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The HiRES airborne geophysical survey of Anglesey: Logistics Report

Environmental Geoscience Baselines Programme

Internal Report IR/09/061

BRITISH GEOLOGICAL SURVEY

GEOPHYSICAL BASELINES

INTERNAL REPORT IR/09/061

The HiRES airborne geophysical survey of Anglesey: Logistics Report

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Keywords

Report; Anglesey, HIRES airborne geophysics, geological mapping

Front cover

Coastal view across north coast of Anglesey, from survey aircraft

Bibliographical reference

BEAMISH, D. AND WHITE, J.C., 2009.

The HiRES airborne geophysical survey of Anglesey: Logistics Report. *British Geological Survey Internal Report*, 61. 24pp.

Keyworth, Nottingham British Geological Survey 2009

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Foreword

This report is a product of a project 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 report provides a summary of the logistics of the HiRES airborne geophysical survey conducted in June 2009 across the island of Anglesey and part of the north-west coastal area of Gwynedd.

Acknowledgements

The JAC survey team, including BGS operators, listed later in this report are thanked for their contributions to the successful HiRES survey project.

TABLE OF CONTENTS

Figures

Tables

Summary

This report provides a summary of the logistics of the HiRES airborne geophysical survey conducted in June 2009 across the island of Anglesey and part of the north-west coastal area of Gwynedd. 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.

The survey was conducted at high resolution (a flight line spacing of 200 m) and at low altitude (56m) rising to >200 m in the vicinity of conurbations. 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 logistical and in-field processing elements of the survey operations.

1 Survey: Location and details

The Anglesey airborne geophysical survey (Figure 1) was designed on the basis of the cost of 6000 line-km. Permitting of the survey was via the CAA and a programme of outreach to local authorities and the public (Figure 2) took place in the months preceding the survey.

