie on a predefined solution surface. Using the individual NE and UV component data measured at the centre of each plate, a system of linear equations is formed which can then be solved for the density of each plate using a least squares inversion method. Once the plate density distribution is determined, it can be used for forward calculation of all tensor components and of vertical gravity.

The Fourier method generates all tensor components but the equivalent source method only generates $\mathbf{G_{DD}}$ and $\mathbf{g_D}$ (and $\mathbf{G_{NE}}$ and $\mathbf{G_{UV}}$ for comparison with the inputs).

The limitations of gravity gradiometry in reconstructing the long wavelengths of gravity can lead to differences in the results of these two methods at long wavelength. The merging of the $\mathbf{g_D}$ data with externally supplied regional gravity such as the DNSC08 gravity provides a way of reducing these differences.

9.11 Terrain Corrections Using Alternate Terrain Densities

Although both uncorrected processed and transformed data and unit density terrain correction data are supplied, it is not recommended that these be used to create final data corrected for any arbitrary terrain correction density. The principal reason for this is that tie line levelling occurs after application of the terrain correction. As a result, levelling errors present in the terrain correction channels by virtue of positional inaccuracy are not removed from these channels and will be present in any data corrected with them. Further, filtering applied in creating the uncorrected, transformed data is not applied to the terrain correction channels. Mixing data filtered in different ways is not advised.

An alternative method (valid only for datasets where waterbody(ies) have not been taken into account when computing the terrain corrections) uses the linear relationship between the terrain corrections at different densities and the corresponding gravity gradient or $\mathbf{g_D}$ values. This method can be applied to either the grid data or the located data. An example is given using $\mathbf{G_{DD}}$:

The new density is referred to as ρ_N, the existing densities as ρ_1 and ρ_2

$$G_{DD}(\rho_N) = G_{DD}(\rho_1) + \left(G_{DD}(\rho_2) - G_{DD}(\rho_1)\right) \times \frac{(\rho_N - \rho_1)}{(\rho_2 - \rho_1)}$$

Note that the terrain correction channel is eliminated by substitution in deriving this equation.

It is recommended that two densities that differ by a reasonable value be used for this method, in order to minimise uncertainties caused by noise in the data. The values of 0.00 and 2.67 g/cm^3 usually delivered should be sufficient to yield useful results.

When the effect of waterbodies are included in deriving the terrain corrections (bathymetry data have been supplied, enabling the creation of a combined bathymetry and elevation grid to be used for the terrain correction); an alternative method is required. This method requires waterbody corrected gradients, or $\mathbf{g_D}$, as part of the equation, rather than the ρ_1 data.

The new density is referred to as ρ_N, the existing density is ρ_2 and *WB* refers to the supplied waterbody corrected data.

$$G_{DD}(\rho_N) = G_{DD_{WB}} + \left(G_{DD}(\rho_2) - G_{DD_{WB}}\right) \times \frac{(\rho_N)}{(\rho_2)}$$

9.12 Noise & Signal

By taking two independent measurements of the NE and UV curvature components at each sample point, it is possible to obtain a direct indication of the reliability of these measurements. The standard deviation of half the difference of the pairs of measurements - (A_{NE},B_{NE}) and (A_{UV},B_{UV}) - provides a good estimate of the survey noise:

$$Noise_{NE} = StdDev\left(\frac{(A_{NE} - B_{NE})}{2}\right)$$
$$Noise_{UV} = StdDev\left(\frac{(A_{UV} - B_{UV})}{2}\right)$$

These difference channels are calculated for each data point. The standard deviation across all data points is the figure quoted for the survey as a whole.

This difference error has been demonstrated to follow a 'normal' or Gaussian statistical distribution, with a mean of zero. Therefore, the bulk of the population (95%) will lie between -2σ and +2σ of the mean. For a typical survey noise estimate of, say, 3 E, 95% of the noise will be between -6 E and +6 E.

These typical errors in the curvature gradients translate to errors in $\mathbf{G_{DD}}$ of about 5 E and in $\mathbf{g_D}$ (in the shorter wavelengths) in the order of 0.1 mGal.

9.13 Risk Criteria in Interpretation

The risks associated with a **FALCON**® AGG survey are mainly controlled by the following factors.

- **Survey edge anomalies** – the transformation from measured curvature gradients to vertical gradient and vertical gravity gradient is subject to edge effects. Hence any anomalies located within about 2 x line spacing of the edge of the survey boundaries should be treated with caution.
- **Single line anomalies** – for a wide-spaced survey, an anomaly may be present on only one line. Although it might be a genuine anomaly, the interpreter should note that no two-dimensional control can be applied.
- **Low amplitude (less than 2σ) anomalies** – Are within the noise envelope and need to be treated with caution, if they are single line anomalies and close in diameter to the cut-off wavelengths used.

- **Residual topographic error anomalies** – Inaccurate topographic correction either due to inaccurate DTM or local terrain density variations may produce anomalies. Comparing the DTM with the G_{DD} map terrain-corrected for different densities is a reliable way to confirm the legitimacy of an anomaly.
- **The low density of water and lake sediments** – (if present) can create significant gravity and gravity gradient lows which may be unrelated to bedrock geology. It is recommended that all anomalies located within lakes or under water be treated with caution and assessed with bathymetry if available.

9.14 References

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Stone, P. M. and Simsky, A., 2001, Constructing high resolution DEMs from Airborne Laser Scanner Data, Preview, Extended Abstracts: ASEG 15th Geophysical Conference and Exhibition, August 2001, Brisbane, 93, 99.

10 APPENDIX IV - FINAL PRODUCTS

Final **FALCON®** AGG digital line data were provided in 8 Hz Geosoft Oasis GDB database files containing the fields and format described in *Table 4* below.

Final aeromagnetic digital line data were provided in 10 Hz Geosoft Oasis GDB database files containing the fields and format described in *Table 5* below.

Grids of equivalent source products, Total Magnetic Intensity, First Vertical Derivative of the Total Magnetic Intensity, as well as the DTM were delivered, as described in *Table 6* below. The grids are in Geosoft GRD format with a 25 m cell size.

Field	Variable	Description	Units
1	Line	Line number	-
2	Time_1980	Universal Time (seconds since January 6 1980)	seconds
3	Time	Universal Time (seconds since midnight)	seconds
4	Flight	Flight number	-
5	Date	Gregorian date	yyyymmdd
6	Latitude	WGS84 latitude	degrees
7	Longitude	WGS84 longitude	degrees
8	Easting	WGS84/UTM17N Easting	metres
9	Northing	WGS84/UTM17N Northing	metres
10	Altitude	GPS antenna height above WGS84 ellipsoid with geoid (EGM96) correction applied	metres
11	Height	Flying height (aircraft's height above terrain as derived from laser scanner and ALTITUDE data)	metres
12	DTM	Terrain height above WGS84 ellipsoid with geoid (EGM96) correction applied (sampled from DTM grid)	metres
13	Turbulence	Estimated vertical platform turbulence (vertical acceleration where g = 9.80665 m/sec/sec)	millig
14	Err_NE	NE gradient uncorrelated noise estimate after levelling	eotvos
15	Err_UV	UV gradient uncorrelated noise estimate after levelling	eotvos
16	T_DD	Terrain effect calculated for DD using a density of 1 g/cm^3 (from DTM grid)	eotvos
17	T_NE	Terrain effect calculated for NE using a density of 1 g/cm^3 (from DTM grid)	eotvos
18	T_UV	Terrain effect calculated for UV using a density of 1 g/cm^3 (from DTM grid)	eotvos
19	A_0_NE	Self gradient corrected NE gradient only with no terrain correction applied	eotvos
20	A_0_UV	Self gradient corrected UV gradient only with no terrain correction applied	eotvos
21	B_0_NE	Self gradient corrected NE gradient only with no terrain correction applied	eotvos
22	B_0_UV	Self gradient corrected UV gradient only with no terrain correction applied	eotvos
23	A_2p67_NE	Self gradient & terrain corrected NE gradient using terrain correction density 2.67 g/cm^3	eotvos

