Tellus

Understanding Underground

Tellus A1 Airborne Geophysical Survey

Logistics, Processing and Merging Report

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Geological Survey of Ireland Report

2016

Geological Survey of Ireland

The Geological Survey of Ireland is responsible for providing geological advice and information, and for the acquisition of data for this purpose. GSI produces a range of products including maps, reports and databases and acts as a knowledge centre and project partner in all aspects of Irish geology. GSI is a division of the Department of Communications, Energy & Natural Resources (DCENR).

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The Tellus Project

Tellus is a geo-environmental mapping project which provides data on soils, waters and rocks across Ireland and integrates these with existing data in the Republic and Northern Ireland. The project is managed by the Geological Survey of Ireland and is funded by the Department of Communications, Energy and Natural Resources (DCENR).

For more information on the Tellus Project please visit www.tellus.ie

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Document Information

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Change record

Date	Author	Version	Details
2nd February 2016	Mohammednur Desissa Ture	2	EM processing revision
4th February 2016	Jim Hodgson	3	Updated edits
8th February 2016	Jim Hodgson	4	Updated edits
15th February 2016	Jim Hodgson	5	Updated edits

Executive Summary

The Tellus Project is a geochemical and airborne geophysical survey programme.

The latest phase of the Tellus programme collected new airborne data within the counties of Dublin, Meath, Kildare, Wicklow, Offaly and Laois in the Republic of Ireland (ROI) and is collectively referred to as block A1. Surveying was carried out between June 2015 and October 2015 by Sander Geophysics Ltd (SGL). Previous airborne geophysical surveys were carried out across Northern Ireland (Tellus) in 2005 and 2006 (Beamish *et. al*, 2006), parts of counties Cavan and Monaghan in the ROI (Kurimo*,* 2006), counties Donegal, Leitrim, Sligo, Cavan, Monaghan and Louth as part of the EU INTERREG IVA-funded Tellus Border Project (Hodgson and Ture, 2012) and across counties Roscommon, Longford and Westmeath as part of the Tellus North Midlands project (Hodgson and Ture 2015). All surveys measured magnetic field, electrical conductivity and gamma-ray spectrometer data (primarily potassium, thorium and uranium). This report summarises the main operations from the latest A1 survey and discusses the processing of the acquired data and its merger with existing datasets to produce seamless merged geophysical datasets.

Acknowledgements

During the operation of the survey Emma Scanlon, Mairéad Glennon, Peter Heath, Kate Knights, Judith Maher and Aileen Doran, along with Morrow Communications all helped with the successful undertaking of the outreach program. The crew of SGL are thanked for the hard work throughout the duration of the survey.

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1 Tellus A1 Block Project Introduction

The Tellus A1 survey follows on from previous airborne surveys carried out under the Tellus Programme, this includes the original Tellus survey of Northern Ireland (2005-2006) and the EU INTERREG IVA-funded cross border survey of the border region of Ireland (2011-2012) along with the Tellus North Midlands survey (2014-2015). All airborne surveys comprised the collection of low-altitude magnetic, gamma-ray spectrometry and electromagnetic data. However, for the north midlands phase Time-domain Electromagnetic (TEM) data was collected in contrast to Frequency-domain EM (FEM) data which was collected for the other surveys. This latest phase of the Tellus survey (A1 Block) was carried out by Sander Geophysics Ltd (SGL 2015), who employed the same FEM system used in earlier phases. The survey aircraft was based at Weston Airport Co. Dublin.

Surveying took place primarily over the counties of the north Dublin, Meath, Kildare, north Wicklow, Offaly and parts of Laois. The airborne survey commenced in June 2015 with the testing and calibration of equipment. The first full production flight took place on 29th June 2015 and the last flight occurred on 31st October 2015, four months after the first flight. Generally there were only a few instrument and aircraft issues which caused minor delays. The survey was completed on schedule helped by good weather towards the end of the survey. The quality assessment of data was carried out by staff from GSI throughout the duration of the survey with final sign-off and order for demobilisation of the aircraft and crew on 4th November 2015. The survey covered 32,643 line km an area of approximately 5810 km^2.

2 Survey Specifications

2.1 Tellus A1 Survey Area

The nominal survey area is shown in Figure 1. It comprises counties Dublin, Meath, Kildare, north Wicklow, parts of Laois and Offaly. Topography and land-use in the area is predominantly low-lying undulating grass farmland, with areas of peat bogs with the exception of the Wicklow Mountains that form high-relief upland areas overlain with blanket peat deposits to the south of Dublin City. The survey was designed to allow an overlap with the Tellus Border and Tellus North Midlands surveys, which would assist the merging of the data. The survey was also designed within the context of a national survey and to complete 50% of this national survey by the end of

2017. Therefore the survey area moves away from one defined by county boundaries and towards a series of blocks to achieve coverage of the northern half of the country (Figure 2).

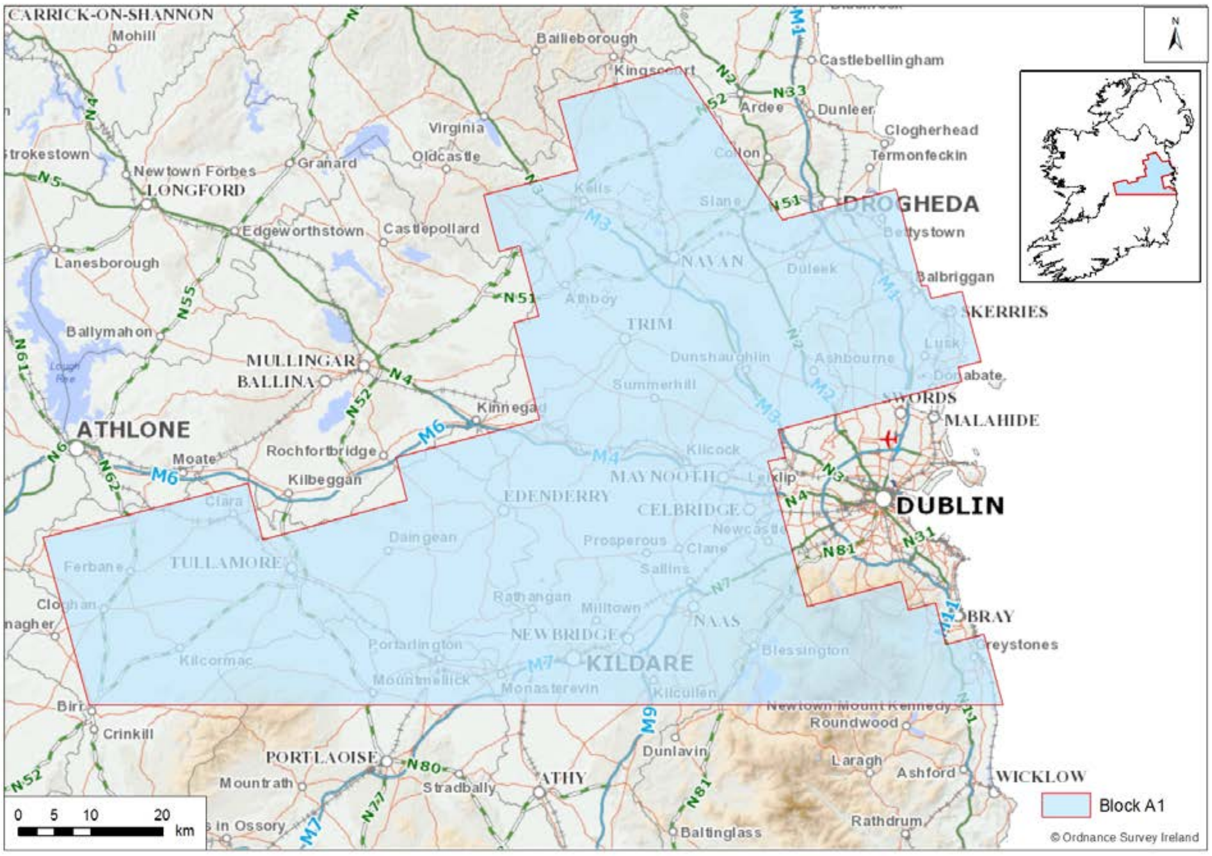

Figure 1: Tellus A1 block survey area.

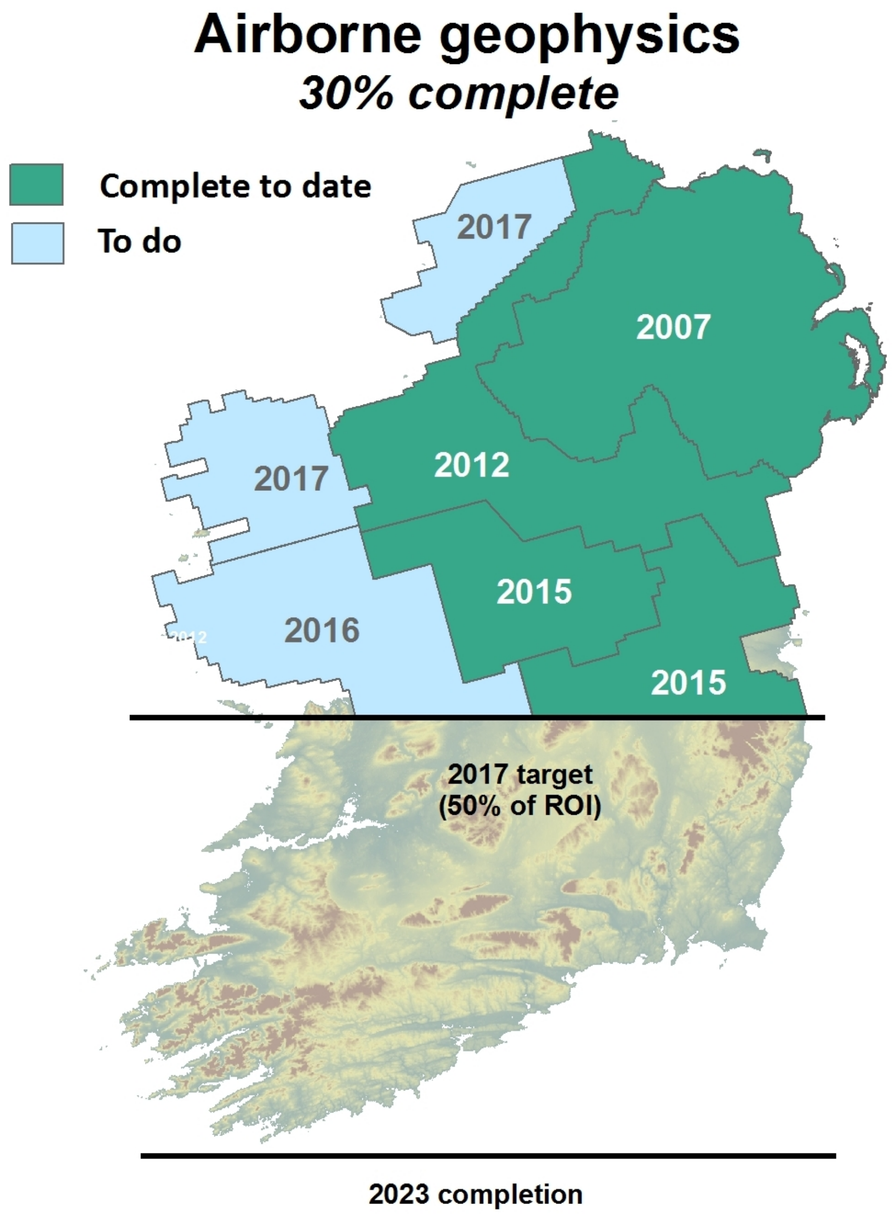

Figure 2: National airborne survey plan 2015-2017 and beyond.

2.2 Flight characteristics and survey pattern

The flight pattern is described in Table 1 below.

Table 1: Flight Pattern

Traverse Line Spacing	200 m
Tie Line Spacing	2000 m
Traverse Line Heading	165/ 345^0
Tie-Line Heading	75/ 255^0
Flying Height (rural / urban)	60/ 240 m subject to pilot's discretion
Projection / Datum	Irish Transverse Mercator

A repeat test calibration line was established close to the town of Bundoran, Co. Donegal in the northwest of Ireland. The test line was the same line as flown during the Tellus Border and North Midlands Surveys, allowing comparisons to be made between surveys. This test line was flown twice during the A1 survey, at the beginning and towards the end of the survey season. The test line was 6 km in length and was flown at six different elevations during each run. The line ran from off-shore to on-shore and was selected based on variable bedrock and superficial geological aspects and is discussed further in Section 3.6.

2.3 Flight permits

The Contractor (Sander Geophysics Ltd.) applied for the required flight permits for a low-level survey in Ireland from the Irish Aviation Authority. The corresponding permit is shown in Appendix 1.

2.4 Geographic projection

Final data was referenced to the Irish Transverse Mercator as defined in Table 2.

Table 2: Irish Transverse Mercator Geographic Projection

IRISH TRANSVERSE MERCATOR	
Reference Ellipsoid:	GRS80
Central Meridian	08° 00’ 00” West
Vertical Datum:	Malin Head
Map Projection:	Transverse Mercator (Gauss Conformal)
True origin:	53° 30’ 00” North, 08° 00’ 00” West
False origin:	600Km west, 750 km south of true origin
Scale factor on Central Meridian:	0.999820

2.5 Re-flight specifications

Data was received from the contractor on a weekly basis for quality assessment. The following re-flight conditions were enforced during the survey.

- Where flight line deviation for traverse-lines is greater than 45m from the planned line over a distance of 2.5km or more, or greater than 90m from the planned line over any distance (except where ground conditions dictate otherwise, for example to avoid radio-masts etc.).

- Where flight line deviation for tie-lines is greater than 100m from the planned line over a distance of 2.5km or more, or any deviation greater than 200m from the planned line over any distance.
- Where terrain clearance exceeds +/- 20 metres from the nominal survey height for more than 5 continuous kilometres or 40 m of nominal survey height at any time on any line, unless local topography makes this unavoidable.
- Where the nominal survey flying speed (60m/s) is exceeded by more than 30% (78 m/s) for more than 5 continuous kilometres.
- Where the noise envelope of the magnetic records exceeds 0.1nT as determined by the normalised fourth difference.
- If, during data acquisition, magnetic variations recorded at the local base magnetometer exceed 12nT over any 3 minute chord or exceed 2nT over any 30 second chord, on flight lines or tie lines. The base magnetometer must be fully operational during all on-line data collection.
- Where the average line gamma spectra for any line appears anomalous by comparison with previously acquired data then the data of that line will be investigated in detail and re-flown if necessary.
- If the calibration of the EM system deviates significantly from the norm.
- If both primary and secondary GPS base stations fail to record for 30 minutes or more, simultaneously.
- If both primary and secondary magnetic base stations fail to record for 30 minutes or more, simultaneously.

These conditions may be exceeded without re-flight where such constraints would breach air safety regulations, or in the opinion of the pilot, put the aircraft and crew at risk. All such exceptions were logged and a log of all flights can be found in the technical report produced by SGL (SGL, 2015). Data typically met the required specifications although some altitude deviations were encountered, these were often related to client enforced high fly zones due to urban areas, stud farms, radio masts and pilot safety requirements.

2.6 Survey equipment and aircraft systems

2.6.1 Survey Aircraft

The contractor Sander Geophysics Ltd used a De Havilland DHC-6 twin Otter (registration number C-GSGF) for all survey work. The same aircraft was used in the Tellus survey of Northern Ireland (2005-6), under the registration OH-KOG. During this survey it was operated by JAC (Joint Airborne-geoscience capability), which was a partnership between the Geological Survey of Finland and the British Geological Survey. The aircraft was also used under its current registration for the Tellus Border Survey (2011-2012). This aircraft is an all metal, fixed-wing, twin-engine, short take-off and landing aircraft (Figure 3). The aircraft can be flown at speeds from 80 to 160 knots (41 to 82 m/s). The Twin Otter is equipped with airborne magnetic, radiometric and frequency-domain electromagnetic (FEM) systems as outlined by Hautaniemi *et al*., 2005. The aircraft houses two magnetometers; one attached to a rear boom and one in the left wing tip pod. The four frequency EM transmitter was housed in the right wing tip pod and the receiver in the left wing tip pod. The GR spectrometer crystal packs were housed in the rear of the aircraft (Figure 4).

The NavDAS system developed by SGL was used for airborne navigation and data acquisition. The system displays all incoming data on a flat panel screen for real-time monitoring.

Figure 3: Survey Aircraft – De Havilland Twin Otter

2.6.2 Geophysical Instrumentation

Table 3 below outlines the survey equipment used by SGL during the project. Further detail of the instrumentation is given by SGL (2015).

Table 3: Survey Equipment

Survey Method	Equipment used
Magnetometer	Aircraft: 2 x Geometrics G-822A, optically pumped caesium split beam sensors, tail stinger and wing tip, sampling rate:10 Hz Base station: 2 x Geometrics G-822A SGComp, post-flight compensation
EM system	SGFEM: Four frequency (0.9, 3, 12 and 25 kHz), sampling 10 Hz. Wingtip coils
Gamma-ray spectrometer	Exploranium GR-820 gamma-ray spectrometer 256-channels, self-calibrating, 50.4 litres downward, 12.6 litres upward looking, pressure and temperature sensors, sampling rate 1 Hz.
Altimeter	Collins radar altimeter (AL-101), sampling 10 Hz SGLas-P Riegl laser rangefinder altimeter LD90-3300VHS-FLP Honeywell Barometric Pressure sensor Omega RTD-805 Outside air temperature probe
GPS	SGRef system, DGPS receiver (10 Hz) NovAtel Millenium 12 channel dual frequency
Video	SGDIS – Digital imaging system (avi format)
Data location system	Post-process DGPS based on NovAtel OEM-V receivers in aircraft and at base.
Data transfer medium	Solid state hard drives and FTP

<u>Magnetometers</u>

For both aircraft and ground sensors, Geometric's G-822A, optically pumped caesium split beam sensors were used. These were housed on the left wing pod and within a rear tail stinger. The two base station magnetometers were located close to the field base. All magnetometers had a sensitivity of 0.001 nT and a magnetic gradient tolerance of >20,000 nT with a sensor noise less than 0.05 nT. Measurements were delivered at 10 Hz intervals.