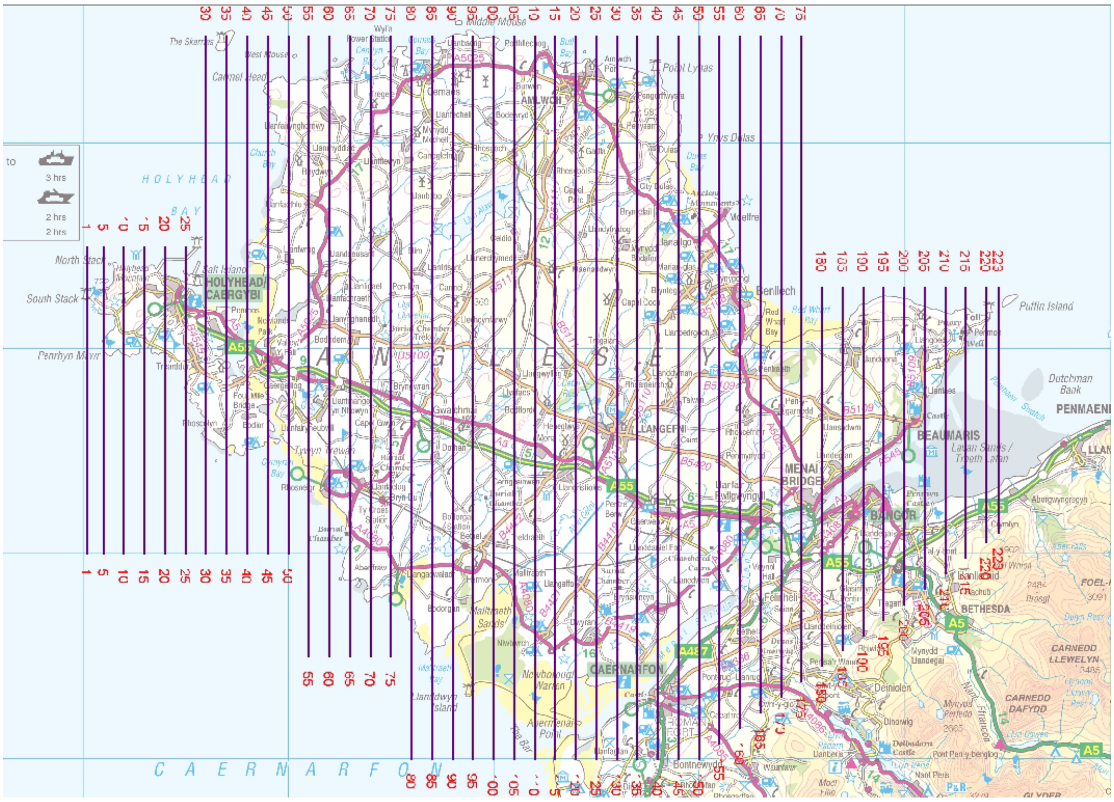
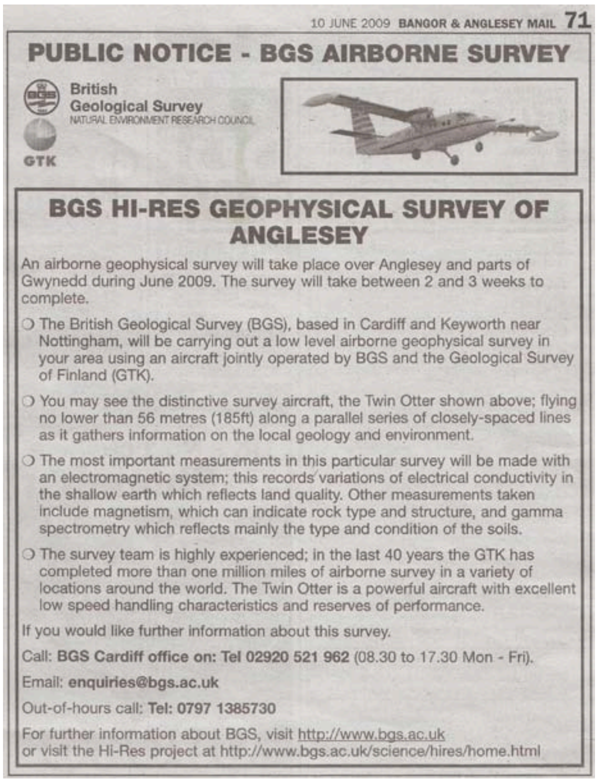


Figure 1. Flight line plan plotted over topographic map. Every fifth line shown.

The survey area is a polygon (Figure 3) contained in a rectangle of 44.6 x 35.25 km encompassing the whole island and a coastal zone of the mainland. The area of the survey polygon is 1198 km^2 whilst the survey flight direction (N-S) was chosen to intersect two of the dominant trends (i) geological (NE-SW) and (ii) the Tertiary dyke swarms (NW-SE). Flight line spacing is 200 m (as in previous HiRES surveys) with a flight altitude of 56 m. The area provides for 6000 km of survey line-km, with line lengths of between 12 and 35.25 km. The survey comprises 223 flight lines as indicated on the enclosed map.



10 JUNE 2009 BANGOR & ANGLESEY MAIL 71

PUBLIC NOTICE - BGS AIRBORNE SURVEY

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

GTK

BGS HI-RES GEOPHYSICAL SURVEY OF ANGLESEY

An airborne geophysical survey will take place over Anglesey and parts of Gwynedd during June 2009. The survey will take between 2 and 3 weeks to complete.

- The British Geological Survey (BGS), based in Cardiff and Keyworth near Nottingham, will be carrying out a low level airborne geophysical survey in your area using an aircraft jointly operated by BGS and the Geological Survey of Finland (GTK).
- You may see the distinctive survey aircraft, the Twin Otter shown above; flying no lower than 56 metres (185ft) along a parallel series of closely-spaced lines as it gathers information on the local geology and environment.
- The most important measurements in this particular survey will be made with an electromagnetic system; this records variations of electrical conductivity in the shallow earth which reflects land quality. Other measurements taken include magnetism, which can indicate rock type and structure, and gamma spectrometry which reflects mainly the type and condition of the soils.
- The survey team is highly experienced; in the last 40 years the GTK has completed more than one million miles of airborne survey in a variety of locations around the world. The Twin Otter is a powerful aircraft with excellent low speed handling characteristics and reserves of performance.

