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The HiRES airborne geophysical survey of the Isle of Wight: Processing Report

Environmental Geoscience Baselines Programme

Open Report OR/09/060

BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOSCIENCE BASELINES PROGRAMME

INTERNAL REPORT OR/09/060

The HiRES airborne geophysical survey of the Isle of Wight: Processing Report

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Front cover

Coastal view from survey aircraft

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Foreword

This report is the published product of a study carried out by the British Geological Survey (BGS). The project is a HiRES airborne geophysical survey carried out by the Geophysical Baselines Team under the Environmental Geoscience Baselines Programme. The survey was intended to form a part of the then current revised mapping being undertaken within the Mesozoic and Tertiary Basins Team. This report describes the processing of the geophysical data acquired by the survey.

Acknowledgements

The JAC survey team, including BGS operators, are thanked for their contributions to the successful HiRES survey project.

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Summary

This report describes the final processing of data acquired during the HiRES airborne geophysical survey of the Isle of Wight and part of the Lymington area. The report is a companion to the logistics report of Beamish and Cuss (2009). The survey was carried out by the Joint Airborne-Geoscience Capability (JAC) established between the Geological Survey of Finland (GTK) and British Geological Survey (BGS). The project is a HiRES survey carried out by the Geophysical Baselines Team under the Environmental Geoscience Baselines Programme.

1 Introduction

This report describes the final processing procedures performed on the HiRES airborne geophysical survey data undertaken over the Isle of Wight and part of the Lymington area. This work was carried out at the BGS offices at Keyworth in the months following the survey. The report also details the naming conventions employed for the final data sets and includes gridded images of the processed data.

The report is subdivided into sections which focus specifically on the three data sets: electromagnetic, magnetic and radiometric.

2 Electromagnetic processing

This section focuses on the processing procedures applied to the Isle of Wight electromagnetic data.

2.1 PRELEVELLING

The in-field prelevelling procedure is further refined during the data processing stage and is the principal step in ensuring an accurate and well levelled data set.

At the beginning of each survey flight the zero-level is adjusted to an artificial level to ensure a large enough scale to register both positive and negative anomalies. As such, the recorded values are independent of the real zero-level. This calibration is performed at a high altitude (greater than 300 metres above ground) to provide a true 'out-of-ground' response. The zero-level calibration procedure is repeated at the end of each flight. The level of the EM data is then corrected linearly using these calibration results.

Preliminary automatic zero-level correction gives good results if the drift is linear and low in magnitude. The linear part of the drift is usually less than 100 ppm/hour if there is no temperature gradient. If the flight lines are long the air temperature can sometimes vary significantly during a traverse, and this may introduce a non-linear drift to the zero-level. A temperature variation results in a change in the coil separation and the zero-level may change by about 70 ppm for a temperature variation of one degree centigrade. It would be possible (in theory) to correct this effect, but unfortunately the wings of an airplane cannot be regarded as a totally rigid item. The wings are made of composite materials, meaning the relationship between temperature and wing length variation may be non-linear. There are also other reasons for this drift, such as temperature variations in the coils and in other analogue components, which are never ideal and lead to a non-linear drift.

The non-linear drift is estimated for each EM component during each flight. An interactive JAC Windows program, EMPRELEV, is used for non-linear drift removal. The user interactively provides a set of points which estimate the drift of each component, see Figure 1 and Figure 2. The outside temperature is usually plotted above the EM data to help to determine whether a high temperature gradient exists. The online/offline parameter is used to define the flight lines and turns.

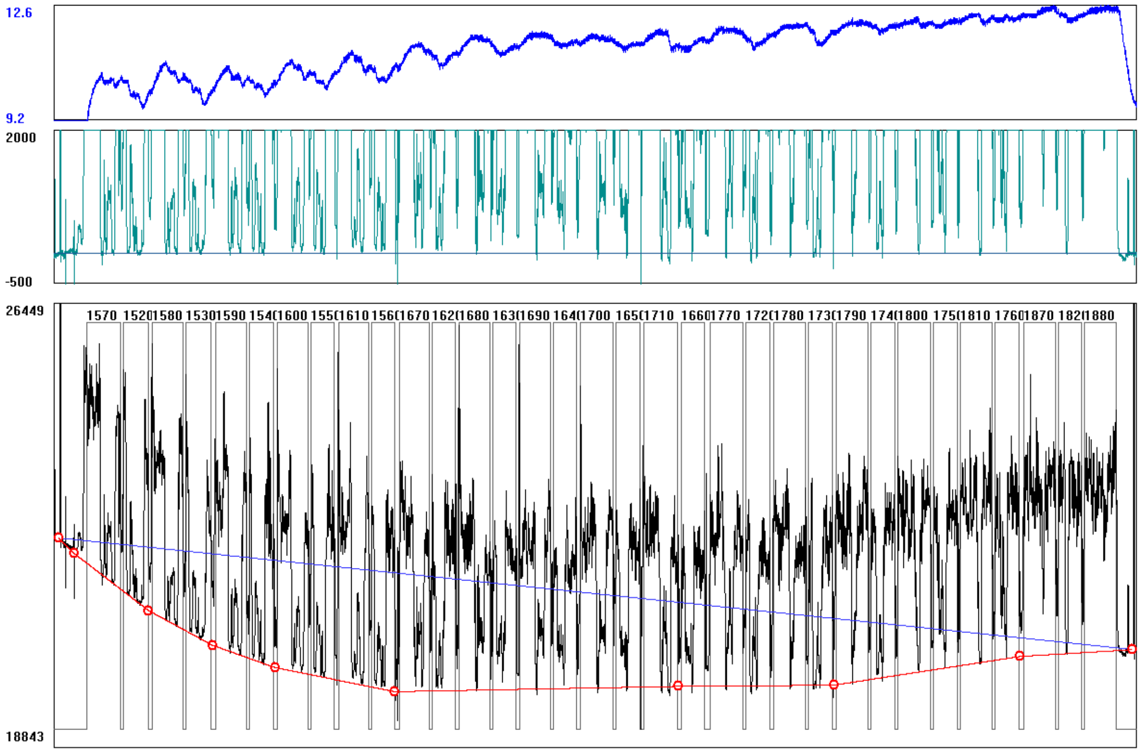

Figure 1. An example of EMPRELEV applying a non-linear drift correction to the real component of the 912 Hz data.

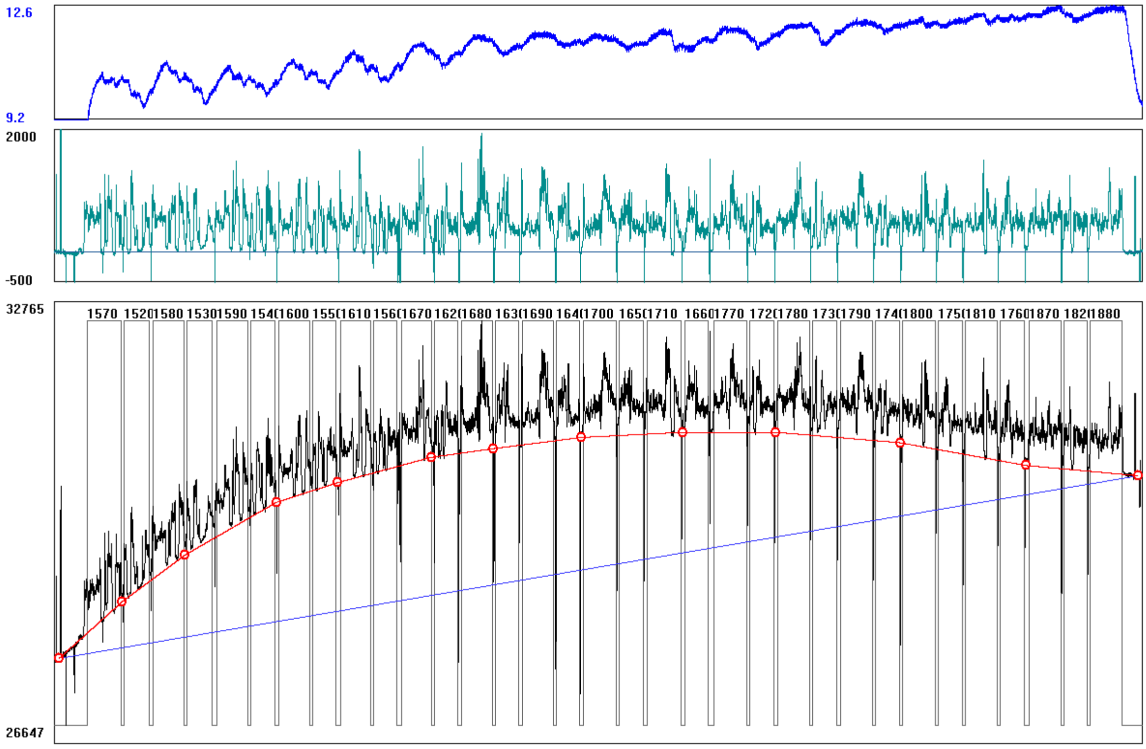

Figure 2. An example of EMPRELEV applying a non-linear drift correction to the imaginary component of the 912 Hz data.

2.2 LEVELLING

The pre-levelling is followed by further line-by-line adjustment (if required) of the zero levels for each component of each line of data. A JAC graphical Windows program, Level32 is used for this purpose. An example of this program is presented in Figure 3. A variable number of profiles of a specific EM component can be presented simultaneously in a window. Lines are sorted, so adjacent profiles are compared to provide information about line-to-line behavior of the zero level. For each line, the user provides a set of points, which determine the revised zero-level. Usually two points are enough to determine any residual small drift curve for correction. However, in regions of rapid drift three or more points might be used.

The above procedures work on EM data from individual lines and enable de-trending procedures (linear and non-linear) and residual offset removal to be applied where necessary. Since these procedures are line-based they do not perturb the EM data anomalies that have an expected wavelength much less than the line length. The data generated are the most appropriate data for use in quantitative procedures (e.g. modeling/inversion) that require minimum filtering/distortion of individual anomalies.

In practice Level32 was not used significantly in the processing of the Isle of Wight survey. The majority of the level error was corrected using EMPRELEV.

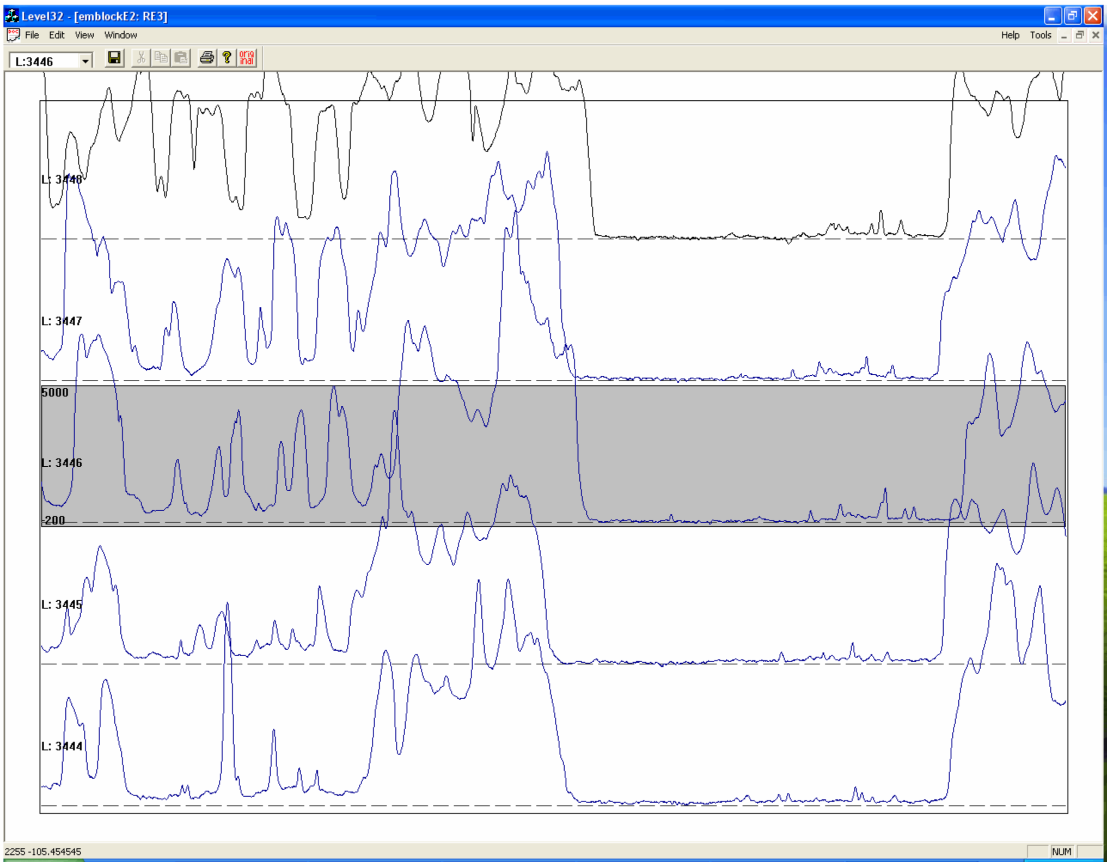

Figure 3. Example of LEVEL32 applied to 3 kHz real component across 5 sequential lines. DC level adjustments are interactively made to each line (current line for adjustment is shown in grey).

2.3 MICROLEVELLING

When the EM data are gridded, small residual line-to-line levelling errors may become apparent. These effects are often referred to as ‘corrugations’ or ‘streaks’; such features are common to all the airborne survey data components. Microlevelling procedures are used to remove such features prior to the production of final grids. Microlevelling procedures apply filters and spatial averages across multiple lines but these methods have limitations and are capable of distorting data. The application of such procedures depends on a set of control parameters (e.g. those associated with filter lengths and spatial wavelengths) for each data set; a level of judgment is required to minimize distortion and provide acceptable microlevelled grids.

For the EM coupling ratio data, JAC uses a microlevelling technique called the Floating Median Difference (FMD) method. Originally developed by Liukkonen (1996), a more recent use of the technique is described by Mauring and Kihle (2006). The microlevelling program EMLEV uses an along line radius (1000 m was used for the Isle of Wight survey) and an across-line radius that controls the number of lines involved in estimating the result at a particular point. An across-line value of 500 m was employed during this study meaning five lines were used in the procedure; given the flight line spacing of 200 m.

The leveling routine will not remove features that are shorter in wavelength than the along line radius. This leaves high frequency features intact. It does, however, adjust all line data to some extent. The amount of filtering this procedure performs is seen as being a good balance between leveling and smoothing. Many procedures exist that would create a much more aesthetically pleasing result, but these all overly smooth data. The FMD routine does have some characteristics that are worth noting. In situations where data levels change rapidly, such as a step, the FMD routine can create large negative spikes on a down-step. Therefore caution has to be taken when deciding which dataset to use for visual presentation of data (microlevelled) or for modeling (non-levelled).

2.4 ESTIMATION OF APPARENT CONDUCTIVITY AND DEPTH

The primary EM in-phase and quadrature components can be transformed to apparent resistivity and apparent depth using a half-space model (Fraser, 1978; Suppala *et al*., 2005). The method returns apparent resistivity and apparent depth at each measured frequency and no misfit error is provided (Beamish, 2002). The transformation is performed using the JAC program TRANSAEM07. The program employs minimum limits on the real and imaginary coupling ratios to identify the noise level in the coupling ratios. Figure 4 shows the applicable ranges for the coupling ratios.

