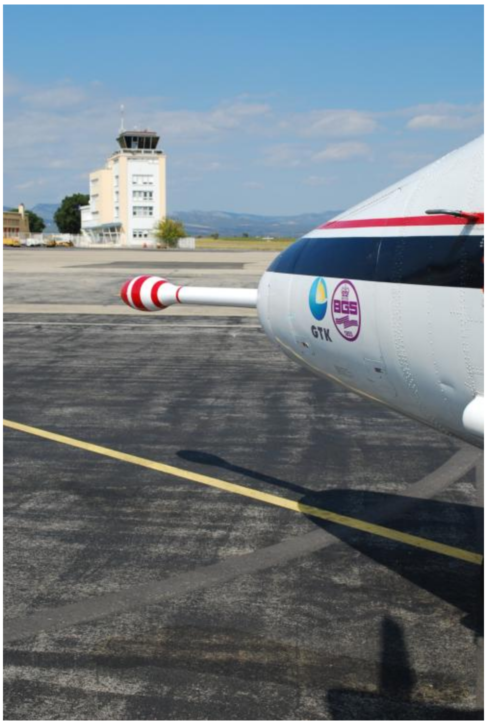
Perpignan Airborne Geophysical Survey

EUFAR projects: Aerosalt&Aerolit



Data Delivery Report

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October 2008

JAC
Joint Airborne-geoscience Capability
Geological Survey of Finland/British Geological Survey

Summary

This report accompanies the delivery of the airborne geophysical survey data from a project conducted in September 2008 in the vicinity of the Gulf of Lyons, in southern France. The Joint Airborne-Geoscience Capability (JAC) established between the Geological Survey of Finland (GTK) and British Geological Survey (BGS), carried out the survey under contract to EUFAR. The projects supported by the survey are AEROSALT and AEROLIT experiments. The principal client for the experiments is the BRGM.

The survey was conducted at high resolution (a flight line spacing of 100 m) and at low altitude (50 m) across the coastal zone of the Roussillon aquifer. The three main data sets acquired are magnetic, radiometric (gamma ray spectrometry) and active frequency domain electromagnetic. The aim of the present report is to provide descriptions of the final processing of the survey data. A previous report fully described the survey, logistics and initial QC and processing of the data.

BGS, Keyworth, October 2008

David Beamish	Robert Cuss
Project Manager	Project Geophysicist

1 Survey: Location and details

The EUFAR airborne geophysical survey in the vicinity of the Gulf of Lyons, east of Perpignan, was designed on the basis of the award of 30 hours survey time. Two joint experiments were awarded 10+10 = 20 hours (AEROSALT) and 10 hours (AEROLIT). The survey data for AEROSALT relates to increasing an understanding of the processes governing the saltwater spatial distribution in the Quaternary aquifers of Mediterranean coastal areas. The survey data for AEROLIT relates to an evaluation of airborne geophysical data in relation to coastal sedimentological studies.

The EUFAR awards for both experiments were in place towards the end of May 2008. The survey, in terms of line-km coverage, was designed using best-estimates of survey parameters to equate the 30 hours survey time to a high-resolution airborne survey design (e.g. a line separation of 100 m) for the two experiments.

Permitting of the survey via the French CAA and local authorities took until early August 2008. The authorities allowed a survey height of 50 m. A required condition was that the survey should not commence until after September 08, due to the potential for distraction of tourists by the survey.

1.1 SURVEY SCHEME

The full survey has been described previously in the survey logistics report. The total (ideal) line-km for the survey is 3948.5 (N-S) line-km with an additional 35 (5 x 7 km) line-km obtained from the 5 cross-lines. The actual survey includes many excess line-km obtained from longer-than-ideal lines. The main survey completed 4,427 line-km as shown in Table 1.

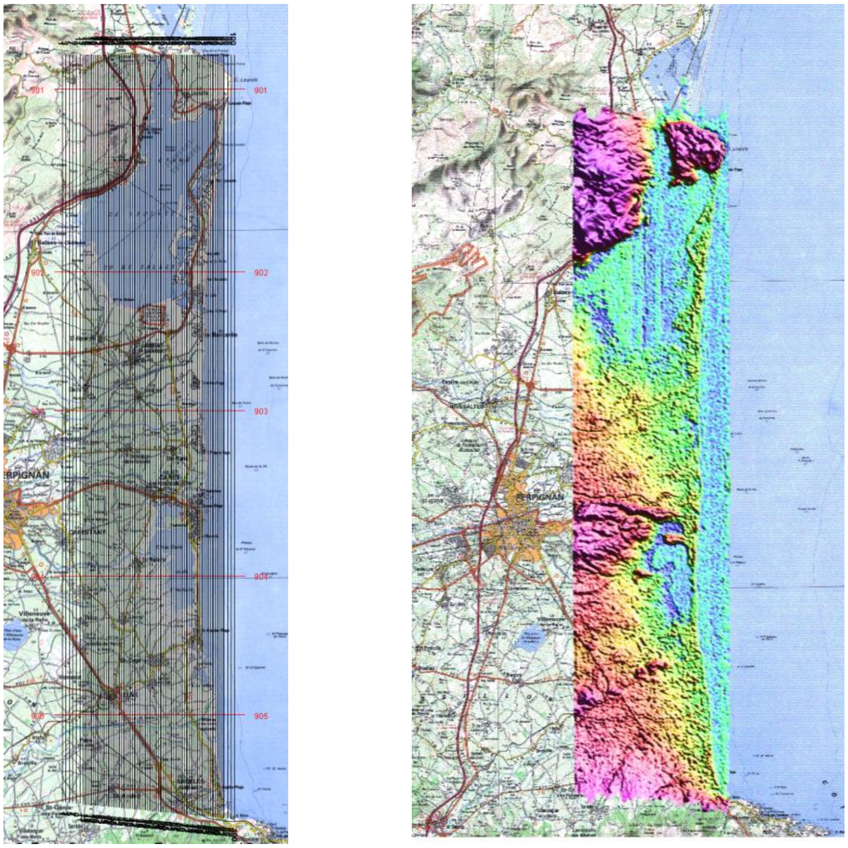


Figure 1. Perpignan survey area. Flight line plan (left) and image of the DTM obtained by the survey.

Table 1. Summary of planned and completed flight lines and survey line-km.

	Direction	***Line separation (m)***	***Number of lines***	***Line-km***
Plan, 2008	0/180	100	100	3,948
Cross-lines (7km)	90/270	8000-9000	5	35
Completed main survey (delivered)	0/180	100	100	4,427

Flights are described in the previous logistics report. Flight logs are supplied as digital scans (Adobe Acrobat) of Flights (138 to 146) as part of the final data delivery.

1.2 QC AND REFLIGHTS

Survey operations and flights are discussed in the previous logistics report. No reflights were undertaken due to technical issues. On the final flight (Flight146), 2 lines (Lines 013 and 014) were reflown due to QC specification limits. For this survey, the nominal reflight specifications applied were as follows:

i. Where ***flight line deviation*** is a maximum of 50 m or exceeds 30 m over a distance of 2 km. (except where ground conditions dictated otherwise, for example to avoid radio-masts etc).

ii. Where ***terrain clearance*** exceeds a maximum of 30 metres from the nominal survey height (50 m) or exceeds 15 m over a distance of 2 km.

iii. Where the ***sample separation*** exceeds 77 m i.e. an increase of 7m/s above the nominal maximum survey speed of 70 m/s.

The above conditions may be exceeded without a reflight where such constraints would breach air regulations, or in the opinion of the pilot, put the aircraft and crew at risk (e.g. wind farms).

The final terrain clearance QC assessment is shown below in Figure 2. Exceptions only occur in the north of the survey area where the topographic gradients exceed the climb/descent rates of the Twin-Otter. The flight path deviation is also shown and a small deviation also occurs in association with the most difficult topography.

1.3 COORDINATE SYSTEM

The local geographical grid system used for the data collection is WGS84 UTM zone 31N. The vertical (Z) coordinate is GPS-Z which is height above geoid (WGS94) in metres.