Spectrometers

The Gamma Ray spectrometer system used was an Exploranium GR-820 model with 256 channels. The system used 50.4L downward looking and 12.6L upwards looking NaI crystals. Data was collected at a sampling rate of 1 second. The system was calibrated at the Geological Survey of Canada's test range at Breckenridge, Quebec, along with ground calibration pad test in Ottawa, Canada before departure to Ireland. Hand sample checks were run on the gamma ray spectrometer before or after each day's flying to check spectral stability and system sensitivity. Relative count rates were measured to achieve background rates that were within two standard deviations of the average sample checks for the survey.

Frequency-domain electromagnetic system

The system used four frequencies, 912, 3005, 11962 and 24510 Hz with a transmitter-receiver coil separation of 21.4m. The transmitter-receiver coil pairs were mounted in a vertical-coplanar orientation which helped reduce noise by minimising coupling with the wingtip surface. A 50/60Hz power line monitor was also employed to help identify cultural interference. Data was sampled at 40 Hz and later decimated to 10 Hz by the contractor during processing of the data.

Figure 4: Exploranium GR-820 spectrometer housed in the aircraft.

2.6.3 Radar altimeter system

Four types of altimeter were employed on the aircraft. These were;

- SGLas-P – Riegl LD90-3300VHS-FLP Laser Rangefinder: This laser altimeter has a range of 400m and a resolution of 0.01m with an accuracy of 5cm and a sample rate of 2000Hz later decimated to 10Hz.
- Collins AL-101 Radar Altimeter: This radar altimeter has a resolution of 0.5 m, an accuracy of 5%, a range of 0 to 762 m and was sampled at 10Hz.
- Honeywell Barometric Pressure Sensor: Measures static pressure to accuracy of +/- 4 m with a resolution of up to 2 m over range of 0 to 9144 m above sea level. Barometric pressure is sampled at 10 Hz.
- Omega RTD-805 Outside Air-temperature probe: Sampled at 10 Hz with a resolution of 0.1 ^{0}C with a range of +/- 100 ^{0}C.

2.6.4 Magnetic Base Station

Two Geometrics G-822A, optically pumped caesium split beam magnetometers were used to measure the daily diurnal variation during the survey. The two ground magnetic base stations were set up approximately 5-6 km to the north of Maynooth, Co. Kildare, within the survey area. The first was placed in a small wooden shed with the GPS antenna about 30m away and the second in an empty stable with the antenna about 30m away in a neighboring field. The co-ordinates for the two base stations are given below;

Table 4: Co-ordinates of magnetic base stations used during the survey.

Station	Easting	Northing	Projection	Elevation
Base A (GND1)	N53°25’ 18.611229	W06°33’59.911862	WGS84	133.71m
Base B (GND2)	N53°25’ 57.802685	W06°36’28.978280	WGS85	150.49m
Base A (GND1)	695271.1 m	742259.4 m	ITM	133.71m
Base B (GND2)	692495.4m	743416.2 m	ITM	150.49m

3 Start-up calibrations & mobilisation

3.1 Magnetic Calibrations

The airborne geophysical equipment system calibrations and tests prior to mobilization were made in Ottawa, Canada, as well as at the Geological Survey of Canada’s Breckenridge Calibration Range in Quebec, further calibration were conducted on site in Ireland. The details of all these tests were reported by SGL and are also outlined in the SGL Technical Report 2015.

The calibrations which were carried out as part of the survey are summarized below.

3.1.1 Magnetic Compensation

A series of magnetic flights were performed at high altitude (roughly 10,000ft). The compensation flights were flown on survey line headings. A series of pitch (+/- 5 deg), roll (+/- 10 deg) and yaw (+/- 5 deg) manoeuvers were performed along two headings and the largest peak to peak differences (P2P) in the compensated magnetic signal for each maneuver on each heading (total of 6 measurements) were summed to compute the Figure Of Merit (FOM). The contract specification required a compensation figure below 3nT for a combination of 12 manoeuvres.

Accordingly the FOM for C-GSGF for the tail magnetometer was 0.72nT within the required specification. During the previous Tellus survey of Northern Ireland values of 2.49 and 1.28nT have been reported for the FOM while during the Tellus Border survey values of 1.7 nT and 0.94 nT were computed based on 12 measurements.

3.1.2 Heading Error Determination

The Heading test was flown on 22nd May 2015 for the tail magnetometer. The test consists of flying a set of 2 orthogonal lines (N-S and E-S) crossing each other at the midpoint. The error based on the heading direction can be established by comparing the magnetic values at the midpoint between the lines flown in reciprocal directions e.g. North v South. The average results of the heading test were -0.59nT and 1.77nT respectively for the north-south and east-west directions respectively.

3.1.3 Lag and Parallax Test

The lag test was flown on 20th May 2015 in Ottawa, Canada. The lag test measures the offset in time between the detection of a magnetic anomaly and when it is actually registered by the airborne acquisition system. This lag is dominated by 2 factors; the electronic lag, which remains constant, and the physical separation between the survey GPS antenna and the magnetic sensors. The lag test consists of flying over a known sharp magnetic anomaly in reciprocal directions. The tail magnetometers show a total lags of 0.462s which has been corrected for.

3.2 Radiometric Calibrations

Before its arrival in Ireland, on 22nd May 2015, C-GSGF undertook a series of radiometric calibrations including a height attenuation test, at the Geological Survey of Canada's Breckenridge Calibration Range in Quebec. Pad calibrations were also performed at Ottawa Airport in Canada on 21st May 2015. Full details of these tests were reported by SGL and are contained in SGL technical Report 2015 and summarised in Table 5. Calibrations were carried out based on guidelines set out in (IAEA, 2003) and (Grasty and Minty, 1995).

Table 5: CGG Spectrometer Processing Parameters for C-GSGF

Spectrometer Processing Parameter – Spectrometer Exploranium, Model GR-820 NaI(Tl) crystals 50.4L, Down, 12.6L Up. At 60m survey altitude.		
Window	**Cosmic Stripping Ratio (b)**	**Aircraft Background (a)**
Total	*0.6563*	*/65.74*
Potassium	*0.0390*	*15.62*
Uranium	*0.0314*	*0.00*
Thorium	*0.0372*	*0.72*
Upward	*0.0084*	*0.56*
Radon Correction	**Radon Ratio (a)**	**(b)**
Total	*13.2227*	*0.0000*
Potassium	*0.831*	*0.0000*
Thorium	*0.0000*	*0.4640*
Upward Uranium	*0.2410*	*0.2454*
Stripping Ratios	**Contribution on the ground**	**Effective height adjustment**
α	*0.2512*	*0.00049*
β	*0.3999*	*0.00065*
γ	*0.7445*	*0.00069*
a	*0.0416*	*0*
b	*0.0000*	*0*
g	*0.0041*	0
Attenuation Coefficients		
Total	-0.00680	
Potassium	*-0.00930*	
Uranium	*-0.00580*	
Thorium	*-0.00740*	
Sensitivities at 60m		
Total Count		
Potassium	*169.4779 cps/%*	
Uranium	*11.2001cps/eU ppm*	
Thorium	*9.3386 cps/eTh ppm*	

3.3 EM Calibrations

Two basic pre-survey calibrations of the EM system were undertaken.

3.3.1. EM System Orthogonality

Prior to each flight, the phase shift between the in-phase and quadrature parts of the EM response is verified and adjusted if required. For each frequency, two pulses of constant amplitude are artificially generated, the first being perfectly in-phase with the primary field, and the second being phase shifted by 90 degrees. Therefore, when the phase orthogonality is properly adjusted, no quadrature response should be observed during the first pulse, and vice versa during the second. This test is usually performed above 300 m to avoid any EM response from the ground and to minimize cultural interference. The compensation of the primary field is verified, enabling EM data to be recorded with reference to an arbitrary zero-level low enough to ensure that the full range of the receiving device can be utilized. This ensures the system is functioning properly. The orthogonality check is also performed following each production flight, while ferrying back to the base.

3.3.2. EM Over-Seawater Calibration

The frequency domain electromagnetic system was calibrated following procedures described by Hautaniemi *et al.* (2005). A test site was chosen over Donegal Bay, in an area where water conductivity and temperature have been measured several times over the years, at every meter from surface to sea floor, by the Irish Marine Institute. The water depth reaches over 60 m, ensuring that the bottom sediments do not contribute to the EM response. Conductivity data from two different stations taken from three different years were analysed, showing conductivity profiles to be essentially consistent at the two stations, and therefore data can be considered constant between the stations. The calibration line location (in red) and the two sampling stations (CE10003_056 and CE10003_057) are shown in Figure 5.

Figure 5: Location of overwater calibration line and sampling locations

The conductivity data was analysed to estimate the conductivity variation with depth. Conductivity changes with respect to temperature were analysed over three different years. Full details of these tests were reported by SGL (2015). The 4.5 km long calibration line was flown on August 6 2015 at several heights from 25 to 100 m. Surface water temperature measured on the same day as the calibration flight also took place (13.36 °C, published by the Irish Marine Institute) enabling the estimation of the water conductivity close to surface.

[0.089 S/m°C x 13.36 °C] + 2.915 S/m = 4.10 S/m [1]

Based on the average conductivity decrease with depth observed over the three years and the result from Equation 1 above, it was possible to estimate the water conductivity at a depth of 30 m ([-0.0025 S/m2 * 30 m] + 4.10 S/m =4.03 S/m), and the average conductivity between the surface and a depth of 30 m at the calibration site (4.07 S/m). Slight changes in conductivity below 30 m are negligible. This conductivity was used to create a single layer model (half-space), which was employed to calculate the EM response for each component of each frequency, for the range of altitudes covered during the calibration flight. The calculation was performed with the software Airbeo, developed by AMIRA.

3.4 Altimeter Calibration

The altimeter calibration test is carried out to ensure proper functioning of the aircraft altimeters. This is done by flying over a flat surface (runway) at a series of different elevations. A correlation coefficient can then be calculated with values greater than 0.97 indicating an accurate calibration result. Results achieved a value of 1 indicating a good result. This test was performed on March 13th 2015 over the run way at Gatineau Airport near Ottawa, with a laser altimeter slope of 0.97 recorded and an intercept of 2.7463 m. Further information is contained in the SGL Technical Report 2015.

3.5 Mobilisation

The contract was awarded by GSI to Sander Geophysics Ltd (SGL) and signed on 26th May 2015. Alison McCleary was appointed as SGL party chief and arrived in Ireland 8th June 2014 along with the chief pilot Steve Gebhardt. Alison McCleary met with project staff at the GSI on Thursday 11th June 2015. Weston airport in Co. Dublin was selected as the field base for the survey with SGL crew based in the nearby area. On 14th June C-GSGF departed Canada and arrived in Ireland on 21st June 2015, following its ferry via Newfoundland, Nunavut, Greenland and Iceland. Configuration of instrumentation on the aircraft along with testing continued until the 29th June 2015 when the first production flight took place.

3.6 Test Line

As part of on-going calibration testing and to help with the integration of different datasets collected during different seasonal conditions a test line was developed. This test line was flown twice during the survey. The line is located close to the town of Bundoran in county Donegal, in the northwest of the country (Figure 5) and runs from the sea to onshore. The test line extends from Irish Grid Co-ordinates E177186.2, N359106.2 to E178745.9, N353312.8. The single line was flown at six different altitudes (90m, 120m, 150m, 180m, 210m and 240m) over a distance of 6km. The test line was chosen to include areas of variable bedrock and superficial geology as well as coastal transition zone and sea water. C-GSGF's first test line flight was on 26th June 2015 at the beginning of the survey and the second on 28th October 2015 just before the final survey flight on the 31st October. The test line was also flown as part of the Tellus Border and North Midlands surveys.

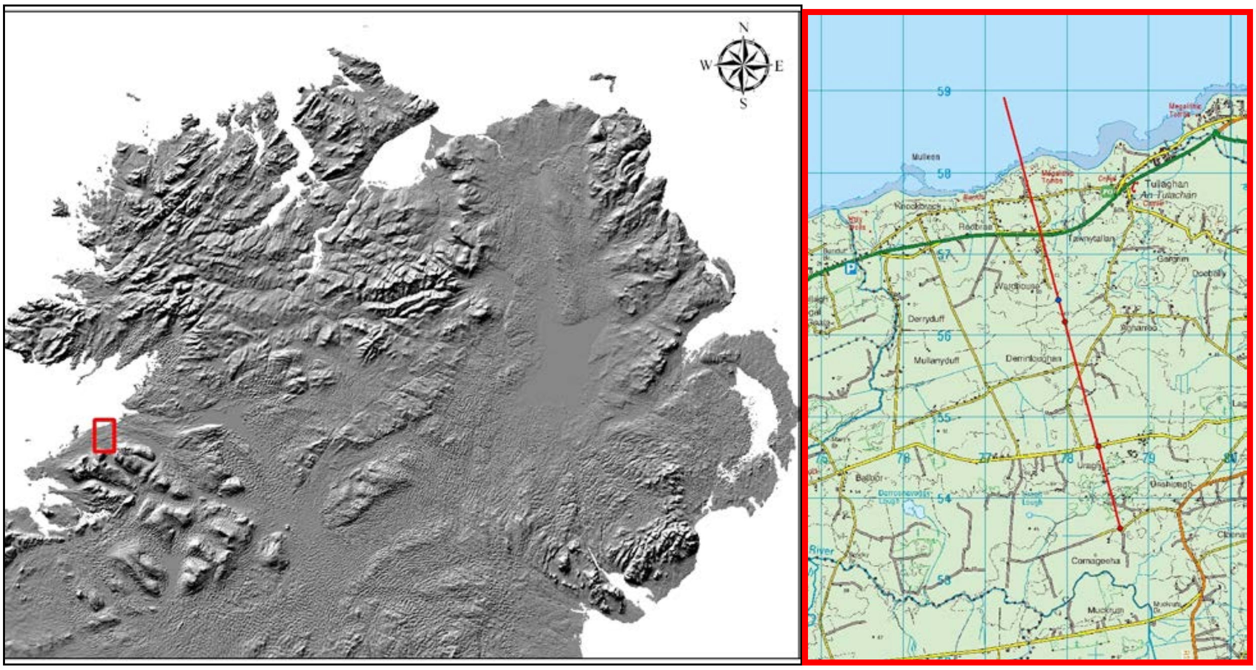

Figure 6: Test Line Location

3.7 Personnel

A number of people from both SGL and the Tellus team were involved in the airborne geophysics operations, the main personnel are listed below in Table 6 and 7.

Table 6: SGL Field Crew

Field Personnel	Name
Operations Manager	Alex Pritchard
Crew Chief	Alison McCleary
Data Processor	Monika Pal, Max Buneta
Chief Pilot	Todd Svarckopf
Lead Pilot	Steve Gebhardt
Technicians	Craig McMahan, Edward McEwen

Table 7: GSI Tellus Team

Field Personnel	Name
Head of Programme / GSI Principal Geologist	Ray Scanlon
Project Manager	Mairead Glennon
Geophysical Programme Manager	Dr. James Hodgson
Geophysicist	Mohammednur Desissa
Communications Assistant	Emma Scanlon
GIS and Data Manager	Peter Heath

4 Outreach Program

4.1 Tellus A1 Public Relations

Due to the low flying nature of the survey (nominal survey altitude of 60m) and the population and land use within the survey area an extensive outreach programme was undertaken. This comprised a comprehensive information campaign including meeting with local stakeholders, interviews on local radio and articles in both national and local newspapers. Over 566,000 information fliers were posted over two separate deliveries, to land owners within the survey area. State agencies including; local authorities, An Garda Síochána and National Roads Authority were also contacted and regularly updated on the progress of the survey. Of particular significance was the bloodstock sector with a large number of equine interests and stud farms present in the survey area. Notifications were given through the Weatherby's Organisation (thoroughbred horse registrations) and the Irish Thoroughbred Breeders Association along with individual visits to stud farms.

As part of this outreach programme a Microsoft Access database was created to log all enquires. Following the outreach programme any land owners, particularly livestock owners, who required notification of the survey in their area were contacted and their land holding digitised and put into a GIS. Working with SGL survey crew, a Tellus team member, before each flight would identify any areas where planned flights for that day intersected land where the owner required notification using the web based Tellus Communications Viewer. All these people where then contacted, allowing stock to be moved or in some cases, a high fly zone (240 m) to be flown above these properties. High fly zones were also introduced over urban areas as required under the permit. During survey activities, an "on-call rota" was established to make sure that there was one person on duty at all times seven-days a week, to deal with urgent enquiries relating to the airborne survey. A free-phone information line (1800 303 516) was in operation and was managed by Morrow Communications in order to take enquiries about the airborne survey. The line was manned during office hours by Morrow Communications and out of hours by the Tellus communications representative on call. All calls were logged in an Access database managed by the GIS/Data Manager.