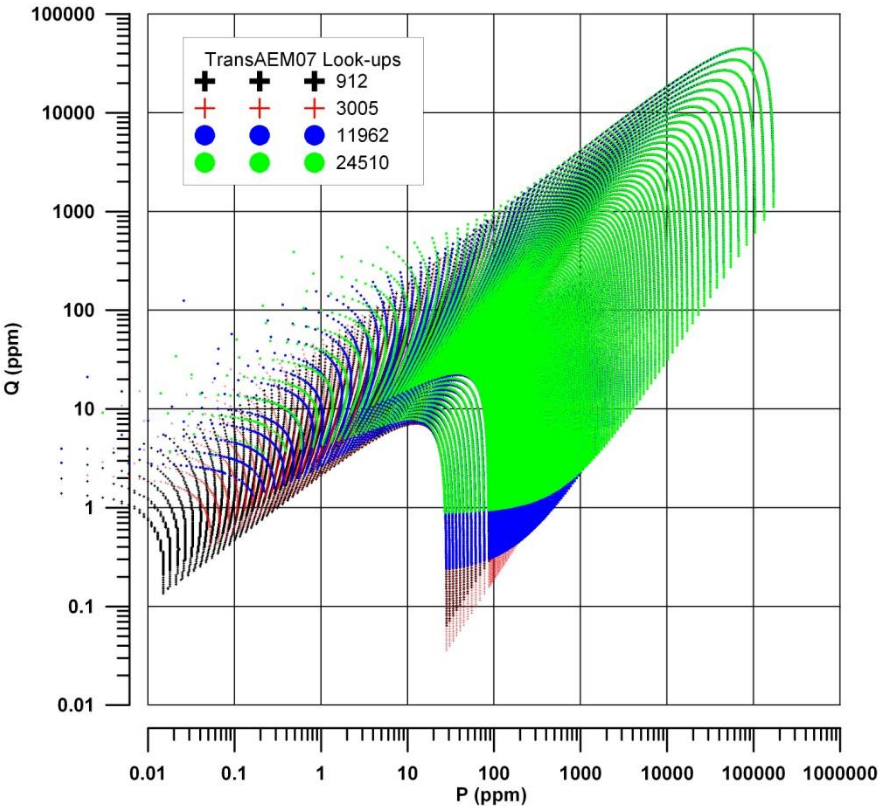

Figure 4. Real and quadrature sampling covers 19716 points for all four frequencies.

In conditions of variable flight elevation, the levels of signal/noise may also vary (signal decreases with increasing elevation). Such effects decrease with increasing frequency and are thus most pronounced in the 912 Hz data.

The apparent resistivity and apparent depth data are an application of a half-space model and should be considered as such. The appropriateness of this model must be ascertained before an interpretation is made. Final detailed interpretation (e.g. modeling, inversion) should be carried out using the original in-phase and quadrature data (i.e. data obtained prior to microlevelling).

2.5 FURTHER MICROLEVELLING

The apparent resistivity and depth data sets can be further microlevelled using a similar method to EMLEV. Once again along and across line radii are required in order to ascertain the two dimensional background level. The level of correction is controlled during the levelling, ensuring that low values, which have a greater relative accuracy, are not corrected as heavily as high values. The along line radius should be selected such that EM anomalies are shorter than this value. For the Isle of Wight processing the along and across line radii were 1000 m and 500 m respectively.

2.6 ELECTROMAGNETIC DATA DELIVERY

The final electromagnetic data is contained in a series of files. The levelled in-phase and quadrature components (after LEVEL32) are summarized in EM_IOW.xyz. The microlevelled version of this data is EM_IOWlev.xyz. The transformed apparent resistivity and depth data is AP_IOW.xyz, whilst the microlevelled equivalent is AP_IOWlev.xyz. IOW_EMAP_main.xyz is a combined dataset of microlevelled coupling ratios and unlevelled apparent resistivities, conductivities and depths. Equivalent data sets containing the 5 additional in-fill lines (see Beamish and Cuss, 2009) have the same name but are appended by an '_all' suffix. A READ_ME file is included in the 'processed' folder and the final data sets include:

<u>For EM_IOW.xyz and EM_IOWlev.xyz</u>

X	Grid Easting (m) – UTM 30N
Y	Grid Northing (m) – UTM 30N
Z	GPS altitude (m) above geoid (WGS84)
PITCH	Pitch (degrees)
ROLL	Roll (degrees)
HEADING	Heading (degrees clockwise)
FLIGHT	Flight number
DAY	Day number (Julian)
TIME	Time (HHMMSS)
DIR	Flight direction (degrees clockwise)
RALT	Radar altitude (m)
LALT	Laser altitude (m)
DTM	Digital Terrain Model (m)
PLM	Power line monitor
RE09	Real (in-phase) component at lowest frequency 912 Hz (ppm)
IM09	Imaginary (quadrature) component at lowest frequency 912 Hz (ppm)
RE3	Real (in-phase) component at low frequency 3005 Hz (ppm)
IM3	Imaginary (quadrature) component at low frequency 3005 Hz (ppm)
RE12	Real (in-phase) component at high frequency 11962 Hz (ppm)

IM12	Imaginary (quadrature) component at high frequency 11962 Hz (ppm)
RE25	Real (in-phase) component at highest frequency 24510 Hz (ppm)
IM25	Imaginary (quadrature) component at highest frequency 24510 Hz (ppm)

For AP_IOW.xyz and AP_IOWlev.xyz

X	Grid Easting (m) – UTM 30N
Y	Grid Northing (m) – UTM 30N
AR09	EM apparent resistivity at lowest frequency 912 Hz (Ohm m)
AD09	EM apparent depth at lowest frequency 912 Hz (Ohm m)
AR3	EM apparent resistivity at low frequency 3005 Hz (Ohm m)
AD3	EM apparent depth at low frequency 3005 Hz (Ohm m)
AR12	EM apparent resistivity at high frequency 11962 Hz (Ohm m)
AD12	EM apparent depth at high frequency 11962 Hz (Ohm m)
AR25	EM apparent resistivity at highest frequency 24510 Hz (Ohm m)
AD25	EM apparent depth at high frequency 24510 Hz (Ohm m)

Whilst IOW_EMAP_all.xyz contains all the above parameters, the derived apparent conductivities (derived from the apparent resistivities) are clipped to 500 mS/m (i.e. if the original value is greater than 500 mS/m then it is set to 500 mS/m)

3 Magnetic processing

This section describes the processing procedures applied to the Isle of Wight magnetic data. The standards used in airborne magnetic processing are well established and documented (e.g. Luyendyk, 1997).

In practice, although in-field processing of the magnetic data was undertaken, all the survey data was reprocessed in the office to provide validated (uniformly correct calibration factors) data sets. The main magnetic software package used in these procedures is MAGCOR.

A full description of the standard processing applied to the JAC magnetic data is given by (Hautaniemi *et al.*, 2005). A review of the procedures for the Isle of Wight data is provided below.

3.1 AIRCRAFT CORRECTION

The aircraft is a magnetised metallic body moving in the Earth's magnetic field. The resultant magnetic effect depends on flight direction (heading) and the movement of the aircraft (pitch, roll, and yaw). These properties also vary with time. The magnetic effects depend on time and place within the Earth's magnetic field, so the calibrations have to be made separately for each survey area, and have to be repeated in cases of prolonged surveying. The procedures for calibration are described by Beamish and Cuss (2009). Data from the aircraft logging system include raw magnetic data and compensated magnetic data. This allows magnetic compensation to be re-calculated post flight, although in practice this was not necessary.

3.2 DIURNAL CORRECTION

Short time variations of the Earth's magnetic field are removed by using a magnetic base station. The magnetic base station is established near the survey area. The magnetic variation during the survey flight has to be small enough so that it can be considered that the magnetic variation has minimum time difference between survey aircraft and the base station. The suitable allowed limits of variation are defined according to local magnetic anomaly level, required accuracy and quality and possible cost and time limits of the survey. Both short and long time variation limits were defined; 12 nT over any 3 minute chord or 2 nT over any 30 second chord. All line data that exceed these limits are rejected in the field and reflown. The data was also checked for significant micro-pulsation activity.

MAGCOR performs the diurnal correction. Base station data are filtered using a default median filter of 24 seconds and mean filter of 16 seconds. Filters of different lengths can be applied either specifying different filter lengths in MAGCOR or when viewing the magnetic base station in Mag32. In practice it was not necessary to adjust the default values.

3.3 LAG CORRECTION

A lag test is performed to verify the recording delay. Due to the real time RMS compensation, the pre-filtering applied, and delays in network data transmission, a small lag exists in the recording of the data. This is verified by repeating a flight line in opposite directions above a sharp and cross-cutting magnetic anomaly source like a railway or thin magnetic dyke. Comparing these repeated measurements, the exact lag is then determined. When flight lines are rejected due to QC considerations the re-flight is always in the opposite direction so as to confirm the lag correction. A lag correction of -0.7 seconds is applied to the data by MAGCOR. This is confirmed as appropriate by the continuation of linear magnetic features that cross-cut the flight line direction obliquely.

3.4 HEADING CORRECTION

The aircraft is a magnetised metallic body moving in the Earth's magnetic field. As such, different magnetic values recorded in the two opposing flight line directions. Heading corrections for the Isle of Wight survey were undertaken in the Geosoft Oasis Montaj processing software.

The heading correction applied by MAGCOR is a simple DC shift of line data based simply on the direction of travel. The heading correction is one of the most common sources of levelling error during data processing. Heading corrections are not always stable with time or may vary when objects are taken from or placed within the aircraft. The heading correction can be determined by examining the statistics of the entire survey. The calculation of the mean for the two different flight directions then determines any error in heading correction.

3.5 AIRCRAFT INFLUENCE

The aircraft has a number of mission-critical avionic systems on board which create a magnetic source that can result in small errors in the magnetic data. A typical disturbance with the Twin Otter aircraft is the effect of the hydraulic pump. The hydraulic pump causes a 1 – 2 nT anomaly which lasts up to two seconds during its operation. The hydraulic pump is mission critical and has been shielded as much as possible but its operation is necessary after long periods of significant rudder and ailerons use, common in mountainous regions. When the pump is operated, the duration is recorded and the magnetic data is then removed automatically in the subsequent processing. Re-flying is not possible as repeat operation of the pump is often observed as the same flying conditions are experienced on the re-flight.

Other sources of magnetic noise include windscreen wipers and the VHF communication system. The former is short period; otherwise the flight line is abandoned. The Isle of Wight survey also specified that flying would not occur during any periods of rain, therefore windscreen wipers were not in operation during this survey. The latter source of noise is not normally a problem in surveying. Communication between the aircrew and Air Traffic Control is coordinated so that it only occurs during turning, i.e. off of survey line. However, there are times when the aircrew are called on-line and they are obliged to respond. This did not occur during this survey.

3.6 DATA QC AND SPIKE REMOVAL

After data processing using the MAGCOR program, the data are imported into Geosoft Oasis Montaj and thoroughly checked. At this stage, all residual remaining errors (such as spikes, VHF communications, etc.) are corrected if observed.

3.7 LEVELLING MAGNETIC DATA

Further levelling of the magnetic data is still required after the corrections described above. Residual errors can be introduced from incomplete diurnal corrections since magnetic base stations are always situated at some distance from the survey aircraft and the transient field varies in both time and space. These errors are generally small but can be seen in high resolution measurements over magnetically flat areas. There are also other possible error sources, for example incomplete compensation and heading correction. The aim in applying any correction is to eliminate errors in the data that have an effect on the true magnetic intensity of the earth; to be avoided is the application of corrections, which have the sole objective of producing smooth and beautiful maps. If the original measured data is poor in quality, acceptable corrections may not be able to bring it to a high quality level.

JAC do not normally fly tie lines. Tie line corrections are generally ineffective due to low survey altitude and typically strong gradients of the anomaly field. The error on intersection points between normal lines and tie lines is very often bigger than the expected accuracy for present high-resolution magnetic surveys. This problem is made worse in areas with high degrees of cultural magnetic noise, where a large proportion of intersection points cannot be used due to excessive gradients seen in the highly disturbed Isle of Wight data.

Normally, JAC uses the virtual tie line approach to level magnetic data but for the Isle of Wight survey data a different approach was adopted. This method develops the approach described by Huang (2008). The technique removes the necessity to level with virtual tie lines and is a quick and easy method that requires minimal user interaction.

The scheme relies upon the long wavelength component of the individual lines capturing the regional field. Taking the unlevelled, but de-spiked, data the regional field is computed by:

- Gridding the data using Geosoft's bi-directional gridding method, whilst applying a low pass filter of 1600 m to generate a grid of the regional field and levelling errors.
- Regridding the grid with the same low pass filter to isolate the regional field and any high frequency noise.
- Removing the high frequency noise by application of a Hanning (3x3) convolution filter.
- Resampling the grid back to the original flight line sampling.

The BGS program Mag_to_regField.exe is then utilised to minimise the difference between the line data and the regional field, see Appendix 1 for details.

3.8 MICROLEVELLING

The microlevelling approach undertaken for the Isle of Wight magnetic survey is the Bi-directional Gridding method recommended by Geosoft. This gridding scheme attempts to isolate the remaining levelling errors and remove them from the data. A low pass filter parameter of 1600 m was used in the processing. This value would generally be considered large but enabled the removal of some longer wavelength effects caused by significant cross-winds to be levelled.

3.9 MAGNETIC DATA DELIVERY

The final magnetic data sets are IOW_MGCL.xyz and IOW_MGCN.xyz. A READ_ME file is included in the 'processed' folder and the final data sets include:

X_BNG	Grid Easting (m) – British National Grid
Y_BNG	Grid Northing (m) – British National Grid
X_UTM	Grid Easting (m) – UTM 30N
Y_UTM	Grid Northing (m) – UTM 30N
Z	GPS altitude (m) above geoid (WGS84)
PITCH	Pitch (degrees)
ROLL	Roll (degrees)
HEADING	Heading (degrees clockwise)
FLIGHT	Flight number
DAY	Day number (Julian)
TIME	Time (HHMMSS)
DIR	Flight direction (degrees clockwise)
RALT	Radar altitude (m)
LALT	Laser altitude (m)
DTM	Digital Terrain Model (m)
BASE	The base station magnetic data

RAW_MGCL/N	The raw recorded magnetic data
DESPIKE_MGCL/N	The despiked raw magnetic data
REGION_MGCL/N	The highly filtered regional magnetic field
CORRECTED MGCL/N	The magnetic data corrected to the regional field
FINAL MGCL/N	The final microlevelled magnetic data

4 Radiometric processing

This section describes the processing procedures applied to the radiometric data. The standards used in airborne radiometric processing stem from procedures described in AGSO and IAEA reference manuals (Grasty and Minty, 1995; IAEA, 1991).

In practice, although in-field processing of the radiometric data was undertaken, all the survey data was reprocessed in the office to provide validated (uniformly correct calibration factors) data sets. The main radiometric software package used in these procedures is RADCOR.

A full description of the processing applied to the JAC radiometric data is given by Hautaniemi *et al*. (2005). The recommended (IAEA) energy rates of the windows used to deliver the Isle of Wight radiometric data are shown in Table 1:

Window	Energy range (MeV)
Thorium	2.41 – 2.81
Uranium	1.66 – 1.86
Potassium	1.37 – 1.57
Total	0.41 – 2.81

Table 1. The recommended (IAEA) energy ranges of the spectral windows.

A review of the main processing procedures is provided below.

4.1 DEAD TIME CORRECTION

The spectrometer needs a short time to process each pulse and as such has some difficulty observing any subsequent pulse arriving while the first one is being processed. This time is referred to as the dead time. The dead time correction is carried out using electronically measured dead time data for each window.

4.2 FILTERING

Digital filters are applied to the radar altimeter data and applied to the processing of the radiometric data. The filtering is used to smooth sudden jumps that can arise when flying over steep terrain. These sudden shifts/spikes in the data, if uncorrected, can cause problems when height correcting the data later. The spectrometer's cosmic channel (see below) is also filtered to reduce statistical noise.

4.3 AIRCRAFT AND COSMIC BACKGROUND CORRECTION

The aircraft has a background radiation component for each of its radiation windows. The background radiation of the aircraft is constant for each window as long as there are no changes made to the aircraft and its contents. Cosmic background radiation increases with height and is proportional to the number of radiation pulses in the high-energy cosmic window (3 – 6 MeV). The determination of the aircraft and cosmic background count rates for each spectral window has been described in IAEA Technical Report 323 (IAEA 1991), and is considered for this survey in the processing report of Beamish and Cuss (2009).

4.4 BACKGROUND RADON

Radon gas makes it difficult to measure uranium concentrations accurately. Since it is not always evenly distributed in the air; eliminating it from background radiation is not simple. Determination of the constants necessary for the correction of the background radon requires several steps and utilizes the upward detectors. The procedure outlined in IAEA (1991) is generally correct, but more recent studies have refined the process. The first step, determining the contribution of atmospheric radon to the various spectrometry windows, is best achieved through a series of test flights over water. The method of least squares allows the constants in equations 4.9 to 4.12 (IAEA, 1991) to be determined. The next step is to determine the response of the upward looking detector to radiation from the ground (equation 4.13, IAEA, 1991). The procedure recommended by Grasty and Hovgaard (1996) is considered more reliable than that in IAEA (1991) for the second step.