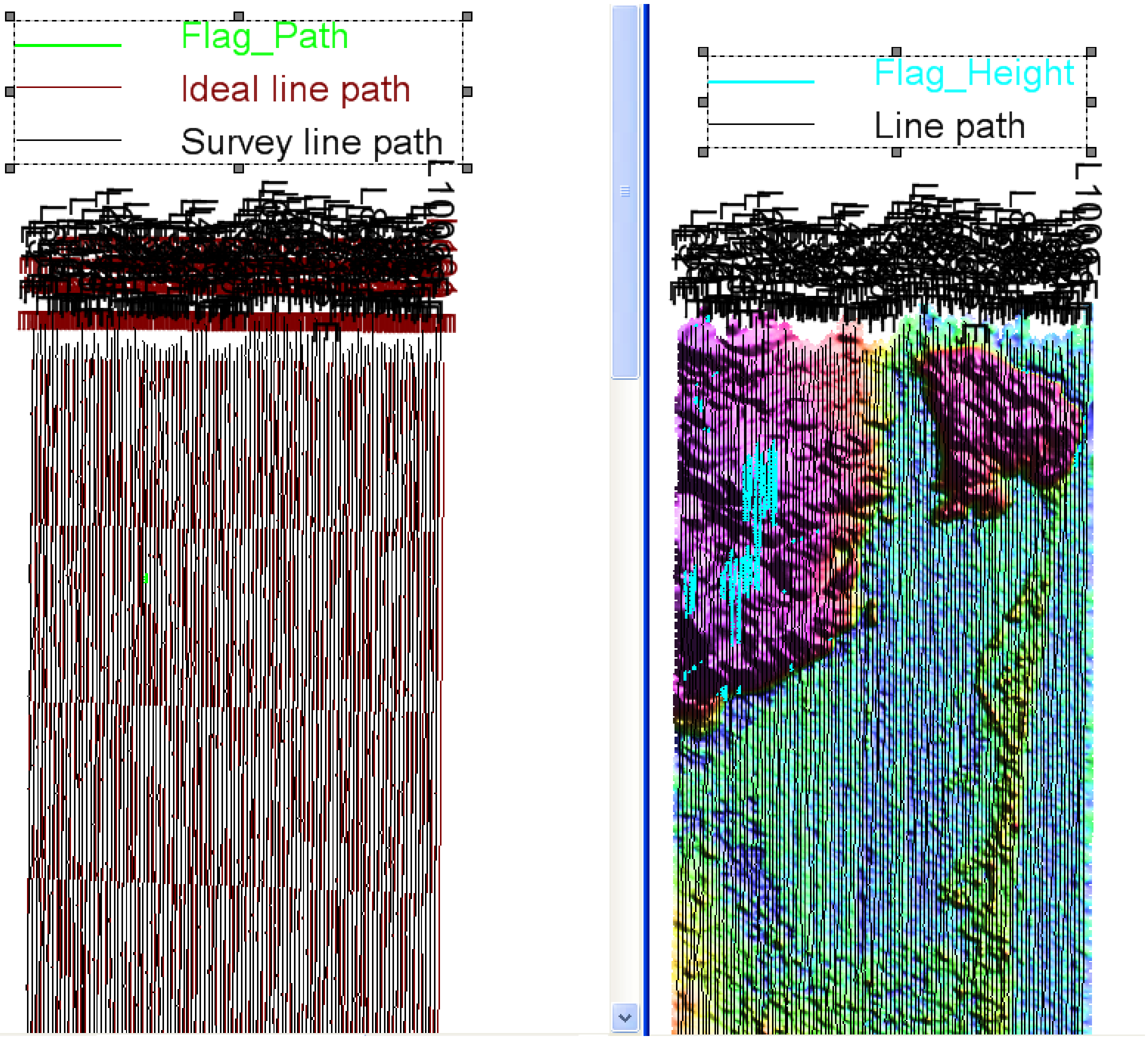


Figure 2. Final QC assessment of flight path deviation (left) and altitude deviation (right) shown on DTM.

2 Final processing

The images of the final delivered geophysical data are presented in Appendix 1. The data are delivered as Geosoft line-based (.xyz) ASCII data files. Line ends have not been trimmed meaning that the delivered xyz files include extended line ends thus providing as much data as possible. The images are produced using the final delivered grids in Geosoft Oasis Montage. The grids are produced by minimum curvature gridding of the final data sets. The images are all plotted using an equal-area colour normalisation of the grid values from lowest (blue) to highest values (red). The following sections describe the final processing applied to the data. Many of the details regarding initial calibration and processing of the data were provided in the previous survey logistics report.

2.1 CROSS-LINES

The survey included 5 E-W cross-lines, each about 7 km long. The line numbers range from 901 in the north to 905 in the south. These data have been processed alongside the main survey data, but are delivered as separate data files. Each of the 5 lines was flown twice in opposite directions i.e. East to West (DIR=270°) and West to East (DIR=90°).

It should be noted that the cross-lines are not intended to be conventional magnetic survey 'tie-lines' used in magnetic survey levelling. JAC normally uses virtual tie-lines during final levelling of the magnetic data. The procedure is described later.

The Crossline data, together with the Testline data (see below), have a number of issues in relation to the processing and levelling of the MAG and EM components. The MAG components have had no directional (i.e. heading) corrections applied and so offsets may be apparent in the data obtained in the two opposite directions. When survey lines are repeated, the line-path will inevitably differ in detail. In cases where strong localised cultural interference is observed, magnetic responses on repeated lines may differ significantly. In addition, cultural interference (and the level and form of the interference) can be temporal. A particular example, noted during the survey, was the intense perturbation to the MAG component that appeared to be associated with a DC railway system in the south of the area.

The Crossline data, together with the Testline data (see below) for the EM data components have proved difficult to process and level accurately because of:

(a) the short length of the lines. This results in difficulties in the estimation of the non-linear drift (EM data prelevelling). The EM prelevelling procedure is described later in Section 3.

(b) the lack of adjacent lines. This results in difficulties in the levelling of the EM components (EM data levelling). The EM levelling procedure is described later in Section 3.

(c) the conductive environment. This results in the higher frequency imaginary components tending to very low values, so that the processing procedures applied in (a) and (b) are further exacerbated.

These difficulties have resulted in only one set of cross-lines (the more reliable set) being included in the delivered EM CrossLine data set. The Crossline data sets for both RAD and MAG contain the 2 line data sets from each of the 5 cross-lines.

2.2 TEST-LINE (905) FOR RADIOMETRICS

The southern-most E-W cross-line 905 was designated a test-line. The test line was flown on 6 separate occasions during the course of the survey. One standard way of designating repeat data along the same line is to extend the line number designation e.g. 905 is the first data set acquired along Line 905, 9051 is the second data set acquired along Line 905, etc. This convention is used here in the delivery of the test-line data set.

3 Electromagnetic data

This section describes the processing procedures applied to the electromagnetic data.

3. 1 PRELEVELLING

The prelevelling procedure is described by Leväniemi et al. (2008). Although this procedure is conducted in the field, it is refined further at the post-processing stage. A zero-level is adjusted to an artificial level at the beginning of each survey flight to ensure a large enough scale to register both positive and negative anomalies. The registered values then are independent of the real zero-level. This calibration is performed at a high altitude (e.g. 300 metres above ground) to provide an out-of-ground response. The zero-level calibration procedure is repeated at the end of each flight. The level of the EM data can be corrected linearly using these calibration results. This preliminary automatic 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 in an hour if there is no temperature gradient. If the flight lines are long, the air temperature can sometimes vary significantly during a flight line, and this may introduce a non-linear drift to the zero-level. A temperature variation of one degree centigrade changes the coil separation so that the zero-level may change by about 70 ppm. 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, which may have a non-linear relationship with the variation in wing length due to temperature change, and hence the coil separation. There are also other reasons for this drift, such as temperature variations in the coils and in other analogue components, which are never ideal.

The non-linear drift is estimated for each flight and for each EM component. 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 during that flight for each component. 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.

The Figure below shows an example of the procedure applied to the real 912 Hz component data.

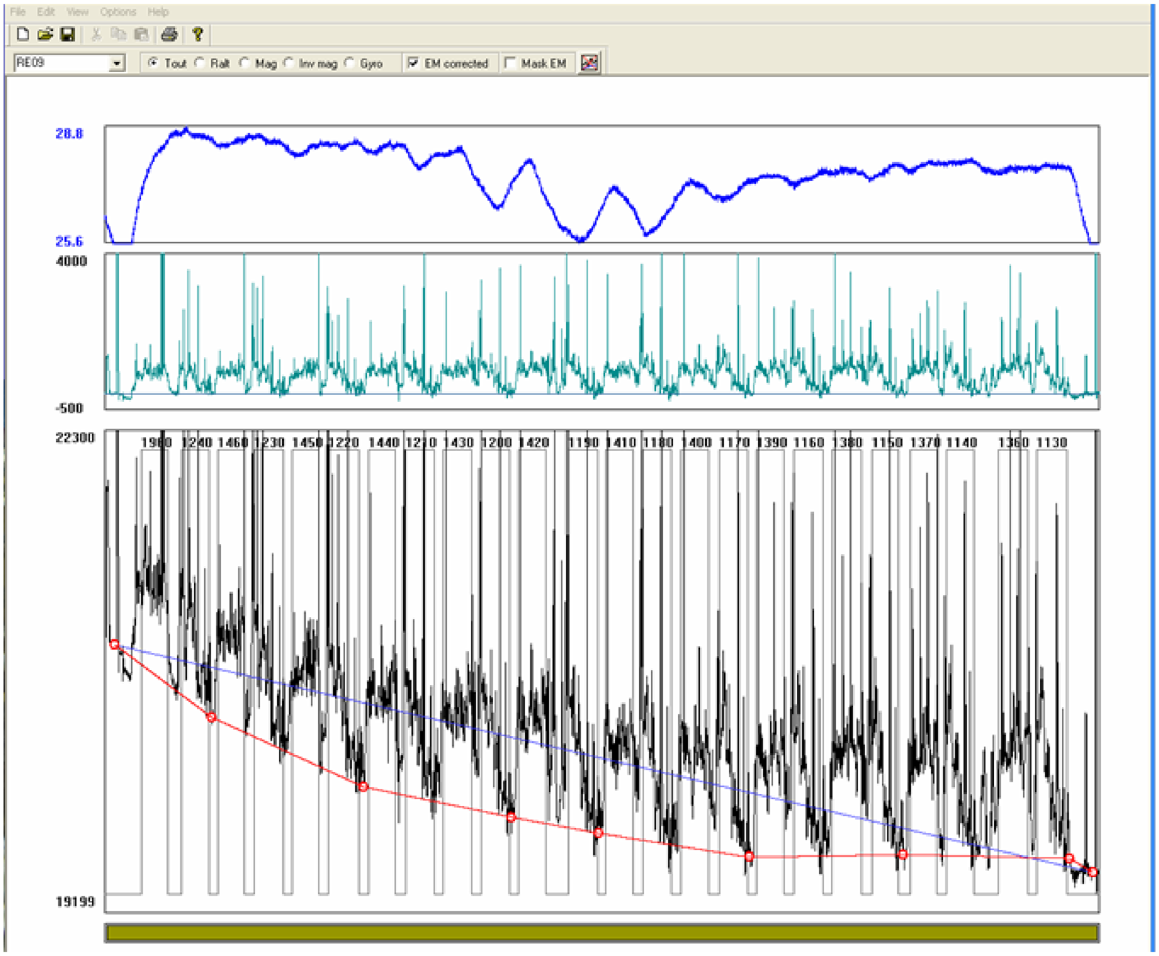


Figure 3 Example of Emprelev applied to 900 Hz real component profile of one complete flight (24 flight lines) presented together with the drift estimation points (small red circles) and linear drift estimation line (blue), which connects the calibration points and the first and last red circles. It can be seen that the non-linear drift estimation gives a far better result than the automatic linear estimation.