If you would like further information about this survey.

Call: **BGS Cardiff office on: Tel 02920 521 962** (08.30 to 17.30 Mon - Fri).

Email: **enquiries@bgs.ac.uk**

Out-of-hours call: **Tel: 0797 1385730**

For further information about BGS, visit http://www.bgs.ac.uk
or visit the Hi-Res project at http://www.bgs.ac.uk/science/hires/home.html

Figure 2. Public notice from Bangor and Anglesey Mail, 10 June 2009.

A summary of the acquisition parameters, based on ideal flight lines, is provided in Table 1.

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

	Direction	*Line separation (m)*	*Number of lines*	*Line-km*
Plan, 2009	180/360	200	223	6,000
Actual	180/360	200	223	6,316

The actual survey includes many excess line-km obtained from longer-than-ideal lines.

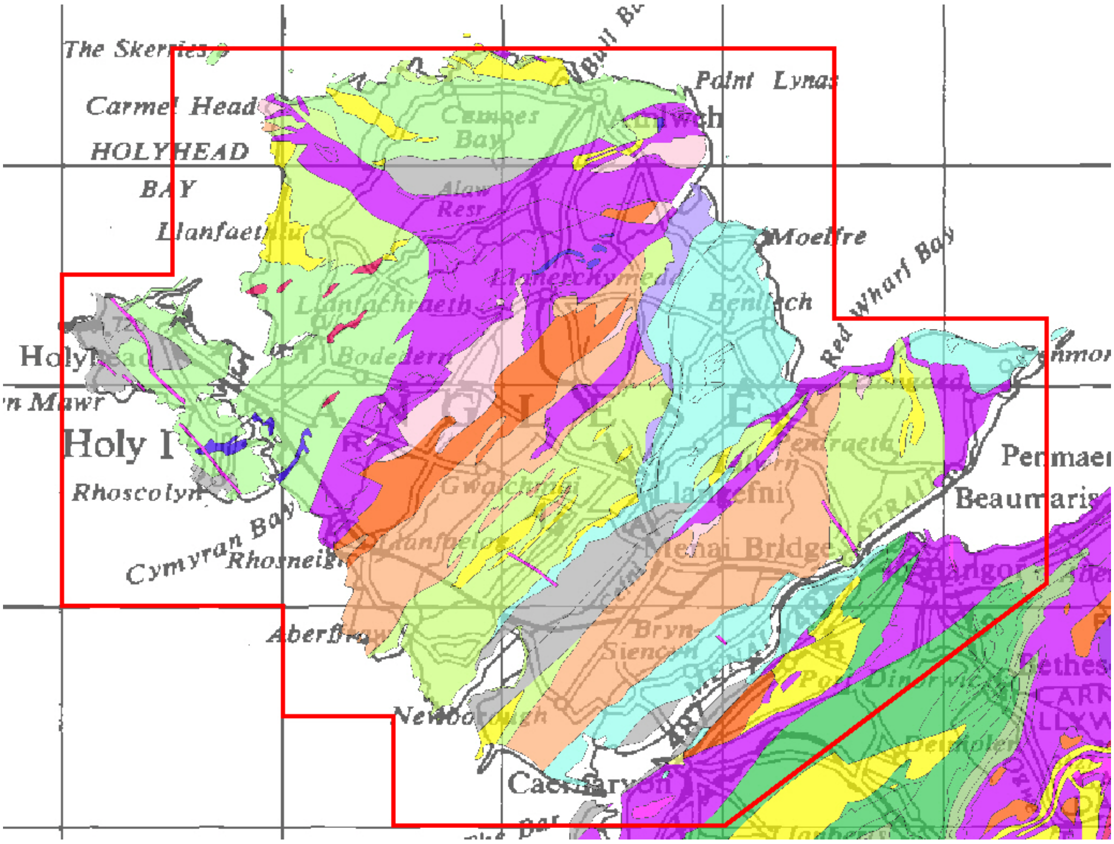


Figure 3. Survey polygon plotted over 1:625k geology.