5 Quality Assessment

5.1 Tellus A1 QA/QC

During the survey operation, data was supplied to the Tellus geophysicists via FTP from SGL on a weekly basis. The data was checked to determine whether it conformed to the required specifications / re-flight requirements as outlined in section 2.5. The following checks were carried out on all data.

- Terrain clearance and altitude deviations
- Flight line accuracy
- Magnetometer noise
- Ground speed
- Magnetic base station – diurnal variations
- Gamma ray stability
- EM noise level and conformity

Weekly QC reports were filed and discussed with the SGL party chief and any required re-flights scheduled into the new flight plan. The weekly QC reports have been collated and can be found as an internal GSI document. Overall technical specifications were adhered to by the contractor with the exception of a number of line deviations due to the presence of radio masts and wind turbines. High altitude zones (mainly due to the inclusion of urban and sensitive livestock areas) were a constant issue. Some flying restrictions (time and altitude) were enforced by Dublin air traffic control in the vicinity of Dublin Airport along with the Curragh military camp in county Kildare.

6 Survey Statistics

6.1 Survey Production

The survey consisted of a total of 32,643 line km of which 29,566.8 km were traverse lines and 3,076.22 km were tie-lines. There were 654 traverse lines and 53 tie lines overall. A full list of all flight logs and a flight line summary is contained within the SGL Technical Report (SGL, 2015).

Table 8: Survey Operation overview

Airborne Survey Contractor	Sander Geophysics Ltd
Survey Aircraft:	De-Havilland DHC-6 Twin Otter (C-GSGF)
Survey Base:	Weston Airport, Co. Dublin
Aircraft arrival:	21st June 2015
Flying dates:	29th June 2015 – 31st October 2015 (125 days)
Total no of Flights Productions, re-flights and test flights):	100
Date of demobilisation:	4th November 2015
Total Production km's flown:	32642.3 km

The airborne survey operated 7 days a week over 21 weeks, although production didn't begin until week 4. Week 5 saw production stop due to issues with the FEM system, this was quickly identified and fixed, apart from this production was steady with few delays and the survey was completed on schedule. The average production across the survey period was 1,813.5 km per week; improvement on the 1,071 km per week average achieved for the Tellus North Midlands survey when using two aircraft. Week 10 saw the highest weekly total of 3,648.6 line Km while the lowest weekly total was 0 km. Between week 7 and 19 production was very consistent with an average of nearly 2,300 km per week maintained. A Tellus Pogramme record of 1,271.6 km were flown on a single day on 11th August.

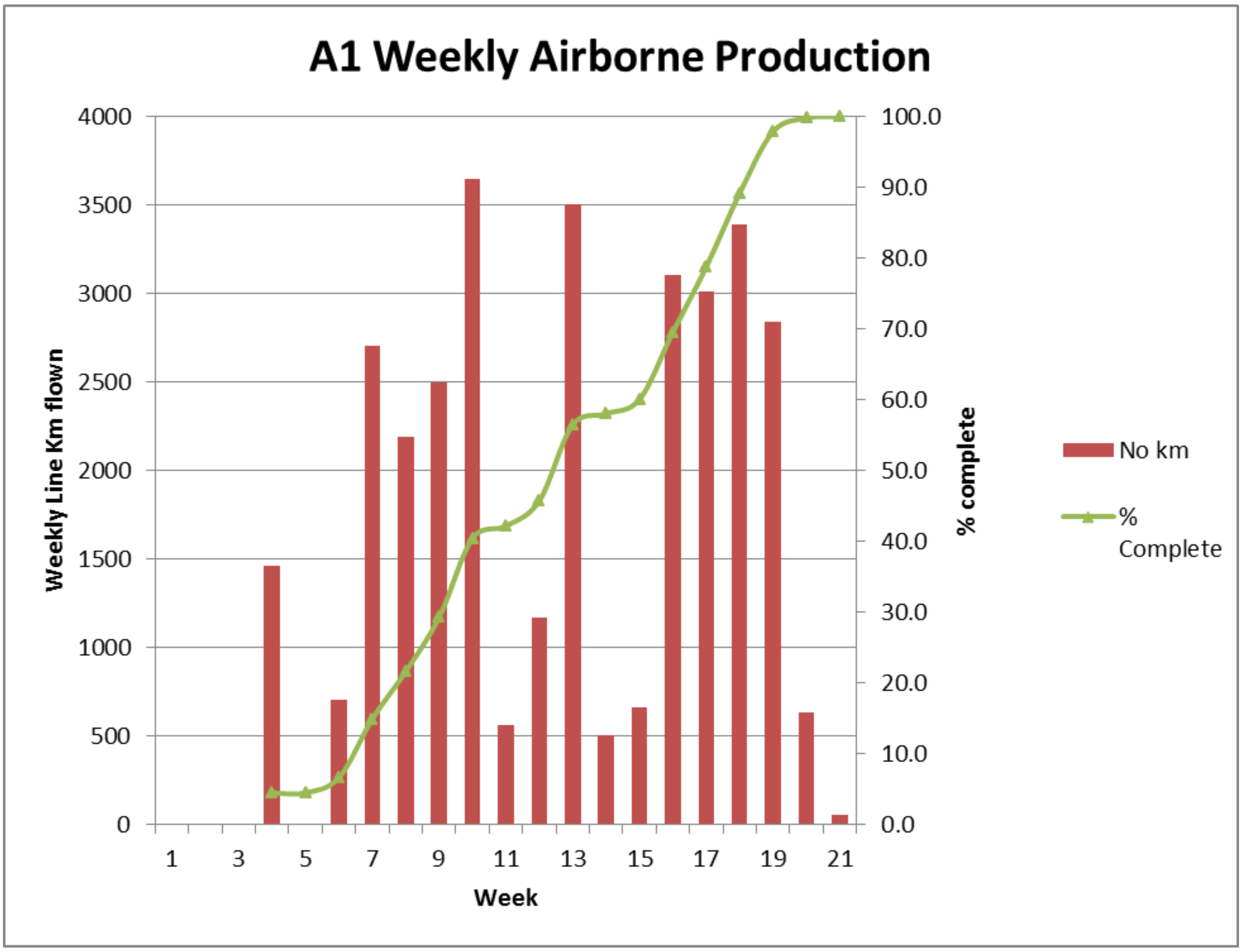

Figure 6: Weekly survey production in line Km for A1 Survey

6.2 Altitude

The survey specifications set a survey altitude of 60 m over rural areas and 240 m over urban areas. The Tellus A1 project operated an extensive outreach programme within the survey area in particular identifying livestock owners, stud farms and farmers to make them aware of the low flying survey. A number of livestock/horse owners requested that the high fly altitude of 240 m be carried out over their lands. Along with these zones, high fly zones were also identified over towns with populations greater than 2000 and private airfields. This resulted in numerous high fly (240m) zones throughout the survey area. Few other altitude deviations were encountered, generally relating to radio masts and wind turbines. These high fly zones have had a significant impact in the overall altitude values across the survey (Figure 7).

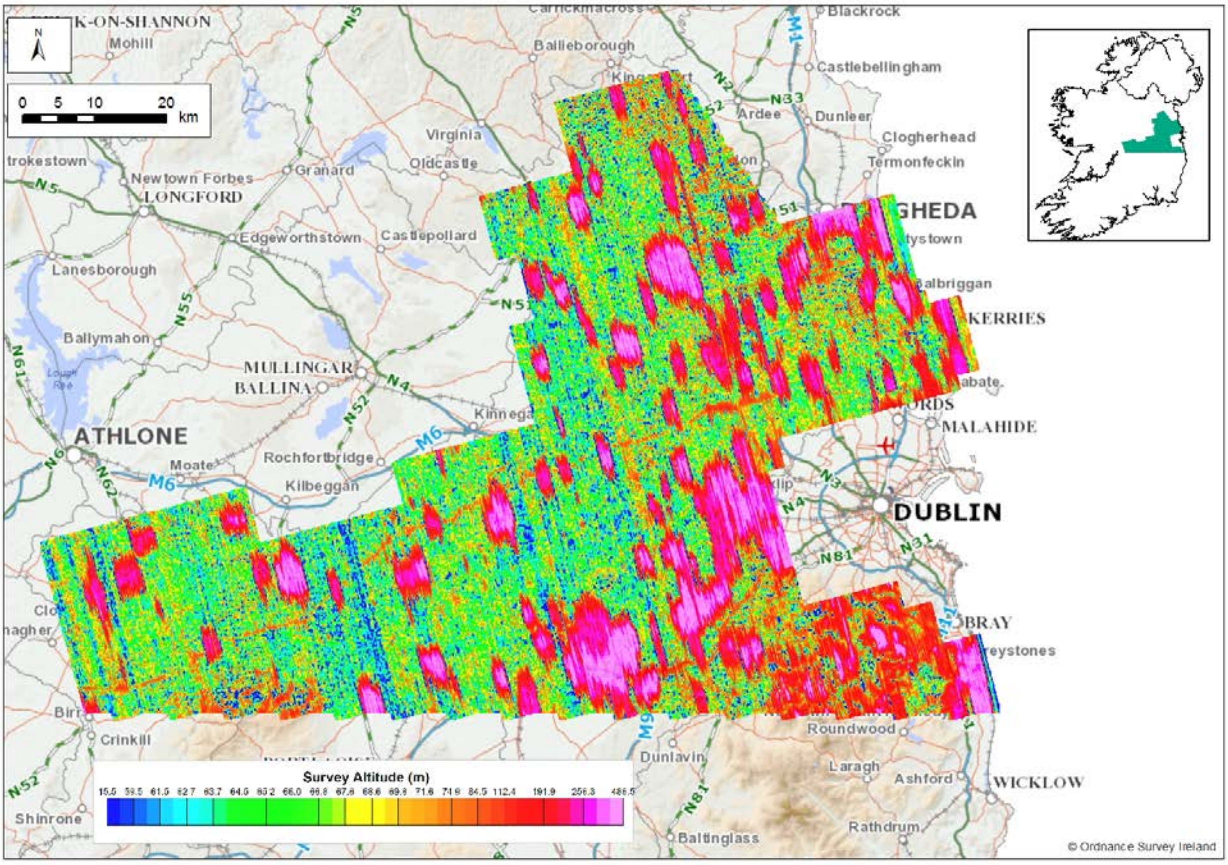

Figure 7: Survey altitude in metres above ground level

As can be seen from Figure 7 obvious high altitude (pinks) zones are seen across the survey area associated principally with towns and requested high fly zones. The area was generally low-lying so no altitude deviations due to steep topographical gradients occurred, except for a few occasions over the Wicklow Mountains within the southeast of the block. The maximum survey altitude recorded was 488.06 m while the mean over the entire survey area was 104.65 m with a standard deviation of 73.5, with approximately 19% of measurements greater than a survey height of 150 m.

6.3 Magnetic Data Summary

For the magnetic data a total of 5.56 Million data points were collect at a sample rate of 10 Hz.

The main statistics for the raw and corrected data are summaries below in Tables 9-11.

6.4

Table 9: Tail magnetometer summary statistics

No data points:	5,560,380
Sample rate:	10 Hz or 0.1 sec
Minimum value:	48367.91 nT
Maximum value:	50096.50 nT
Mean value:	49187.22 nT
Standard Deviation	115.3

Table 10: Compensated, IGRF subtracted and levelled tail magnetometer summary statistics

No data points:	5,560,380
Sample rate:	10 Hz or 0.1 sec
Minimum value:	-445.68 nT
Maximum value:	792.63 nT
Mean value:	32.52 nT
Standard Deviation	61.43

Table 11: Diurnal corrected data summary statistics based on all 100 flights

No data points:	5,560,380
Sample rate:	11 Hz but later decimated to 10Hz
Minimum value:	-43.2 nT
Maximum value:	144.28 nT
Mean value:	5.01 nT
Standard Deviation	26.36

6.5 Radiometric Data Summary

For the radiometric data a total of 509,076 data points were collect at a sample rate of 1 Hz. The main statistics for each element are summaries below in Table 12.

Table 12: Corrected radiometric data summary statistics (no = 509,076)

Element	Min	Max	Mean	SD
Total Count (cps)	0	4466	1195.16	553
Potassium (%)	0	3.9	0.61	0.375
e Thorium (ppm)	0	12.52	3.07	1.809
e Uranium (ppm)	0	16.13	1.98	0.9134
Temp (deg C)	5.2	23.2	14.37	2.353

6.6 Frequency Domain Electromagnetic Data Summary

For the FEM data a total of 5,558,867 data points including tie lines were collected at a sample rate of 10 Hz i.e. measurements at approximately 6m intervals. In EM processing the tie line data are not used since EM is a focused signal and is directionally dependent. The number of data points on standard traverse lines is 5,037,106 and these data points were used in the final processing. High fly zones significantly affect the quality of the data. In total 992,687 locations on survey lines are observed to be higher than an altitude of 150m or 20% of the data is of limited use due to high altitudes while flying. Raw, filtered and levelled In-phase and quadrature component data for each of the 4 frequency channels were delivered for each location. Apparent resistivities and other pertinent processing of EM data are based on the SGL delivered levelled data. Apparent resistivities derived from look up tables were also delivered for each location for each of 4 frequencies from the levelled data set. The main statistics for contractor supplied levelled FEM are summarised below in Tables 13.

Table 13: In-phase, quadrature and apparent resistivity summary statistics for A1 EM data

Frequency Hz	Mean In-phase (ppm)	Mean quadrature (ppm)	Min Apparent resistivity (Ohm-m)	Max Apparent resistivity (Ohm-m)	Mean Apparent resistivity (Ohm-m)
912	104.08	175.7	1.00	167.00	115.79
3005	269.28	439.14	1.00	552.00	289
11962	729.11	704.75	1.00	1671.00	404.88
24510	1119.84	920.91	1.00	3352.00	678.12

Each channel of EM data contains negative ppm values, which reflects low signal to noise ratio due to; high fly altitudes, cultural noise and effects of rocks with strong magnetic susceptibilities. Table 14 shows statistics of negative values in the SGL levelled data.

Table 14: statistics of negative values in A1 EM data

	912 Hz		3005 Hz		11962 Hz		24510 Hz	
	In-phase	Quadrature	In-phase	Quadrature	In-phase	Quadrature	In-phase	Quadrature
min	-2477	-2164	-1237	-1481	-9143	-5233	-2125	-2475
max	-1	-1	-1	-1	-1	-1	-1	-1
mean	-61	-67.35	-68.8	-56.46	-115.21	-117.11	-139.17	-64.61
N0.data	840269	375180	469163	296881	290274	621211	391073	226622
%	16.7	7.4	9.3	5.9	5.7	12.3	7.7	4.5

As can be seen from Table 14, the in-phase component is more significantly affected than the quadrature component. The exception is frequency 11962 where the quadrature is affected more than the In-phase component.

7 Data Processing

7.1 Introduction

Standard processing was carried out on all three datasets (1. Magnetics, 2. Radiometrics and 3. EM) by the contractor and are discussed in detail by SGL (2015). The same processing was adopted as was carried out for previous survey's, outlined in Beamish *et al*., 2006 and reviewed in Hodgson and Ture (2013). The contractors supplied data in ASCII.xyz and Geosoft grid format. However, along with the standard processing of the Frequency Domain EM (FEM) data carried out by the contractor additional processing was required to allow the data to be merged with previous EM data collected as part of the Tellus programme. This data included Time-Domain EM (TEM) data, and it was decided that all EM data be resolved to show apparent conductivities with depth, allowing data to be merged as specified depth intervals and therefore allowing seamless merging of data between different blocks.

7.2 FEM data Processing

To create conductivities with depth from the FEM data so that it could be merged with the TEM data collected as part of the Tellus North Midlands survey it was necessary to carry out an inversion on the data. However, before inversions could be carried out it was necessary to clean the data, as poor quality or noisy data results in poor or false inversion results. The delivered FEM data resulted in a large number of negative in-phase and quadrature values particularly for the lower frequency channels (912 Hz and 3005 Hz). The in-phase component is more affected compared to the quadrature component and these negative values accounted for up to 15% of data in some instances for the 912Hz channel. These are most apparent in areas of high magnetic susceptibility, low signal to noise ratio (high survey altitude) and cultural noise (power lines etc). Negative in-phase and quadrature values are not theoretically possible and are the result of the processing and corrections applied to the data during acquisition. To carry out inversions of such data would provide spurious results. Therefore, the data would need to be cleaned to remove or smooth out these negative responses and other data spikes, without affecting the character of the measured signal.

7.2.1 Noise reduction of FEM

To reduce the effect of negative values within the dataset an inversion software AEMINV1.3 was used. AEMINV is a computer program for geophysical interpretation of frequency domain airborne electromagnetic (AEM) data using one dimensional (1-D) layer earth models (Pirttijärvi, 2014). The model parameters are the electrical resistivity and thickness of the layers and the resistivity and magnetic susceptibility of the basement layer. Depending on the number of frequencies (with a maximum of 10), 1-3 layer models can be utilized. The inversion can also optimize the resistivity of the half-space and the depth to the basement, which is equal to the traditional apparent resistivity (conductivity) and depth transformation.

The Tellus A1 data was divided into 4 sub blocks for ease of data handling to be used in AEMINV so as to reduce/remove negative values from ppm values. The inversion programme outputs the calculated and the original in-phase and quadrature in ppm values. The comparison of the two shows the calculated values are transformed to positive values, however the character of the signal is maintained. The half-space resistivity values are also output if a single frequency is used.