4.5 EFFECTIVE HEIGHT CORRECTION

The count rates depend on the density of air and thus on the temperature and pressure of the air. The filtered radar altimeter data is used in adjusting the stripping ratios, for altitude corrections and also to correct for the attenuation of the radioactivity at nominal height. The filtered radar altimeter data is converted to effective height at standard temperature and pressure (STP). The radiometric results are then corrected to a nominal height to remove the effect of varying survey altitude. The background corrected total count and stripped count rates vary exponentially with aircraft altitude.

4.6 STRIPPING CORRECTION

The spectra of K, U and Th overlap and so one radioelement will also contain some effect from the other two radioelements. This channel interaction must be corrected to produce pure concentration values. The stripping ratios α, β, γ, a, b and g are determined over calibration pads as described in Chapter 4 of IAEA 1991 and are discussed by Beamish and Cuss (2009). The dimensions of our transportable calibration pads are 1m × 1m × 30cm and the weight of each one of them is approximately 660 kg. The principal ratios α, β, and γ vary with standard temperature and pressure (STP) and altitude above the ground and are usually adjusted before stripping is carried out. Using the six stripping ratios, the background corrected count rates in the three windows can be stripped to give the counts in the potassium, uranium and thorium windows that originate solely from potassium, uranium and thorium. These stripped count rates are given by equations 4.44 to 4.47 in the IAEA 1991 document.

4.7 CONVERSION TO APPARENT RADIOELEMENT CONCENTRATIONS

The fully corrected count rate data is used to estimate the concentrations in the ground of each of the three radioelements; potassium, uranium and thorium. The procedure determines the concentrations that would give the observed count rates, if uniformly distributed in an infinite horizontal slab source. Because the U and Th windows actually measure ^{214}Bi and ^{208}Tl respectively, the calculation implicitly assumes radioactive equilibrium in the U and Th decay series. The U and Th concentrations are therefore expressed as equivalent concentrations, eU and eTh.

4.8 LEVELLING OF RADIOMETRIC DATA

Radiometric data are commonly affected by atmospheric radon, which may not be fully removed by the processing procedure outlined above. This problem is usually seen as a DC shift of a complete line.

The method of Green (1987) uses data for U, Th and K in order to identify the error in U based on its relationship with Th and K by regression. This results in an estimate for mean uranium per flight line based on the Th and K data and this mean value is removed from every uranium data point along line.

As stated above, the uranium data set suffers from background changes usually associated with the decay of atmospheric radon. The magnitude of this atmospheric background is dependent upon the weather and the time of day. The same changes are evident in the Total Count channels but they do not affect the thorium and potassium channels to the same extent. Consequently, images of these channels usually show little banding of the type seen in the uranium and Total Count images. The Green’s levelling procedure will tend to isolate background fluctuations by looking at the residuals from a regression of the uranium and Total Count channels on the other two channels. More specifically, a multiple linear regression for the uranium and Total Count channels is performed on a line-by-line basis for thorium and potassium: $\overline{Y} = a * \overline{K} + b * \overline{T}h + c$, where Y stands for uranium or Total Counts.

Green's levelling has been performed on uranium and total counts, but it should be noted that they have not made significant differences to the quality of the data. As Green's method is a statistical procedure there is always the danger that data are actually degraded during levelling but this problem was not noted for the Isle of Wight data set.

4.9 RADIOMETRIC DATA DELIVERY

The final radiometric data set is IOW_RAD.xyz. A further data set containing the equally spaced line data and the additional 5 lines of in-flown data is also available as IOW_RAD_ALL.xyz. A READ_ME file is included in the processed folder and the final data sets include:

X_BNG	Grid Easting (m) – British National Grid
Y_BNG	Grid Northing (m) – British National Grid
X_UTM	Grid Easting (m) – UTM 30N
Y_UTM	Grid Northing (m) – UTM 30N
Z	GPS altitude (m) above geoid (WGS84)
FLIGHT	Flight number
DAY	Day number (Julian)
TIME	Time (HHMMSS)
DIR	Flight direction (degrees clockwise)
RALT	Radar altitude (m)
LALT	Laser altitude (m)
BALT	Barometric altitude (m)
TOUT	External temperature (^{o}C)
DTM	Digital Terrain Model (m)
D_TOTlev	Total counts (Ur units)
D_KAL	Potassium (%K)
D_URAlev	Uranium (ppm, eU)
D_THO	Thorium (ppm, eTh)

5 Positional processing and line trimming

Post-processing differential correction is done after a survey flight, allowing greater positional accuracy. The purpose is to find the exact coordinates for each of the measuring sensors in the local coordinate system. Real-time differentially corrected coordinates are not as accurate as the post-flight differentially corrected ones since the post-processing differential correction program (Javad Pinnacle™) processes the data forwards and backwards in its algorithms, which is not possible in real time. The inputs are the flight and base station satellite recordings. The quality of the satellite coordinates is verified by observing the number of satellites and by using a quality (PDOP, Position Dilution of Precision) parameter. The JAC program GPS2KOG uses the differentially corrected GPS WGS84-coordinates to transform to a local grid (planar) coordinate system. The local geographical grid system used for the processing of the Isle of Wight survey was UTM30N.

A digital terrain model is calculated from the survey data as the height from the reference ellipsoid (WGS-84). The data used are GPS height and the height above the ground/terrain as measured by the radar altimeter. With single frequency GPS+GLONASS receivers in differential mode we can measure the reference height to an accuracy of less than 1.5 metres. The accuracy of the radar altimeter is typically better than 0.5 metres. It should be noted that the radar measures a distance to the nearest reflecting object. Buildings, trees and major constructions typically provide such reflections, so that the elevation measurement is better described as a *Terrain* rather than an *Elevation* model. A typical resultant accuracy of 2 metres is anticipated for the DTM measurements. Ground control sites would be needed to convert these geocentric heights to height above sea level.

Radar Altitude (RALT), GPS altitude above geoid (Z) and the resulting DTM are provided with all the processed geophysical data sets. When the nominal survey altitude above ground is less than ~146 m, we anticipate the type of accuracies quoted above. With increasing altitude (e.g. due to CAA regulations), the RALT and hence DTM measurement becomes less accurate.

All delivered data are untrimmed. Some of the images are clipped to coast to better utilise the range of the colour palette.

6 Maps of the survey area

All the images presented in this section are derived from the final levelled data sets.

6.1 OVERVIEW

In overview, the magnetic data respond to both at-surface and concealed magnetic rocks at all depths (wavelength dependent). The magnetic data shown here are Total Magnetic Intensity (TMI, in nT). The radiometric data respond to about 30 cm of the radiogenic content of the surface material. The actual content might relate to either the soil material (e.g. mineralogy but also moisture content) and/or the parent geological material. The basic EM data comprise coupling ratios that may be difficult to interpret in a simple fashion, due to both a dependence on sensor elevation and the fact that both in-phase and quadrature components are required to understand the response. The coupling ratios are converted to estimates of apparent resistivity and apparent depth as described previously. Apparent resistivity (AR) may also be converted to apparent conductivity (AC) using the formula AC = 1000.0/AR, where AR is in Ohm.m and AC is in mS/m. The half-space parameters form more convenient interpretation products but, as they derive from a uniform Earth assumption, they have limitations when geology/resistivity varies rapidly.

The depth of investigation of the JAC EM data may (typically) vary between 60 and 100 m. This is a simplification in that:

i) sensitivity to resistivity variations is a maximum at the surface and decreases with depth

ii) the statement only refers to the vertical distribution of resistivity

In broad terms, data at the lowest frequencies (900 Hz and 3 kHz) may reveal deeper structure while data at the highest frequency (25 kHz) relates to the shallow subsurface. When a resistivity anomaly occurs at or near the surface, data at all frequencies may respond with the amplitude of the response decreasing with decreasing frequency.

6.2 SIGNAL/NOISE FEATURES IN THE DATA

When data are acquired across populated areas, several issues are worth noting.

The first is that regulatory/safety high-fly conditions result in zones of reduced or loss of geophysical signal. The spatial pattern of high-fly is imposed on the resulting images, and this ‘spatial convolution’ may be complex. Typically the magnetic data retains a signal but at a reduced amplitude while RAD and EM may show ‘out-of-ground’ effects. An image highlighting the regions where the radar altitude records a height over 100 m is included below.

The geophysical data may respond to both geology and/or cultural features across any given survey area. Detailed interpretation of the geophysical responses ultimately requires an understanding on the non-geological responses e.g. topographic and other maps must be used in conjunction with the geophysical data.

Magnetic data typically responds to buildings/structures with high metal content. The distortions are usually easily observed when examining detailed line-based data while in gridded images, the distortions appear as highly localised ‘bulls-eyes’ (closed contours). Therefore magnetic data require careful consideration of cultural features when interpreting.

The radiometric signal above made-ground and structures should reduce to zero (theoretically) however the footprint of the response (height dependent) is typically so large that the response is averaged (smeared) across both geological and non-geological zones.

The EM data (being an active source measurement) is perhaps, most prone to man-made interference. Noise distortion is entirely survey area specific. For this reason, reference should be made to images of the power-line monitor (PLM). In addition, linear/quasi linear features observed in the EM images may also relate to roads, or to road-side routing of services (e.g. electricity, gas, water).

6.3 IMAGES

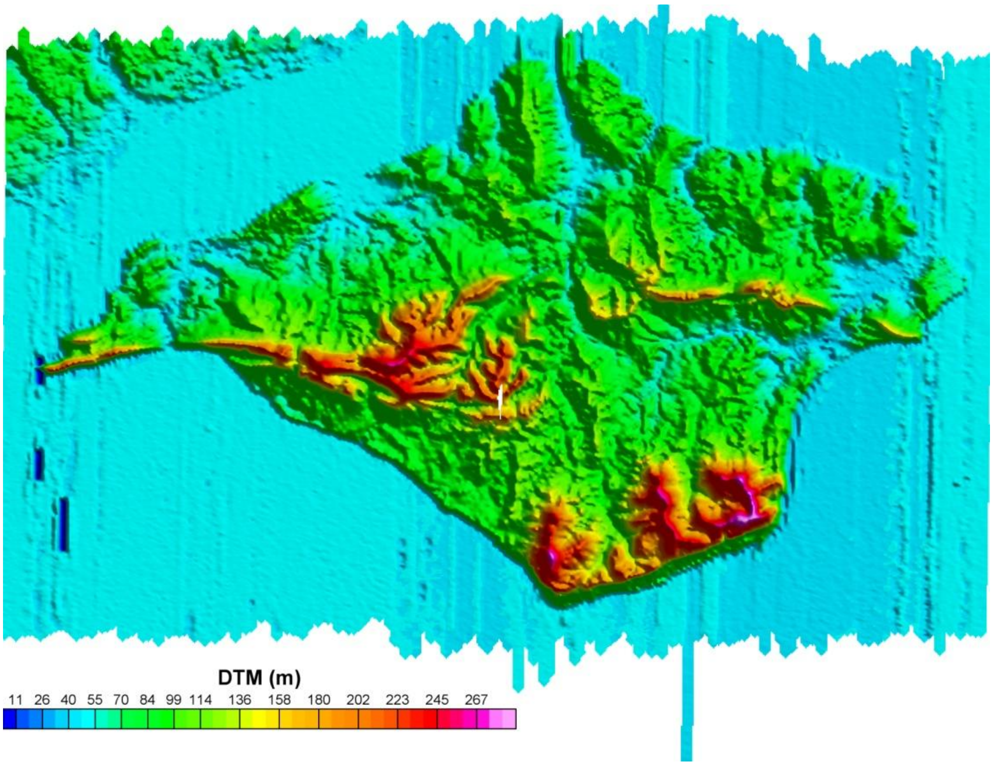

Figure 5. Isle of Wight: Digital terrain model.

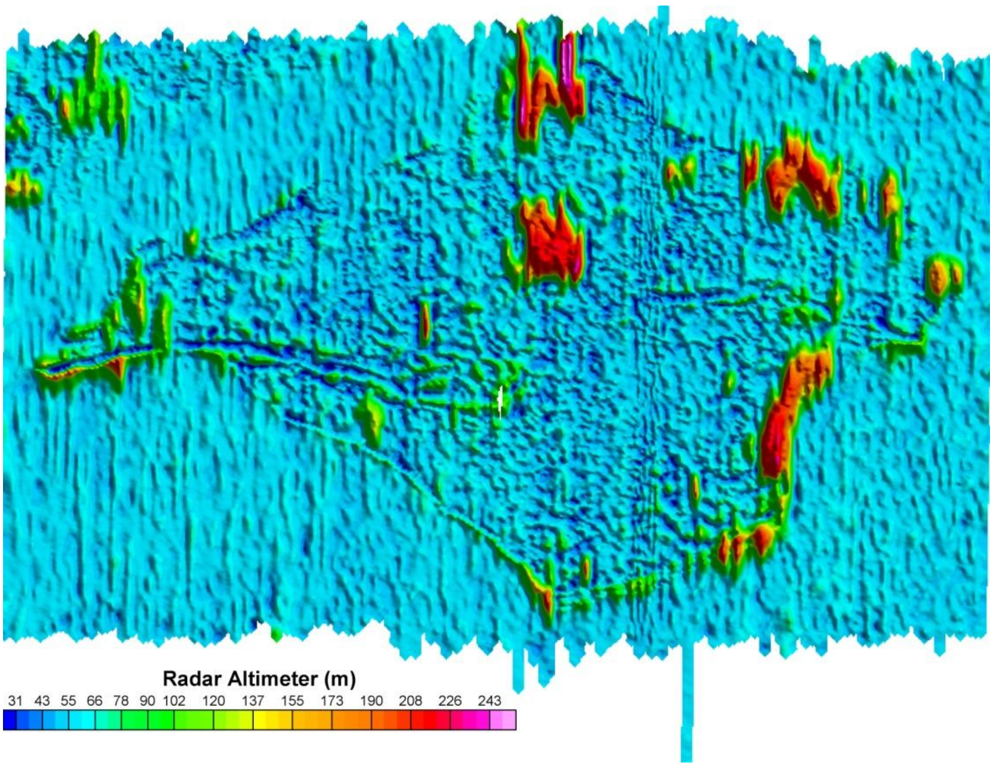

Figure 6. Isle of Wight: Altitude.

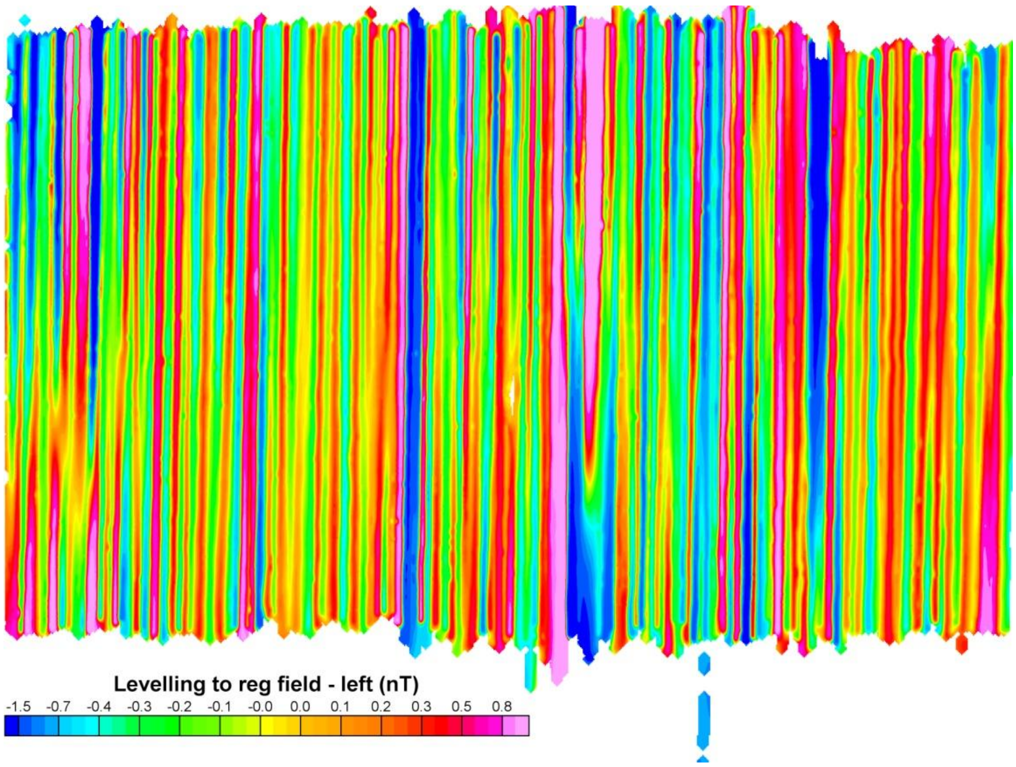

Figure 7. Isle of Wight: Magnetic data. Levelling corrections applied after minimisation to regional field (left wing tip magnetometer).