24	A_2p67_UV	Self gradient & terrain corrected UV gradient using terrain correction density 2.67 g/cm^3	eotvos
25	B_2p67_NE	Self gradient & terrain corrected NE gradient using terrain correction density 2.67 g/cm^3	eotvos
26	B_2p67_UV	Self gradient & terrain corrected UV gradient using terrain correction density 2.67 g/cm^3	eotvos
27	gD_Equiv_0	Equivalent source derived vertical gravity with no terrain correction applied	mGal
28	GDD_Equiv_0	Equivalent source derived vertical gravity gradient with no terrain correction applied	eotvos
29	GED_Equiv_0	Equivalent source derived Ged horizontal EW gradient with no terrain correction applied	eotvos
30	GEE_Equiv_0	Equivalent source derived Gee gradient with no terrain correction applied	eotvos
31	GND_Equiv_0	Equivalent source derived Gnd horizontal NS gradient with no terrain correction applied	eotvos
32	GNN_Equiv_0	Equivalent source derived Gnn gradient with no terrain correction applied	eotvos
33	GNE_Equiv_0	Equivalent source derived Gne curvature gradient with no terrain correction applied	eotvos
34	GUV_Equiv_0	Equivalent source derived Guv curvature gradient with no terrain correction applied	eotvos
35	gD_Equiv_2p67	Equivalent source derived vertical gravity using terrain correction density 2.67 g/cm^3	mGal
36	GDD_Equiv_2p67	Equivalent source derived vertical gravity gradient using terrain correction density 2.67 g/cm^3	eotvos
37	GED_Equiv_2p67	Equivalent source derived Ged horizontal EW gradient using terrain correction density 2.67 g/cm^3	eotvos
38	GEE_Equiv_2p67	Equivalent source derived Gee gradient using terrain correction density 2.67 g/cm^3	eotvos
39	GND_Equiv_2p67	Equivalent source derived Gnd horizontal NS gradient using terrain correction density 2.67 g/cm^3	eotvos
40	GNN_Equiv_2p67	Equivalent source derived Gnn gradient using terrain correction density 2.67 g/cm^3	eotvos
41	GNE_Equiv_2p67	Equivalent source derived Gne curvature gradient using terrain correction density 2.67 g/cm^3	eotvos
42	GUV_Equiv_2p67	Equivalent source derived Guv curvature gradient using terrain correction density 2.67 g/cm^3	eotvos
43	Drapesurface_Equiv	Equivalent source drape surface	metres

Table 4: Final FALCON® AGG Digital Data – Geosoft Database Format

Field	Variable	Description	Units
1	Line	Line number	-
2	Time	Universal Time (seconds since midnight)	seconds
3	Time_1980	Universal Time (seconds since January 6 1980)	seconds
4	Flight	Flight number	-

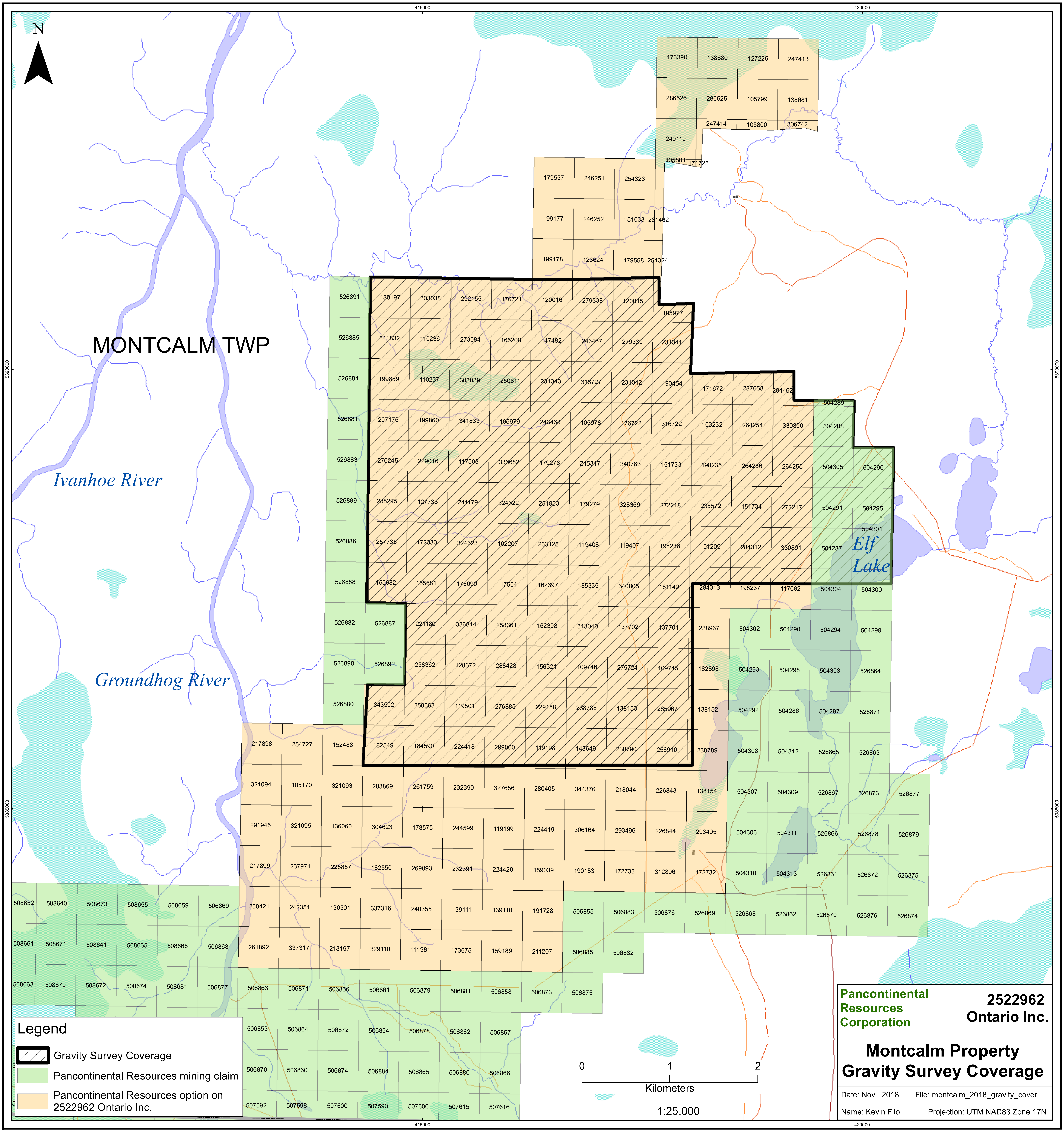
5	Date	Gregorian date	yyyymmdd
6	Latitude	WGS84 latitude	degrees
7	Longitude	WGS84 longitude	degrees
8	Easting	WGS84/UTM17N Easting	metres
9	Northing	WGS84/UTM17N Northing	metres
10	Altitude	GPS antenna height above WGS84 ellipsoid with geoid (EGM96) correction applied	metres
11	Height	Calculated Laser Scanner Clearance (gpsz – dtm)	metres
12	DTM	Terrain height above WGS84 ellipsoid with geoid (EGM96) correction applied (sampled from DTM grid)	metres
13	Drape	Planned Drape (Referenced to EGM96 geoid)	metres
14	Diurnal	Magnetic Ground Base Station	nT
15	Mag_Raw	Total Magnetic Intensity (Uncompensated)	nT
16	Mag_Comp	Total Magnetic Intensity (Compensated)	nT
17	Mag_Diurnal	Total Magnetic Intensity (Compensated, Lagged, IGRF and Diurnal Corrected)	nT
18	Mag_TMI	Total Magnetic Intensity (Levelled)	nT
19	IGRF	International Geomagnetic Reference Field	nT
20	Flux_X	Fluxgate component x	nT
21	Flux_Y	Fluxgate component y	nT
22	Flux_Z	Fluxgate component z	nT