3.2 LEVELLING

The prelevelling is followed by a further line-by-line checking and adjustment (if required) of the zero levels of each line of data and of each component. A JAC graphical Windows program, Level32 is used for this purpose. An example of this program is presented below.

A variable number of profiles of an EM component can be presented simultaneously in a window. Lines are sorted in the data file, and adjacent profiles are compared to provide information about line-to-line behaviour 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 case of a fast drift three or more points might be used.

Using the above procedures, the EM data from individual lines, may have been de-trended (linear and non-linear) and a residual offset may have been applied. These procedures are line-based and do not perturb the EM data anomalies that have an expected wavelength much less than the line length. The data provided are the most appropriate data for use in quantitative procedures (e.g. modeling/inversion) that require minimum filtering/distortion of individual anomalies.

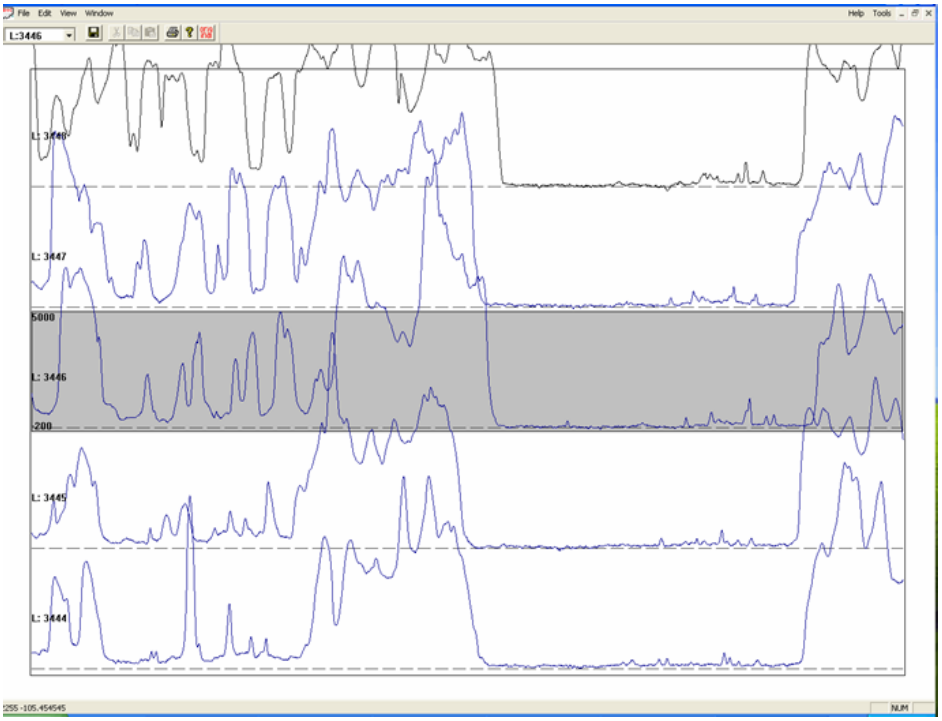


Figure 4 Example of LEVEL32 applied to 3 kHz real component across 5 sequential flight lines (3 are usually used). DC level adjustments are interactively made to each line (current line for adjustment is shown in grey).

3.3 MICROLEVELLING

When the above data are gridded, small residual line-to-line levelling errors may become apparent. This is especially true when gridding EM data that are line-spaced by small amounts, such as 100m, as is the case in the Perpignan survey. These may be 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 and images. Most microlevelling procedures apply filters and spatial averages to individual and multiple lines. All such procedures have limitations and are capable of distorting data. The application of such procedures depends (usually) on a set of control parameters (e.g. those associated with filters and spatial wavelengths). For each data set, a level of judgement is required to balance/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 (typically 1000 m for regional surveys, 500 m was used here) and an across-line radius that controls the number of lines involved in estimating the result at a particular point. Using a value of 150 m, 3 lines are used in the procedure (for a flight line spacing of 100 m). This can be regarded as ‘light’ levelling.

The levelling 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 extend. The amount of filtering this procedure performs is seen as being a good balance between levelling and smoothing. Many procedures exist that would create a much more esthetically pleasing result, but these all overly smooth data. The FMD routine does have some characteristics that are worth noting. In data situation where data levels change rapidly, such as a step, the FMD routine can create large negative spikes on a down-step.

3.4 ESTIMATION OF APPARENT RESISTIVITY AND APPARENT 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. No misfit error is provided (Beamish, 2002). The transformation programs used are based on a JAC version of TRANSAEM. The program employs minimum limits on the real and imaginary coupling ratios to identify the noise level in the coupling ratios. The figures typically used here are 10, 30, 50 and 70 ppm for frequencies of 09, 3, 12 and 25 kHz. The same levels were applied to both real and quadrature components. If either the real or imaginary components (or both) fall below these threshold values, the half-space calculation is deemed unsafe, and the component is set to the threshold value.

The behaviour of the AEM-05 coupling ratios for a range of half-space resistivities is shown below.

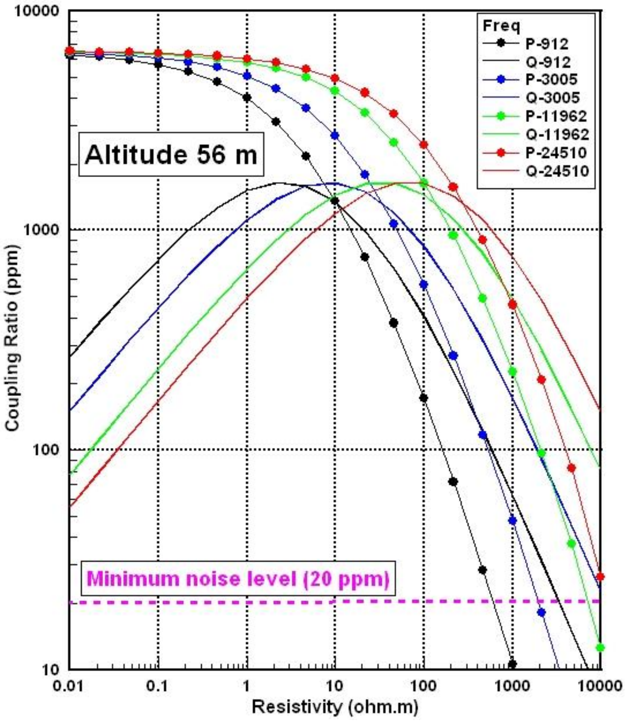


Figure 5 Four frequency AEM-05 coupling ratios (in-phase = P, quadrature = Q) across a range of half-space resistivities, at an elevation of 56 m.

A system noise level of 20 ppm is indicated. The actual survey noise levels in the EM channels may be higher. It can be seen that, particularly in resistive terrains, the lower frequency in-phase (P) components may approach and descend into the noise level. This behaviour limits our ability to obtain valid estimates of apparent resistivity and depth. 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.

In areas of very low resistivity (high conductivity), the imaginary component tends to zero; the effect is most pronounced at the highest frequency. When the imaginary component value falls below the noise level, the estimate of the half-space resistivity becomes uncertain and noisy. The apparent resisivity data have been clipped to a low value of 0.05 ohm.m (20,000 mS/m), although, at the highest frequencies noise may enter the estimate of apparent conductivity as values exceed 5000 to 6000 mS/m.

Under certain conditions, apparent resistivity and depth data require microlevelling as previously described for the EM in-phase and quadrature components. A special version of the Floating median difference (FMD) method for apparent resistivity has been developed for that purpose. The microlevelling program APLEV uses an along line radius (500 m for this survey) and an across-line radius that controls the number of lines involved in estimating the result at a particular point. Using a value of 150 m, 3 lines are used in the procedure (for a flight line spacing of 100 m).