The character of the signal is maintained, with only negative/low values corrected. The following parameters were used in AEMINV processing;

- Source-receiver system = broadside coplanar vertical Magnetic Dipole (VMD)
- Layer = 1, half space, multiple lines
- Global Lagrange multiplier (LG) = 5 (higher values produce smoother models)
- Im-scale = 1, relative weight between in-phase and quadrature (equal importance)
- F-length (filter length) = 2, used to compute the parameter roughness (2 is default)
- Iter = 10, number of iterations
- Z-wght = 0.2, which is local Lagrange multiplier, this value is zero for 2 and 3 layers
- Susceptibility = on
- Roughness = on

Before the cleaned outputted data from AEMINV is used for inversion to determine apparent conductivities with depth, the data is further cleaned with any remaining spikes removed. The data is then written to a database and formatted so it can then be inverted using the inversion software EMIGMA (PetRos EiKon Inc., 2011).

7.2.2 EMIGMA and 1D inversion of FDEM

The results of the AEMINV inversion are used as an input for 1-D inversion in EMIGMA. EMIGMA provides point-by-point one-dimensional inversion for both frequency and time domain data (PetRos EiKon Inc., 2011). In each of these domains, inversion is available for both airborne and ground data. The A1 EM data was sampled at 10 Hz, approximately every 6m along survey lines as opposed to previous data sets, which were sampled at 4 Hz (15 m interval). Due to this sampling rate the number of data locations is greater than those for previous survey data. The 1D inversion was carried out using only the quadrature component, as less negative values were apparent. Not all individual data points could be included. Out of the 787 lines inverted for the A1 block, 8 of the lines experienced difficulties performing the inversion data. This is primarily due to sudden changes or strong gradients along the lines. To smooth the data and to allow successful inversion along these lines the data was decimated by deleting every second point. These lines were: L1069, L1211, L1237, L1262, L1263, L1460, L1465 and L1528.10. Inversion was difficult to achieve along longer lines (greater than 80 km) and therefore these longer lines were split in to two or three segments and merged back after inversion was done. Most blocks were inverted as they were and filtering only applied when necessary to a few blocks. This filtering comprised using a 1-D Gaussian spatial filter, that calculates average distance between data points along the given line and gradient removal as well as data reduction procedures available in EMIGMA. The gradient removal was helpful when extreme variability between adjacent points from partial lines were encountered. The 1-D inversion parameters used in EMIGMA were;

- All four frequencies were used
- Only quadrature component was used
- Rx-TX separation for low frequencies (912Hz & 3005Hz) = 21.35 m
- Rx-TX separation for high frequencies (11962Hz & 24510Hz) = 21.38 m
- Inversion technique: Enhanced Conjugate Gradient Occam with Susceptibility Extension
- Number of uniform layers = 10
- Total thickness = 50 m
- Inversion parameters = joint (resistivity and susceptibility)
- Resistivity 100Ω-m initial
- Susceptibility = 1, 0.001SI
- Resistivity lower and upper bounds are 1 and 10,000 Ωm
- Susceptibility lower and upper bounds are 0 and 1
- Enforced bounds = both
- Data type = type 2 (In-phase and quadrature)
- Maximum iteration = 10
- Target fit = 0.001
- Model epsilon = 0.1
- Minimum tolerance = 0.1

7.3 Levelling using interactive spectral filter

One of the important data processing steps was to eliminate levelling problems. This can be achieved by using a filtering procedure applied to a gridded dataset to reduce or remove non-geological effects caused by short-wavelength noise along survey lines (Geosoft Technical notes www.geosoft.com). This procedure was performed in Oasis Montaj MAGMAP 2D module using a Fast Fourier Transform (FFT).

An interactive spectral filter was used. This displayed and calculated radially averaged power spectrum of the FFT, which transforms the image from the spatial domain to frequency domain. A selected filter profile and the resultant (filtered) power spectrum profile can then be compared in an interactive window. Filter parameters were modified interactively to obtain the best results for the data. Grid preparation consisted of the following steps:

1. Grid trend removal. The trend which is removed is stored in the user area of the grid header and is filtered together with the zero wave number. First order trend removal based on edge points was applied.
2. Expanding the dimensions of a grid by adding dummy areas to the grid edges to produce either a *square* (used for this process) or a rectangular grid. The system uses the Winograd FFT algorithm for dimensions up to 2520 X 2520 cells. Beyond this dimension, it switches to a power of 2 FFT methods. 10% grid expansion was applied.
3. Replacing all dummies in a grid with interpolated values from the valid parts of the grid. The FFT routines require a completely filled grid resulting in some interpolation of data at the grid edges.

A grid expansion of about half the size of the features of interest within the gridded dataset was used, a multi-expansion method was then used to fill the grid. The Multistep Expansion method extends the data inside a bounding rectangle within the same range of signal wavelength and amplitude as the real data. After the grid was prepared in the frequency domain, a radially averaged power spectrum is calculated (Figure 8) with a Gaussian regional/local separation filter then applied. A filter length of 1.2 was used for A1 datasets. This filter produces a levelling error grid (Figure 9), which can then be removed from the grid. This allows high frequency noise along the survey lines to be filtered without minimising the geological signal. It should be noted that data along the first and last lines which form the edge of the defined rectangular grid may end up being partly dummied due to the boundary difference of the line and the rectangle used during the grid preparation procedure.

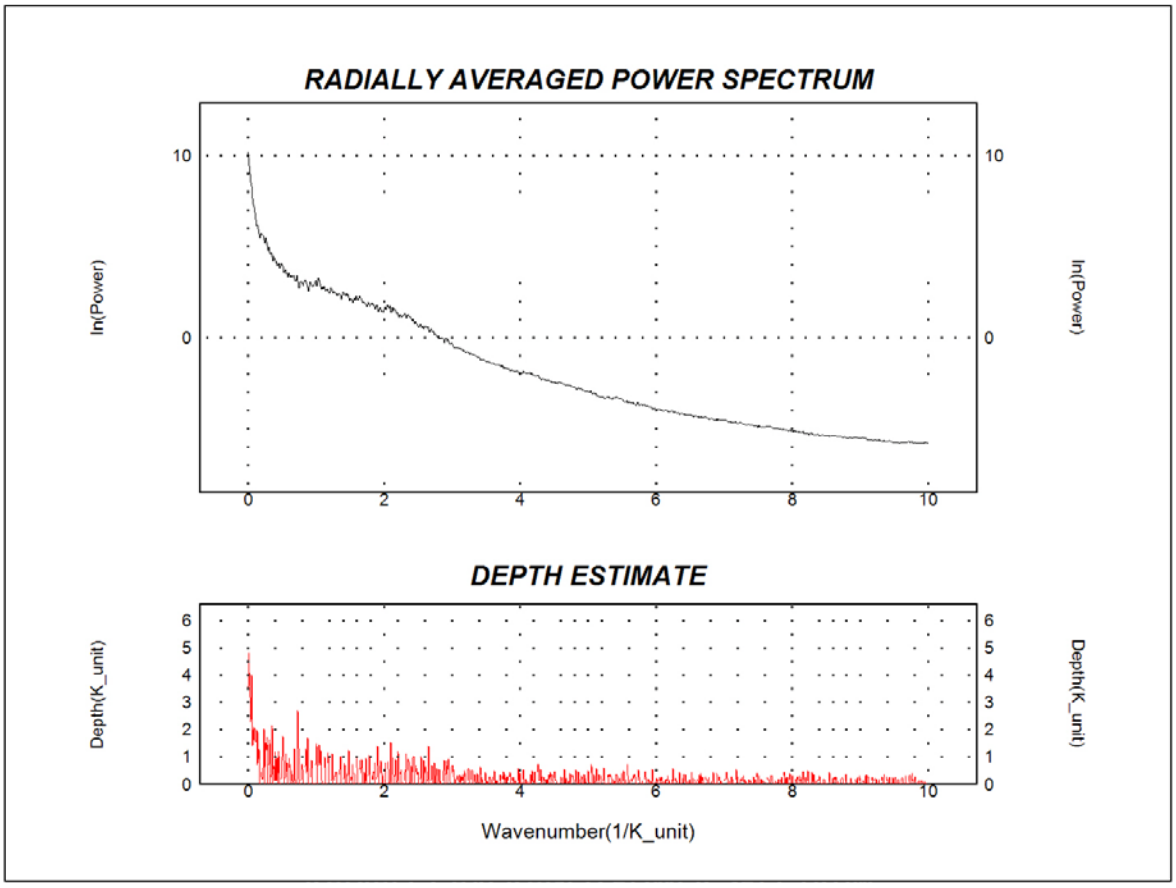

Figure 8: Radially averaged power spectrum for 15m depth EM data

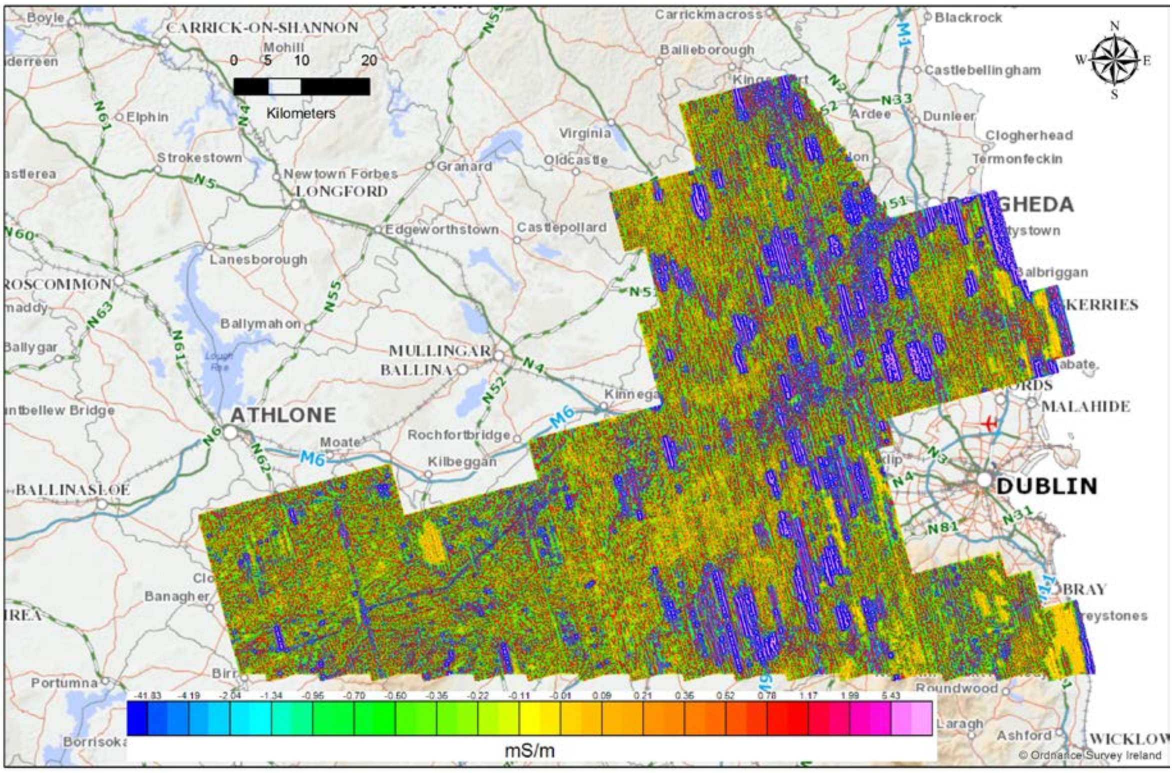

Figure 9: Levelling error grid at 15 m depth for the A1 block.

7.4 A1 Processed Grids

Figures 10-13 show the final processed grids of residual magnetic anomaly, calculated concentrations for Total Counts, Potassium, Thorium and Uranium and apparent resistivity for the A1 block.