Table 5: Final Aeromagnetic Digital Data –Geosoft Database Format

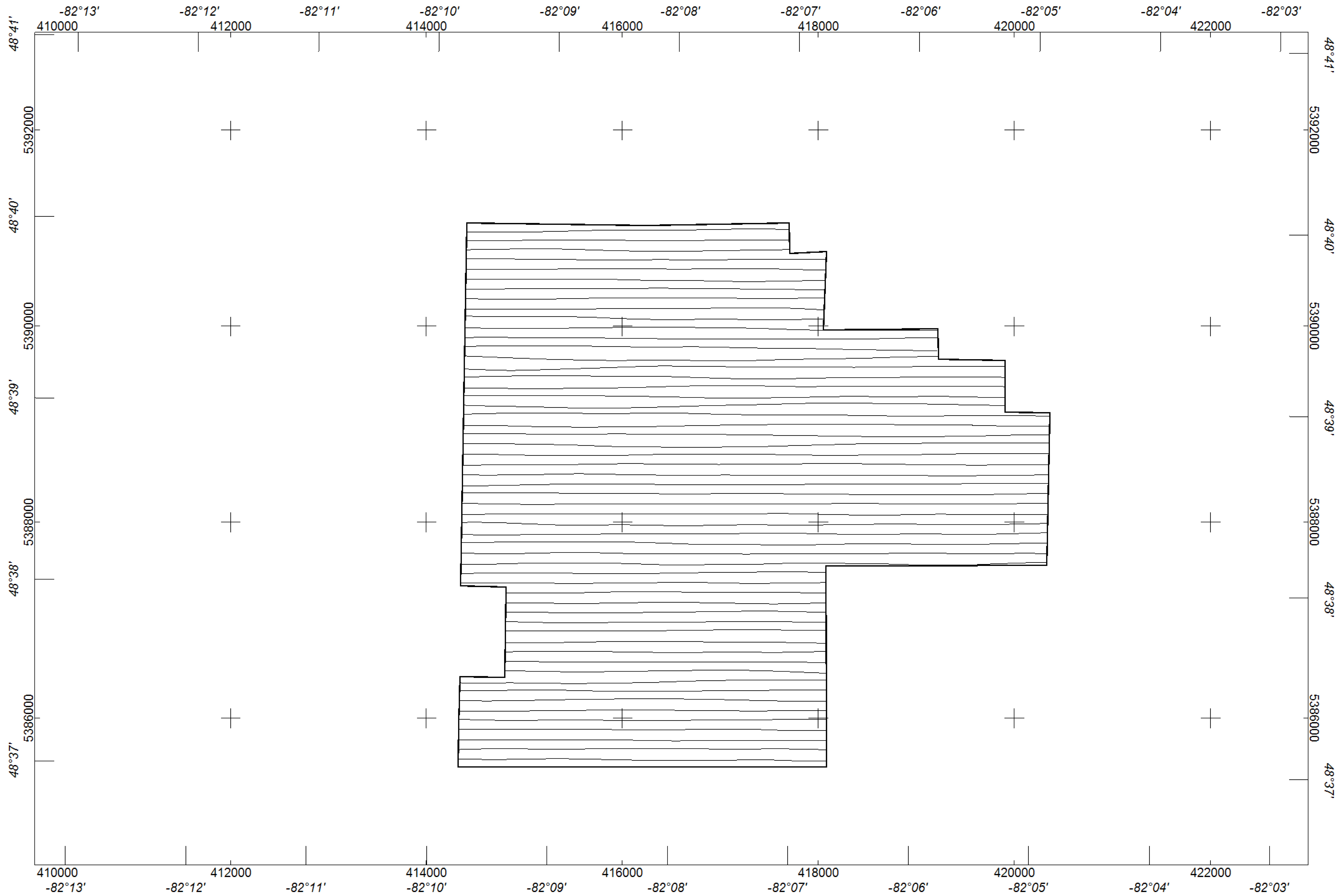
File	Description	Units
802494_1_TMI_Final	Total Magnetic Intensity	nT
802494_1_VD1_Final	First Vertical Derivative	nT/m
802494_1_DTM_Final	Terrain height above WGS84 ellipsoid with geoid (EGM96) correction applied (sampled from DTM grid)	metres
802494_1_Drapesurface_Equiv_Final	Equivalent source drape surface	metres
802494_1_gD_Equiv_0_Final	Equivalent Source derived vertical gravity with no terrain correction applied	mGal
802494_1_gD_Equiv_2p67_Final	Equivalent Source derived vertical gravity using terrain correction density 2.67 g/cm^3	mGal
802494_1_GDD_Equiv_0_Final	Equivalent Source derived vertical gravity gradient with no terrain correction applied	eotvos
802494_1_GDD_Equiv_2p67_Final	Equivalent Source derived vertical gravity gradient using terrain correction density 2.67 g/cm^3	eotvos
802494_1_GED_Equiv_0_Final	Equivalent Source derived Ged horizontal EW gradient with no terrain correction applied	eotvos
802494_1_GED_Equiv_2p67_Final	Equivalent Source derived Ged horizontal EW gradient using terrain correction density 2.67 g/cm^3	eotvos
802494_1_GEE_Equiv_0_Final	Equivalent Source derived Gee gradient with no terrain correction applied	eotvos

802494_1_GEE_Equiv_2p67_Final	Equivalent Source derived Gee gradient using terrain correction density 2.67 g/cm^3	eotvos
802494_1_GND_Equiv_0_Final	Equivalent Source derived Gnd horizontal NS gradient with no terrain correction applied	eotvos
802494_1_GND_Equiv_2p67_Final	Equivalent Source derived Gnd horizontal NS gradient using terrain correction density 2.67 g/cm^3	eotvos
802494_1_GNE_Equiv_0_Final	Equivalent Source derived Gne curvature gradient with no terrain correction applied	eotvos
802494_1_GNE_Equiv_2p67_Final	Equivalent Source derived Gne curvature gradient using terrain correction density 2.67 g/cm^3	eotvos
802494_1_GNN_Equiv_0_Final	Equivalent Source derived Gnn gradient with no terrain correction applied	eotvos
802494_1_GNN_Equiv_2p67_Final	Equivalent Source derived Gnn gradient using terrain correction density 2.67 g/cm^3	eotvos
802494_1_GUV_Equiv_0_Final	Equivalent Source derived Guv curvature gradient with no terrain correction applied	eotvos
802494_1_GUV_Equiv_2p67_Final	Equivalent Source derived Guv curvature gradient using terrain correction density 2.67 g/cm^3	eotvos

Table 6: Final Aeromagnetic and AGG Grids – Geosoft Format



N
MONTCALM TWP
Ivanhoe River
Groundhog River
Elf Lake
Legend
Gravity Survey Coverage
Pancontinental Resources mining claim
Pancontinental Resources option on 2522962 Ontario Inc.
0 1 2
Kilometers
1:25,000
Pancontinental Resources Corporation
2522962 Ontario Inc.
Montcalm Property
Gravity Survey Coverage
Date: Nov., 2018
File: montcalm_2018_gravity_cover
Name: Kevin Filo
Projection: UTM NAD83 Zone 17N