1.1 COORDINATE SYSTEM

The coordinate system used during acquisition and in processing is the British National Grid.

1.2 REFLIGHT SPECIFICATIONS

Specific conditions for reflights due to technical reasons were according to the JAC internal Quality Manual. 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 (56 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).

1.3 SURVEY OPERATIONS

1.3.1 Survey Duration

The Twin-Otter ferry flight from Pori (Finland) to Caernarvon took place over 2 days (9th June to 10th June 2009) and totalled 8 hrs 20 minutes (flight time) or 8 hrs 59 minutes block time.

The survey data acquisition was conducted between 11th June and 18th June 2009. The survey base was Caernarvon airfield (Airworld) and flight operations occupied a 6 day week. The operational chronology of data acquisition is provided in Table 2. The Table summarises the dates, the time duration and the number of lines accepted for each sortie. The survey comprised 13 operational flights on 7 operational days with Flight/Material numbers from 020 to 032.

Table 2. Survey duration. Times are Block Times.

Flight	*Date*	*Julian day*	*Out (UTC)*	*In (UTC)*	*Flight time*	*Accepted lines*
020	11/06/09	162	16:18	17:21	01:03	Compensation 1
021	12/06/09	163	07:40	08:32	00:52	Compensation 2
022	12/06/09	163	09:57	14:03	04:06	18
023	13/06/09	164	08:14	12:30	04:16	18
024	13/06/09	164	14:27	18:30	04:03	22
025	15/06/09	166	07:37	12:06	04:29	22
026	15/06/09	166	14:36	18:46	04:10	20
027	16/06/09	167	07:11	11:32	04:21	42
028	16/06/09	167	14:51	17:29	02:38	12
029	17/06/09	168	15:47	19:59	04:12	34
030	18/06/09	169	07:19	07:22	04:13	22
031	18/06/09	169	14:01	15:42	01:41	9
032	18/06/09	169	16:51	18:00	01:09	6

1.3.2 Personnel

A list of personnel involved in the survey is provided in Table 3.

Table 3. List of project personnel.

Position	*Name*	*Affiliation*
Project Manager/ Geophysicist	Dr. David Beamish	BGS
Geophysicist/ Party Chief	Dr James White	BGS
Electronics engineer/Operator	Mr Veli Leoninen (short visit)	GTK
Operator	Mr Ed Haslam	BGS
Operator	Mr Andy Hulbert	BGS
Operator	Mr Dave Morgan	BGS
Operator	Ms Helen Taylor	BGS
Flight Crew		
Captain	Capt Raimo Vartiainen	FAA
Pilot	Mr Mika Raivonen	FAA
Navigator	Mr Esa Tiainen	FAA
FAA a/c Engineer	Mr Jussi Jarvinen	FAA

1.3.3 Flying instructions and restrictions

Permitting for the survey was conducted through the CAA. David Grove (Airspace Utilisation Section) provided the Airspace Utilisation Notice with Activity 2009-06-0239. The authorities allowed a survey height of 185 feet rising to 800 feet msd (mean separation distance) in relation to structures. The main control authority was RAF Valley on Anglesey. A close operational protocol was established with their ATC Section, in particular, Sqn. Ldr. Egryn Huskisson.

RAF base activities in the west of the area partially restricted timing of flights in a series of three zones. Close communications were adopted. CAA provided a special permit to overfly Wylfa Nuclear Power station, although at a 'safe' operational height.

1.3.4 Technical and quality control

The survey geophysicist carries out daily technical quality control. The main emphasis of the technical quality control is related to flight path deviation and flight elevation. Quite often these specifications are exceeded due to safety reasons and piloting decisions. In these cases re-flights are not issued. Table 4 summarises the statistical data of the technical parameters. The figures are calculated using the final radiometric data.