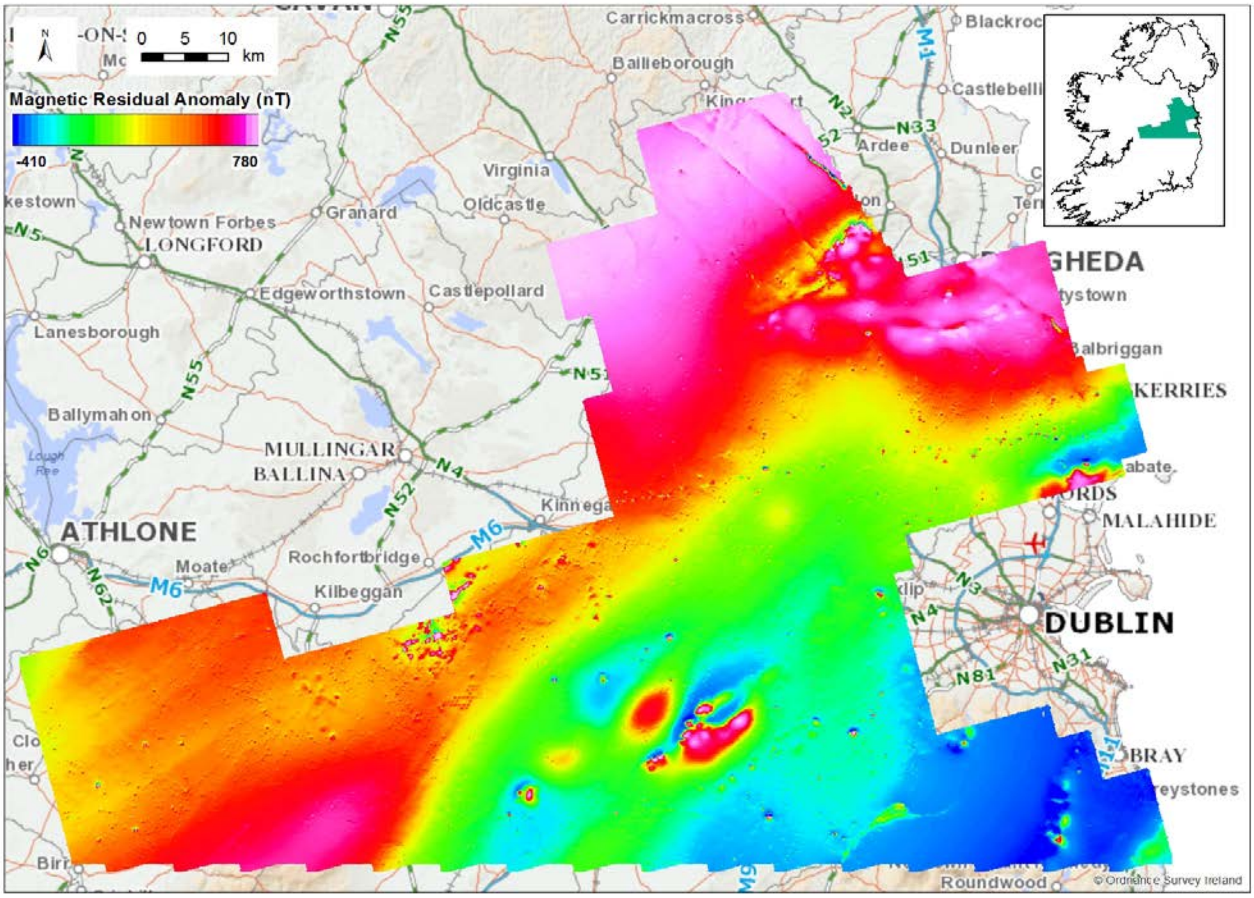

Figure 10: Residual magnetic anomaly for the A1 block

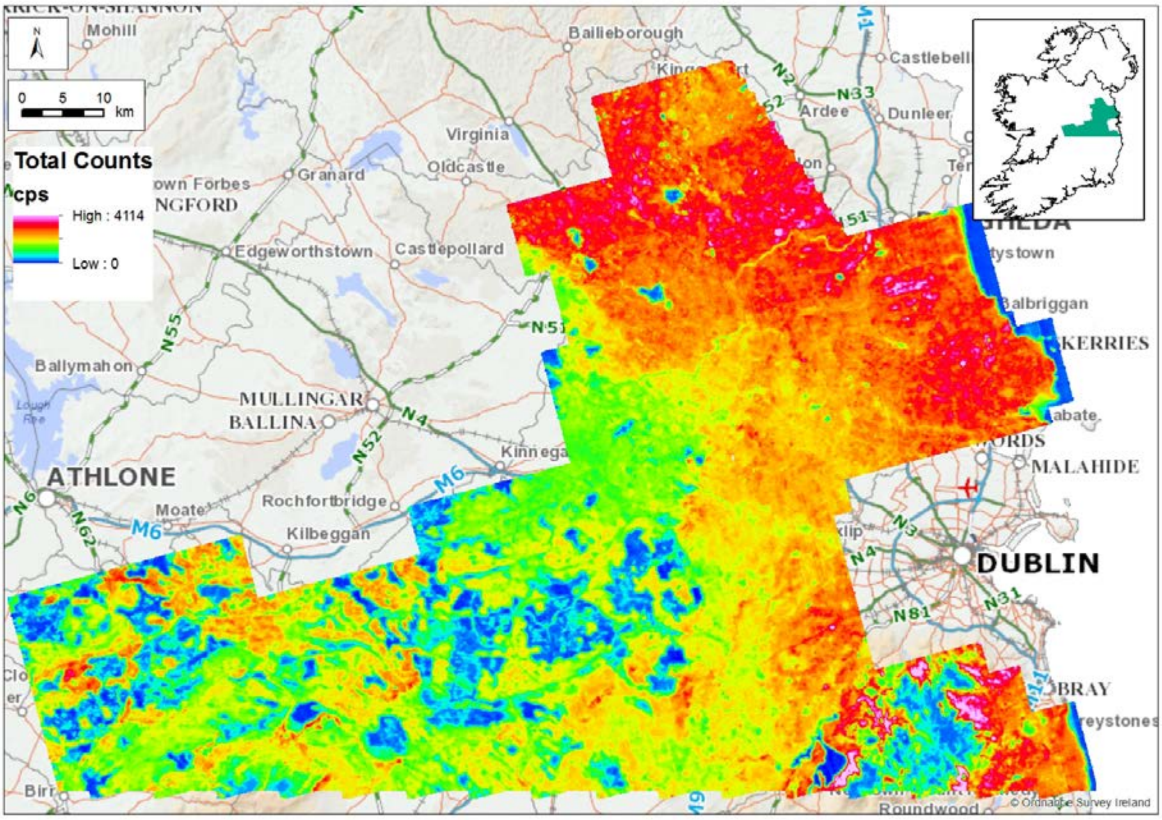

Figure 11: Corrected total count values for the A1 block

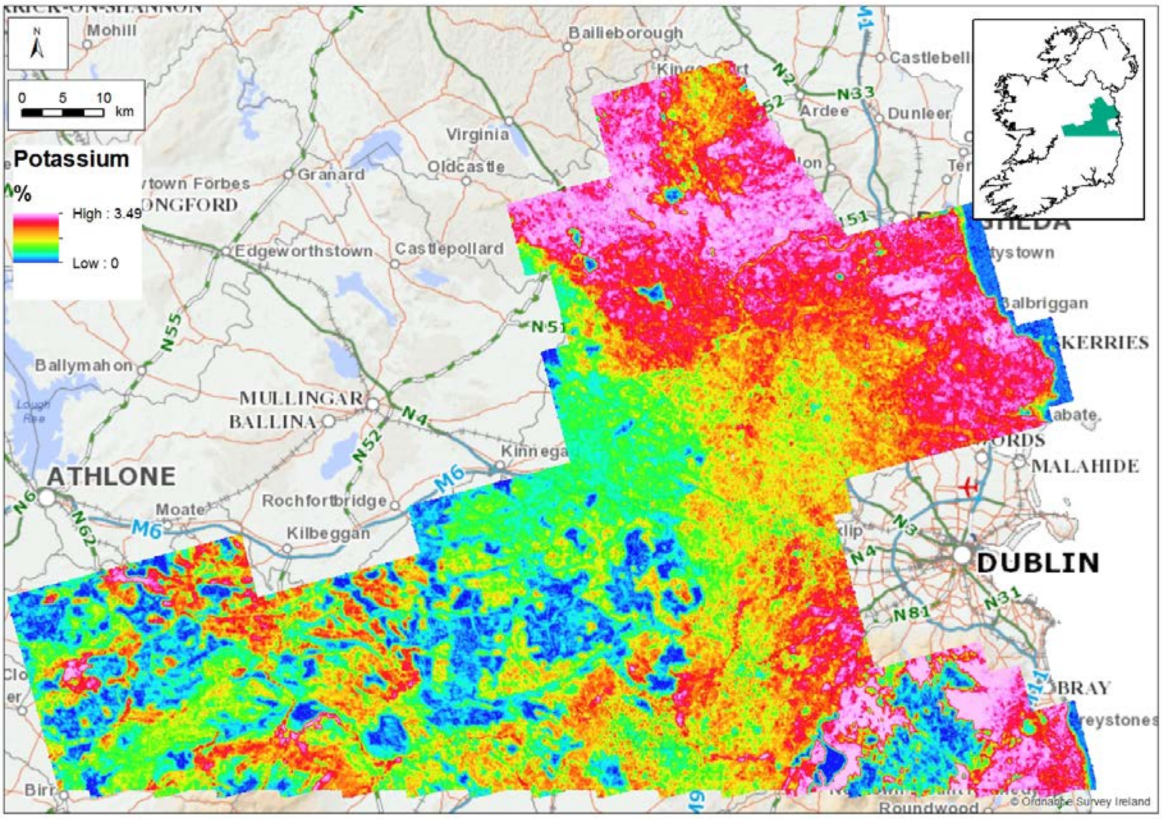

Figure 8: Corrected potassium values for the A1 block

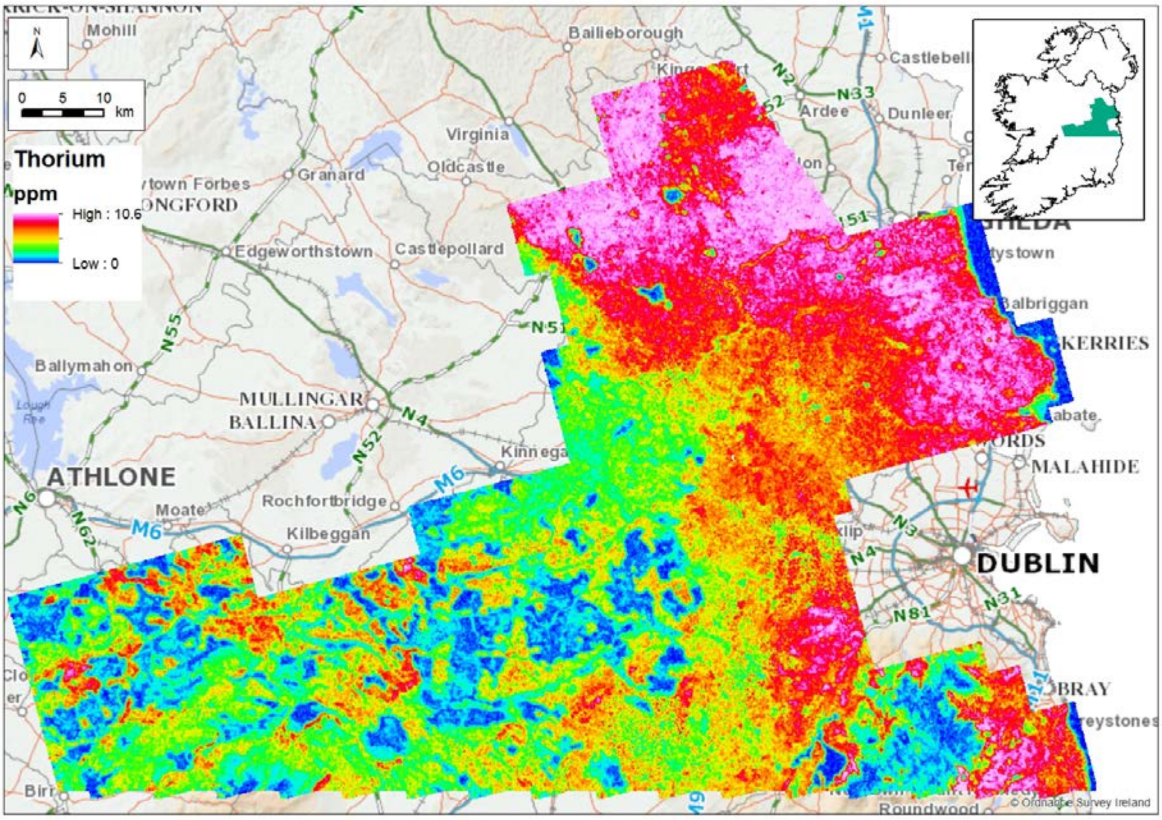

Figure 9: Corrected equivalent thorium values for the A1 block

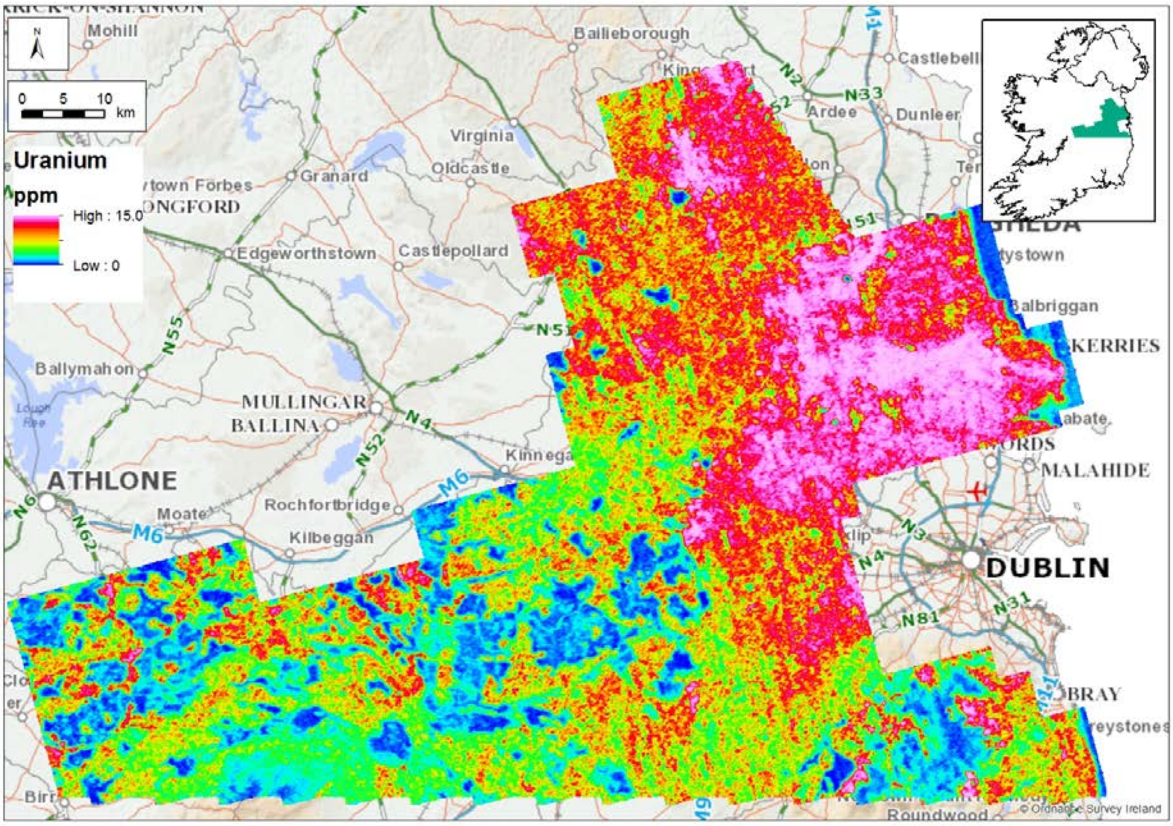

Figure 10: Corrected equivalent uranium values for the A1 block

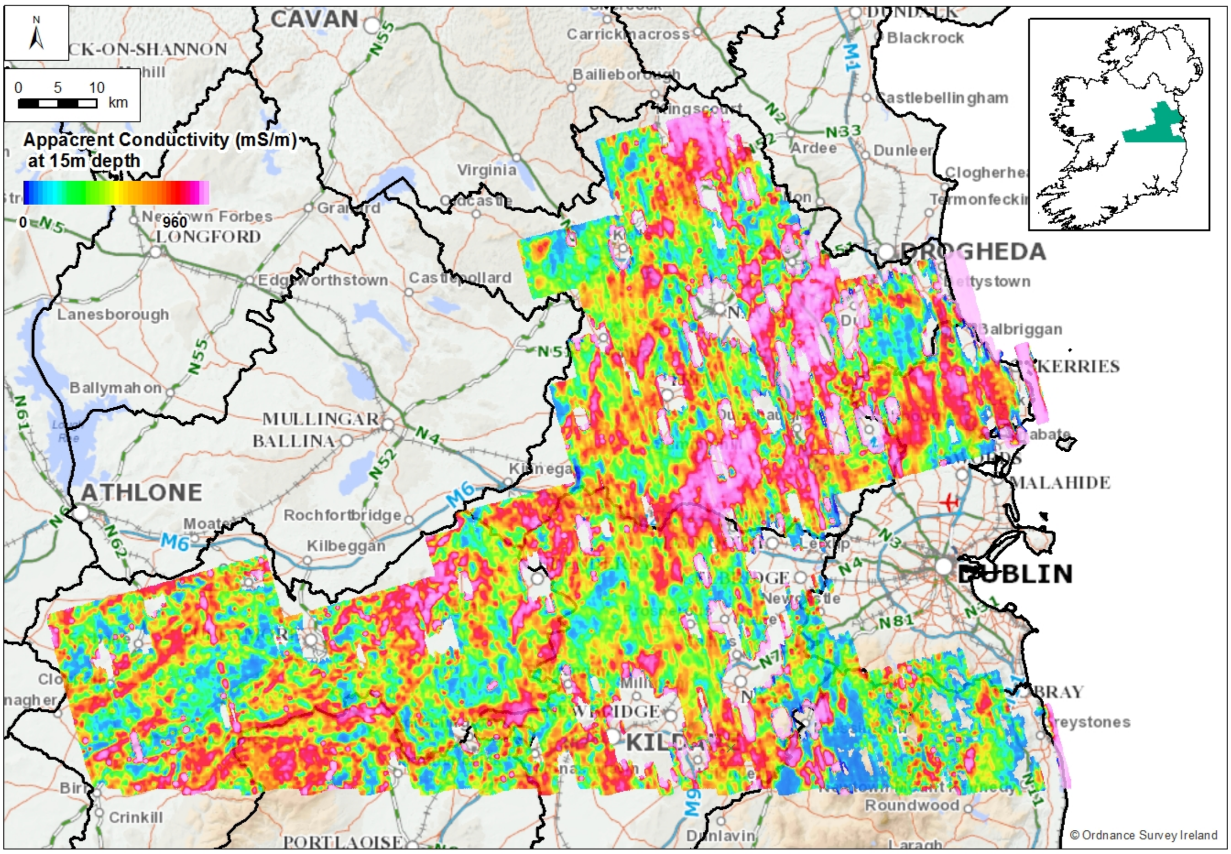

Figure 11: Levelled 1D conductivity map at 15 m depth for the A1 block clipped to 150 m altitude.

8 Data Merging Overview

8.1 Master Database

A master database was created from the A1, merged Tellus Border and Cavan (TBCAV) and Tellus North Midlands (TNM) databases. Individual databases were trimmed to defined survey polygons, removing all potential overlaps. Lines that overlapped although useful when comparing data for merging where clipped, with all lines abutting one another. Tie-lines were also removed from the final Master database.

Not all channels from the contractor-supplied data were deemed necessary for the final master database and therefore relevant channels were selected from each database (1) magnetics, (2) radiometrics and (3) electromagnetics to conform to previous delivered datasets. A uniform name was applied to each of the relevant channels for each database.

To avoid any confusion in identifying the source of the data within the master database a Survey ID (SID) channel has been produced, where;

- **A1** indicates Tellus A1 data
- **TB** indicates Tellus Border data
- **CAV** indicates Cavan data
- **TNM** indicates Tellus North Midlands data

The databases were merged into one master database using the gridknit and merge database tools in Geosoft. Once data was corrected following assessment of data within the overlap zones, grids of the corrected data were created. The grid data was then sampled to the new master database for each relevant channel.

8.2 Co-ordinates

Since 2014 it has been the policy of the Geological Survey of Ireland to use the Irish Transverse Mercator (ITM) co-ordinate system for all mapping. Previous surveys (Tellus Border and Cavan Monaghan) were delivered using Irish National Grid co-ordinates. Therefore all previous datasets were translated into ITM co-ordinates to match with data from A1 and Tellus North Midlands (TNM) and fit with the policy of the GSI.

Table 15: Summary of ITM co-ordinate system

IRISH TRANSVERSE MERCATOR	
Reference Ellipsoid:	GRS80
Central Meridian	08° 00’ 00” West
Vertical Datum:	Malin Head
Map Projection:	Transverse Mercator (Gauss Conformal)
True origin:	53° 30’ 00” North, 08° 00’ 00” West
False origin:	600Km west, 750 km south of true origin
Scale factor on Central Meridian:	0.999820

8.3 Magnetic Data Merging

The A1 data block overlapped with both the Tellus North Midlands and Tellus Border survey blocks. Therefore the levelled and International Geomagnetic Reference Field (IGRF) corrected data from A1, TBCAV and TNM datasets were compared in the regions of overlap, allowing direct comparison. It should be noted that the TNM was acquired at a higher nominal survey altitude of 90m than that for the A1 and TBCAV data which was flown at 60m. This can be seen in the reduction of cultural noise in the TNM dataset. A grid of magnetic anomaly was then created for each database using the minimum curvature method and a cell size of 50 m. A consistent offset was found between the calculated means of two grids of 5.0 nT. This offset was also apparent along individual lines as well as within gridded data. The TNM and TBCAV merged data was lower than data from A1. To create a seamless merge between the two datasets a value of 5.0 nT was added to the merged TNM & TBCAV data to bring it to the same level of the new A1 data.

The corrected data was then knitted together using the grid knitting program from Geosoft, using the suture stitching method and an output grid cell size of 50 m. The de-trending method for both grids was set to none. The final fully merged grid was then re-sampled into the Master database using the sample-a-grid function in Geosoft. Figure 12 below shows the gridded result of the merged magnetic database.