Flight Path

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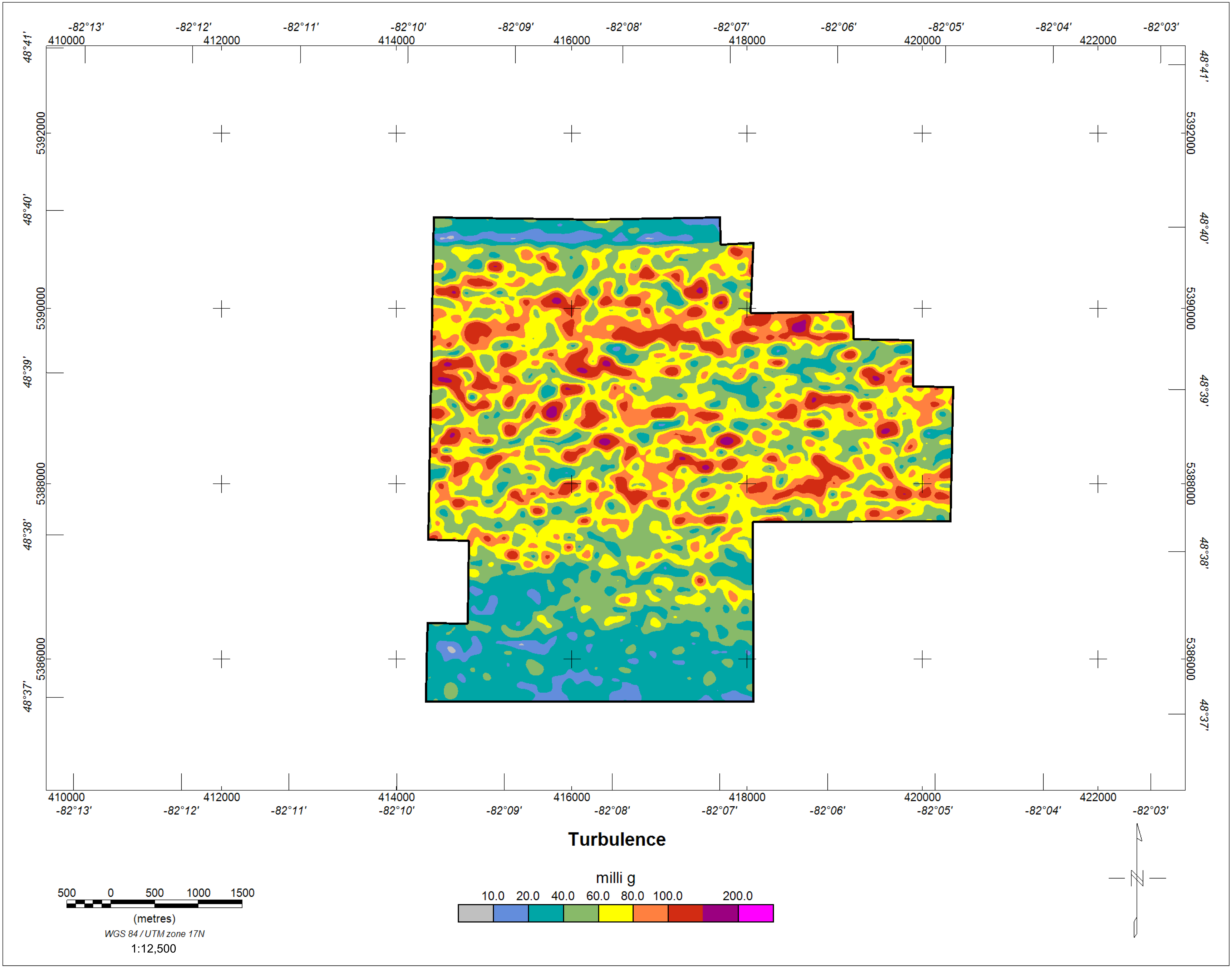
(metres)