Table 4. Statistics for technical parameters (radar altitude, distance from the nominal line and flying speed). Results are calculated using all the data including exceptions.

	Mean	Standard deviation	Min	Max
Radar altitude (m)	57.3	17.9	26.9	230.5
Laser altitude (m)	58.0	18.5	30.3	339.0
Speed (m/s)	60.54	4.9	37.5	76.0

The survey acquired 223 lines of data. Line 180 was repeated in the reverse direction. Omitting the repeat line, the raw (untrimmed) data points obtained were:

Radiometric data: 104,543 data points

Electromagnetic data: 416,387 data points

Magnetic data: 1,040,633 data points

2 Equipment

The airborne survey equipment used on the survey comprises a geophysically equipped de Havilland Twin-Otter aircraft (OH-KOG). The aircraft is owned by the NERC/BGS and the geophysical equipment is owned by the JAC/GTK. The BGS and GTK undertake airborne geophysical survey work in a partnership venture known as the Joint Airborne geoscience Capability (JAC). The aircraft is operated by the Finnish Aviation Academy (FAA) based in Pori, Finland.

A background to the development of the geophysical equipment used by the JAC is given by Hautaniemi et al. (2005). The main components of the geophysical measurement system are summarised in Table 5.

Table 5. Outline specification of main geophysical systems

Electromagnetic system	GTK AEM-05 four frequency
Aircraft Magnetometer	2 Scintrex CS-2 caesium vapour sensors, located at the left wingtip and nose stinger
Magnetic Compensator	RMS Instruments Automatic Aeromagnetic Digital Compensator (AADCII)
Gamma-ray spectrometer	Exploranium GR-820/3 gamma-ray spectrometer 256-channels, self-calibrating
Altimeter	Collins radar altimeter
Navigation/data location system	Real time DGPS based on Ashtech GG-24 GPS+GLONASS receiver, when RDS signal available
Data acquisition system	GTK proprietary: control unit including server, power unit, alarm box, Local Area Network

Standard ancillary equipment includes an external temperature sensor and barometric height sensor and a power-line (50/60 Hz) sensor (housed in the nose of the aircraft). Details of these devices are included in section 2.2.

Figure 4. Survey flight line to south of Caernarvon.

2.1 AIRCRAFT

The aircraft used in the survey is a fixed-wing, twin-engine DHC-6/300 Twin Otter (registration sign OH-KOG, registered in Finland).

Table 6. Specifications of survey aircraft OH-KOG.

Normal flight speed	210-220 km/h
Rate of climb	7.5 m/s
Total flight hours	About 18000 hours to date
Landings	About 8500 landings to date

This aircraft was built in Canada in 1979 and has been in use since 1980 for aerogeophysical measurements. During the manufacturing of the Twin Otter several modifications were made to its electrical systems in order to reduce the electrical noise levels. The aircraft offers several major advantages in terms of utility and cost, including excellent performance reserves, low-speed handling characteristics and operational flexibility allowing the use of unsupervised and unpaved air strips.

2.2 GEOPHYSICAL EQUIPMENT

Magnetics

- Two Scintrex CS-2 Caesium magnetometers, one at the left wingtip and one at the nose stinger
- Automatic compensation unit RMS AADCII

- Sampling rate of 10 Hz

Electromagnetic four-frequency unit

- Model AEM-05, vertical-coplanar coil configuration
- Frequencies in use: 912 Hz, 3005 Hz, 11962 Hz and 24510 Hz
- Coil separation of 21.4 meters
- Sampling rate of 4 Hz

Gamma-ray spectrometer

- Exploranium GR-820/3
- Two sets of NaI crystals, each containing four downward looking and one upward looking package
- Total volume 42 litres
- Sampling rate of 1 Hz

Navigation system:

- Ashtech GG24 (24-channel GPS + Glonass receiver)
- Accuracy 7 m / 16 m (50% / 95 %)
- Real time DGPS when differential signal available
- Sampling rate 1 Hz

Altitude

- Collins radar altimeter
- Resolution 0.1 m, accuracy 0.5 m
- Sampling rate of 10 Hz