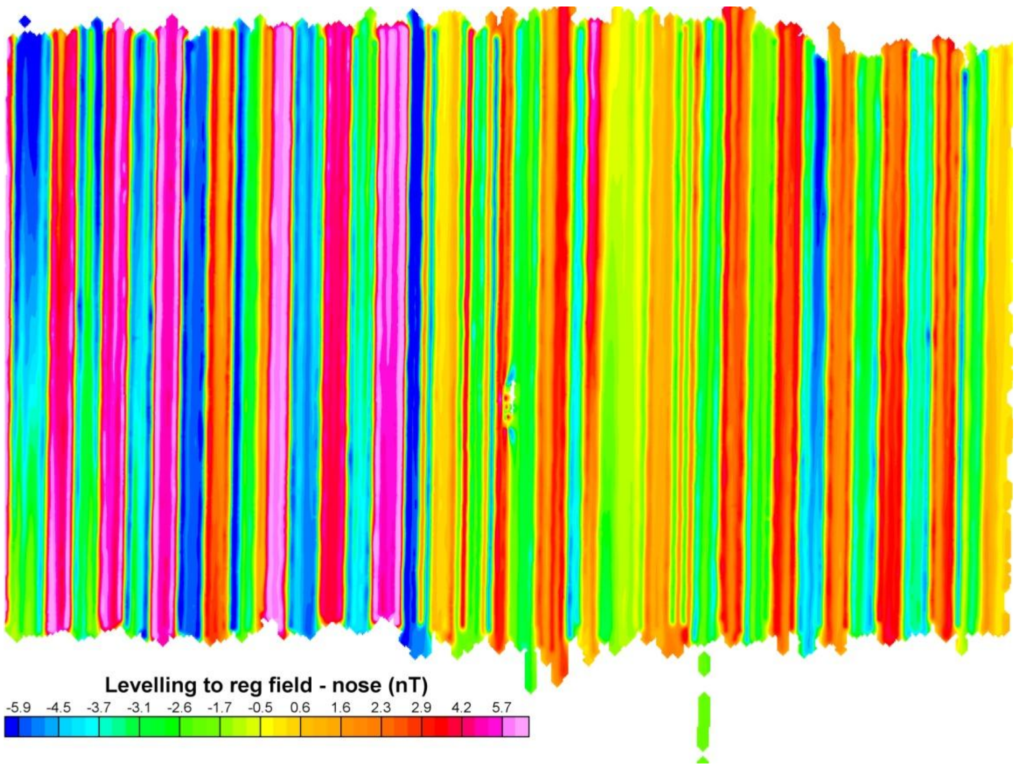

Figure 8. Isle of Wight: Levelling corrections applied after minimisation to regional field (nose tip magnetometer).

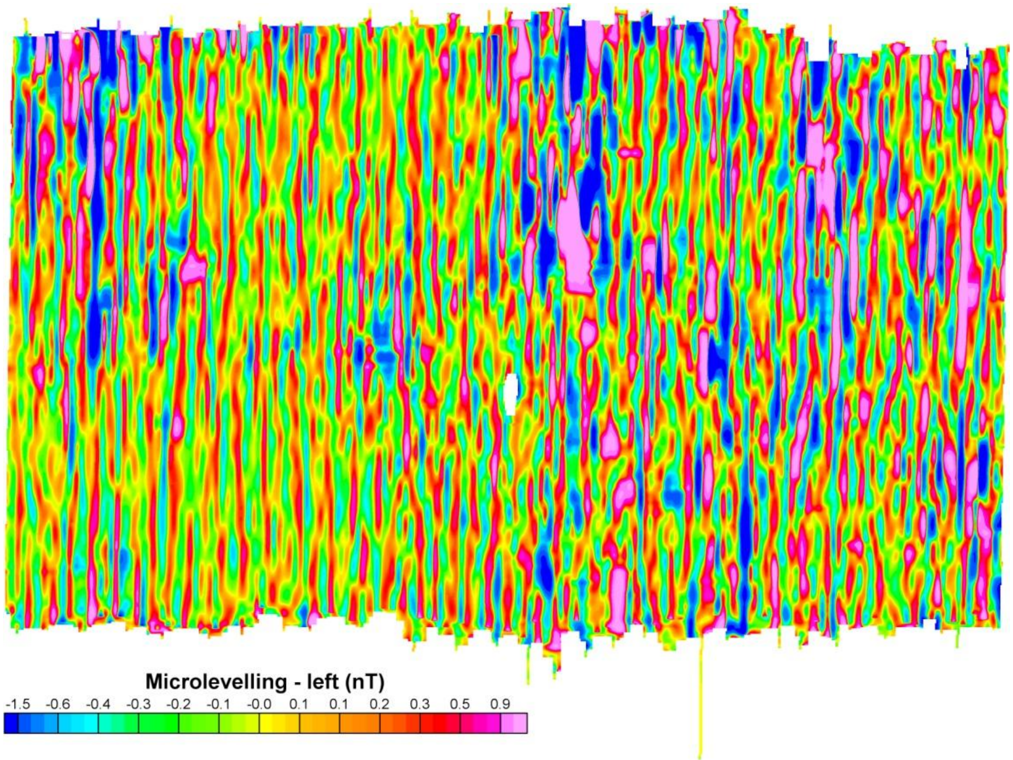

Figure 9. Isle of Wight: Magnetic data. Levelling corrections applied by microlevelling procedure (left wing tip magnetometer).

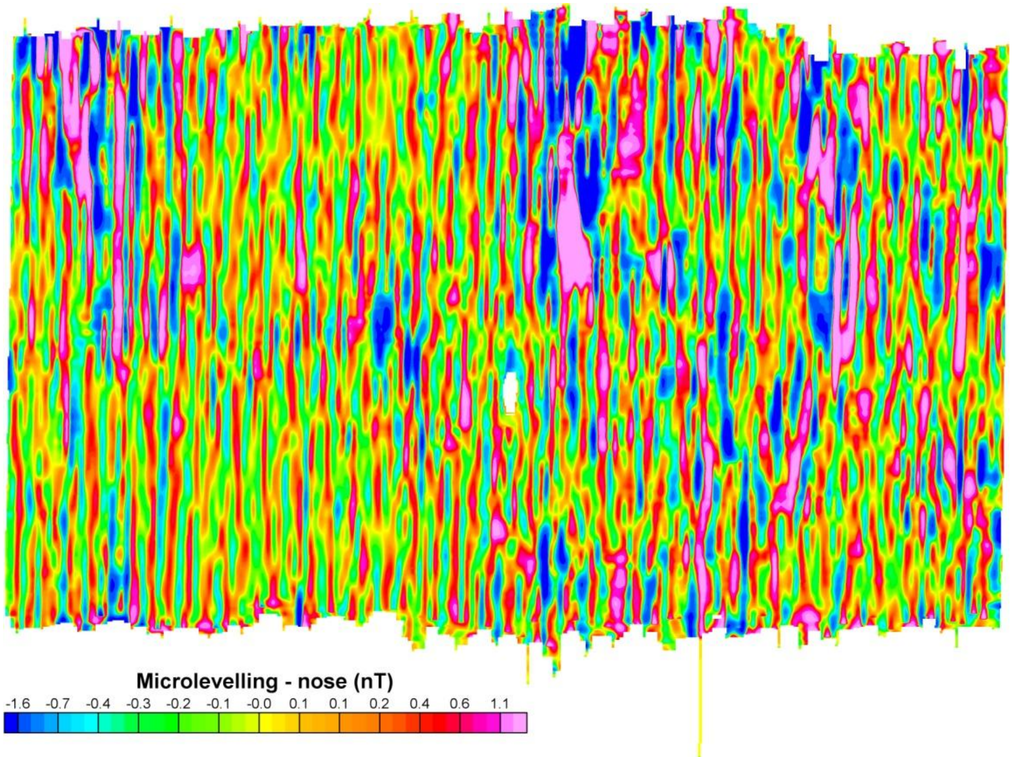

Figure 10. Isle of Wight: Magnetic data. Levelling corrections applied microlevelling procedure (nose tip magnetometer).

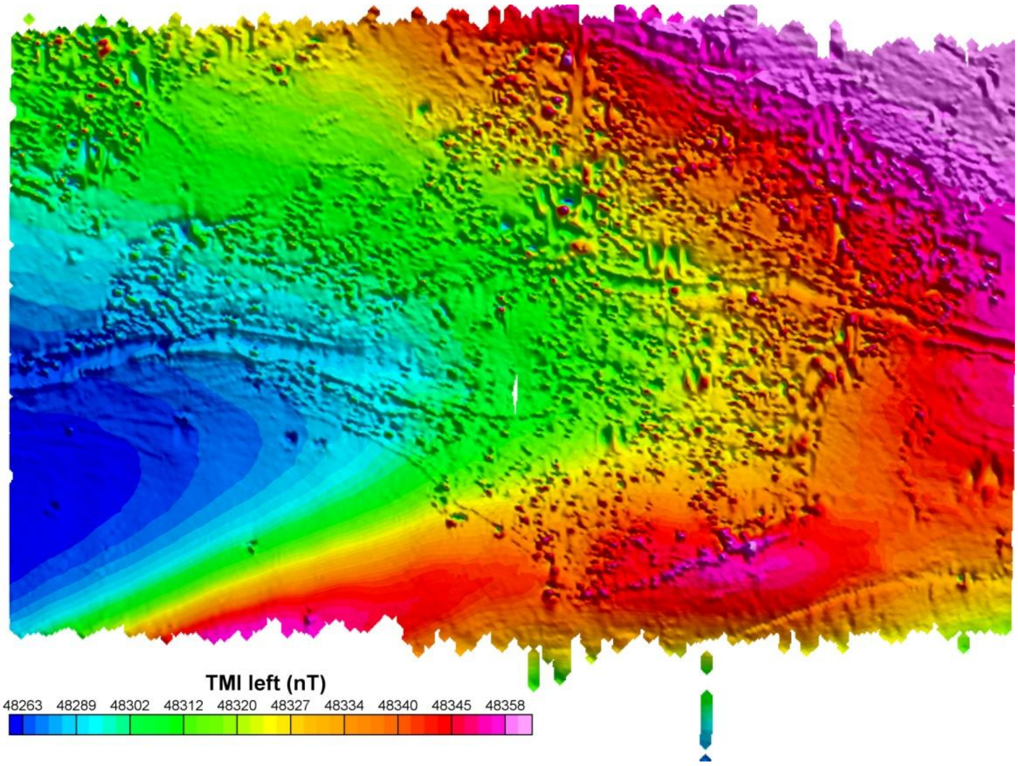

Figure 11. Isle of Wight: Magnetic data. Total magnetic intensity (left wing tip).

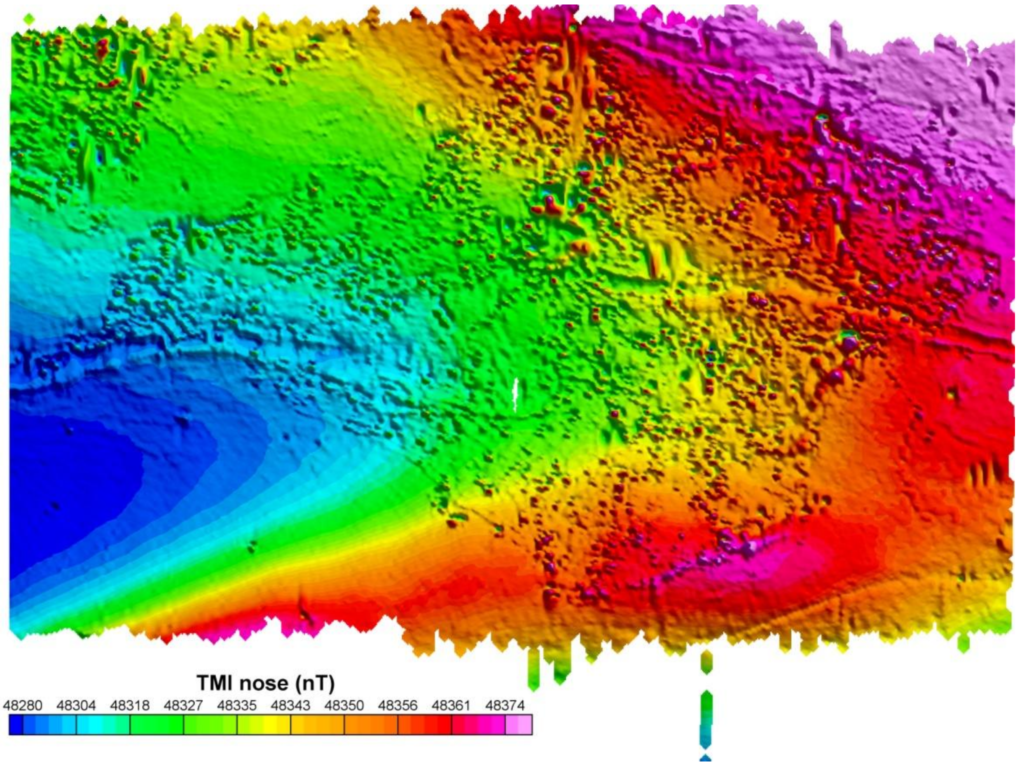

Figure 12. Isle of Wight: Magnetic data. Total magnetic intensity (nose tip).

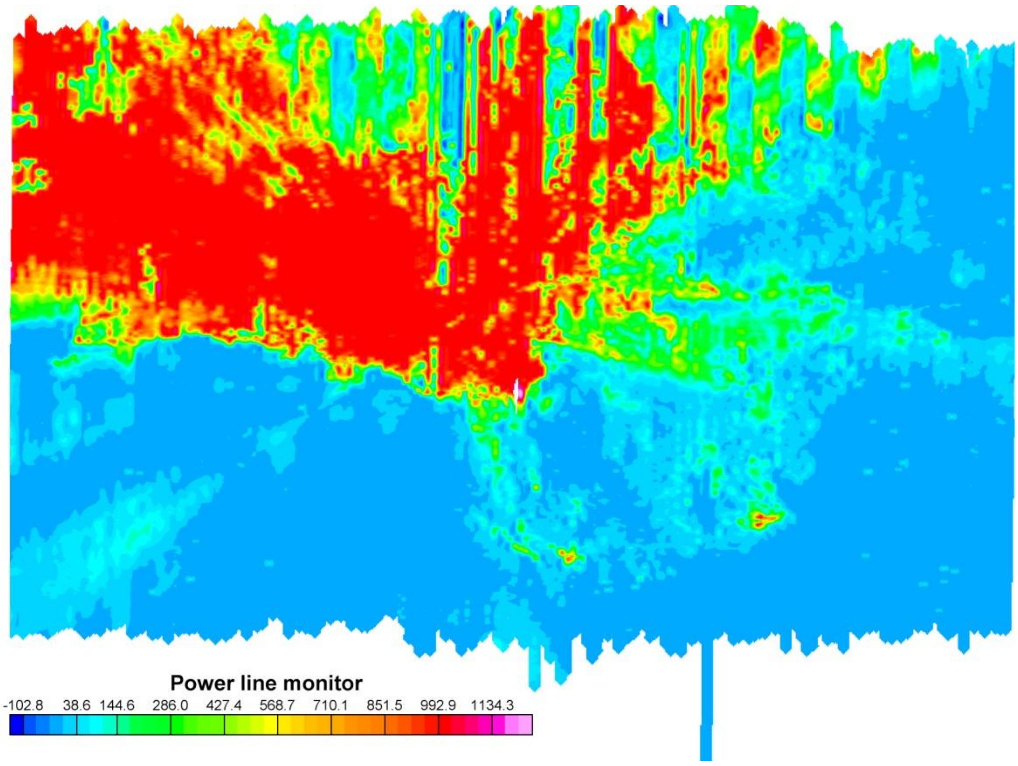

Figure 13. Isle of Wight: Power line monitor

Figure 14. Isle of Wight: Radar altitude less than 100 m (red).