WGS 84 / UTM zone 17N

1:12,500



Turbulence
milli g
10.0
20.0
40.0
60.0
80.0
100.0
200.0
500
0
500
1000
1500
(metres)
WGS 84 / UTM zone 17N
1:12,500
410000
412000
414000
416000
418000
420000
422000
5392000
5390000
5388000
5386000
-82°13'
-82°12'
-82°11'
-82°10'
-82°09'
-82°08'
-82°07'
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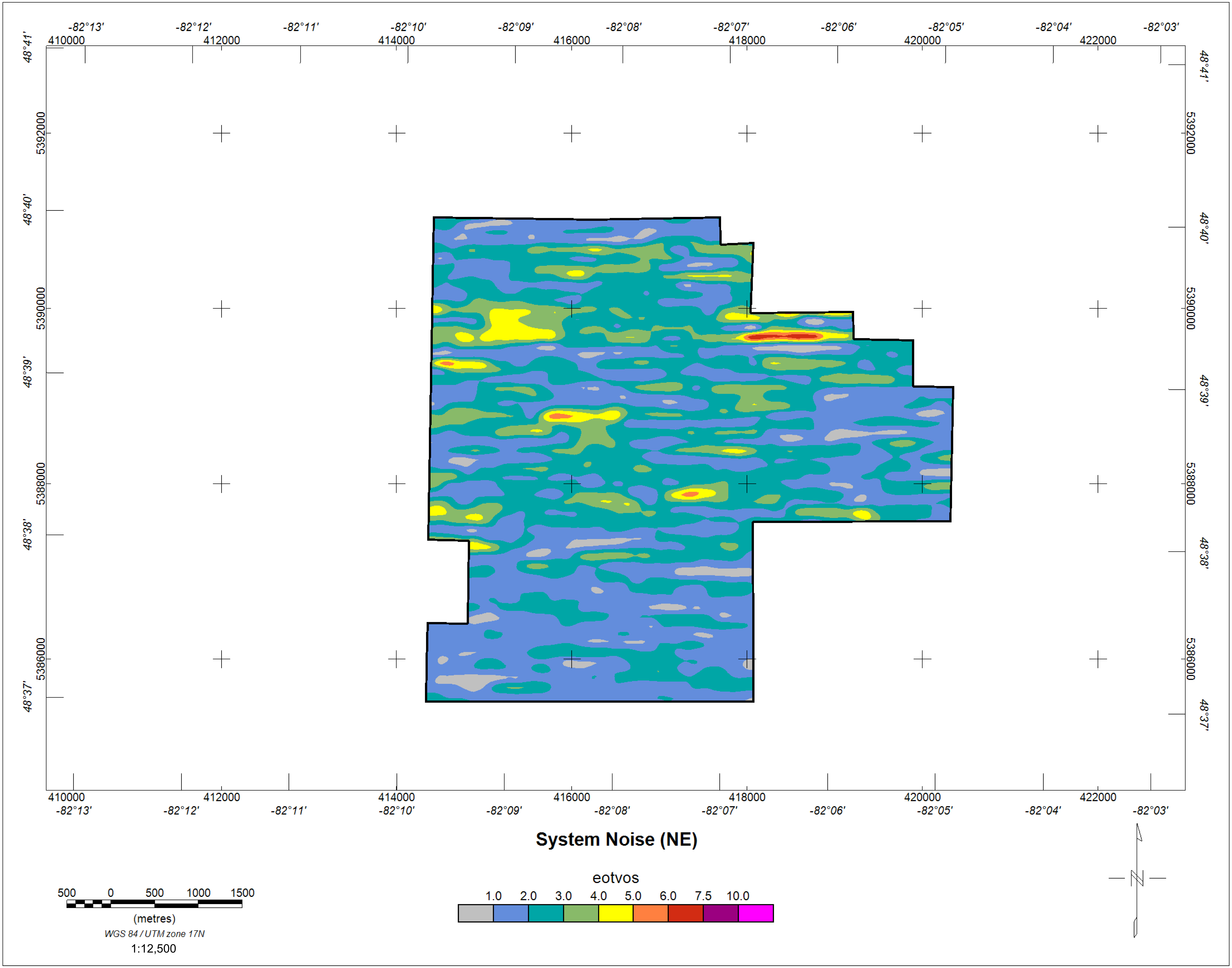
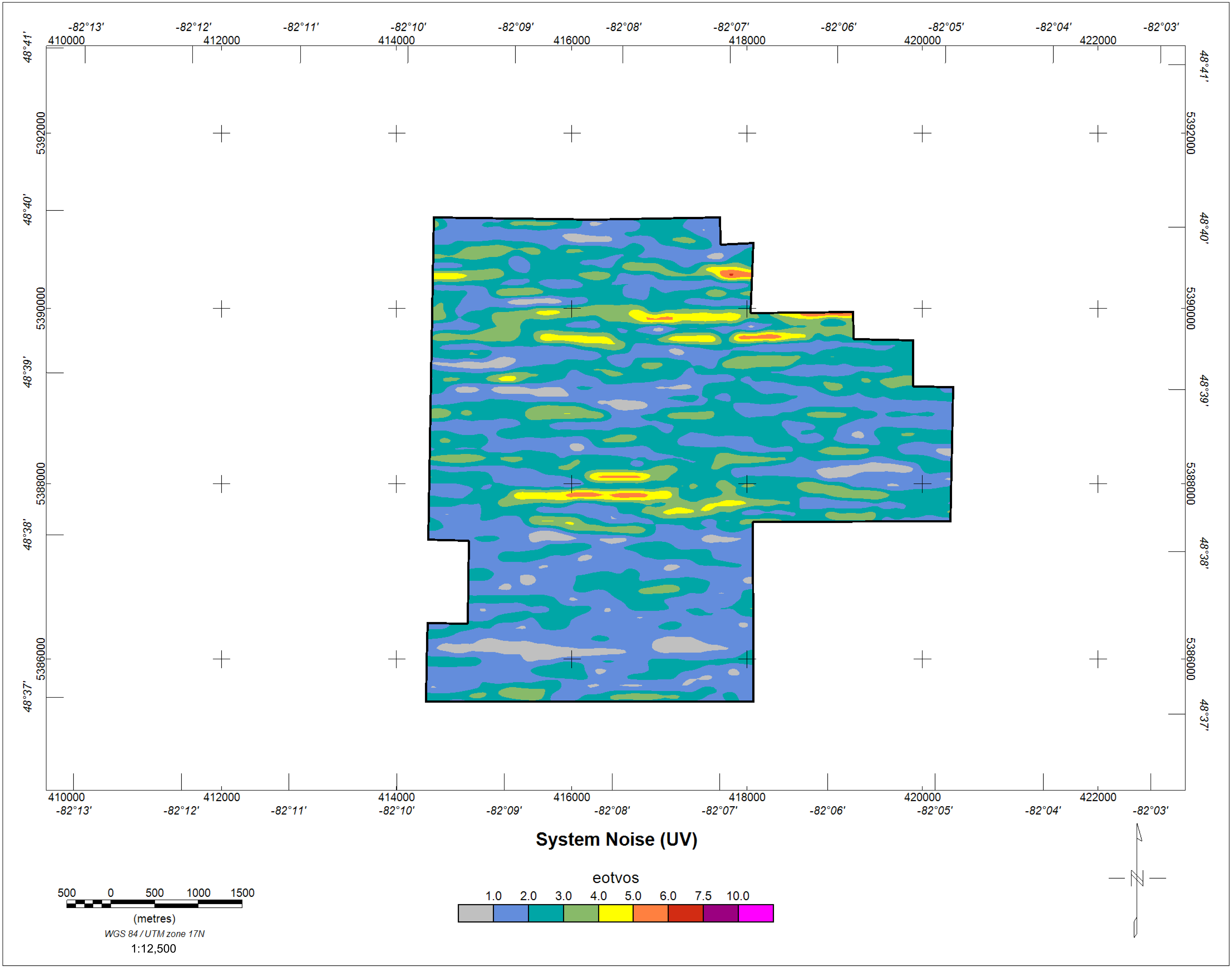
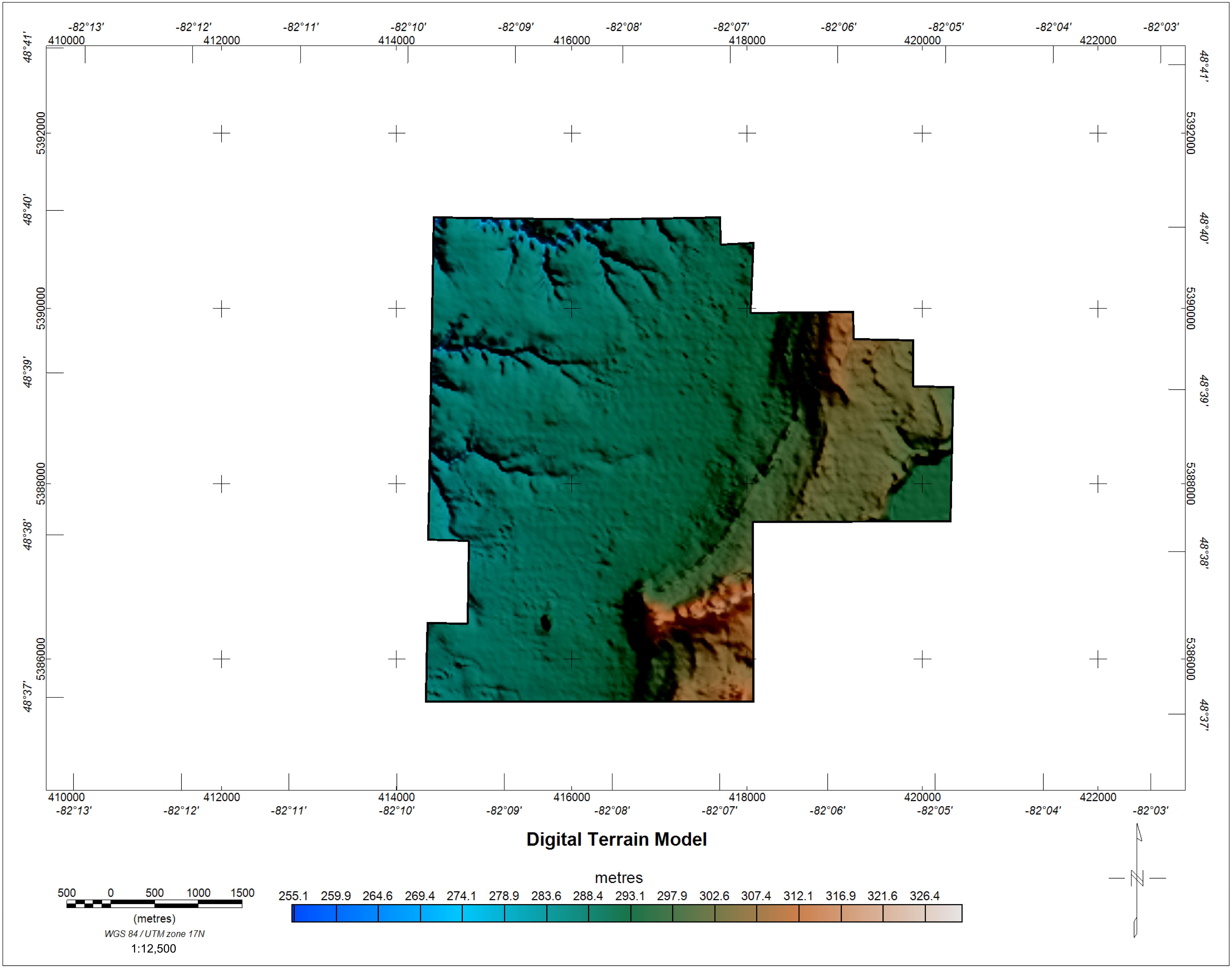
48°40'
48°39'
48°38'
48°37'