Auxiliary equipment

- Digital camera
- Riegl laser altimeter
- Barometer, thermometer, accelerometer

Base station equipment

- Scintrex CS-2 sensor for magnetic recording
- Ashtech Ranger GPS receiver for DGPS correction
- Picodas MEP-7110 magnetometer

2.3 GROUND-BASED EQUIPMENT

Ground-based equipment comprises a base magnetometer and a GPS station. The primary base station records magnetic and GPS data prior to, during, and after each flight. The data from this station are used to post process the airborne data. The base magnetic data are used to correct diurnal variations of the airborne magnetic field records. The base GPS records are used to perform differential processing of the airborne GPS recordings.

The magnetic data are logged at 1-second intervals and displayed on a base station laptop that controls data acquisition. The continuous display of the base station data (rolling screen) provides a capability for monitoring the magnetic disturbance conditions that might lead to a reflight condition.

Figure 5. Base station. Magnetometer and control unit inside a tent, to the east of Caernarvon Airfield. Snowdon range in background.

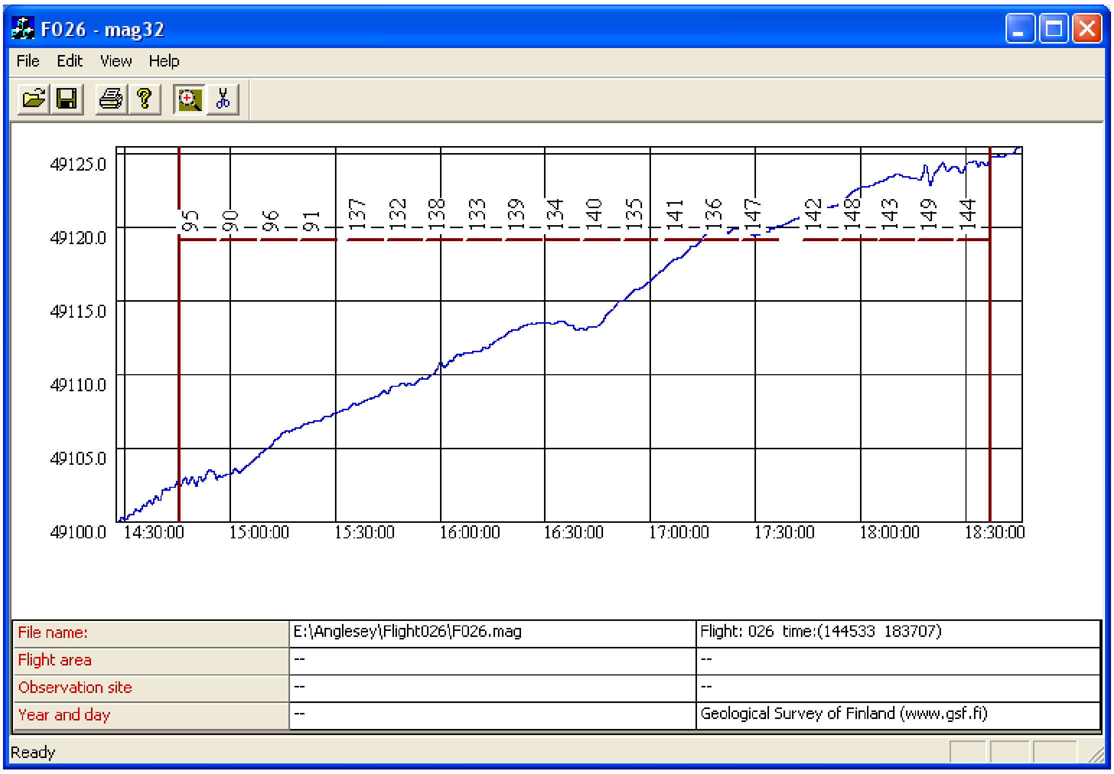


Figure 6. Base magnetic station data recording of Flight 026, showing overlay of Line numbers. Time is UT.

Complete base station operations and precise locations are summarised in Table 7.