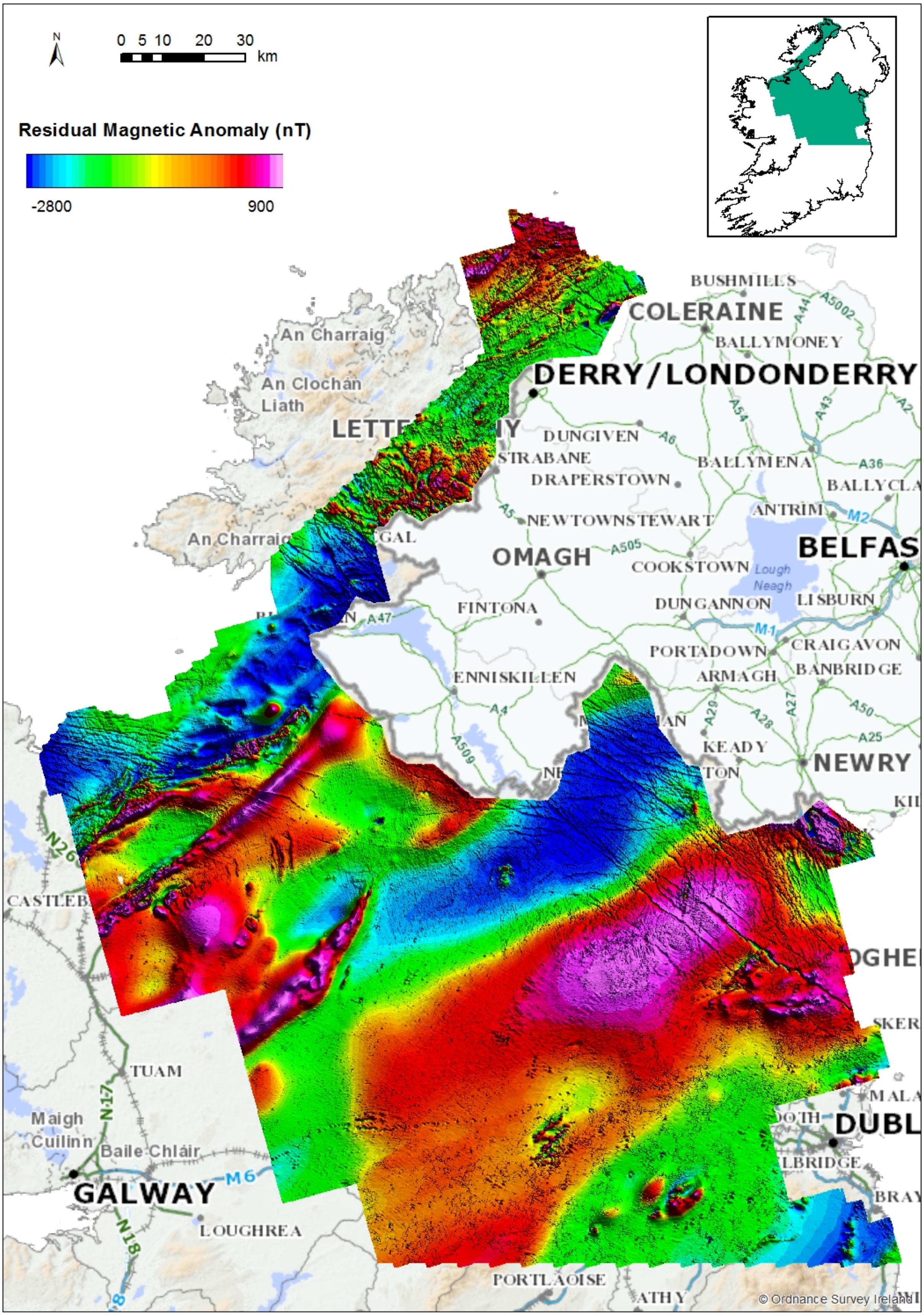

Figure 12: Merged Residual magnetic intensity from A1, TBCAV and Tellus North Midlands data, illuminated from an angle of 45 degrees.

8.4 Radiometric Data Merging

Following detailed assessment of the data in the region of overlap between the A1 and the TNM and TBCAV survey blocks, differences between the radiometric data levels were apparent. This is understandable in that the new data was collected using a larger downward-looking NaI crystal volume of 50.4 l compared to 33 I for the two previous surveys. TNM data were flown at a nominal survey altitude of 90 m compared to 60 m for the other surveys although this was corrected to 60 m to be consistent with the other datasets. There was also a difference in the survey period with TNM and TBCAV data collected over a winter period while the new A1 block was mostly collected during summer months. With a larger crystal and summer flying it would be expected that higher counts would be recorded. Data for the A1 block were calculated using energy windows shown below (Table 16).

Table 16: Energy windows for radiometric survey

Element	Energy Window
Potassium (K)	1368 keV to 1572 keV
Thorium (Th)	2411 keV to 2807 keV
Uranium (U)	1655 keV to 1859 keV
Total Counts	413 keV to 2807 keV

Details of all processing procedures and calibrations for the A1 data can be found in the technical report produced by the contractor (SGL, 2015) and are consistent with standard processing procedures as outlined by IAEA (2003) and Grasty and Minty (1995).

It was decided that all elements should be corrected to correspond with values measured for the most recent survey, i.e. A1. After comparing statistics on data in the overlap zones correction factors were determined on calculated means of gridded data. Correction factors were used rather than a simple shift (addition/subtraction) as this better reflects the radiometric data. Applying a simple subtraction, as applied to the magnetic data, may have resulted in negative concentration values in areas of low values which would be meaningless. The following correction factors were applied to the TNM and TBCAV merged data (Table 17).

Table 17: Radiometric correction factors

	Correction factor applied to merged TB, CAV and TNM dataset
Potassium (%k)	1.196
eThorium (ppm)	1.047
eUranium (ppm)	2.453
Total Count	1.734

Correction factors for potassium and thorium seem reasonable being close to one and the elevated correction factor for total counts is primarily a result of a 50% increase in the size of the crystal used. However, the large correction factor for the Uranium with the newly acquired data showing significantly elevated levels compared with previous surveys is worth further attention. On review of the sensitivities calculated for the uranium data from the A1 block carried out by the contractor at the Breckenridge test range in Canada. The data may suggest that the ground survey performed recorded relatively high values for uranium compared to the other elements and may have been under-corrected for radon. The collection of new data for the planned A2 block in 2016 which includes overlap with the A1 block provides an opportunity to assess the uranium data. This new data, in conjunction with further information from the test range, will inform if any adjustments to the A1 uranium data is required.

Following the application of the correction factors a new grid was then created for each element using the new corrected values. These grids were then merged together using the suture stitching method, of the grid knitting program from Geosoft. A cell size of 50 m was used with the de-trending method for both grids set to 'none'. This merged grid was then resampled to the master database.

A final merged grid was then created from the master database for each element using the inverse distance weighted method and a cell size of 50 m. This gridding method was employed rather than the minimum curvature method (used for other datasets) as it helps to represent the large footprint from which the radiometric data is determined rather than from a single point. Figure 13-16 below shows resultant grids for merged, total counts, potassium, equivalent thorium and equivalent uranium maps.

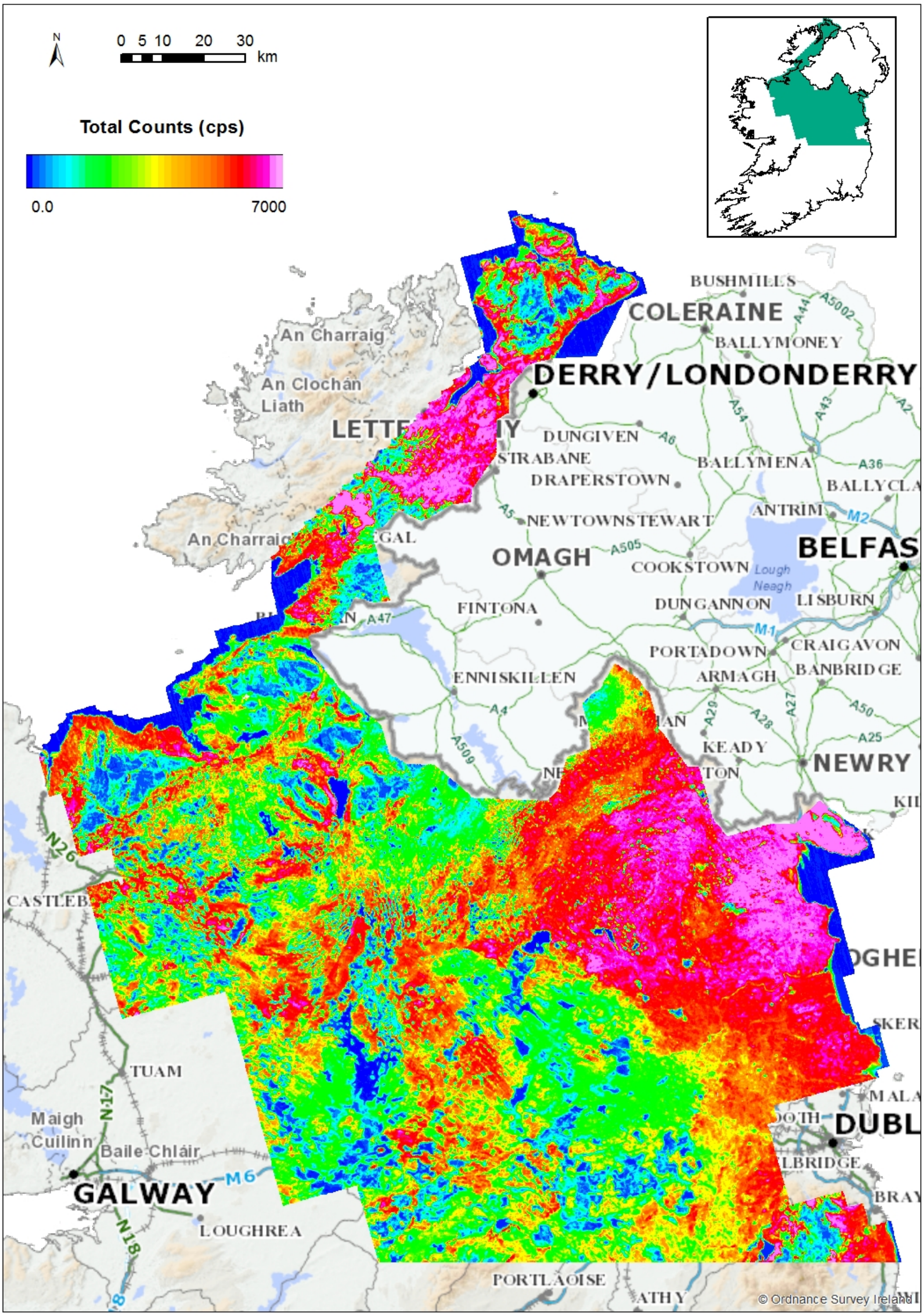

Figure 13: Merged Total Counts from A1, TNM and TBCAV datasets

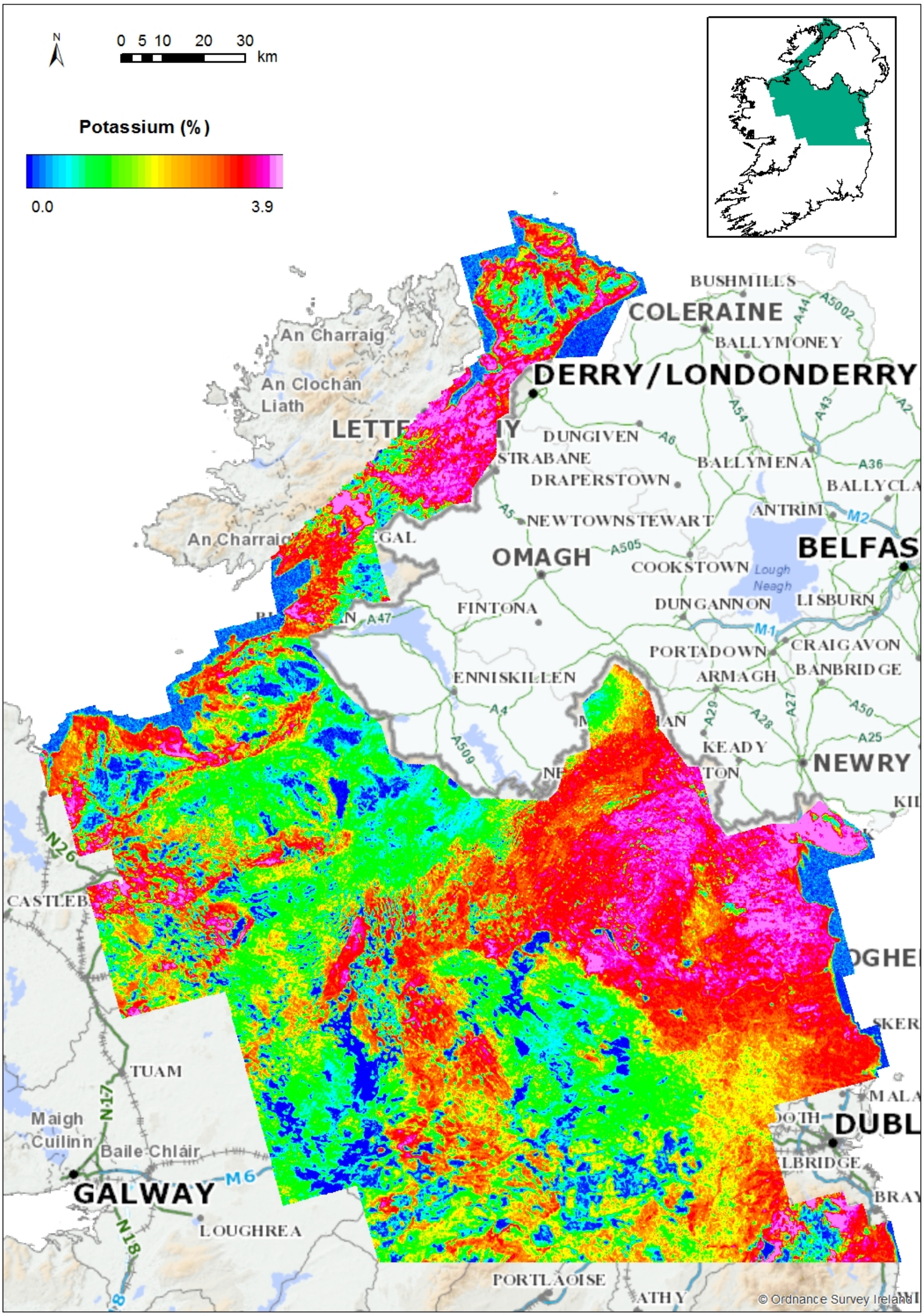

Figure 14: Merged potassium from A1, TNM and TBCAV datasets.