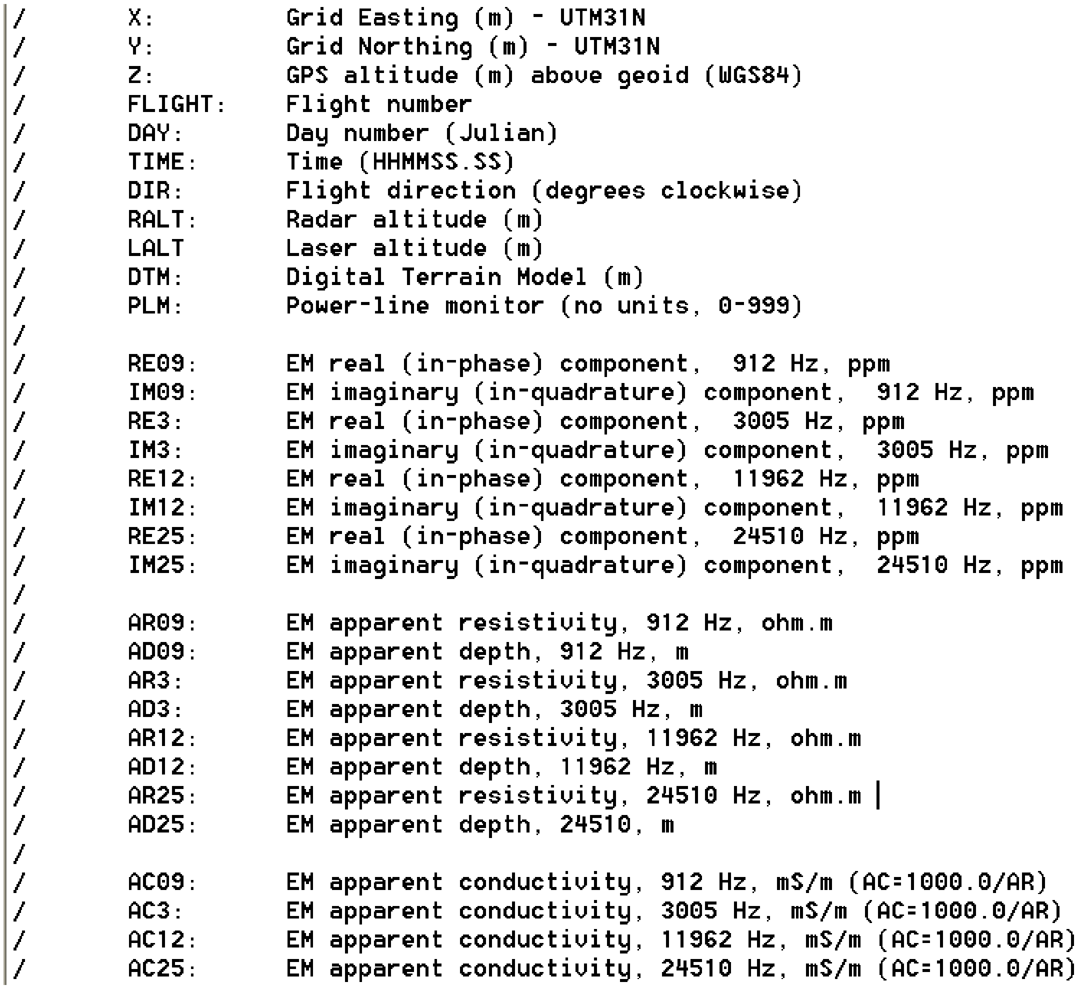
One ought to be aware that the apparent resistivity and depth data and maps are an application of a half-space model. The appropriateness of this model must be ascertained before an interpretation is made. The method used assumes:

- Uniform half-space (i.e. 1D) with fixed resistivity
- Relative magnetic permeability = 1, and ignoring dielectric effects (electrical permittivity).
- No other sources of EM (no power-line interference, etc)

3.5 EM DATA DELIVERY

Electromagnetic data are delivered as a single data set. The following summarises the header of the supplied EM data:

Perpignan_EM_AP.xyz. This file contains the levelled (but not microlevelled) EM data. The AR/AD half-space parameters have been microlevelled. The AC parameters are converted from the AR parameters using AC=1000.0/AR. This is the main data set.



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/       X:          Grid Easting (m) - UTM31N
/       Y:          Grid Northing (m) - UTM31N
/       Z:          GPS altitude (m) above geoid (WGS84)
/       FLIGHT:     Flight number
/       DAY:        Day number (Julian)
/       TIME:       Time (HHMMSS.SS)
/       DIR:        Flight direction (degrees clockwise)
/       RALT:       Radar altitude (m)
/       LALT        Laser altitude (m)
/       DTM:        Digital Terrain Model (m)
/       PLM:        Power-line monitor (no units, 0-999)
/
/       RE09:       EM real (in-phase) component,  912 Hz, ppm
/       IM09:       EM imaginary (in-quadrature) component,  912 Hz, ppm
/       RE3:        EM real (in-phase) component,  3005 Hz, ppm
/       IM3:        EM imaginary (in-quadrature) component,  3005 Hz, ppm
/       RE12:       EM real (in-phase) component,  11962 Hz, ppm
/       IM12:       EM imaginary (in-quadrature) component,  11962 Hz, ppm
/       RE25:       EM real (in-phase) component,  24510 Hz, ppm
/       IM25:       EM imaginary (in-quadrature) component,  24510 Hz, ppm
/
/       AR09:       EM apparent resistivity, 912 Hz, ohm.m
/       AD09:       EM apparent depth, 912 Hz, m
/       AR3:        EM apparent resistivity, 3005 Hz, ohm.m
/       AD3:        EM apparent depth, 3005 Hz, m
/       AR12:       EM apparent resistivity, 11962 Hz, ohm.m
/       AD12:       EM apparent depth, 11962 Hz, m
/       AR25:       EM apparent resistivity, 24510 Hz, ohm.m
/       AD25:       EM apparent depth, 24510, m
/
/       AC09:       EM apparent conductivity, 912 Hz, mS/m (AC=1000.0/AR)
/       AC3:        EM apparent conductivity, 3005 Hz, mS/m (AC=1000.0/AR)
/       AC12:       EM apparent conductivity, 11962 Hz, mS/m (AC=1000.0/AR)
/       AC25:       EM apparent conductivity, 24510 Hz, mS/m (AC=1000.0/AR)
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4 Radiometric data

The standard corrections and calibrations made to the Radiometric data were described in the previous logistics report. Here some further additional notes relating to the delivery of the final radiometric data are provided.

4.1 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 214Bi and 208Tl 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.

4.2 RADON BACKGROUND

Radon gas makes it difficult to measure uranium concentrations accurately. It is not always evenly distributed in the air and thus eliminating it from background radiation is not simple. Determination of the constants necessary for the correction of the background due to radon using upward detectors requires several steps. 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 Minty (1995) is more reliable than that in IAEA (1991) for the second step.

Examination of the upward looking data and the Uranium result for this survey suggests that there is not a problem with Radon. The problems radon creates are usually very localised and not consistent from flight line to flight line. This usually results in flight lines that appear "out-of-level." Radon is the main cause for levelling issues with Uranium.

4.3 LEVELLING OF RADIOMETRIC DATA

Radiometric data are commonly affected by atmospheric radon, which is not fully removed by the processing procedure. This problem is usually seen as a raised “level” of a complete line. There are a number of processing procedures designed to level data, some of which are specific to radiometrics and others that are general for geophysical data. Levelling errors are usually only observed in Uranium and Total Count.

The method of Green (1987) uses data for U, Th and K in order to identify the error in U based on their 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 is removed from every uranium data point along line; therefore only DC-shifts are applied per line.

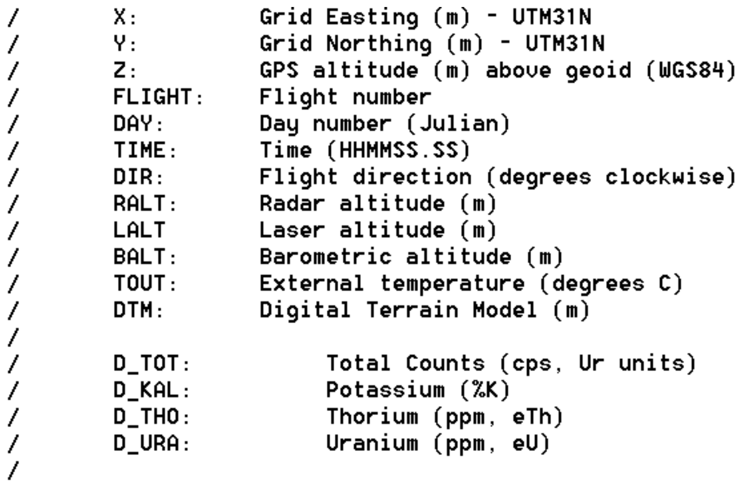
The uranium data set suffers from background changes usually associated with the decay of atmospheric radon. The magnitude of this atmospheric background is dependent upon the weather and the time of day. The same changes are evident in the Total Count channels but they do not affect to the same extent the thorium and potassium channels. 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 of flight-line means for the uranium and Total Count channels is performed on the flight-line means for thorium and potassium: $\overline{Y} = a * \overline{K} + b * \overline{T}h + c$, where Y stands for uranium or Total Counts.

On close inspection of the radiometric data there are only minor levelling issues (probably with less than 5 lines). Green's levelling has been performed on uranium and total counts, but these do not seem to have changed data values very much.

4.4 RADIOMETRIC DATA DELIVERY

Radiometric data are delivered as a single data set. The following summarises the header of the supplied data:

Perpignan_RAD.xyz.



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/       X:          Grid Easting (m) - UTM31N
/       Y:          Grid Northing (m) - UTM31N
/       Z:          GPS altitude (m) above geoid (WGS84)
/       FLIGHT:     Flight number
/       DAY:        Day number (Julian)
/       TIME:       Time (HHMMSS.SS)
/       DIR:        Flight direction (degrees clockwise)
/       RALT:       Radar altitude (m)
/       LALT        Laser altitude (m)
/       BALT:       Barometric altitude (m)
/       TOUT:       External temperature (degrees C)
/       DTM:        Digital Terrain Model (m)
/
/       D_TOT:            Total Counts (cps, Ur units)
/       D_KAL:            Potassium (%K)
/       D_THO:            Thorium (ppm, eTh)
/       D_URA:            Uranium (ppm, eU)
/
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5 Magnetic data

This section describes the processing procedures applied to the Perpignan 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 acquired were reprocessed in the office to provide validated (uniformly correct calibration factors) data sets. The main magnetic software package used in these procedures is the JAC software package MAGCOR.

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

5.1 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. 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.

5.2 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 exceeds these limits are rejected in the field and reflown, but all data are re-checked for 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 basestation in the JAC software package Mag32. In practice it was not necessary to adjust the default values.

5.3 LAG CORRECTION

A lag test is performed to verify the recording delay. Due to the real time RMS compensation, it's pre-filtering, 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 but sideways wide 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.

5.4 HEADING CORRECTION

The aircraft is a magnetised metallic body moving in the Earth's magnetic field. This results in different magnetic values recorded in the two flight line directions (000/180°). Heading corrections for the Perpignan survey were as follows:

Direction	Left magnetometer	Nose Magnetometer
000	0.0	+0.2
180	-7.9	-12.6

The heading correction applied by MAGCOR is a simple DC shift of line data based simply on the direction of travel.