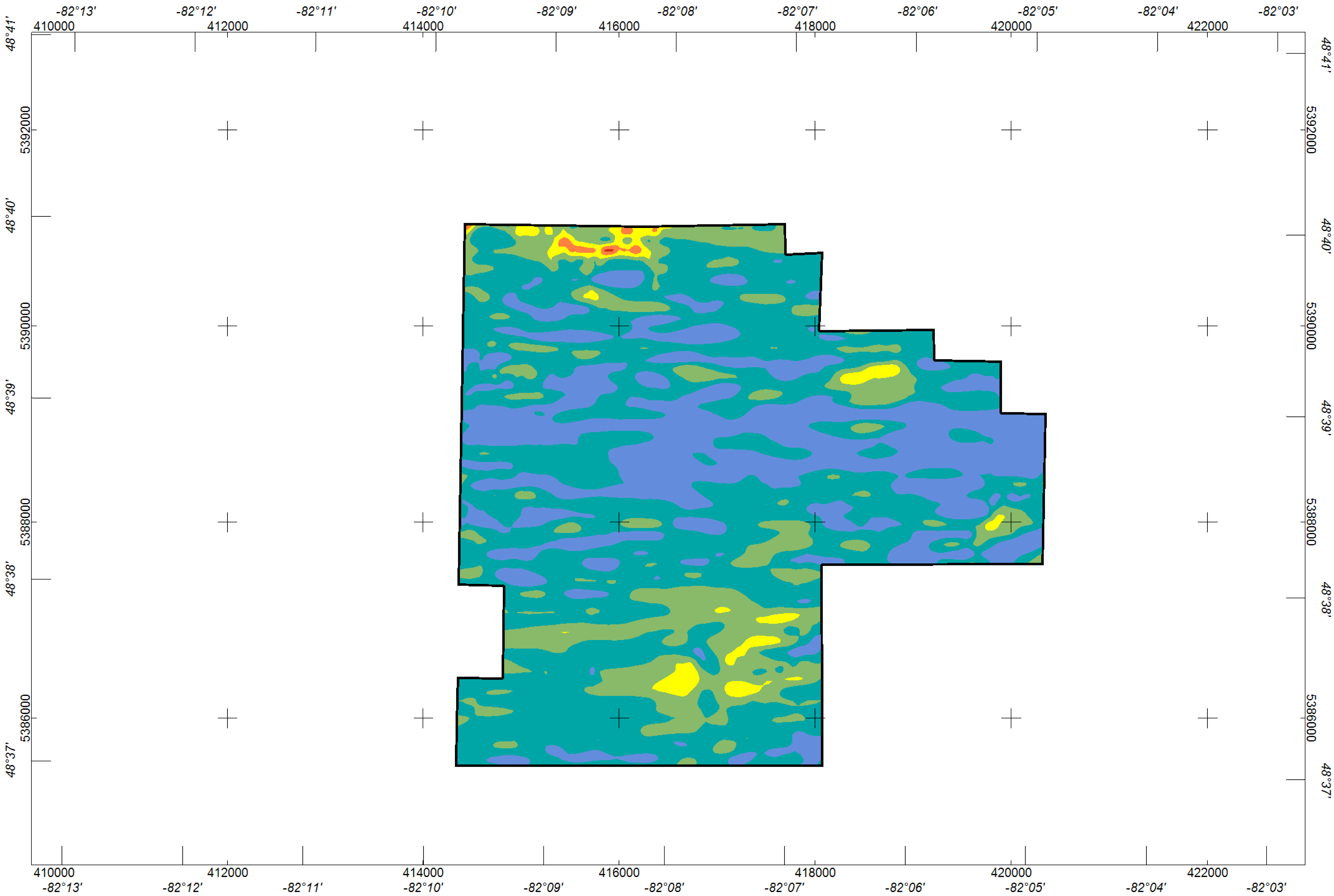
System Noise (NE)
eotvos
1.0 2.0 3.0 4.0 5.0 6.0 7.5 10.0
500 0 500 1000 1500
(metres)
WGS 84 / UTM zone 17N
1:12,500
410000 412000 414000 416000 418000 420000 422000
-82°13' -82°12' -82°11' -82°10' -82°09' -82°08' -82°07' -82°06' -82°05' -82°04' -82°03'
5392000 5390000 5388000 5386000
48°41' 48°40' 48°39' 48°38' 48°37'



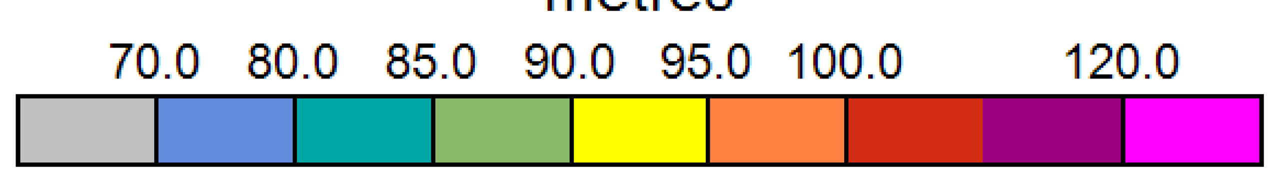
System Noise (UV)

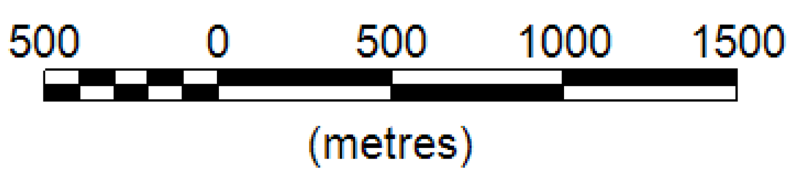


-82°13'
-82°12'
-82°11'
-82°10'
-82°09'
-82°08'
-82°07'
-82°06'
-82°05'
-82°04'
-82°03'
410000
412000
414000
416000
418000
420000
422000
48°41'
48°40'
48°39'
48°38'
48°37'
5392000
5390000
5388000
5386000
Digital Terrain Model
metres
255.1
259.9
264.6
269.4
274.1
278.9
283.6
288.4
293.1
297.9
302.6
307.4
312.1
316.9
321.6
326.4
500
0
500
1000
1500
(metres)
WGS 84 / UTM zone 17N
1:12,500