Table 7. Summary of primary base station used during survey,

Primary Base Station	Field to the east of Caernarvon Airfield.
Start Date (Julian Day)	10/06/2009 (161)
End date (Julian Day)	18/06/2009 (169)
Geographic Latitude (North)	53:06:18.68400
Geographic Longitude (West)	04:19:35.99220
Elevation (m)	57.06883

The precise coordinates of the GPS base station (given above) were determined using a differential correction with the Holyhead station of the GPS permanent reference station network. During field processing a magnetic base level of 49124 nT was applied to the magnetic data.

3 Calibration Data

3.1 MAGNETIC COMPENSATION

The effect caused by the movements of the aircraft is removed/diminished automatically during the flight by use of compensation data. During the compensation flight the aircraft flies at 3 km altitude in the two flight line directions and also in directions perpendicular to those and performs pitch (±5º), roll (±10º) and yaw (±5º) manoeuvres along each direction. After recording, the magnetic effects of all twelve movements, the AADCII compensator (RMS Instruments) computes the compensation coefficients, and stores the results to provide real-time corrections during the actual survey.

The effectiveness of the compensation is verified by a Figure-Of-Merit (FOM) survey immediately after the compensation. The same movements are repeated and the new compensation parameter file is utilized. All three compensated movement effects are summarized in all four directions, and the FOM parameter is thus the sum of these 12 peak-to-peak anomaly values of the compensated magnetic field. The compensated FOM values are a judgement of the peak/trough amplitudes observed during each manoeuvre.

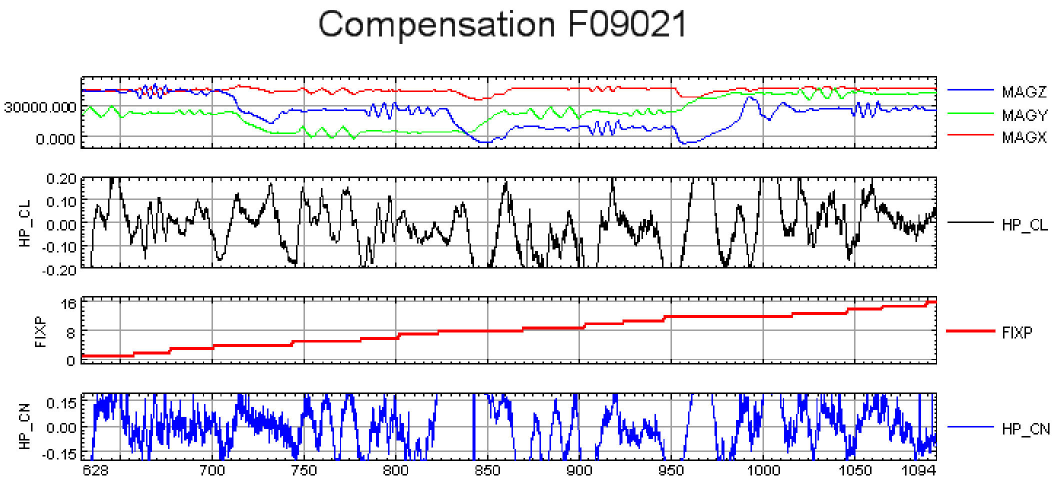


Figure 7. The profiles of magnetometer compensation data for the 4x3 =12 set of manoeuvres (FixP). Upper panel: Fluxgate magnetometer data. Second panel: Compensated Left magnetometer data, scale in nT. Third panel: FixP showing 12 manoeuvres. Lower panel: Compensated Nose Magnetometer data, scale in nT.

The location of the compensation flight was just offshore and to the survey area. The area was located on the basis of low magnetic gradient. The FOM parameters of each direction and each movement are summarised in Table 8.