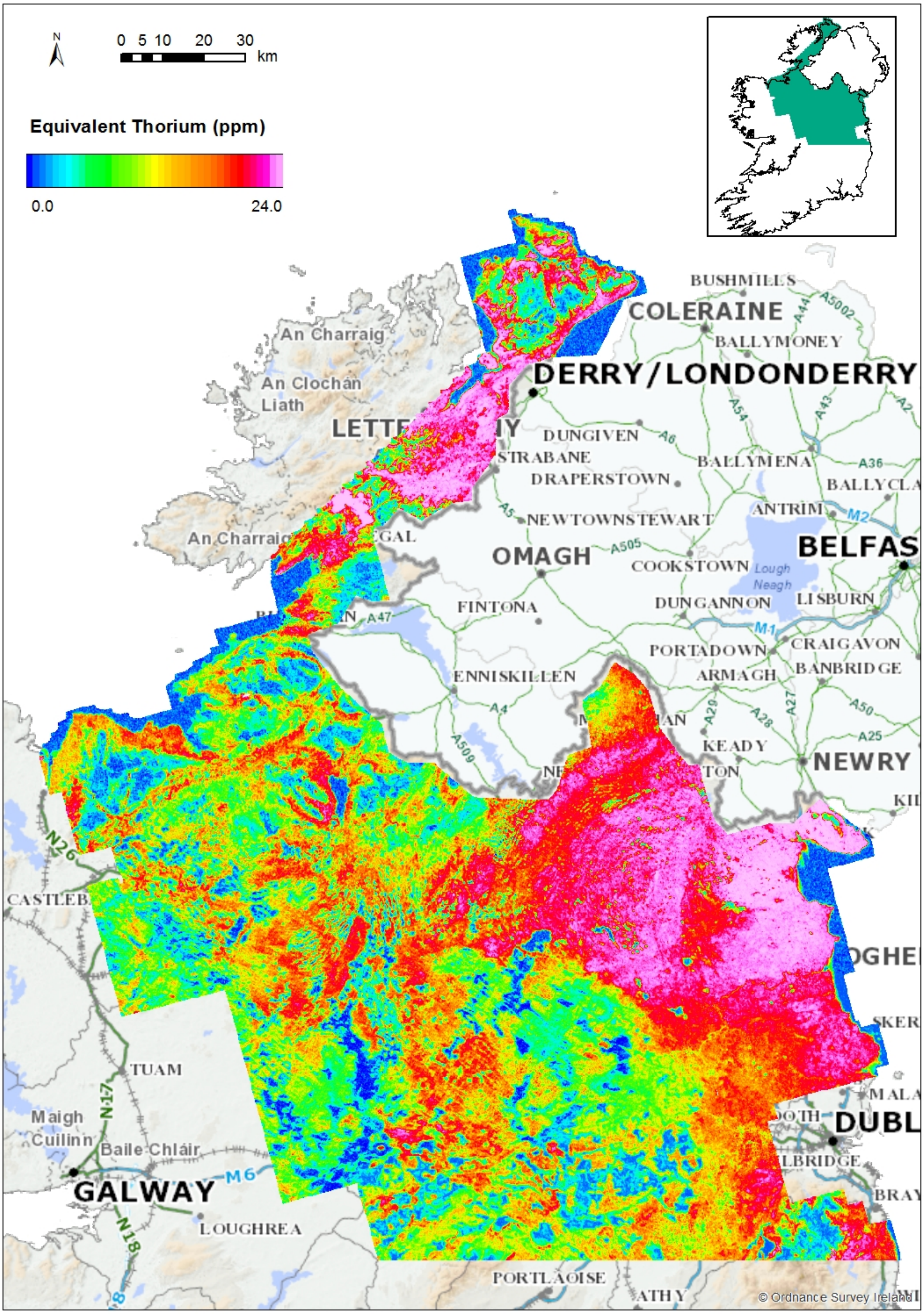

Figure 15: Merged Thorium from A1, TNM and TBCAV datasets

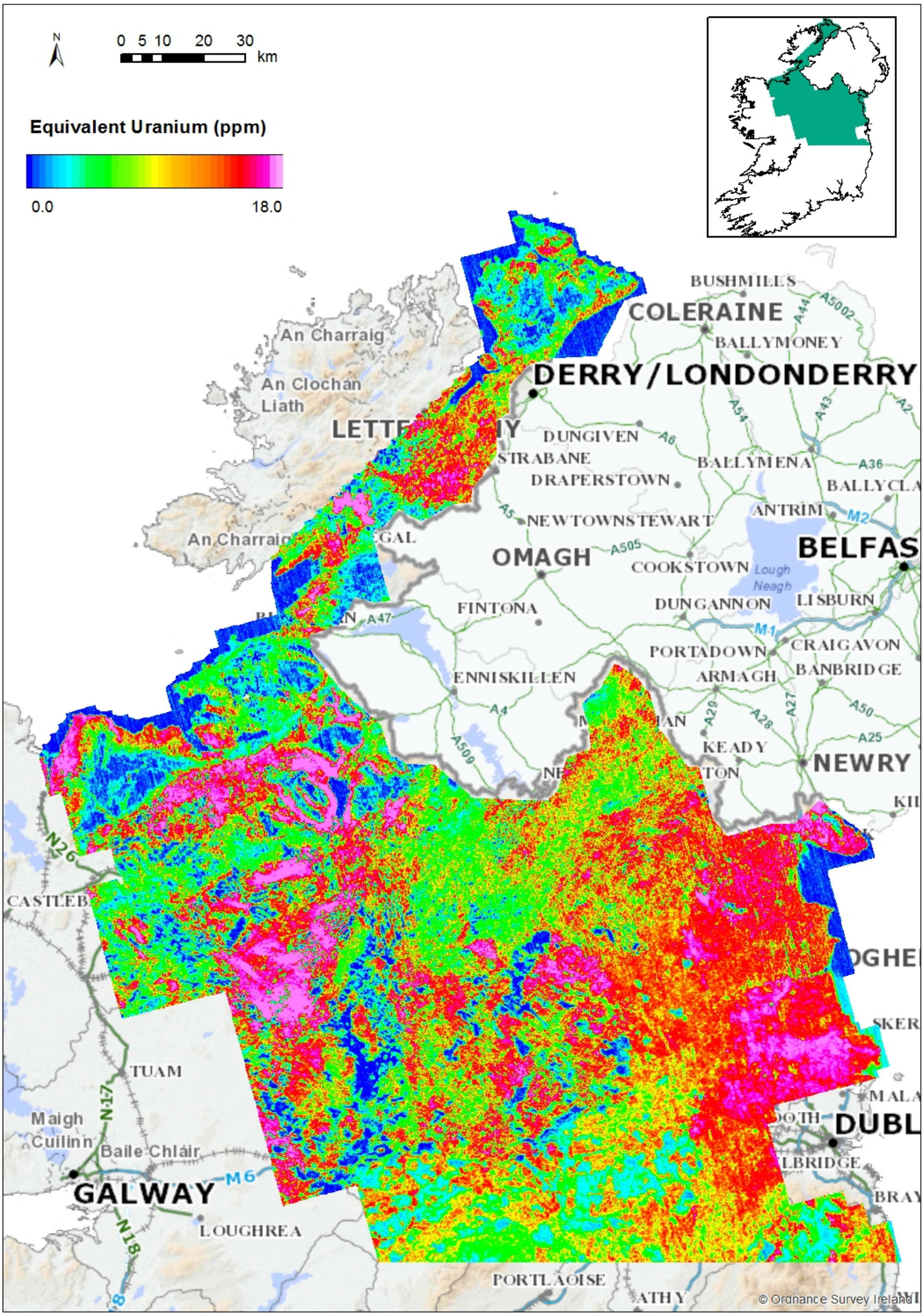

Figure 16: Merged equivalent Uranium from a1, TNM and TB datasets

8.5 Electromagnetic merging

As different types of EM data has been collected as part of the Tellus programme it was decided that the best method to merge different datasets would be to create conductivities at specified depths for both FEM & TEM datasets. These data were merged together giving merged TBCAV & TNM data set (Ture & Hodgson, 2015). After initial data smoothing, to minimise the effect of negative values which can affect low frequency data in high magnetic susceptibility areas, the frequency domain data of A1 block was inverted with conductivities derived at 5 m interval to 50 m depth. Grids of the derived conductivities at the same depth were compared and merged with the previously merged database on values within the overlap zones.

8.5.1 Merging of apparent conductivities from A1, TBCAV and TNM at specified depths

To minimise the effect of negative values, the A1 block data was smoothed using an inversion process performed using the AEMINV software (Pirttijärvi, 2014). Following this the A1 frequency domain data was then inverted producing conductivities derived at specified depths. Grids of the derived conductivities at the same depth were compared and merged with TBCAV_TNM data sets based on values in the overlap zones. 1D inverted and levelled A1 grid and TBCAV_TNM grids were knitted together to give A1_TBCAV_TNM merged EM database.

A levelled grid of A1 block EM data (as discussed in section 7.3) and the previously merged TBCAV and TNM grids were knitted together and sampled back in the new master database created to accommodate A1 & TBCAV &TNM data sets. The merging was done using overlapping points from the two grids and the grid knit function in Geosoft platform using the following parameters:

- stitching method of *suture*
- de-trending method *to each other*
- trend *none*

The resultant merged A1, TBCAV and Tellus North Midlands grid of apparent conductivity at 15 m depth is shown in Figure 16. Each derived apparent conductivity grid was resampled back to a master database. The process was carried out for each apparent conductivity grid, at each 5 m depth interval from 5 m to 50 m depth.

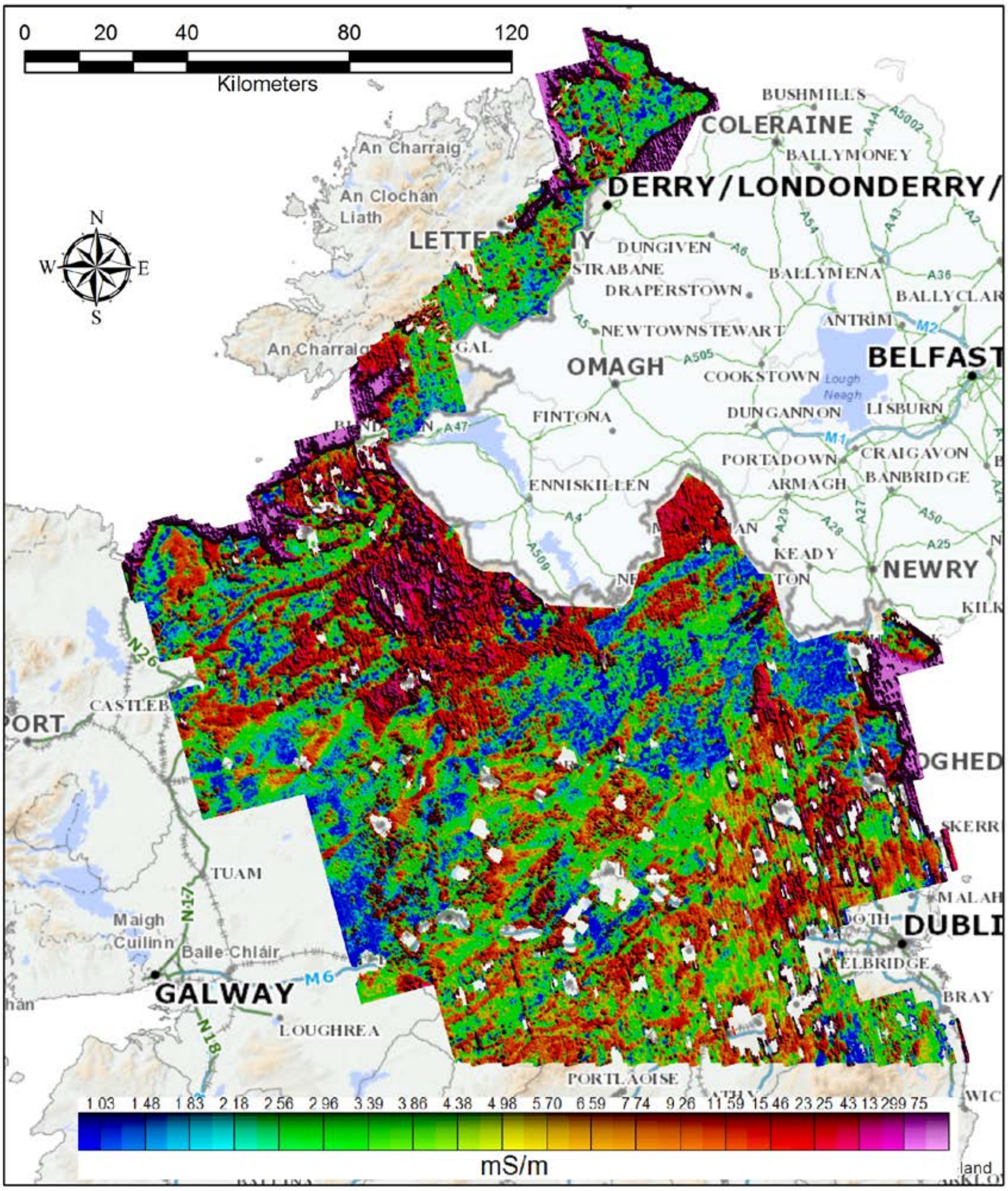

Figure 17: Example of A1, TBCAV and TNM merged conductivity at 15 m depth

9 Data Assessment and Consideration

9.1 High Fly Zones

Survey altitude has a major impact on the electromagnetic signals with increasing altitude attenuating the signal. Increasing altitude also reduces the effective depth penetration of the system particularly for FEM data. Typically, the measured FEM data can be inverted to a consistent depth of 50m bgl while the TEM data can extend to depths of 200 m. Therefore, the merging of conductivity data from the two systems can only be reasonably derived for the upper 50 m depth. To reduce the altitude effect on conductivity data, the whole FEM data was clipped to an altitude of 150m, as the signal cannot always be resolved from the background noise level. Altitudes above 150m were dummied and culled from the data. TEM data was affected and was reviewed on a case-by-case scenario. The 150m altitude level was determined from observations of data collected and compared from different altitudes along the test line.

The Tellus Border and A1 surveys were issued with a flying permit from the Irish Aviation Authority (IAA) for 59m altitude in non-congested (rural) areas. However, in upland areas which affected aircraft climb and descend rates and due to the presence of numerous wind farms some areas have been surveyed at higher altitudes. Tellus North Midlands (TNM) survey was flown at a nominal survey altitude of 90m (with EM receiver 45m below). The TNM survey was also flown with a drape system. Numerous enforced high flown zones often clustered together along with urban areas in the region resulted in large areas of high fly zones. Figure 17 shows altitude greater than 150 m and data in these areas should be deemed to be less reliable.

Gamma-ray spectrometry data is also sensitive to survey altitude with a decrease in Gamma-rays sampled with increasing altitude. Although less sensitive than frequency-domain EM systems and with a larger crystal volume used in the A1 survey, data recorded at altitudes greater than 240m is considered less reliable, even when allowing for corrections made for altitude.

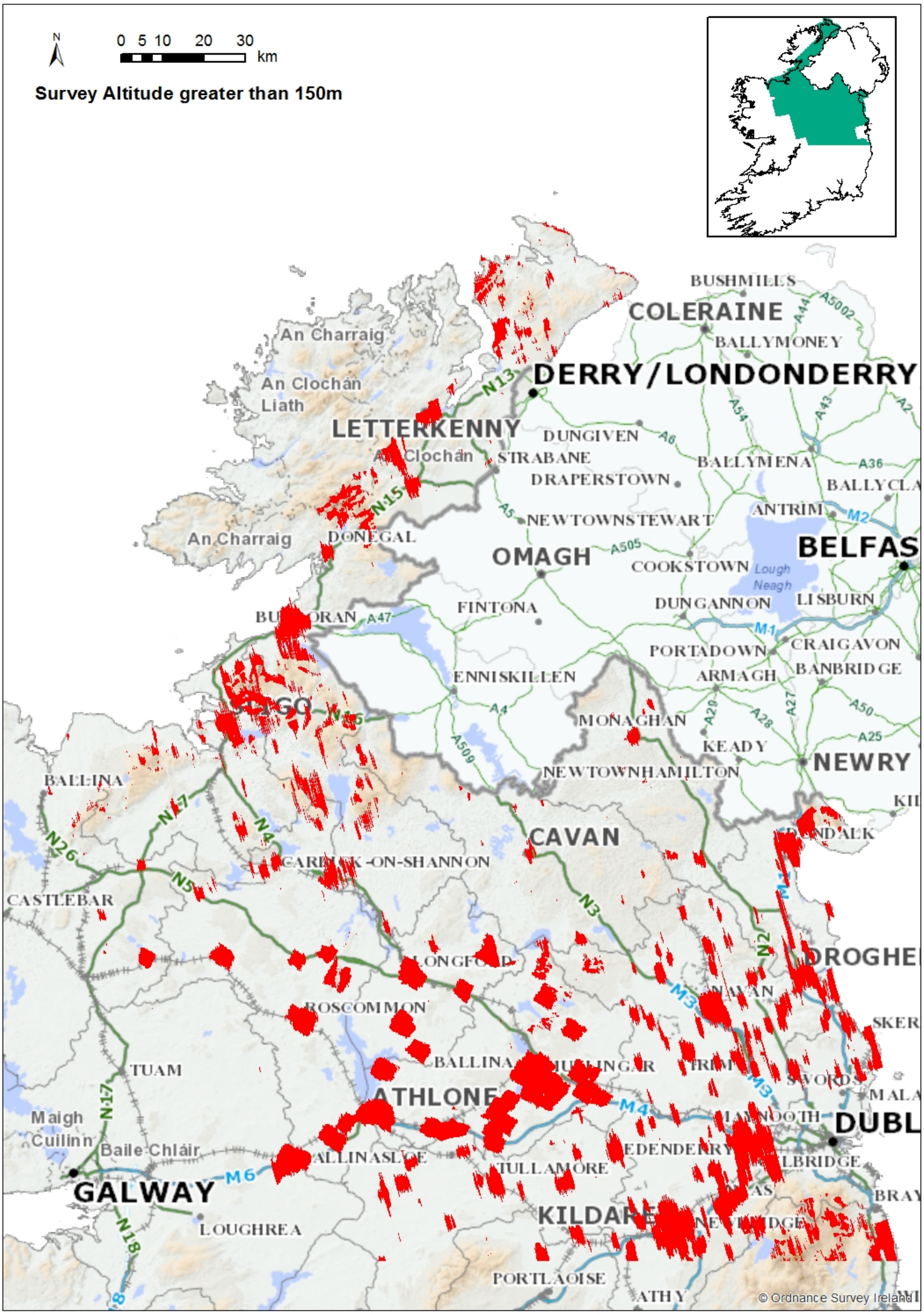

Figure 18: Survey altitude greater than 150m above ground level shown in red.

As can be seen from Figure 17 significant high fly zones (> 150m) are present across the whole region. These include urban areas with populations greater than 2000, along the M1 motorway corridor in counties Dublin and Meath, over areas of sensitive livestock and stud farms and requests from the public and hilly terrain particularly in the northwest of the area.

9.2 Magnetic Noise

Magnetic data were measured using a Geomatrics G-822A caesium vapour instruments which have a sensitivity of 0.005 nT. Figures of Merit (FOM) derived from magnetic compensation tests during the A1, Tellus Border and Tellus North Midlands surveys showed values in the range of 0.72nT, 0.4 nT to 1.28 nT. These values are corrected within the standard processing sequence but indicate possible background noise levels of approximately FOM/10 i.e. better than ~0.128 nT within the measured data.

Cultural interference is the main source of noise affecting the data. Cultural interference from anthropogenic sources such as houses, farm buildings, roads, power lines, etc. create spikes throughout the data. Both automatic and manual processes were used to help assess individual anomalies, using ortho-photographs and buildings databases to remove affected data points. Tellus Border, Cavan, Tellus North Midlands and A1 datasets were not subjected to de-culturing. However, a number of well-developed smoothing procedures are available. The upward continuation method is widely used and it does not produce mathematical artefacts. This method could be used to minimize high frequency cultural noise in the magnetic data.

Diurnal and IGRF corrections have been made to all datasets. All data has been corrected to the most recent model of the IGRF. The largest corrections due to IGRF are found in the north of the survey areas.