Heading correction error is one of the most common sources of levelling error after data processing. Heading corrections are not always stable with time or may vary when objects are taken from or placed within the aircraft. A heading correction refinement can occur later in the processing stream prior to levelling by examining the statistics of entire survey data. The calculation of the mean for the two different flight directions can show the error in heading correction. This extra stage of heading correction was applied to the Perpignan survey and merely makes the virtual tie-line levelling stage (described later) shorter.

5.5 AIRCRAFT INFLUENCE

The aircraft has a number of mission-critical system on board that create a magnetic source that 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 1 – 2 seconds during its operation. The hydraulic pump is mission critical and has been shielded as much as possible. It tends to operate after long periods of significant rudder and ailerons use, such as in mountainous regions. When the pump is operated, the duration is recorded and the magnetic data is then removed automatically. 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 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.

The nature of the hydraulic pump, VHF and windscreen wipers is not predicable and cannot be easily corrected for. Therefore data removal is the only option.

5.6 DATA QC

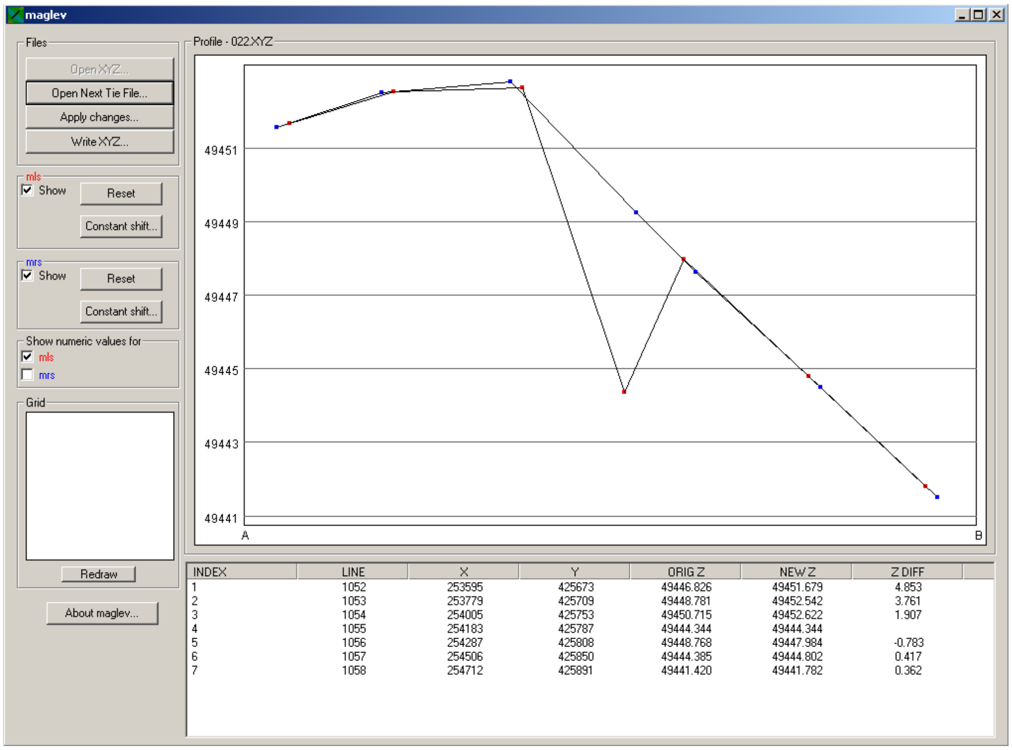
After data processing using the MAGCOR program, the data are imported into Geosoft Oasis montaj and are thoroughly checked. At this stage, all residual remaining errors (such as spikes, VHF communications, etc.) are corrected if observed.

5.7 LEVELLING MAGNETIC DATA

Some levelling of magnetic data is still needed after all the corrections described above. One source of residual error is the incomplete diurnal correction. Magnetic base stations are almost always located some distance from the measuring aircraft; but the transient field varies in time and also space. The error is small, usually less than 1 nT, but it can be very clearly 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. The tie line correction is ineffective due to the 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 at these points. As this survey included cross-lines it was possible to attempt traditional tie-line levelling techniques. However, the fact that the majority of the survey is affected by cultural noise sources, this method did not work.

JAC uses the Virtual Tieline Levelling approach in order to level magnetic data. This uses the MAGLEV program. Left and Nose channel data are read into the program, along with virtual tielines. These are lines that are digitised from within Geosoft Oasis montaj on maps of magnetic data. Lines are selected that crosscut flight lines in areas of low magnetic gradient. Data are then displayed in MAGLEV, as shown below. Commonly it is easy to spot singular lines that are out of level and these can be adjusted into level interactively. A simple DC shift for each adjusted line is applied to the entire line. It is common to digitise two lines that cross all suspect lines so as to reduce the likelihood of adjusting a flight line based on a localised gradient as opposed to the regional gradient. When levelling errors are derived from heading corrections, it is common to observe that one of the magnetometers, e.g. the left one, is well adjusted and that the other (nose magnetometer) is not. This then usually dictates that the nose one would be adjusted to the level of the left one, or vice versa.



INDEX	LINE	X	Y	ORIG Z	NEW Z	Z DIFF
1	1052	253595	425673	49446.826	49451.679	4.853
2	1053	253779	425709	49448.781	49452.542	3.761
3	1054	254005	425753	49450.715	49452.622	1.907
4	1055	254183	425787	49444.344	49444.344	
5	1056	254287	425808	49448.768	49447.984	-0.783
6	1057	254506	425850	49444.385	49444.802	0.417
7	1058	254712	425891	49441.420	49441.782	0.362

Figure 6 The MagLev program as used for virtual tie line levelling. This view shows that the left magnetometer values (in red) are being adjusted to match the right ones (in blue). One flight line is still to be adjusted. This example is not from the Perpignan survey.

The high degree of cultural noise in the Perpignan survey area meant that virtual tie-line levelling did not remove all the levelling error. Therefore other methods had to be explored in order to level the data.

The data were levelled using the bi-directional levelling routine. This technique aims to separate the long-wavelength, regional, magnetic field. The high frequency shallow geological signal is then adjusted to this regional field. This method was unsuccessful for the Perpignan survey for two reasons. Firstly the survey area is not very substantial in size, so the regional field cannot be separated very well. This problem is compounded by the degree of cultural noise in the area. For overlapping anomalies, such as seen in towns or villages, these can often get separated out as longer wavelength features and can appear geological. This technique did not produce satisfactory results.

A short experiment was conducted to see if the JAC RADLEV routine would work on magnetic data, or at least identify the regional field. RADLEV is a median filter that has a width and length about every survey point. With trial and error appropriate parameters can be selected to adjust cross-line levelling errors. RADLEV is similar to EMLEV. With experience we are aware of the limitations of RADLEV, which can cause artefacts when clear steps are seen in the data.

RADLEV was run on the magnetic data and the results were imported into Geosoft. The difference between the starting un-levelled data, and the RADLEV result were carefully examined. This showed that too much geological signal was being removed. A B-spline was fit to the microlevelled result to create a much more acceptable long wavelength correction. The result of this is delivered as MGCL_Lev. The full RALEV microlevelled result is also delivered for MGCL_RALEV.

5.8 SHORT-PERIOD DRIFT OF THE MAGNETOMETERS

When data are closely spaced small variations in magnetic signal between the left and nose magnetometer are obvious when data are gridded using minimum curvature. No correction is made to the altitude of both magnetometers, therefore if the aircraft is nose down in pitch the difference in altitude between the nose mounted and wing-tip magnetometers is greatest. In the condition of nose-up pitch the altitude difference is reduced. Variations are also encountered based on roll and yaw. These movements lead to small variations that make tying in both magnetometers very difficult and virtual tie line levelling may not solve fully the problem.

In order to tie the two dataset together it was necessary to first level the data using the virtual tie line approach, this only applied DC shifts per flight line. At this point both left and nose magnetometers are close to being in sync. Left data were then microlevelled using the technique described above.

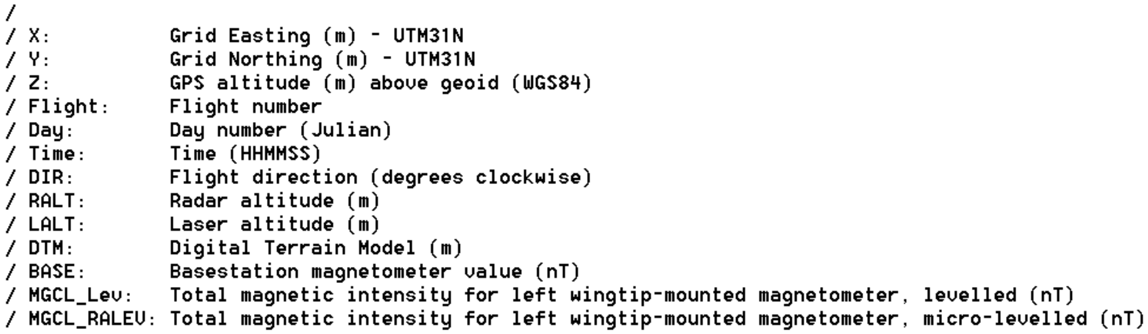
Data from the left magnetometer are gridded and imported into the database containing the nose magnetometer data. The difference between the sampled data and the recorded data can be seen to be similar to the noise grid created for the left magnetometer. As before, closely controlled statistics are applied to this “noise.” However, DC shifting of data does not remove all of the difference between the two magnetometers. This is due to the fact that the differences created by changing pitch, roll and yaw are not constant along the entire line. For this reason, a simple B-spline is applied to the data. This spline has to be carefully selected so as not to include the higher frequency component in the data, which is created by real gradient variation between the sensors.