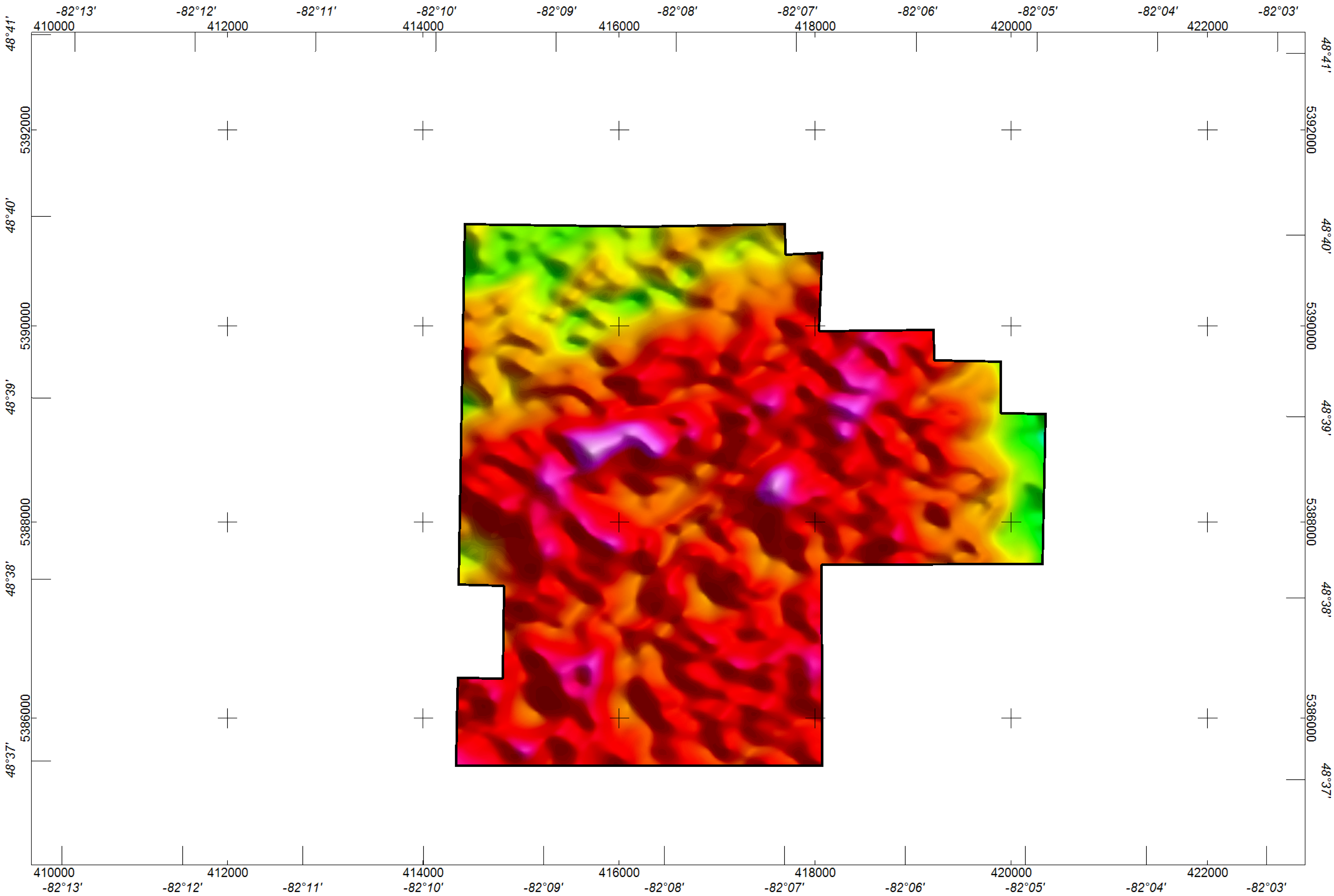
Terrain Clearance



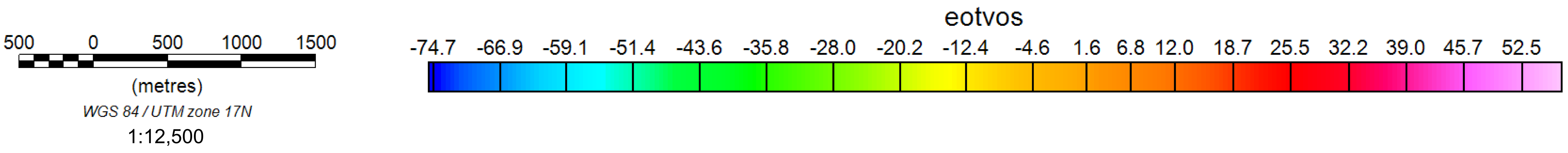


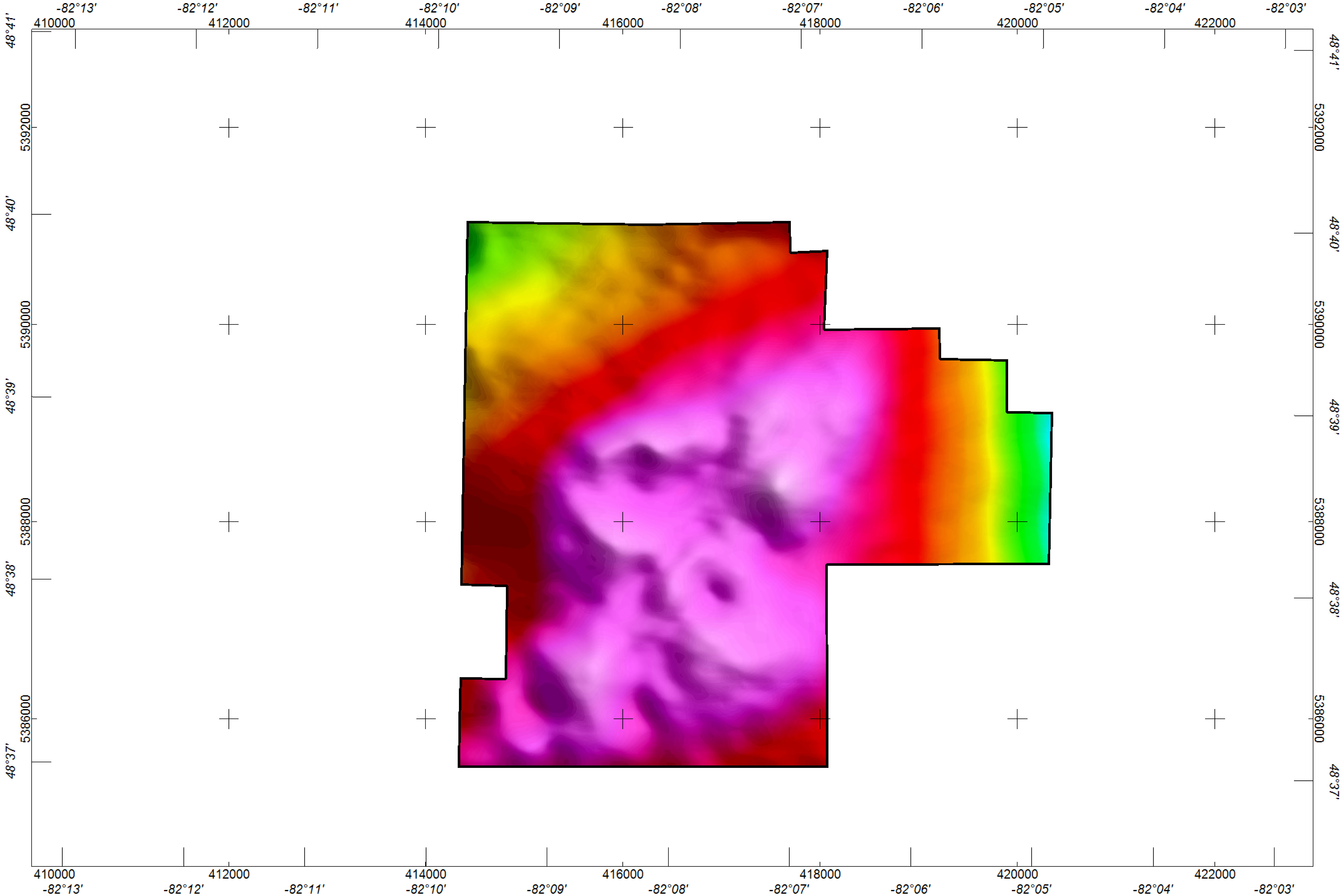
WGS 84 / UTM zone 17N

1:12,500



Equivalent Source GDD





Equivalent Source gD

mGal

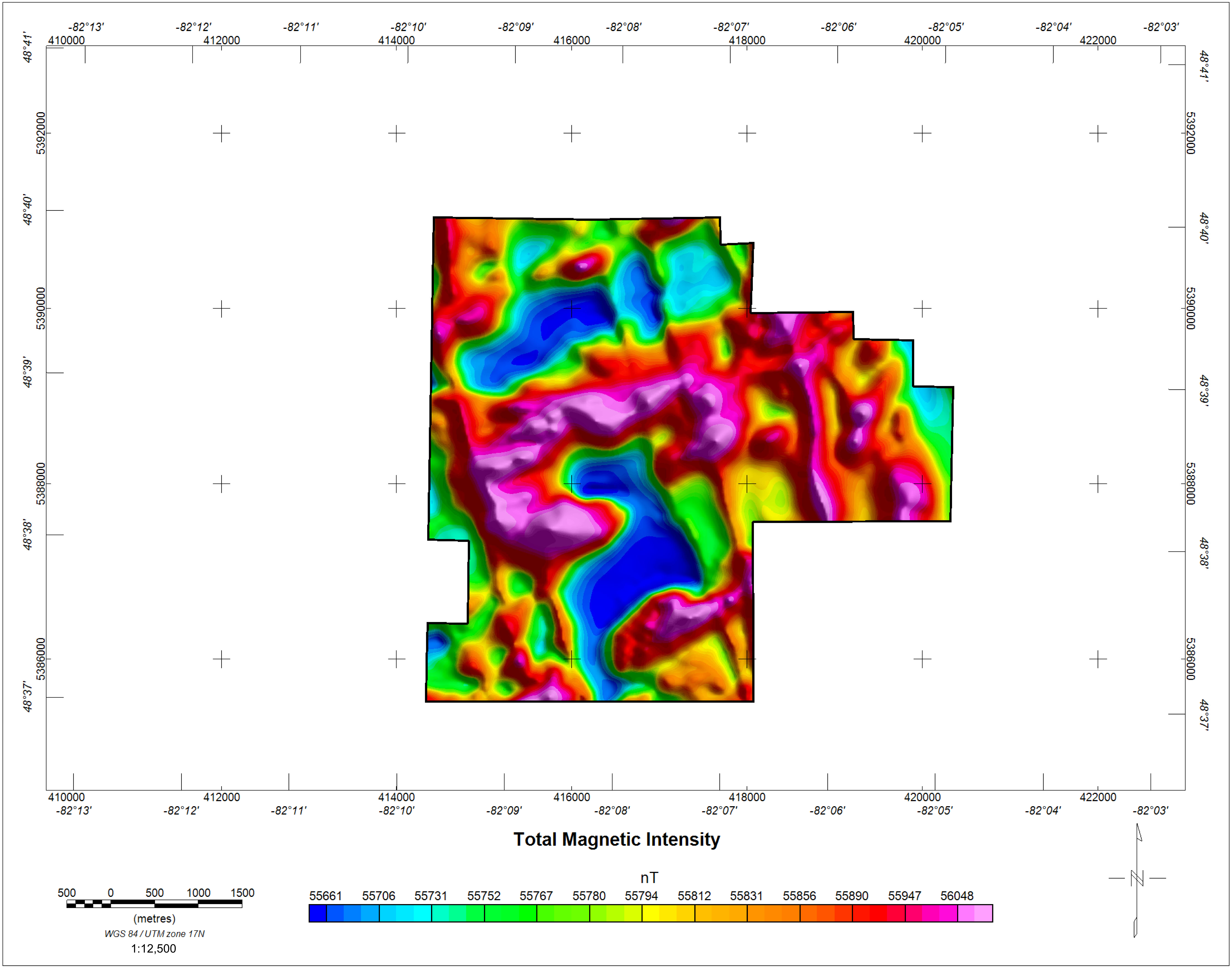
-5.6 -5.2 -4.7 -4.2 -3.8 -3.3 -2.9 -2.4 -1.9 -1.5 -1.0 -0.6 -0.1 0.4 0.8 1.1 1.5 1.9 2.3 2.7 3.1 3.4 3.8

500 0 500 1000 1500

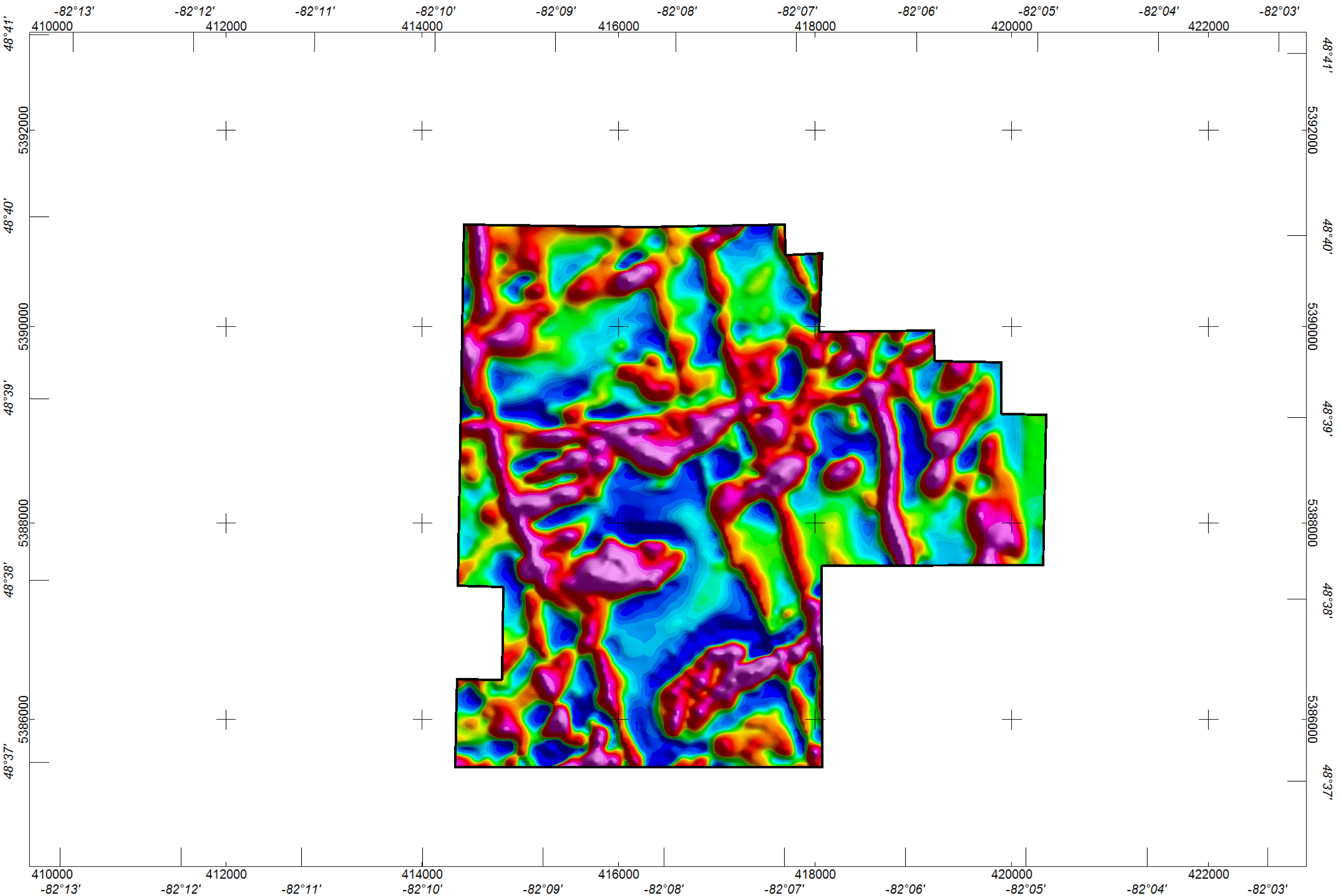
(metres)

WGS 84 / UTM zone 17N

1:12,500



-82°13′
-82°12′
-82°11′
-82°10′
-82°09′
-82°08′
-82°07′
-82°06′
-82°05′
-82°04′
-82°03′
410000
412000
414000
416000
418000
420000
422000
48°41′
48°40′
48°39′
48°38′
48°37′
5392000
5390000
5388000
5386000
Total Magnetic Intensity
nT
55661
55706
55731
55752
55767
55780
55794
55812
55831
55856
55890
55947
56048
500
0
500
1000
1500
(metres)
WGS 84 / UTM zone 17N
1:12,500



First Vertical Derivative of the Total Magnetic Intensity