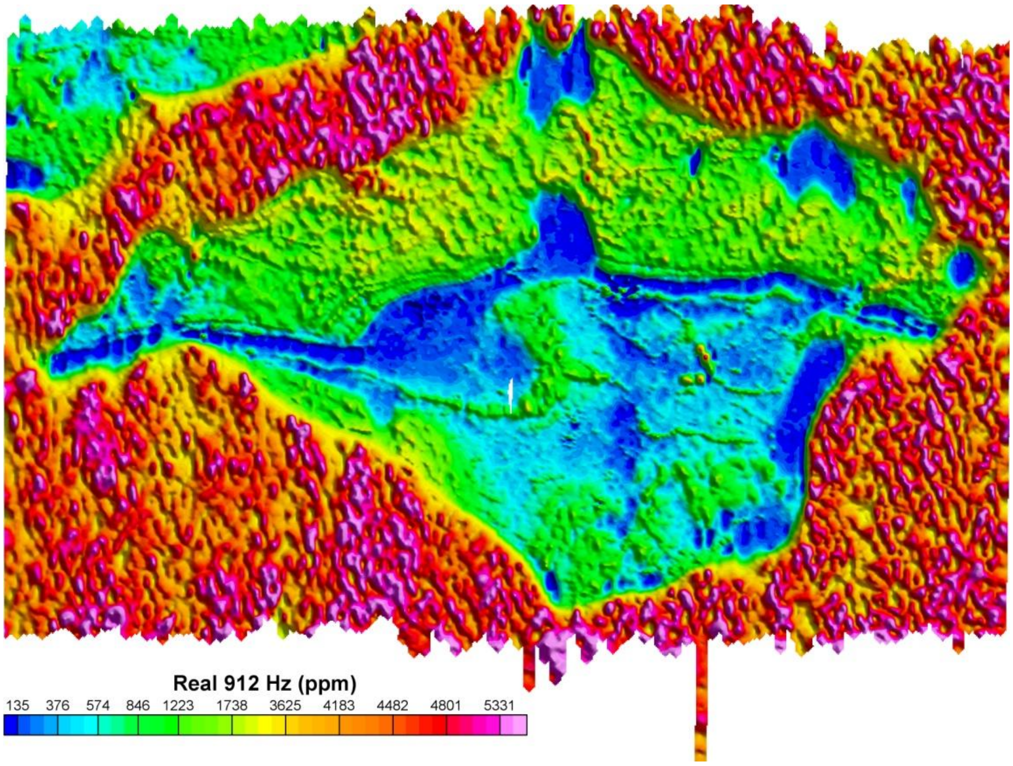

Figure 15. Isle of Wight: EM data. Real component, 0.912 kHz.

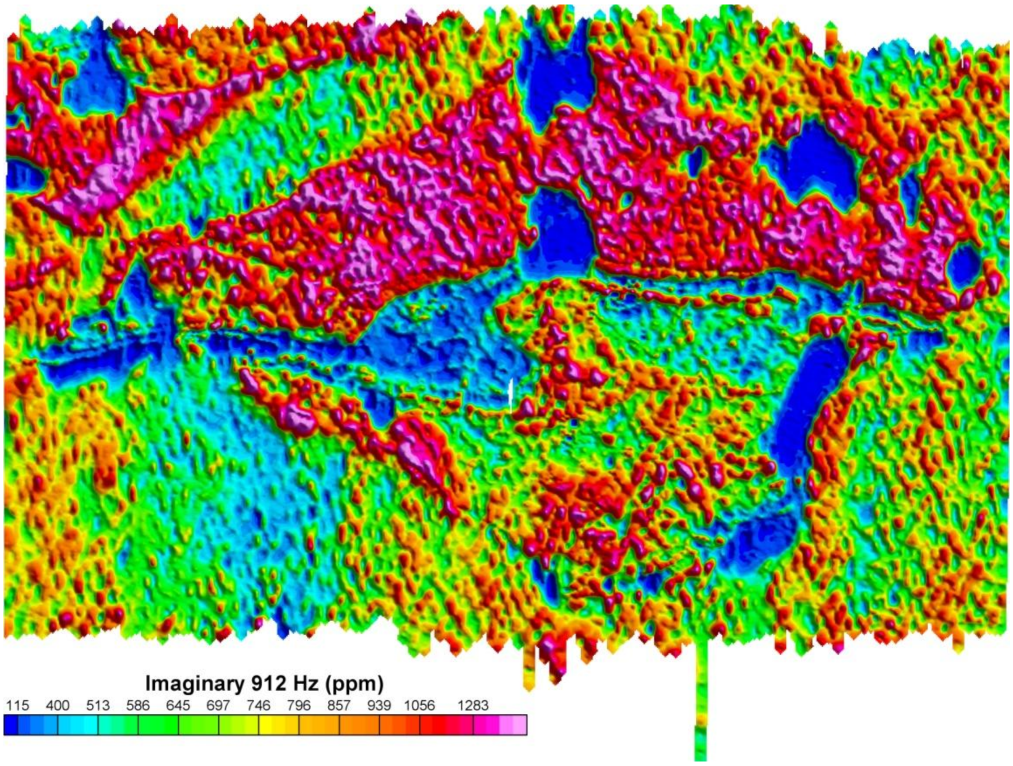

Figure 16. Isle of Wight: EM data. Imaginary component, 0.912 kHz.

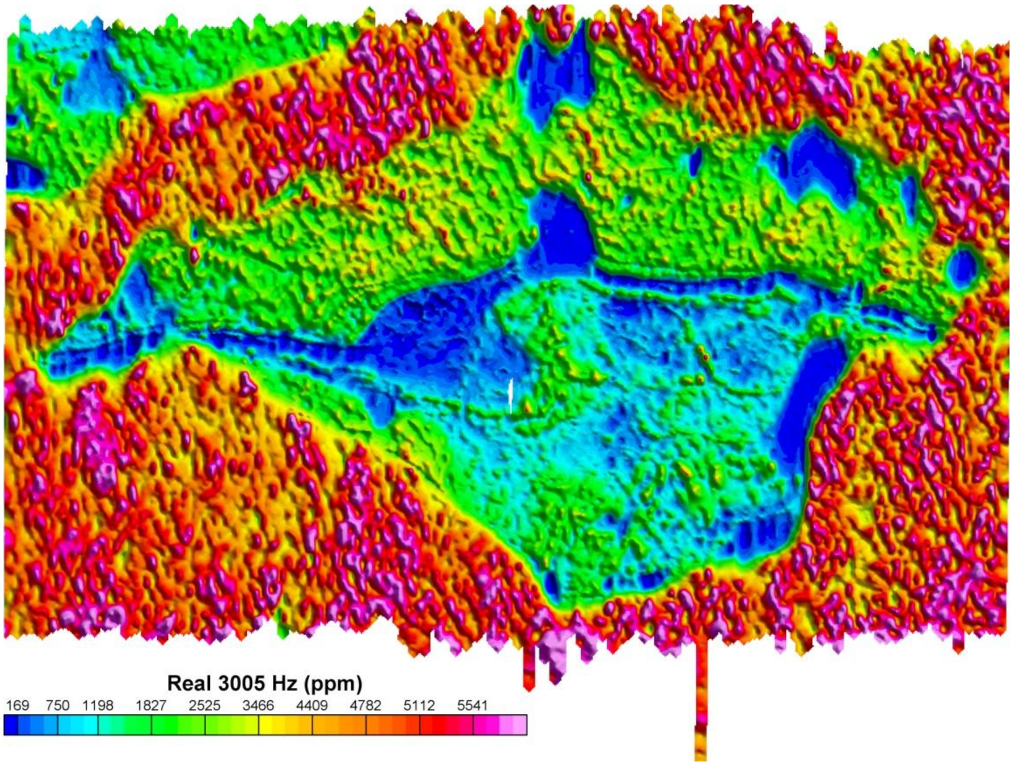

Figure 17. Isle of Wight: EM data. Real component, 3 kHz.

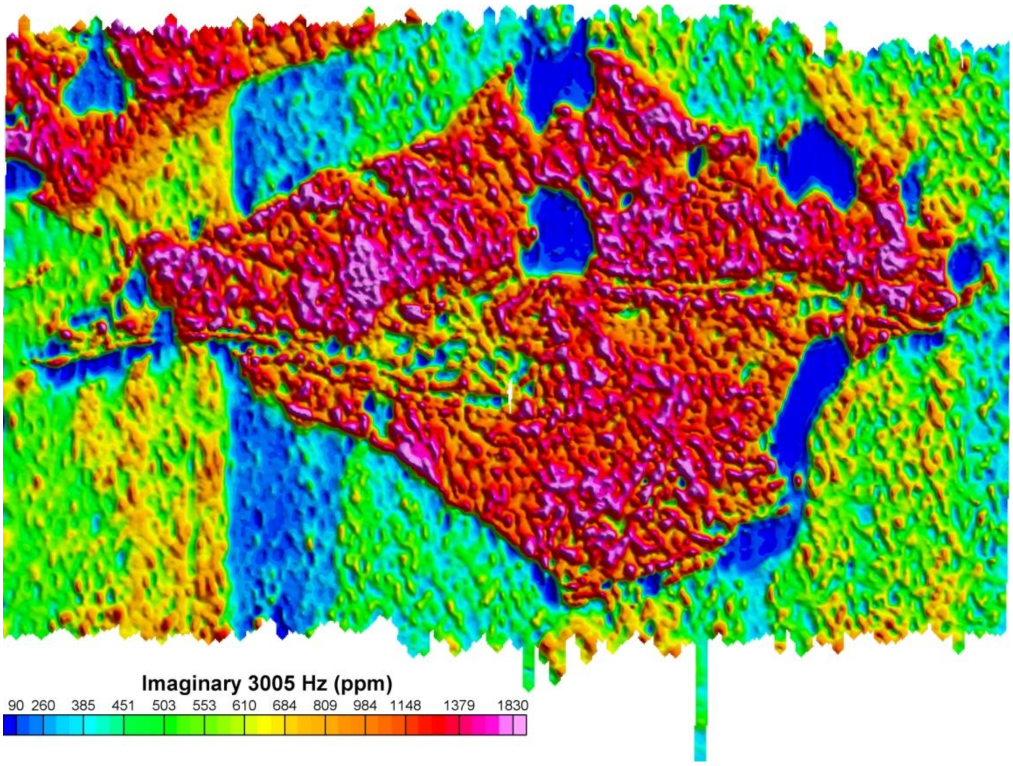

Figure 18. Isle of Wight: EM data. Imaginary component, 3 kHz.

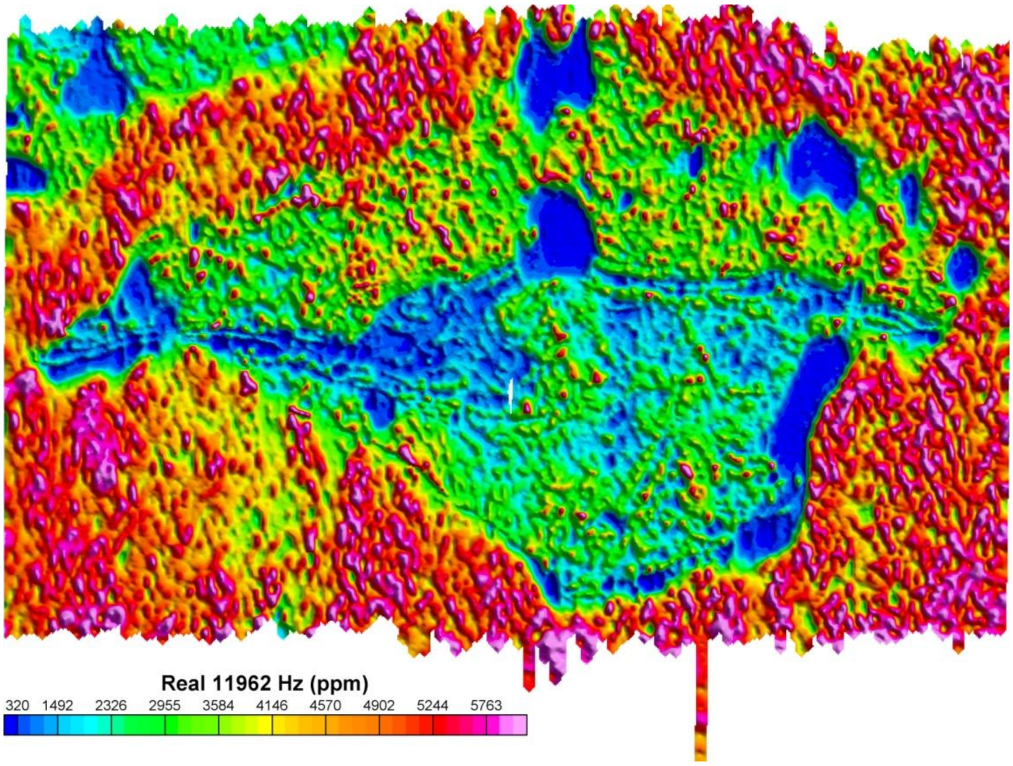

Figure 19. Isle of Wight: EM data. Real component, 12 kHz.

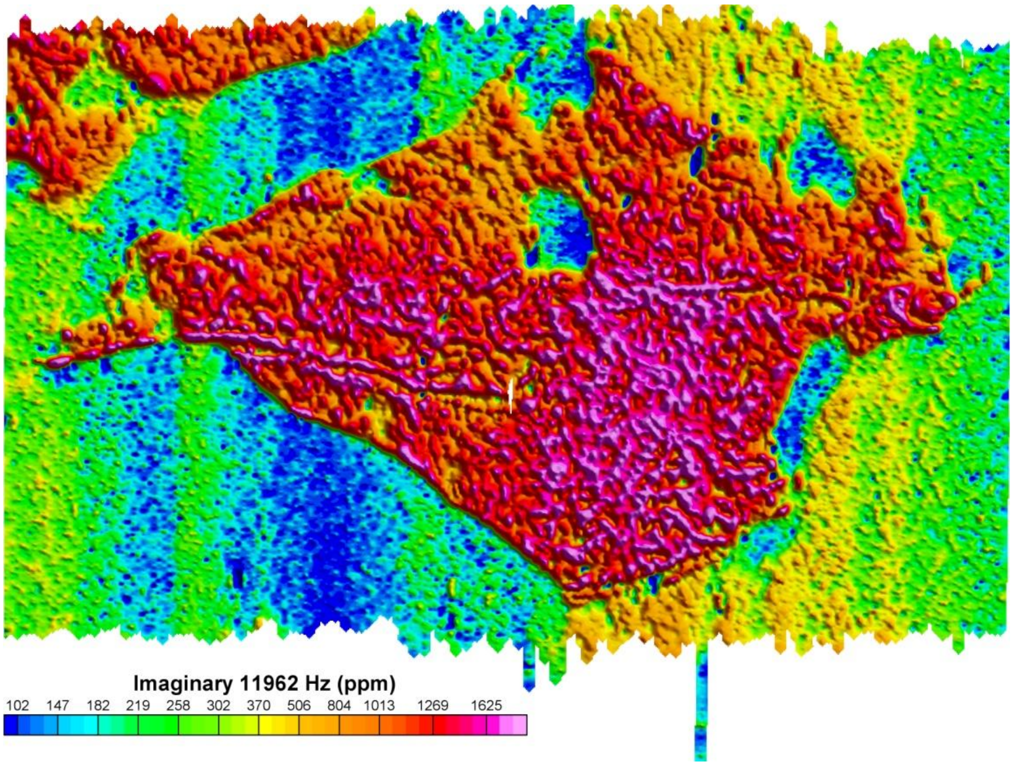

Figure 20. Isle of Wight: EM data. Imaginary component, 12 kHz.