Examination of the nose magnetometer data after the removal of a B-spline shows a visually pleasing result. When both left and nose data are combined the gridded result is acceptable. Areas of mismatch are seen and there is a possible correlation between this mismatch and aircraft pitch.

5.9 MAGNETIC DATA DELIVERY

Magnetic data are delivered as two separate processed data sets for the left (L) and nose (N) magnetometers; each dataset includes levelled and microlevelled data in one single dataset. The following summarises the header of the supplied data:

Perpignan_MAGL.xyz



```
/
/ X:          Grid Easting (m) - UTM31N
/ Y:          Grid Northing (m) - UTM31N
/ 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)
/ DTM:        Digital Terrain Model (m)
/ BASE:       Basestation magnetometer value (nT)
/ MGCL_Lev:   Total magnetic intensity for left wingtip-mounted magnetometer, levelled (nT)
/ MGCL_RALEV: Total magnetic intensity for left wingtip-mounted magnetometer, micro-levelled (nT)
```

Perpignan_MAGN.xyz

The data for the nose magnetometer (MGCN) follows the same format as that above. Note that since the two sensor locations are different, the X, Y locations are different in the two files.

6 Cross-line & test-line data

The cross-line and test-line data are delivered separately. RAD, EM and MAG data sets are delivered as a Crossline data file and as Testline data file. The acquisition of both data sets constitutes ‘isolated’ line acquisition at different times and on different days (in the case of the Testline data). As discussed in Section 2, this leads to issues in levelling and microlevelling in relation to the standard procedures applied to EM and MAG data. The testline data, in particular, should be regarded as testlines for the evaluation of the variance in radiometric data only. The formats of the data files follow those of the main survey. The four Crossline data files are:

- CrossLine_MagL.xyz (10 flight lines)
- CrossLine_MagN.xyz (10 flight lines)
- CrossLine_Rad.xyz (10 flight lines)
- CrossLine_EM_AP.xyz (5 flight lines)

The four Testline data files, all containing 6 flight lines, are:

- TestLine_MagL.xyz
- TestLine_MagN.xyz
- TestLine_Rad.xyz
- TestLine_EM_AP.xyz

7 References

Beamish, D., 2002. The canopy effect in airborne EM. Geophysics, 67, 1720-1728

Fraser, D.C., 1978. Resistivity mapping with an airborne multicoil electromagnetic system. Geophysics 43, 144-172.

Grasty, R.L. and Minty, B.R.S., 1995. A guide to the technical specifications for airborne gamma-ray surveys. Australian Geological Survey Organisation, Record, 1995/20.

Green, A.A., 1987. Levelling airborne gamma-radiation data using between-channel correlation information. Geophysics, 52, 1557-1562.

Hautaniemi, H., Kurimo, M., Multala, J., Leväniemi, H. and Vironmäki, J. 2005. The ‘three in one’ aerogeophysical concept of GTK in 2004. In: Airo, M-L. (ed.) Aerogeophysics in Finland 1972-2004: Methods, System Characteristics and Applications, Geological Survey of Finland, Special Paper 39, 21-74.

IAEA, 1991. Airborne gamma ray spectrometer surveying, International Atomic Energy Agency, Technical Report Series, No. 323.

Leväniemi, H., Beamish, D., Hautaniemi, H., Kurimo, M., Suppala, I., Vironmäki, J., Cuss, R.J., Lahti, M. and Tartaras, E. [2008] The JAC airborne EM system AEM-05. Journal of Applied Geophysics, in press.

Liukkonen, J., 1996, Levelling methods for aerogeophysical data: 10 August 2005. http://www.gsf.fi/¡«liukkonen/public/publications.html

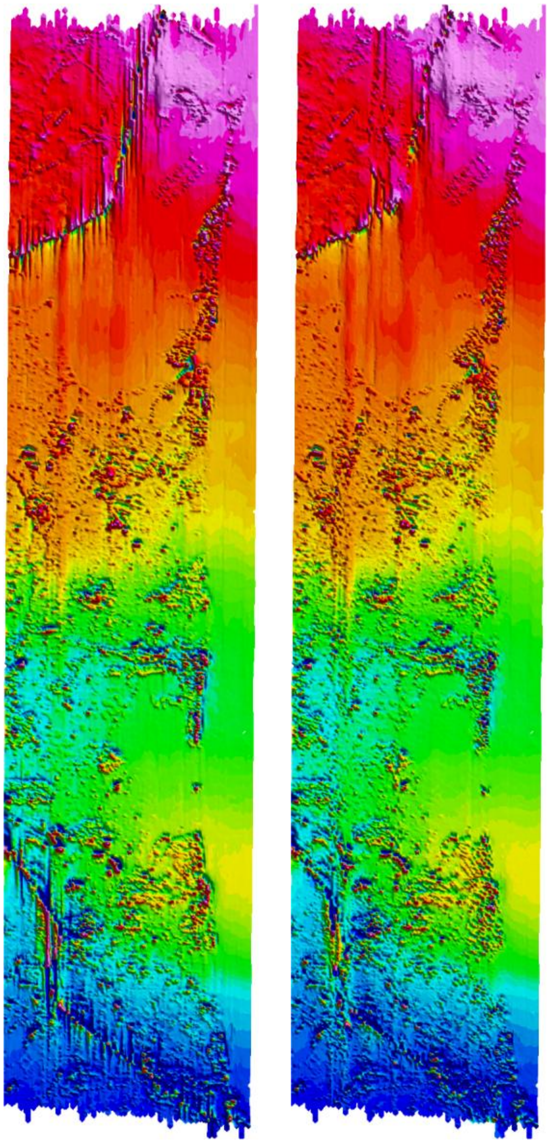
Luyendyk, A.P.J. 1997 Processing of airborne magnetic data. AGSO Journal of Australian Geology and Geophysics, 17, 31-38

Mauring, E. and Kihle, O., 2006. Levelling aerogeophysical data using a moving differential median filter. Geophysics, 71, 5-11.

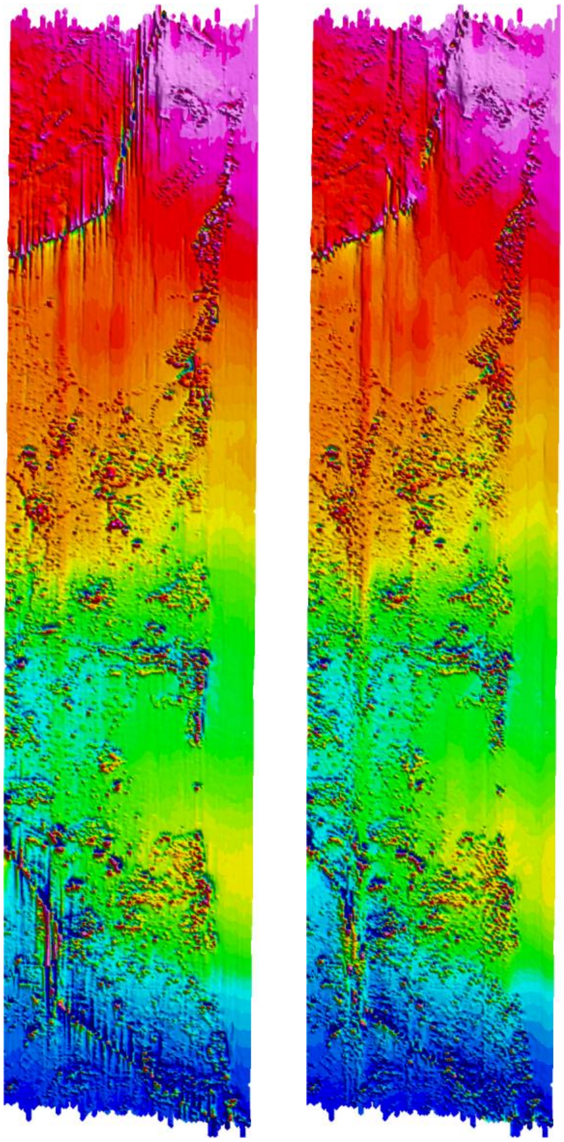
Suppala, I., Oksama, M. and Hongisto, H. 2005. GTK airborne EM system: characteristics and interpretation guidelines. In: Airo, M-L. (ed.) Aerogeophysics in Finland 1972-2004: Methods, System Characteristics and Applications, Geological Survey of Finland, Special paper 39, 103-118.

Appendix 1: Geophysical Images of the Survey Area

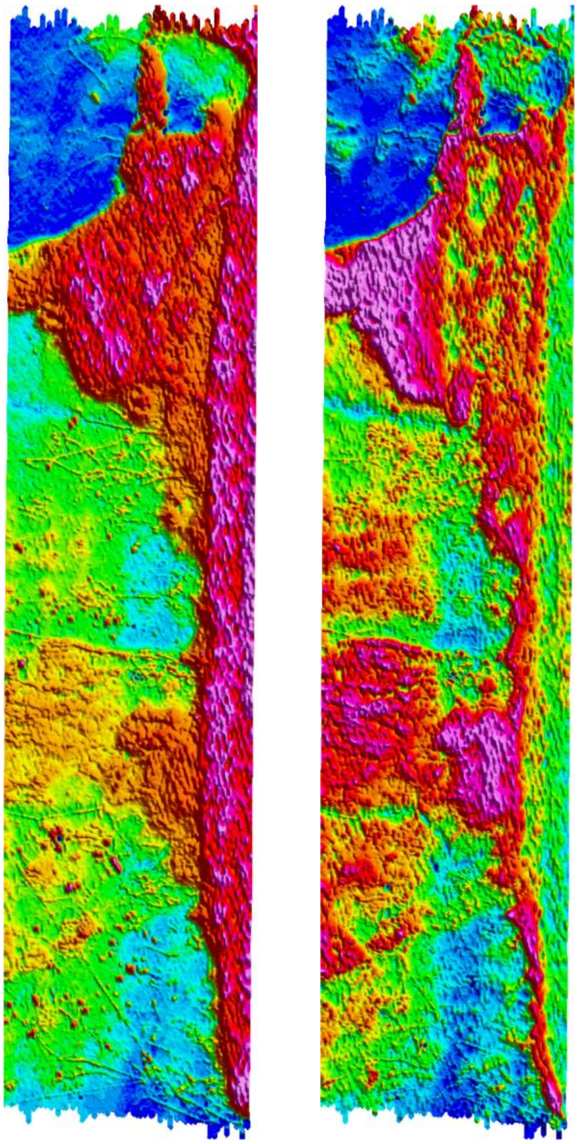
Appendix 1: Figure 1. Perpignan Total magnetic intensity (TMI), left sensor data. Left image, micro-levelled data. Right image, RA-microlevelled data.