9.3 Radiometric Noise

To assist in the assessment of the radiometric data, a 6 km test line was flown throughout the duration of Tellus Border survey and at the beginning and end of the Tellus North Midlands and A1 surveys. The test line was flown at 7 different nominal altitudes and crossed from sea to land. The test line data, once re-sampled, allows direct comparisons at the same locations to be made over the duration of the survey, giving insight into the sensitivity of the system and any environmental impacts. Total count data along the test line during the A1 survey shows that readings vary by factors of 0.95 to 1.03 from their calculated means. This would therefore indicate that measured values vary by up to 5% from the mean.

Rainfall data was taken from the Finner Meteorological Station in Co. Donegal which lies approximately 7 km to the NW of the test line to assist in the assessment of seasonal effects. As expected a negative relationship exists between total counts and increasing rainfall, whereby for every ~1 mm increase in rainfall, total count values decrease by about 0.8 %. Rainfall data was taken for each day of the flight as well as over a 3 day average and 14 day average. Taking rainfall only on the day of each flight may have led to errors as the measurement was for the entire day and flights may have occurred before any measured rainfall for that day. The 3 and 14 day averages may indicate the degree of saturation of the ground. Recent studies have investigated how both soil and bedrock type together with the degree of saturation of the ground can influence the attenuation of gamma rays (Beamish, 2013 and Beckett, 2008).

9.4 Electromagnetic noise

Both frequency-domain and time-domain electromagnetic data are particularly prone to interference from electromagnetic fields from power lines, buildings and electric fences, which can create sources of noise which cannot easily be resolved. The amplitudes of the measured coupling ratios or corresponding time gate channels decrease over areas of high resistivity / low conductivity. Because of this, the signal-to-noise ratio is reduced in highly resistive areas sometimes making it impossible to distinguish the true signal. In resistive zones levelling of the data also becomes more difficult and can result in small amplitude undulations. This is particularly the case for the low frequencies within FEM systems, as this is most susceptible to highly resistive zones (Hautaniemi *et al.,* 2005). Time domain data seems less affected by cultural noise affects and is generally able to penetrate deeper into the earth (depending on time / frequency windows used).

Survey altitude has a major impact on the all electromagnetic signals with increasing altitude attenuating the signal. Increasing altitude also reduces the effective depth penetration of the system particularly for FEM data. It is therefore recommended that FEM data collected at survey altitudes exceeding 150 m should not be considered. TEM data is less affected and should be reviewed on a case-by-case scenario. Typically, the measured FEM data can be inverted to consistent depth of 50 m bgl while the TEM data can extend to depths of 200m. Therefore the merging of conductivity data from the two systems can only be reasonably derived for the upper 50 m depth.

Full details of the electromagnetic processing and a review of the inversion procedure can be found in Beamish (2013), Hodgson and Ture (2013), CGG (2015) and SGL (2015), Ture and Hodgson 2015).

9.5 Data filtering

There are many different approaches to data filtering however, it has been decided that the Geological Survey of Ireland will provide data for the public to use with the minimum processing carried out. This will allow the individual user to carry out their own processing and filtering of the data to their own requirements and specifications. Therefore no filtering of the magnetic and radiometric data has been carried out. The delivered data consists of the contractor supplied final data and merged data with corrections applied to allow seamless merger of different datasets. Additional filtering may be required i.e. upward continuation of magnetic data to remove cultural interference etc.

10 Data Delivery

10.1 Overview & Delivered Data

Standard processing was carried out on all three datasets (1. Magnetics, 2. Radiometrics and 3. EM) by the contractor and are discussed in detail in Beamish *et al*., 2006 and reviewed in Hodgson and Ture (2013) for Tellus Border and Cavan – Monaghan data and by CGG (2015) for the Tellus North Midlands data and SGL (2015). The contractors supplied data in ASCII.xyz and Geosoft grid format.

The merger of the Tellus North Midlands (TNM) and the Tellus Border and Cavan-Monaghan (TBCAV) datasets is outlined in Hodgson and Ture (2015). Tables 3-5 outline all the delivered data for the newly merged A1, TNM and TBCAV datasets. Contractor supplied data for each survey phase is also available upon request from www.tellus.ie.

Table 18: Merged (2016) A1-TNM-TBCAV, magnetic merged data

No	***Name***	***Units***	***Description***
1	X_ITM	m	X coordinate, Irish Transverse Mercator
2	Y_ITM	m	y coordinate, Irish Transverse Mercator
3	LAT	Degree	Latitude
4	LONG	Degree	Longitude
5	DATE	YYYYMMDD	Date (year, month, day)
6	SID	-	Survey ID (A1-A1, TB-Tellus Border, TEL – Tellus, CAV - Cavan
7	RALT	m	Altimeter height
9	MAG_MERGE	nT	Magnetic Anomaly (IGRF & Diurnal corrected, Levelled)
11	IGRF	nT	Reference Field at January 1st 2015

Table 19: Merged (2016) A1-TNM-TBCAV, radiometric merged data

No	***Name***	***Units***	***Description***
1	X_ITM	m	X coordinate, Irish Transverse Mercator
2	Y_ITM	m	y coordinate, Irish Transverse Mercator
3	LAT	Degree	Latitude
4	LONG	Degree	Longitude
5	DATE	YYYYMMDD	Date (year, month, day)
6	SID	-	Survey ID (A1-A1, TB-Tellus Border, TEL – Tellus, CAV - Cavan
7	RALT	m	Altimeter height
9	K_Merge	%	Merged Corrected Potassium Concentration
10	TH_Merge	ppm	Merged Corrected Thorium Concentration
11	U_Merge	ppm	Merged Corrected Uranium Concentration
12	TC_Merge	cps	Merged Corrected Total Count

Table 20. Merged (2016) A1-TNM-TBCAV, EM Conductivity delivered data

Number	***Name***	***Units***	***Description***
1	X_ITM	m	X coordinate, Irish Transverse Mercator
2	Y_ITM	m	y coordinate, Irish Transverse Mercator
3	LAT	Degree	Latitude
4	LONG	Degree	Longitude
5	DATE	YYYYMMDD	Date (year, month, day)
6	SID	-	Survey ID (A1-A1 block, TB-Tellus Border, TNM – Tellus North midlands and CAV - Cavan
7	RALT	m	Altimeter height, height above ground
8	GPS_H	m	WGS-84 Altitude, Height above sea level
9	DIST	m	Distance along the line
11	AC_5	mS/m	Conductivity at 5 m depth, clipped to 150 m
12	AC_10	mS/m	Conductivity at 10 m depth, clipped to 150 m
13	AC_15	mS/m	Conductivity at 15 m depth, clipped to 150 m
14	AC_20	mS/m	Conductivity at 20 m depth, clipped to 150 m
15	AC_25	mS/m	Conductivity at 25 m depth, clipped to 150 m
16	AC_30	mS/m	Conductivity at 30 m depth, clipped to 150 m
17	AC_35	mS/m	Conductivity at 35 m depth, clipped to 150 m
18	AC_40	mS/m	Conductivity at 40 m depth, clipped to 150 m
19	AC_45	mS/m	Conductivity at 45 m depth, clipped to 150 m
20	AC_50	mS/m	Conductivity at 50 m depth, clipped to 150 m

All data was processed and exported using the Oasis Montaj Geosoft programme and is available in .xyz format. Geosoft grids of different mapped elements are also available upon request.

It is the policy of the Geological survey of Ireland that all data is free. Data can be downloaded from the project website www.tellus.ie.

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Appendix 1: Flight Permit

IAA

IRISH AVIATION AUTHORITY

AERIAL WORK PERMISSION

1. Pursuant to Article 9(2) of the Irish Aviation Authority (Operations) Order, 2006 (S.I. No.61 of 2006), Rules 5 and 6 of the Irish Aviation Authority (Rules of the Air Order), 2004 (S.I. No.72 of 2004) and the Direction set out in AIC 13/00, the Irish Aviation Authority hereby grants, subject to the conditions specified in Schedule 2 of this Permission, an Aerial Work Permission to:

SANDER GEOPHYSICS LTD.
260 Hunt Club Road
Ottawa
Ontario
Canada K1V 1C1

having been satisfied that the said Operator of the aircraft specified in Schedule 1 of this Permission shall ensure the safe operation of flights for the purpose of Aerial Work, specifically Aerial Survey, including Magnetic, Radiometric and Electromagnetic Surveying, and also for any flights carried out for the purpose of training for such operations.

2. The Permission shall not be valid during the continuance of any breach of condition thereof.

3. This permission shall have effect from the **12th day of May 2015**, until the **11th day of May 2016**, both dates inclusive, unless previously varied, suspended or revoked:-

Signed and re-issued on behalf of the Irish Aviation Authority on 11th May, 2015.

Tony Harkin
Aeronautical Officer

Official Stamp:

IRISH AVIATION AUTHORITY
11 MAY 2015
FLIGHT OPERATIONS DEPT

Note: This Permission may be revoked if at any time it is found to be inconsistent with a standard adopted pursuant to the European Union Regulation on the Harmonisation of Technical Standards for Civil Aviation.

AERIAL WORK PERMISSION

SCHEDULE 1 – AIRCRAFT TYPE AND REGISTRATION

AIRCRAFT TYPE	AIRCRAFT REGISTRATION
De Havilland Twin Otter	C-GSGF

-END OF SCHEDULE-

AERIAL WORK PERMISSION

SCHEDULE 2 – CONDITIONS

1. This Permission shall be deemed invalid during any period exceeding 28 days in which the holder of the Permission is in default in payment of any of the fees payable in respect thereof in accordance with the provisions of the schedules of fees for aerial work operations of the IAA (Fees) Order, (S.I. 805 of 2007).

2. Any person authorised by the Authority in that regard shall have access to any premises in the occupation or control of the holder of this Permission for the purposes of examining the premises and to any document, equipment, tool, material or other items of whatsoever nature, relating to the operation of aircraft there-under, kept or used, or intended to be used, in conjunction with the operation of the aircraft pursuant to this Permission.

3. Every flight carried out under this Permission shall be conducted in accordance with Irish Aviation Authority regulations and the relevant Aerial Work provisions of the holder's Operations, Maintenance and Flight manuals. This shall also apply in respect of Flight Time and Duty Limitations provisions as set out in EU Ops and must also comply with the requirements of S.I. 507 of 2006 - European Communities (Organisation of Working Time)(Mobile Staff in Civil Aviation).

4. The holder of this Permission shall give to the Authority not less than 14 days notice in writing:

   (a) of the intended abolition of the following posts, or of any intended change in the person holding the following posts:

   CHIEF PILOT/OPERATIONS MANAGER

   (b) of any intended amendments of the holders operations and maintenance manuals relating to Aerial Work provisions.

5. A flight plan shall be filed with the appropriate Air Traffic Control Service Unit for each flight undertaken pursuant to this Permission and the AW Permission Number of this Permission must be included at Item 18 - Other Information.

6. Unless otherwise authorised, permitted or exempted by the Authority, any flight made pursuant to this Permission shall be conducted in accordance with European Regulation 923/2012 (SERA) and by day only and in accordance with other relevant Irish Aviation Authority Regulations.

7. Unless otherwise authorised, permitted or exempted by the Authority only the Pilot-in-Command of the aircraft and competent persons essential to the conduct of the aerial work activity undertaken may be carried on any flight pursuant to this Permission.

8. A copy of this Permission shall be included in the Operations Manual and carried onboard the aircraft.

9. Operational control, safety oversight and a review of the risk assessment of Aerial Work operations conducted pursuant to this Permission shall be exercised by the **Chief Pilot Todd Svarckopf, Sanders Geophysics Ltd.**

10. Pursuant to this Permission, **Chief Pilot Todd Svarckopf** shall be responsible for making application to the Irish Aviation Authority for any Authorisation, Exemption or Permission required pursuant to Irish Aviation Authority Regulations.

11. Any flight carried out under the terms of this Permission shall be conducted solely within the territories of the State.

12. For any flight carried out under the terms of this Permission the flight crew shall hold a Commercial Pilots Licence issued or validated by the State of Registry of the aircraft, including appropriate ratings and qualifications. Additionally, they must have achieved the minimum experience requirements, including recurrent training and checking, as set out in holder's Operations Manual.

13. Access to any photographs taken, to any data recorded or to any aircraft equipment or materials used by the operator pursuant to this Permission shall be granted at any time to:

    i) an Officer of the Irish Aviation Authority,
    ii) an Officer of An Garda Síochaná (Irish Police),
    iii) an Officer of the Irish Customs and Excise,
    iv) a member of the Irish Defence Forces.

14. Survey Flights carried out pursuant to this permission over Dublin City shall not be conducted at an altitude below FL 090 unless with the permission of Dublin ATC.

15. A Low Flying Permission, LFP No. 05 of 2015, has been issued to Sanders Geophysics Ltd. in conjunction with this Aerial Work Permission.

16. This Permission may, at any time, be suspended, varied or revoked by the Irish Aviation Authority.

- END OF SCHEDULE -

- THE IRISH AVIATION AUTHORITY -

IRISH AVIATION AUTHORITY

LOW FLYING PERMISSION

The Irish Aviation Authority, in exercise of the powers conferred on it by Sections 5, 58, and 60 of the Irish Aviation Authority Act, 1993 (No 29 of 1993), as amended by the Air Navigation and Transport Act, 1998 (No 24 of 1998), and as amended by the European Communities (European Aviation Safety Agency) Regulations 2003 (S.I. No. 469 of 2003) and the European Communities (European Aviation Safety Agency) (Amendment) Regulations (S.I. No. 95 of 2008) and Having regard to Regulation (EC) No 216/2008 of the European Parliament and of the Council of 20 February 2008, giving effect to Commission Implementing Regulation (EU) No 923/2012 of 26 September 2012 (SERA.3105 Minimum heights), hereby permits as follows a Low Flying Permission to:-

Sander Geophysics Ltd.,
260 Hunt Club Road,
Ottawa,
Ontario,
Canada K1V 1C1.

Being satisfied that the said operator is competent to secure the safe operation of the aircraft specified in AWP No.14 of 2015 and Schedule 1 hereto on flights for the purpose of Aerial Work Operations.

1. This Permission shall not be valid during the continuance of any breach of any condition thereof.

2. This Permission shall remain in force unless previously suspended, varied or revoked by the Irish Aviation Authority from 12th May, 2015 to 11th May, 2016 both dates inclusive.

Signed and issued on behalf of the Irish Aviation Authority on 26th May, 2015.

Tony Harkin
Flight Operations Inspector
For the Irish Aviation Authority.

Official Stamp:

IRISH AVIATION AUTHORITY
26 MAY 2015
FLIGHT OPERATIONS DEPT

LOW FLYING PERMISSION

SCHEDULE 1 – AIRCRAFT TYPE AND REGISTRATION

Type	Registration
DeHavilland Twin Otter DHC-6	C-GSGF

- END OF SCHEDULE -

LOW FLYING PERMISSION

SCHEDULE 2 - CONDITIONS

1. This Permit shall not be valid for low-level flights over or in the vicinity of the congested areas, towns or settlements or low-level flights over or in the vicinity of power stations and industrial chimneys or over or in the vicinity of an open air assembly of persons.

2. Flights made pursuant to this permit shall be conducted so that in the event of a power unit failure at any time, the aircraft can alight without undue hazard to persons or property on the surface or carry out a safe flyaway by establishing a OEI positive rate of climb as set out in the AFM.

3. This Permission is not valid for low-level operations:-

   (i) within a Control Zone or Restricted Area (where active), unless with the express permission of the appropriate Air Traffic Services Unit; or

   (ii) within a Prohibited Area unless with the express permission of the Department of Justice;

   A flight plan shall be filed with the appropriate ATS or AIS Unit at least one hour before commencement of each flight. Flights shall be visual contact flights and shall not be conducted in accordance with a special VFR clearance or at night.

4. It is the responsibility of the pilot-in-command to become acquainted with sensitive areas within the operational areas such as Private Estates, Stud Farms, Schools, Places of Worship, Livestock Farms, Nature Habitats etc. and to ensure that contact is established with associated interested parties, to forewarn them of intended low-level operations and to obtain their consent for intended operations.

5. The pilot-in-command shall, where possible, avoid repetitive or prolonged flight of more than five minutes duration over or in the vicinity of sensitive areas, as mentioned in 4 (above).

6. Flights made pursuant to this Permission for Aerial Survey shall be conducted not below 60 metres (200 feet) AGL and no closer than 60 metres to any person, vehicle, vessel or structure subject to compliance with Condition 2 above and the Operator conducting an individual risk assessment for each operation in accordance with their Safety Management System.

7. The pilot-in-command shall maintain records of each flight sector operated pursuant to this Permit and shall make such records or any details of such records available to an Authorised Officer of the Irish Aviation Authority on demand.

8. By accepting this Low Flying Permit, Sander Geophysics Ltd., accepts full financial and legal liability for any loss of life, injuries to persons or animals or damage to property or any other liability resulting either directly or as a consequence of any flight operated under this permit.

9. Operational control, safety planning and oversight of all low flying operations made pursuant to this permit shall be the responsibility of Sander Geophysics Ltd. Flights shall be conducted in accordance with the details and data of the safety case submitted to the Irish Aviation Authority.

10. A copy of this permit shall be included in the operations manual and carried on board the aircraft.

11. This permit may be cancelled, suspended, varied or revoked at any time by the Irish
Aviation Authority.

12. This permit may only be exercised in conjunction with Aerial Work Permission 14 of 2015.

- END OF SCHEDULE -

IRISH AVIATION AUTHORITY