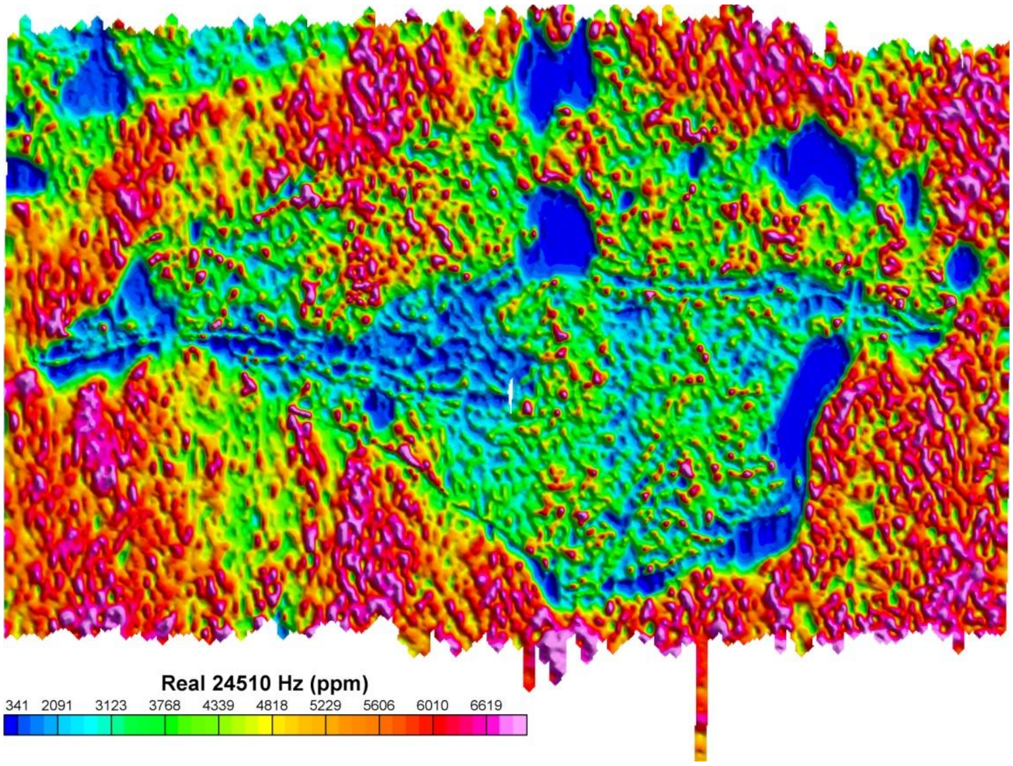

Figure 21. Isle of Wight: EM data. Real component, 24.5 kHz.

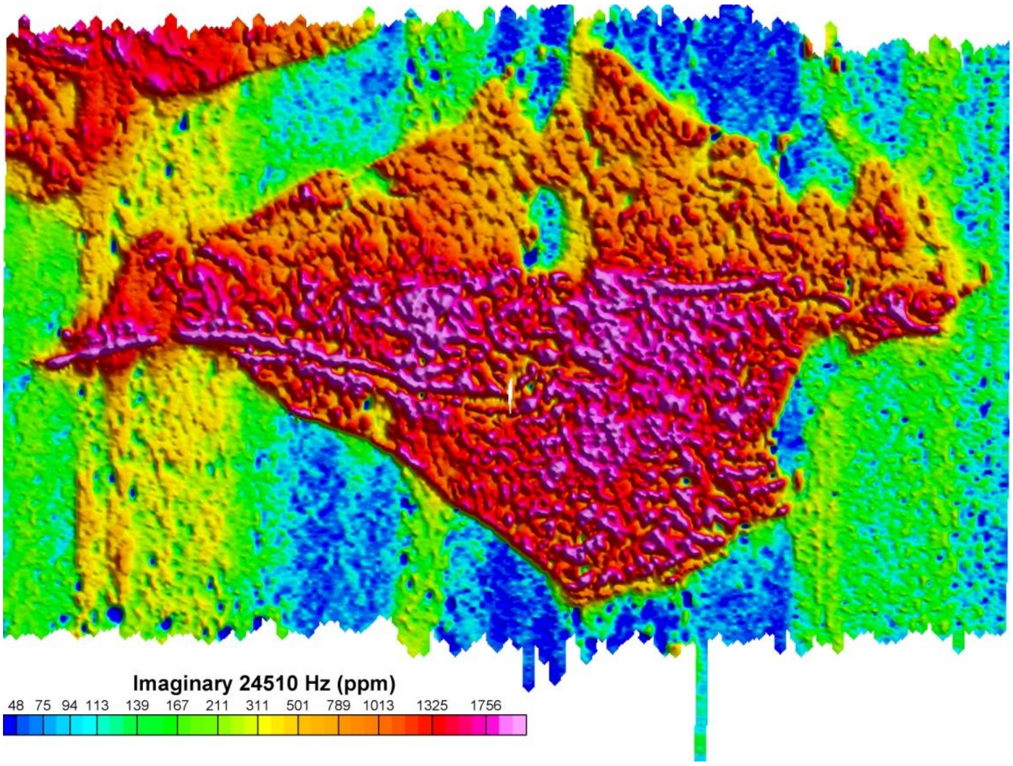

Figure 22. Isle of Wight: EM data. Imaginary component, 24.5 kHz.

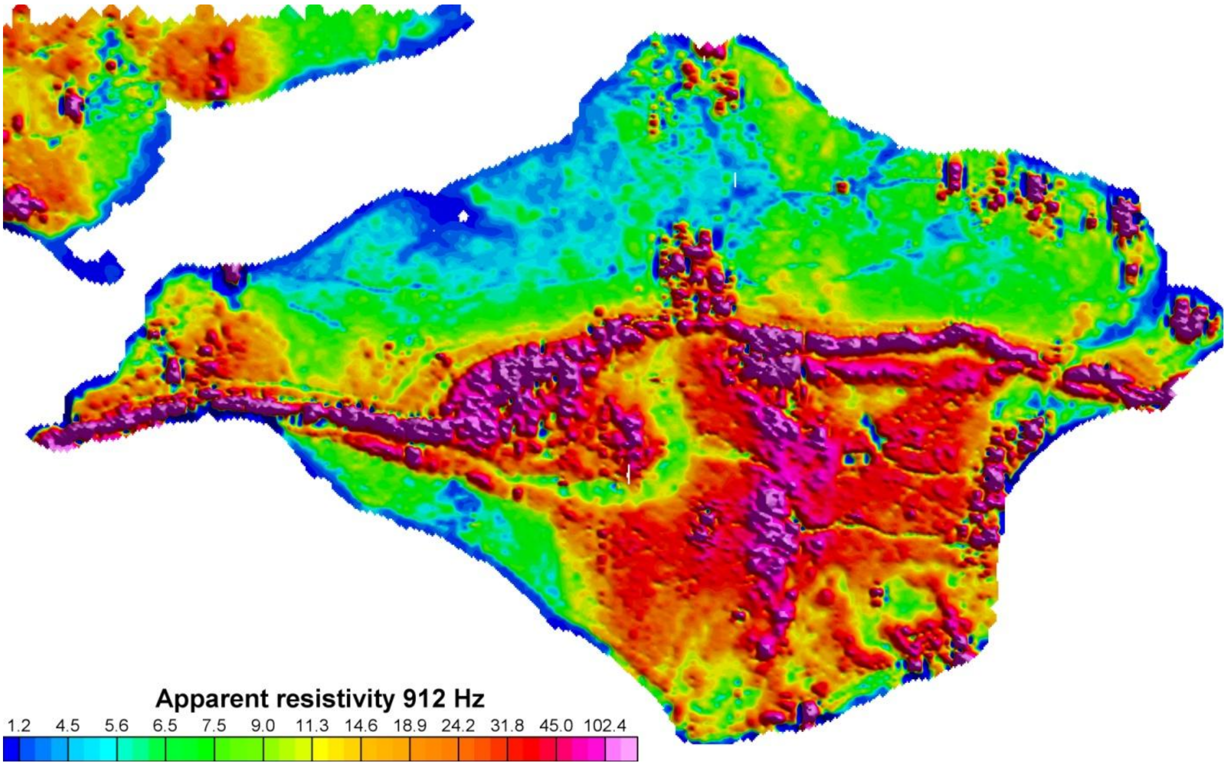

Figure 23. Isle of Wight, cut to coast: Apparent resistivity, 0.912 kHz.

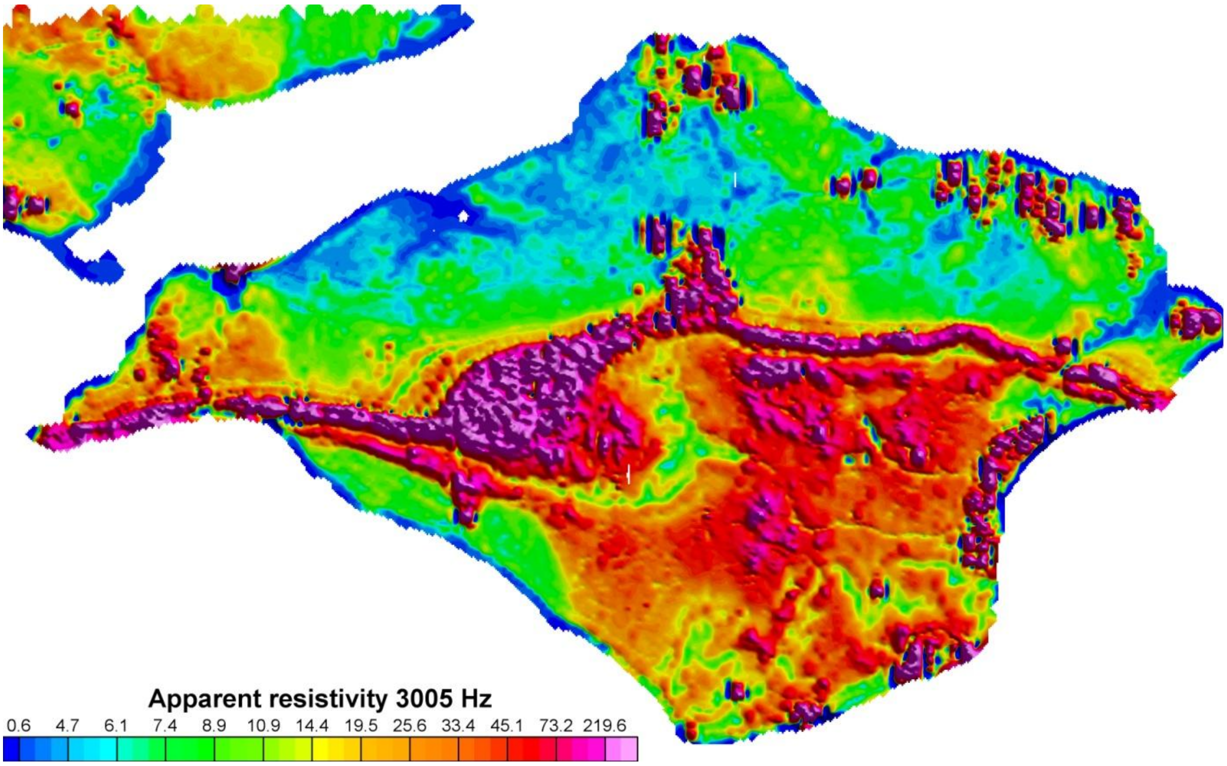

Figure 24. Isle of Wight, cut to coast: Apparent resistivity, 3 kHz.

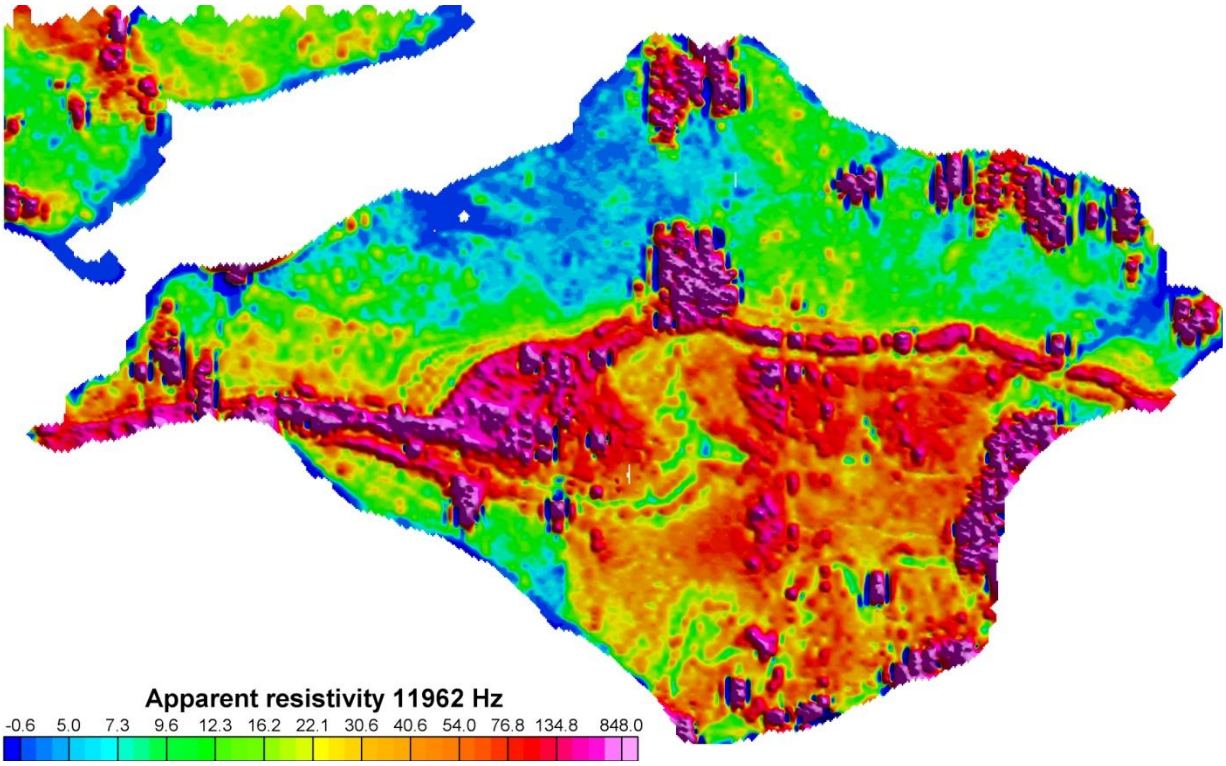

Figure 25. Isle of Wight, cut to coast: Apparent resistivity, 12 kHz.

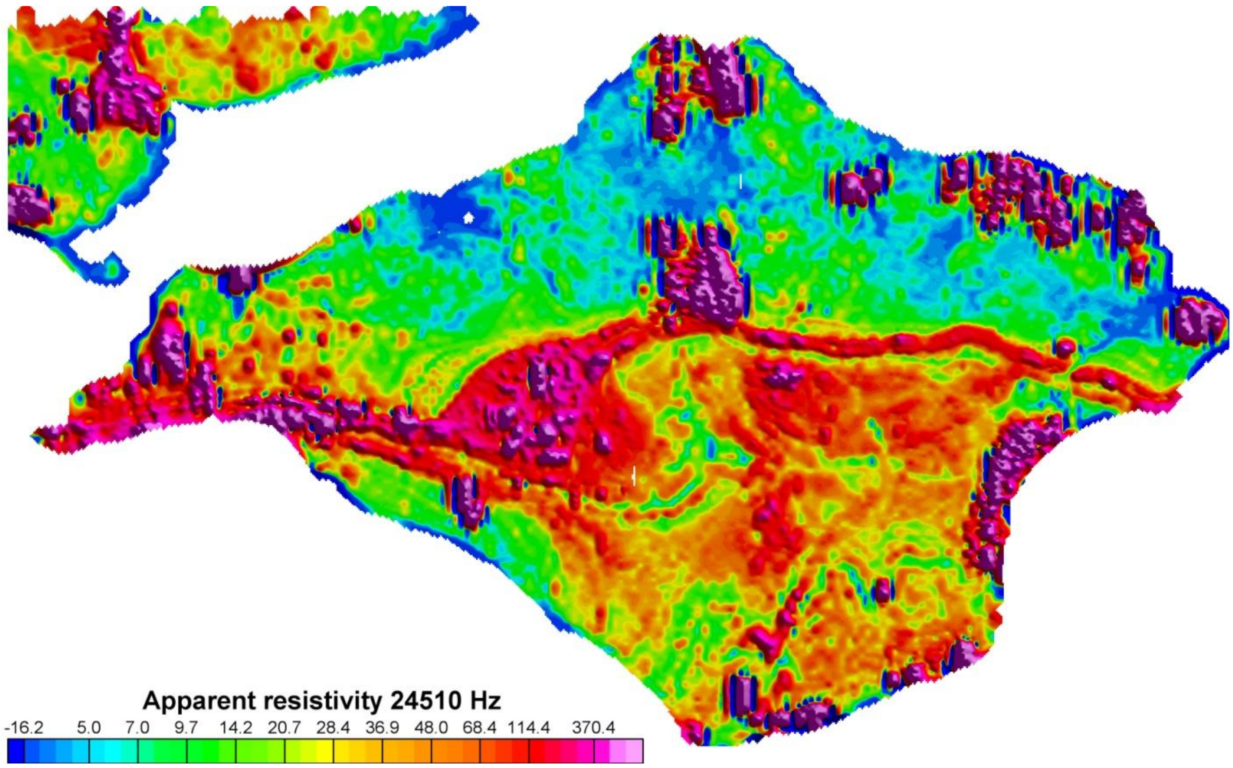

Figure 26. Isle of Wight, cut to coast: Apparent resistivity, 24.5 kHz.