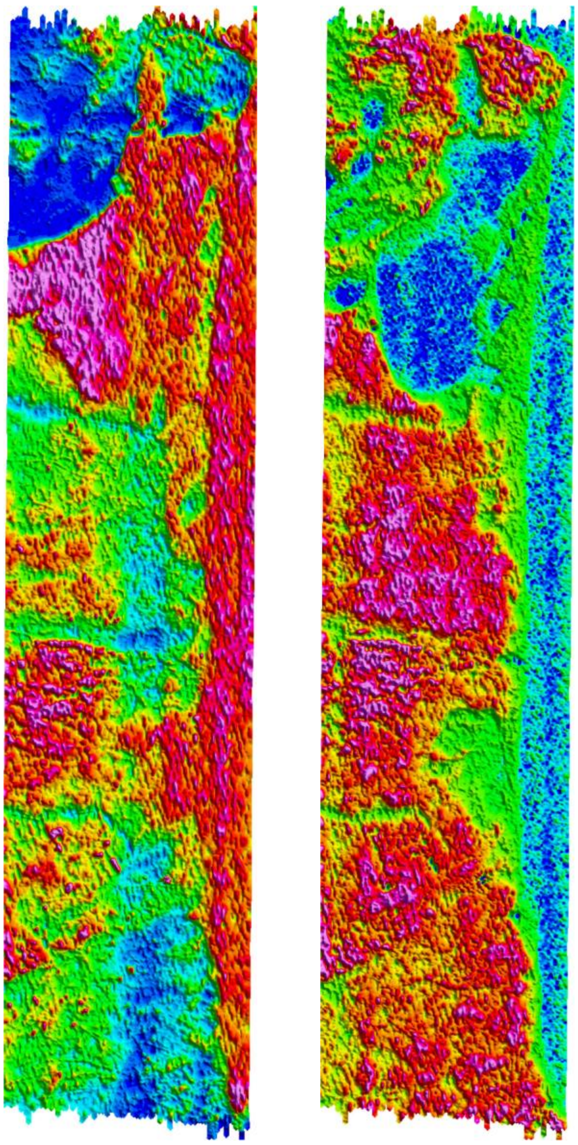
Appendix 1: Figure 1. Perpignan Total magnetic intensity (TMI), nose sensor data. Left image, micro-levelled data. Right image, RA-microlevelled data.



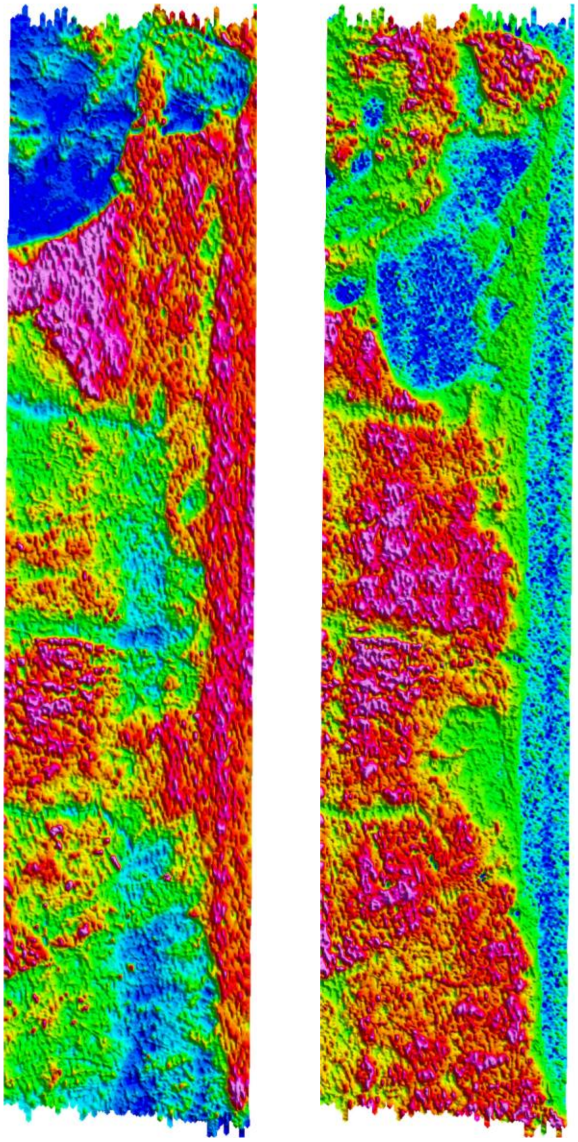
Appendix 1: Figure 2. Perpignan Real and imaginary components, 0.9 kHz



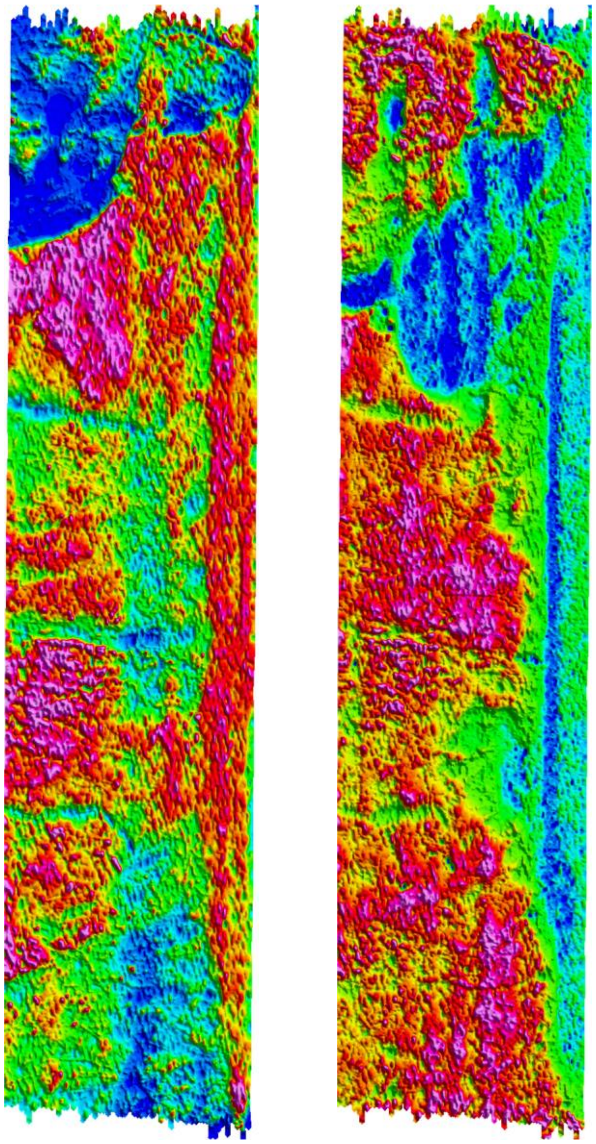
Appendix 1: Figure 3. Perpignan Real and Imaginary components, 3 kHz