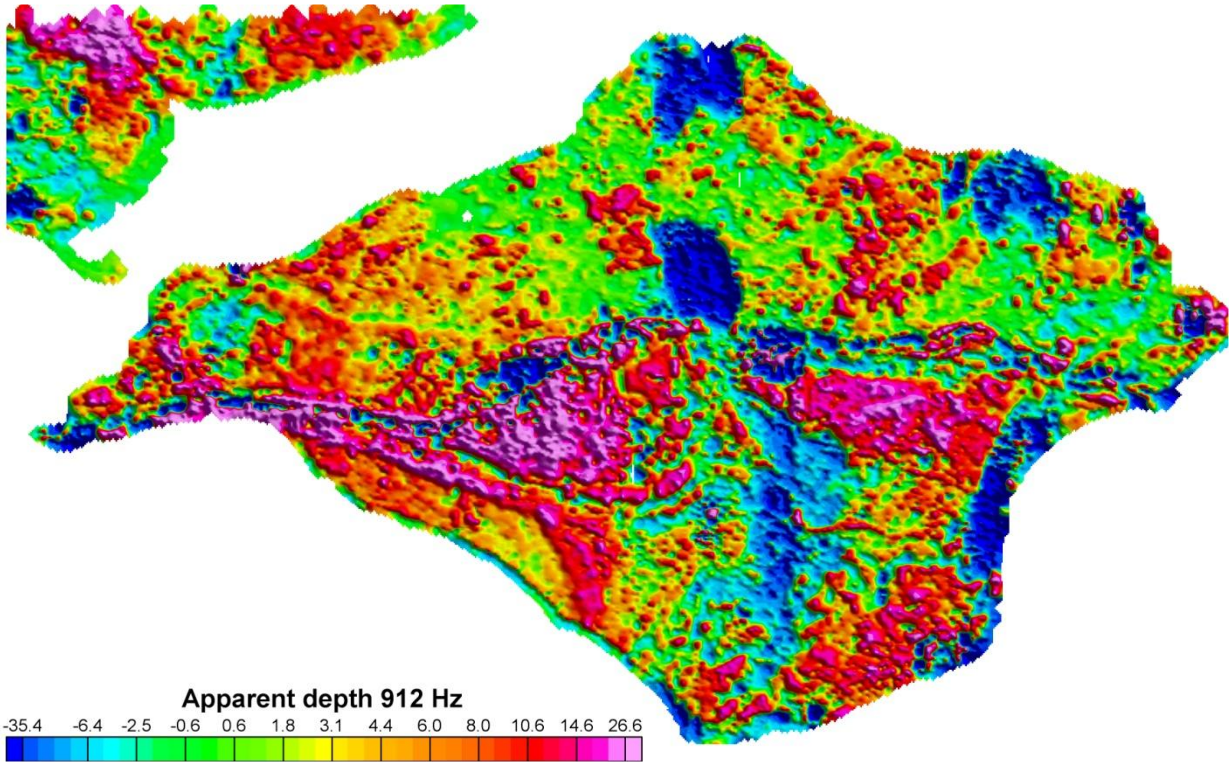

Figure 27. Isle of Wight: Apparent depth, 0.912 kHz.

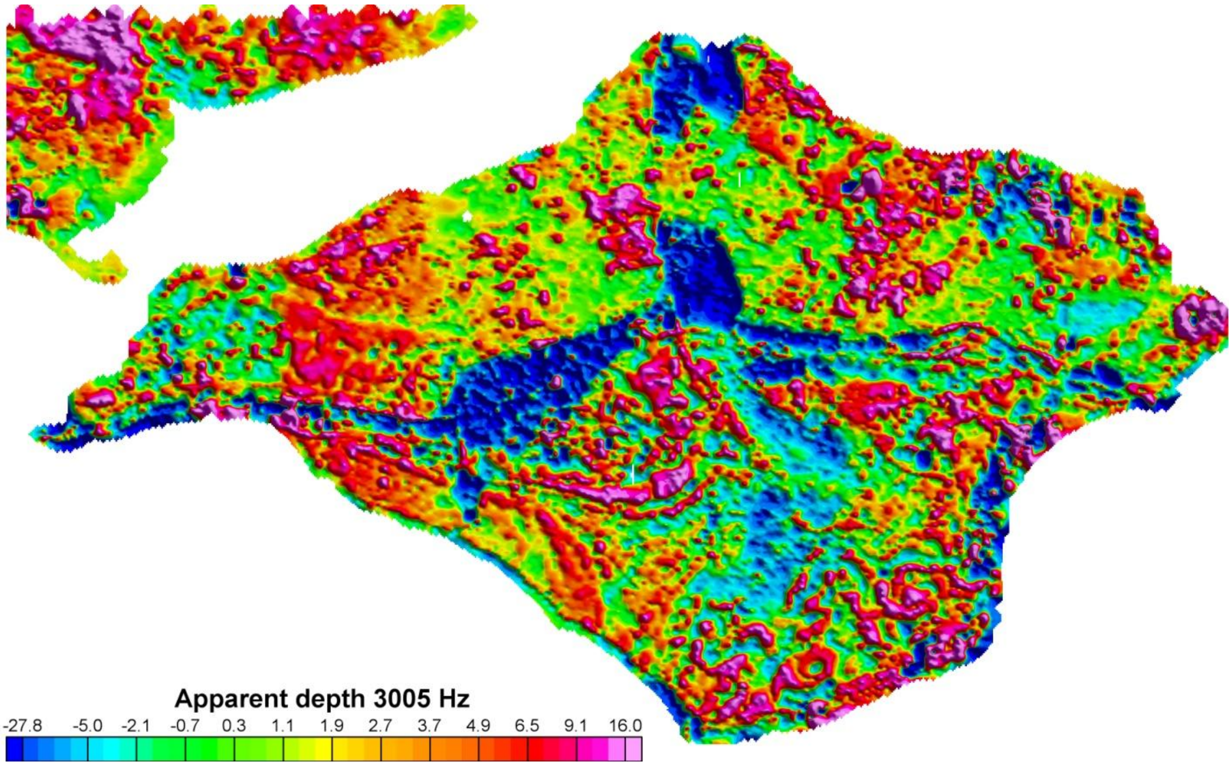

Figure 28. Isle of Wight: Apparent depth, 3 kHz.

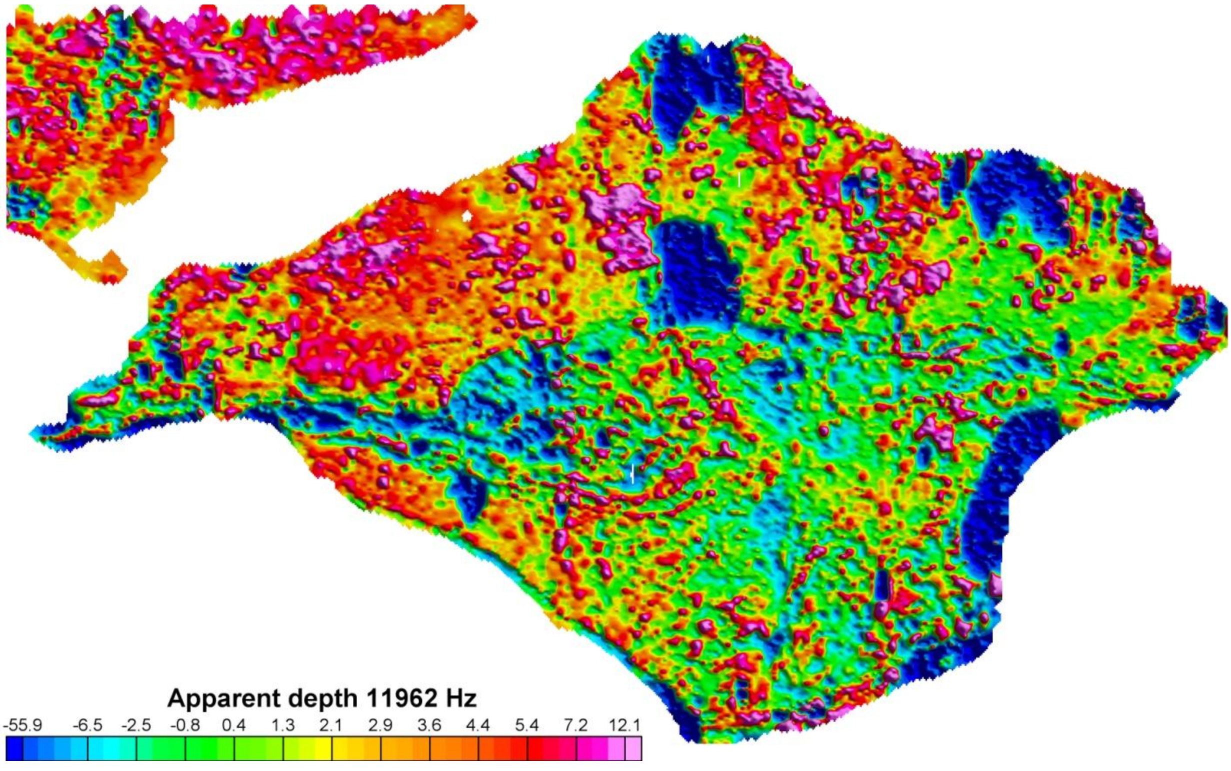

Figure 29. Isle of Wight: Apparent depth, 12 kHz.

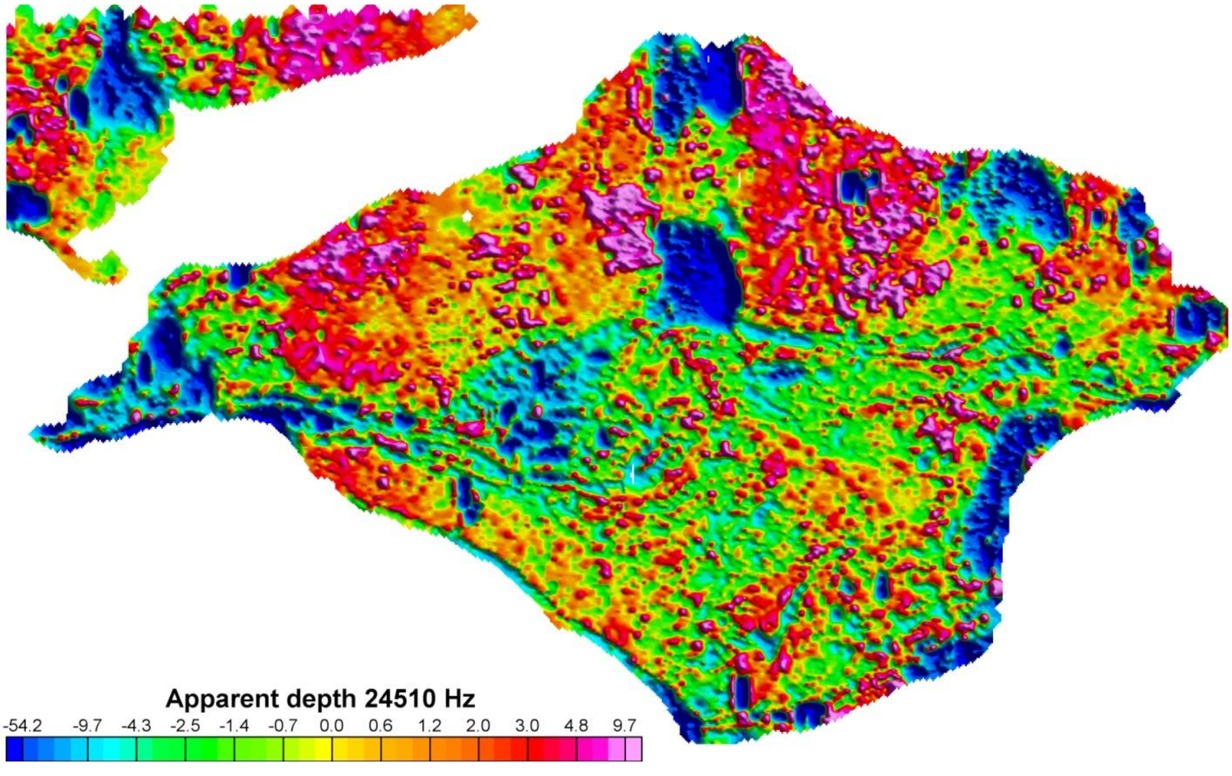

Figure 30. Isle of Wight: Apparent depth, 24.5 kHz.

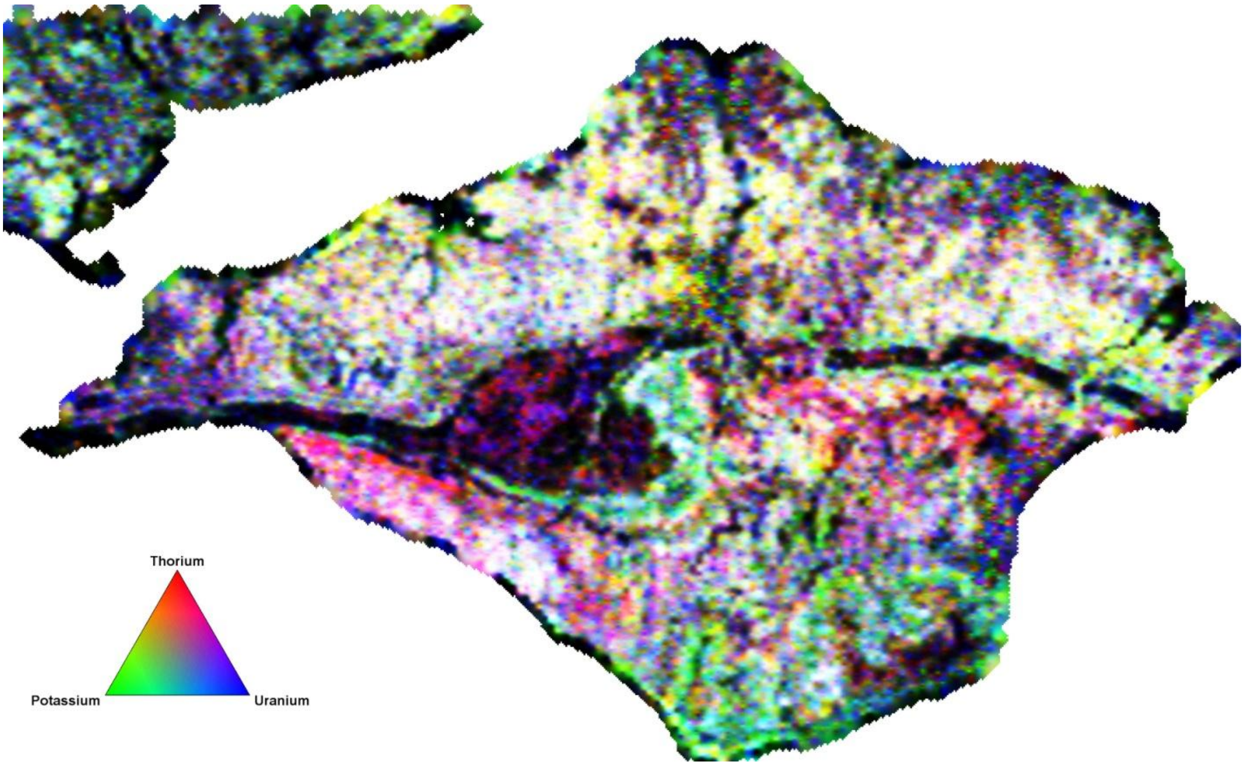

Figure 31. Isle of Wight: Radiometric ternary image.