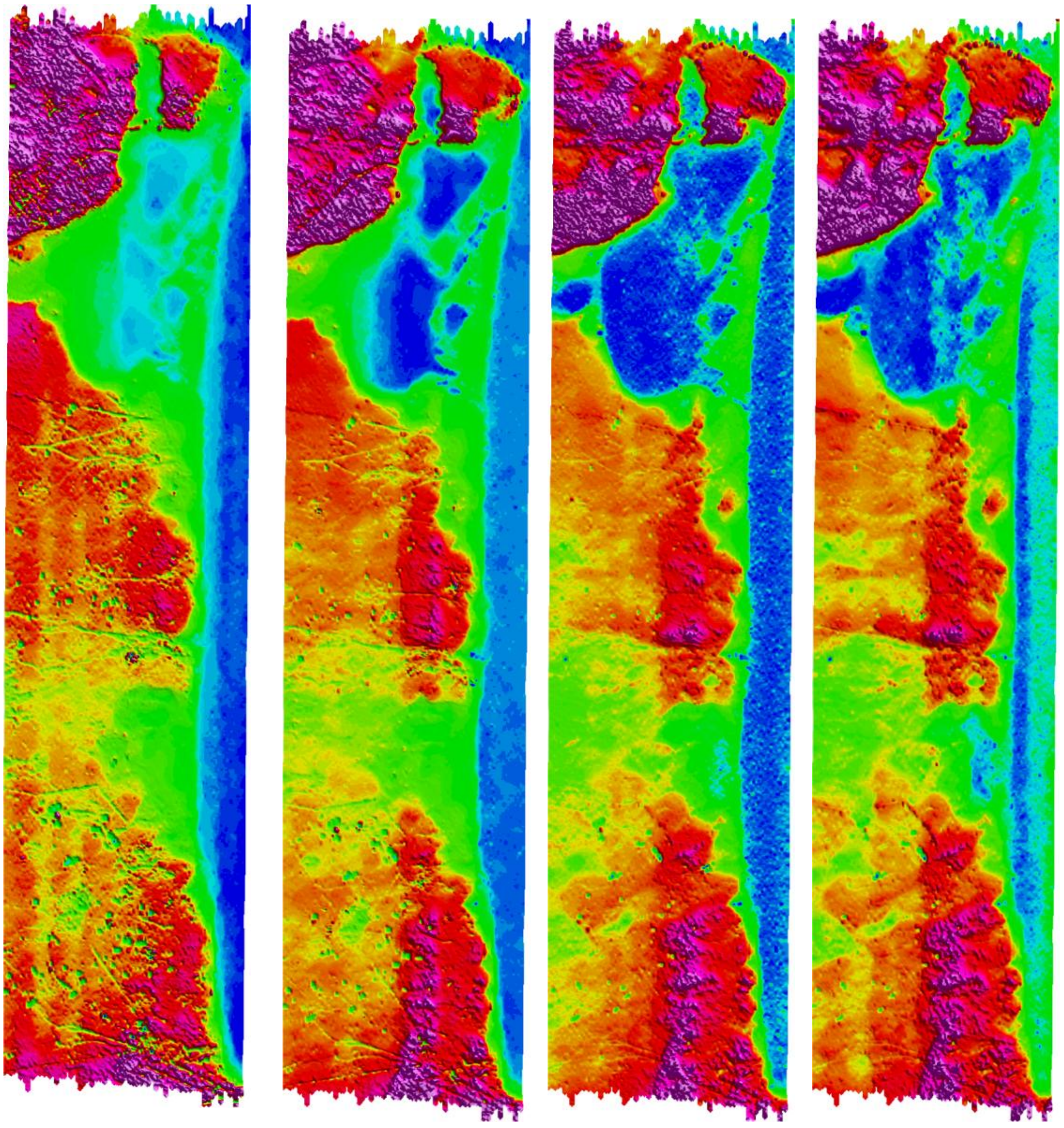
Appendix 1: Figure 4. Perpignan Real and Imaginary components, 12 kHz



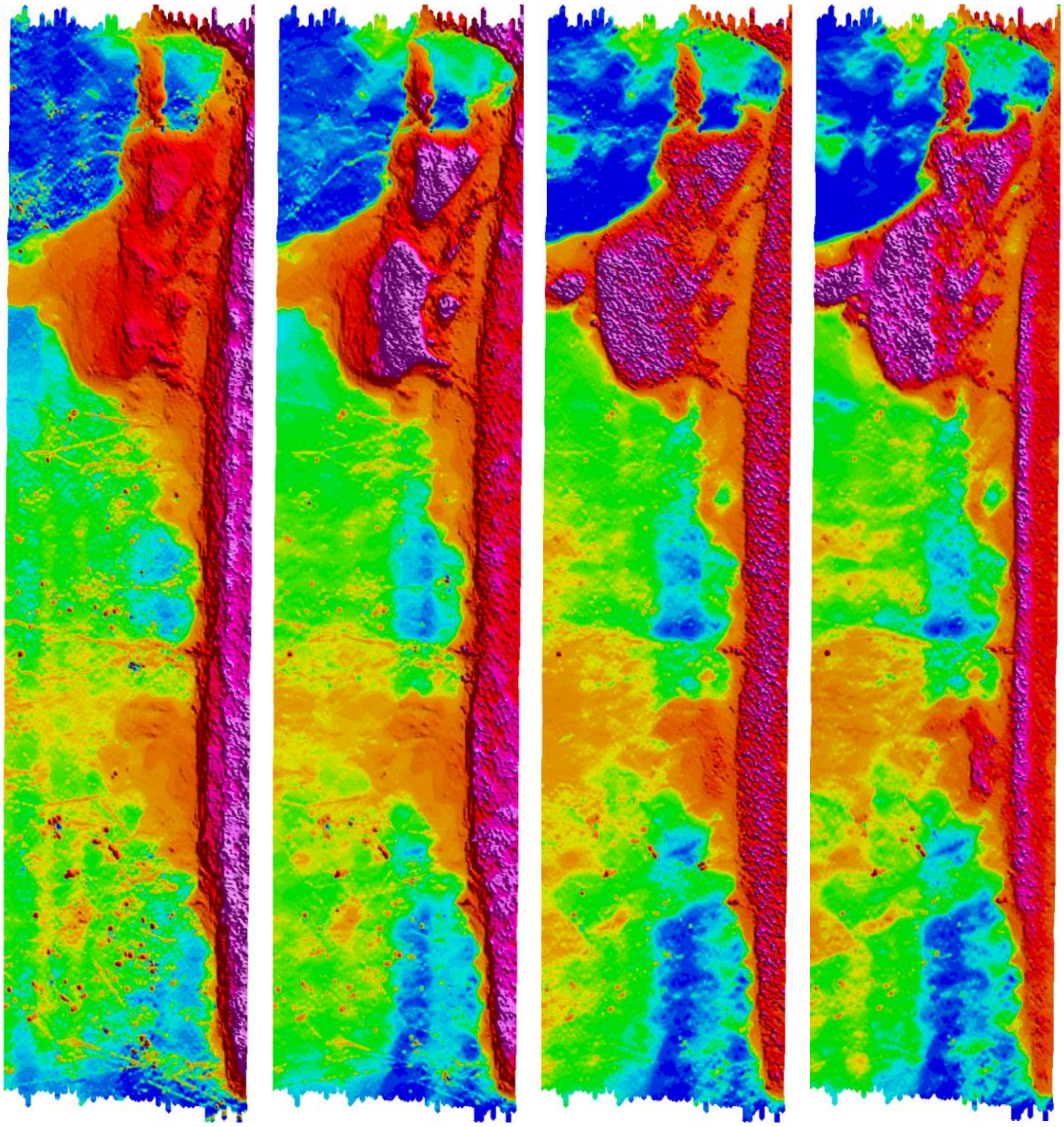
Appendix 1: Figure 5. Perpignan Real and Imaginary components, 25 kHz



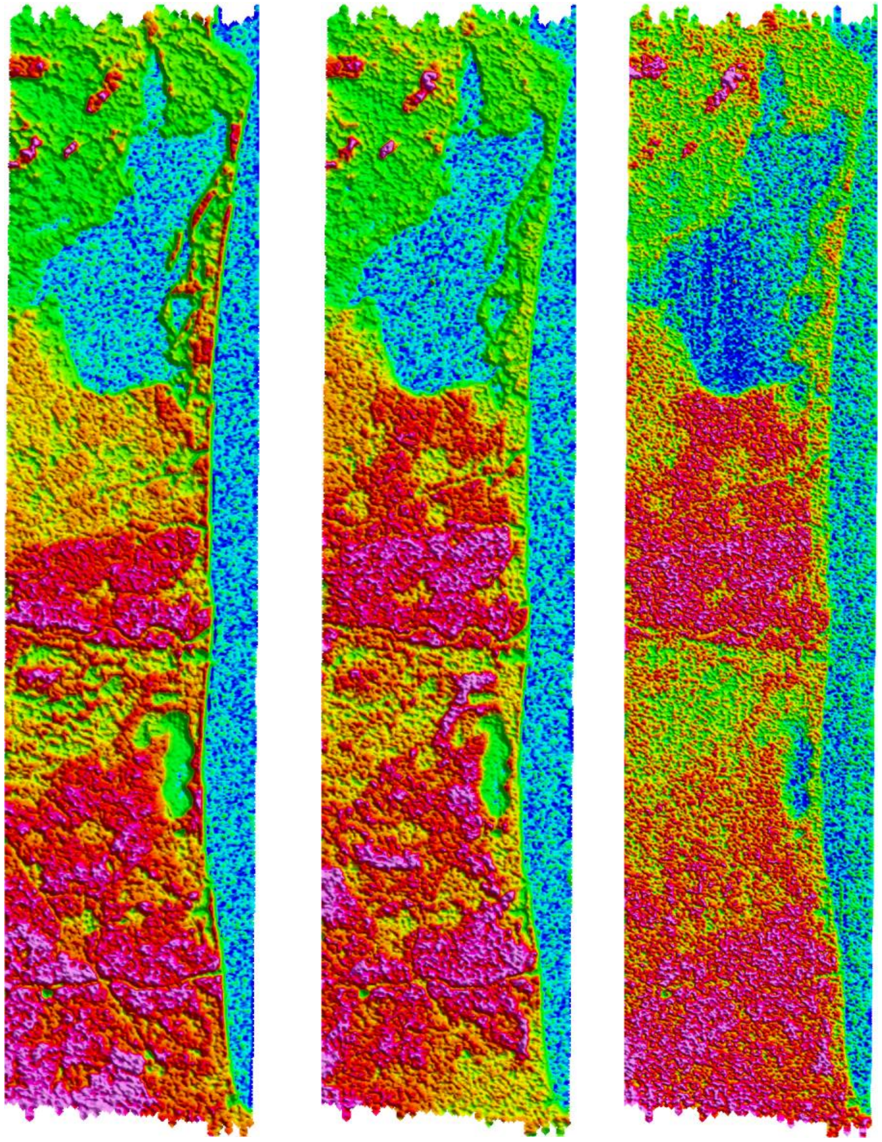
Appendix 1: Figure 6. Perpignan Apparent Resistivity, 09, 3, 12 and 25 kHz (left to right)



Appendix 1: Figure 7. Perpignan ApparentConductivity, 09, 3, 12 and 25 kHz (left to right)



Appendix 1: Figure 8. Perpignan Radiometric components: Potassium (KAL, left), Thorium (THO, centre) and Uranium (URA, right)



Appendix 1: Figure 9. Perpignan Imaginary component, 24.5 kHz