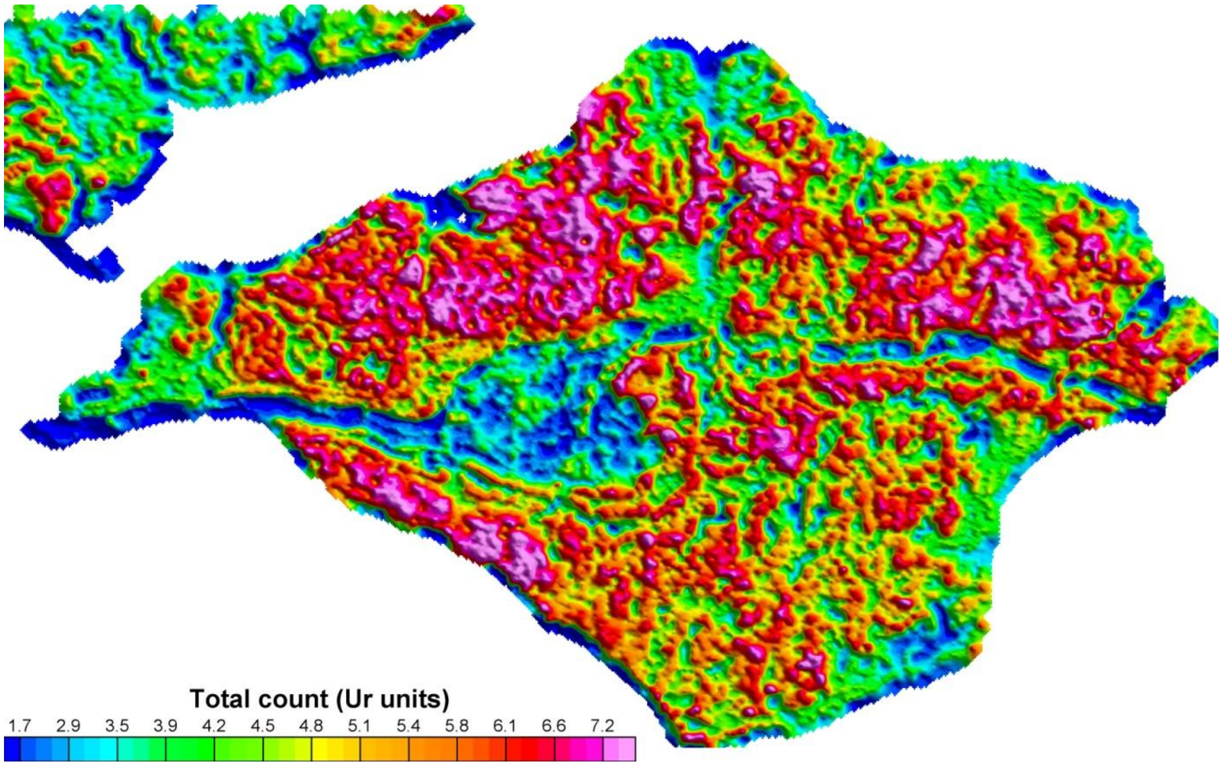

Figure 32. Isle of Wight: Total Count radiation (shaded relief).

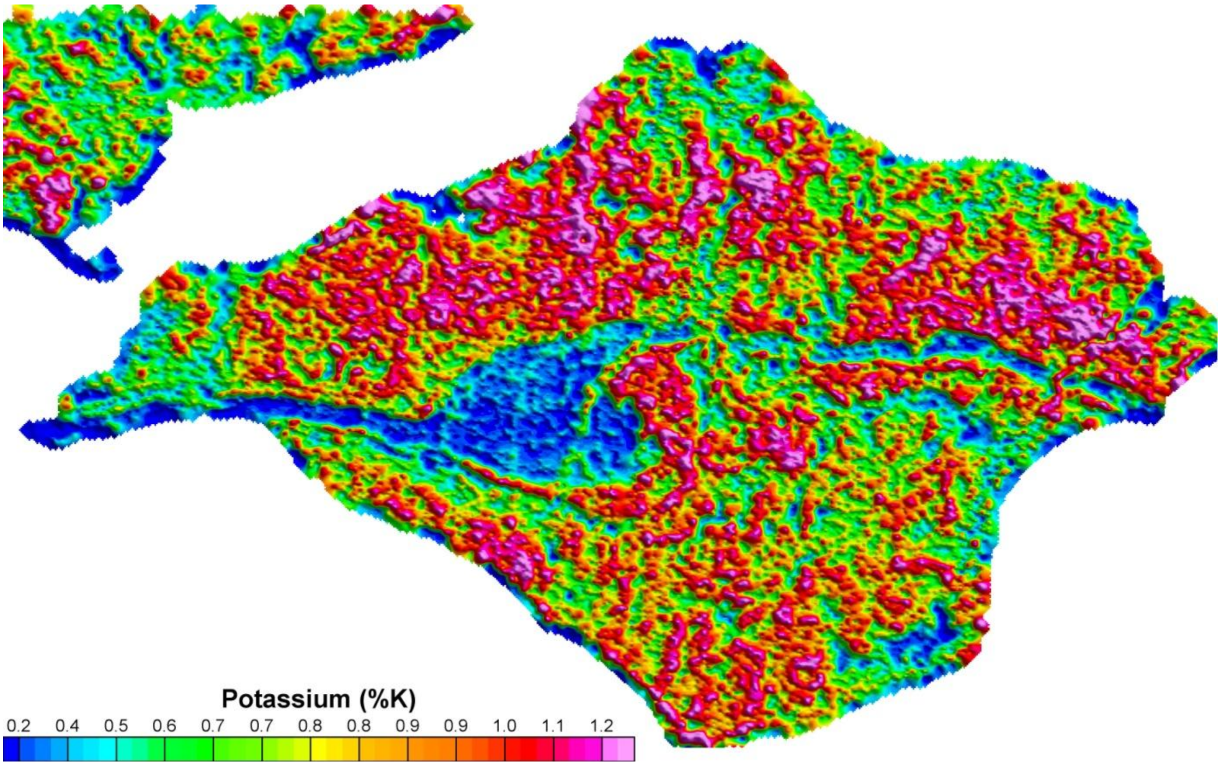

Figure 33. Isle of Wight: Potassium concentration (shaded relief).

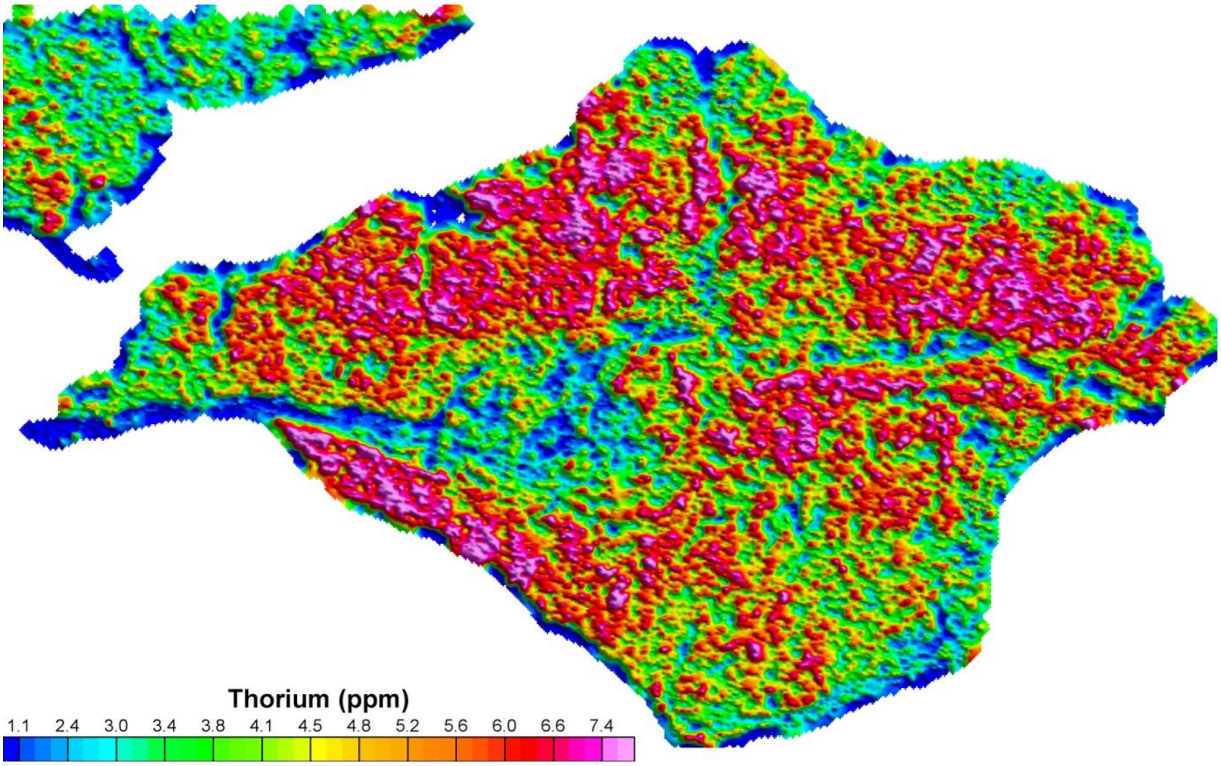

Figure 34. Isle of Wight: Thorium concentration (shaded relief).

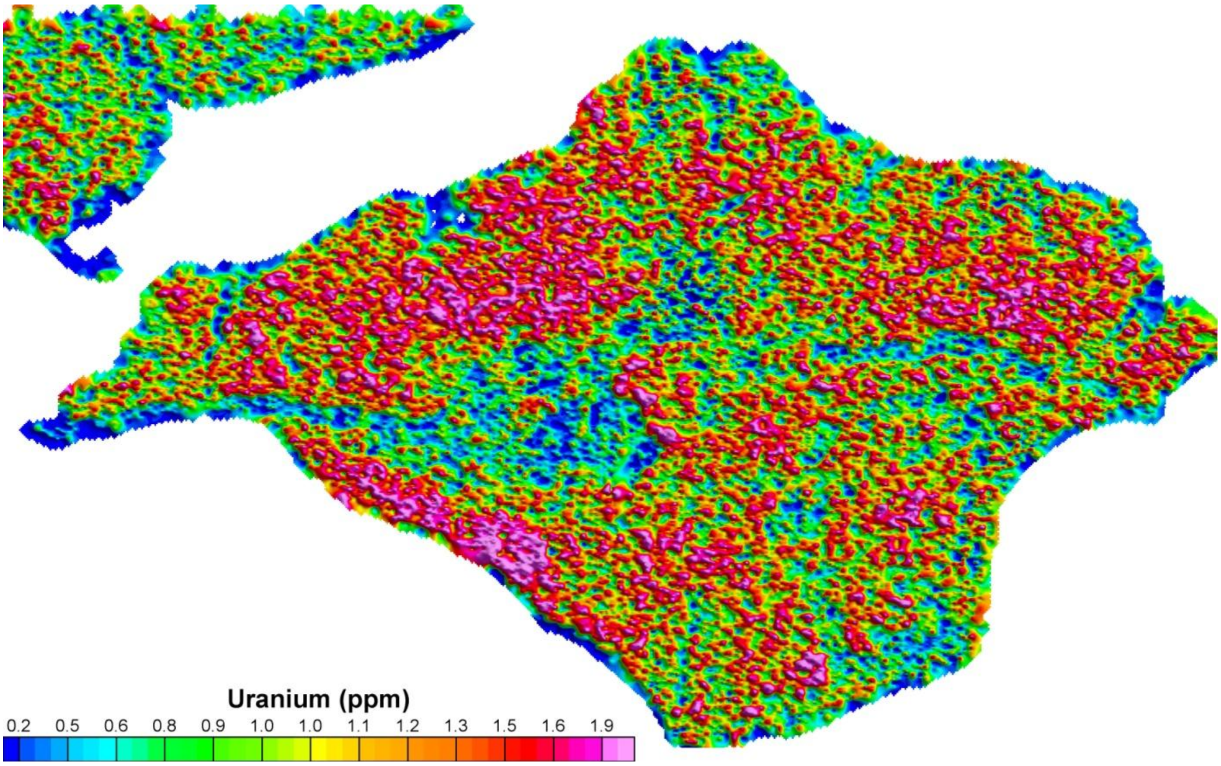

Figure 35. Isle of Wight: Uranium concentration (shaded-relief).

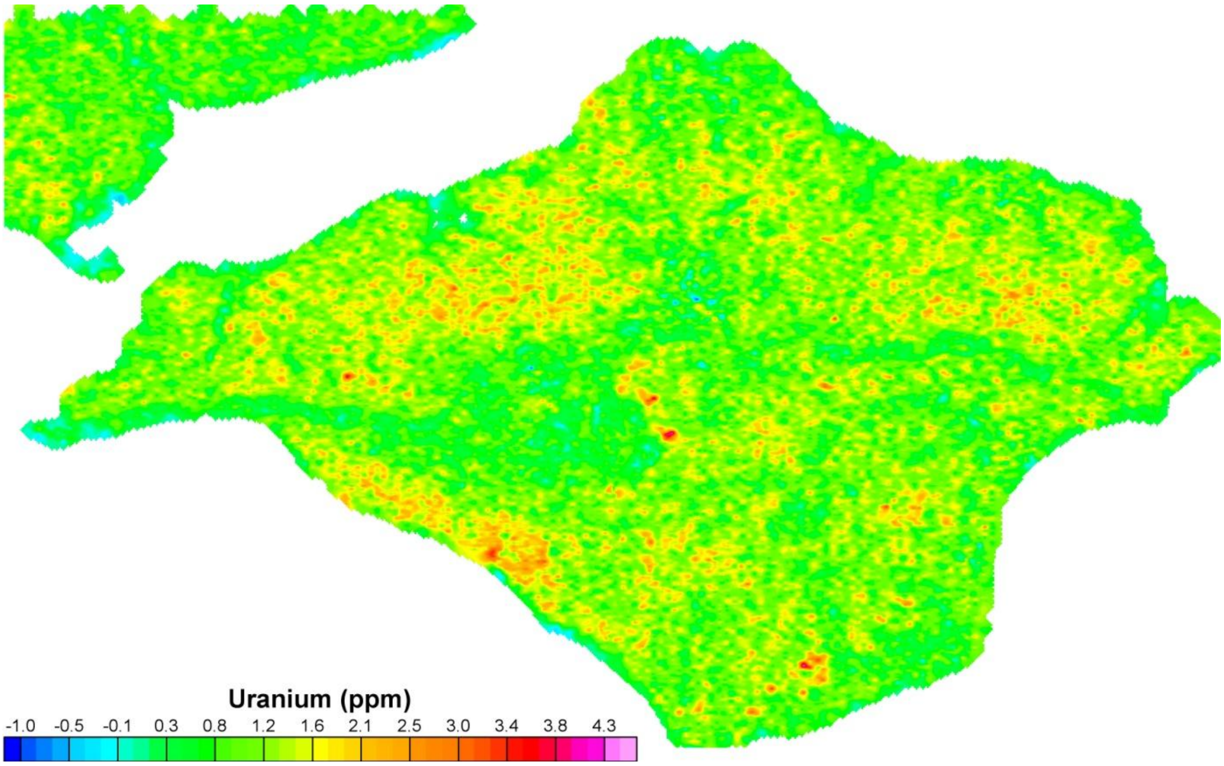

Figure 36. Isle of Wight: Uranium concentration (linear distribution).

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Appendix 1

THE MINIMISATION OF ERROR BETWEEN THE LINE DATA AND THE REGIONAL FIELD

Assuming that for each line the regional field can be expressed as $\mathbf{d^0}$, and the unlevelled line data as $\mathbf{d^1}$, both sampled equally at $\mathbf{x}$, where

$$\mathbf{d^0} = (d_1^0, d_2^0, \dots, d_N^0)^T$$

$$\mathbf{d^1} = (d_1^1, d_2^1, \dots, d_N^1)^T$$

$$\mathrm{x} = (x_1, x_2, \dots, x_N)$$

The error between equivalent nodes on $\mathbf{d^0}$ and $\mathbf{d^1}$ is determined to calculate $\Delta\mathbf{d}$ then a least squares minimisation is undertaken to calculate the optimal d.c. shift and tilt, expressed as f($\mathbf{x}$), to apply to line $\mathbf{d^1}$.

$$\mathrm{f}(\mathrm{x}) = a_0 + a_1 x$$

$$|\Delta\mathbf{d} - \mathrm{f}(\mathrm{x})|^2 = min$$

The minimisation technique is a fairly simplistic simulated annealing method that steps to a minimum solution unless specific criteria are met and random steps are introduced. Application of these corrections to $\mathbf{d^1}$ enables the method to output a levelled data set that maintains the line specific features without removal of any high frequency content.