Table 8. Figure of merit calculations for magnetic data (Flight 021)

Left Sensor Uncomp

Dir	Pitch	Roll	Yaw	
270	1.92	3.71	1.11	6.74
180	1.93	6.65	2.97	11.55
90	0.81	8.75	2.10	11.66
360	1.71	5.69	1.20	8.60
	6.37	24.80	7.38	**38.55**

Left Sensor Comp

Dir	Pitch	Roll	Yaw	
270	0.26	0.16	0.10	0.52
180	0.21	0.17	0.05	0.43
90	0.18	0.16	0.06	0.40
360	0.14	0.03	0.01	0.18
	0.79	0.52	0.22	**1.53**

Left Sensor Ratios

Dir	Pitch	Roll	Yaw	
270	7.38	23.19	11.10	12.96
180	9.19	39.12	59.40	26.86
90	4.50	54.69	35.00	29.15
360	12.21	189.67	120.00	47.78
	8.06	47.69	33.55	25.20

Nose Sensor Uncomp

Dir	Pitch	Roll	Yaw	
270	7.91	11.65	4.30	23.86
180	8.27	9.85	5.52	23.64
90	3.12	5.39	1.31	9.82
360	17.61	6.88	2.50	26.99
	36.91	33.77	13.63	**84.31**

Nose Sensor Comp

Dir	Pitch	Roll	Yaw	
270	0.21	0.36	0.10	0.67
180	0.40	0.22	0.25	0.87
90	0.55	0.05	0.06	0.66
360	0.25	0.09	0.11	0.45
	1.41	0.72	0.52	**2.65**

Nose Sensor Ratios

Dir	Pitch	Roll	Yaw	
270	37.67	32.36	43.00	35.61
180	20.68	44.77	22.08	27.17
90	5.67	107.80	21.83	14.88
360	70.44	76.44	22.73	59.98
	26.18	46.90	26.21	31.82

The figures of merit (FOM) are 1.53 (Left) and 2.65 (Nose).

3.2 RADIOMETRIC CALIBRATION DATA

As noted previously the radiometric instrument employed is the Exploranium GR-820 with 256-channels. The commonly adopted standard in carrying out airborne gamma-ray measurements is to calibrate and process the data in a manner presented in AGSO and IEAE reference manuals (Grasty and Minty, 1995; IAEA, 1991). The radiometric system was calibrated prior to the survey using locations and calibration ranges in Finland that have been used for over 25 years. The following sections summarise the calibrations that were performed prior to this survey.

3.2.1 Cosmic and background coefficients

To determine the aircraft and cosmic background, a test flight was carried out over the sea near the base airport, at flight surfaces from 5000 to 10000 ft. Linear regression from the mean counts in each channel and equivalent cosmic channel count rate provide the constant and linear coefficients. The constant represents the background radiation from the aircraft and the linear coefficient is used to calculate the varying part of background radiation because of cosmic radiation.

The cosmic coefficients were found to be:

cos_tot	42.20 (0.896)	Total counts
cos_kal	5.07 (0.042)	Potassium
cos_ura	0.45 (0.029)	Uranium
cos_tho	0.03 (0.033)	Thorium
cos_Ur	0.33 (0.008)	Uranium upward

The numbers in parentheses are the linear coefficients.

3.2.2 Stripping ratios

The stripping ratios were determining using 4 transportable calibration pads (1m x 1m x 0.3m) prior to the survey season in Pori, Finland. Each pad was measured for 10 minutes and the stripping ratios were calculated using the Padwin program provided by the manufacturer of the pads. The calculated values are very close to the manufacturer's and IAEA's ideal values.

The results of the calibration are:

TH INTO U (ALPHA = A23/A33)	0.2408 (0.0629)
TH INTO K (BETA = A13/A33)	0.4071 (0.1330)
U INTO K (GAMMA = A12/A22)	0.7327 (0.1760)
U INTO TH (A = A32/A22)	0.0453 (0.0638)
K INTO TH (B = A31/A11)	-0.0031 (0.0342)
K INTO U (G = A21/A11)	0.0032 (0.0335)

Stripping Ratios 2009 are:

KAL	0.2151 0.7525
URA	0.2475
THO	0.0625

The numbers in parentheses are estimated standard deviations.

3.2.3 Height attenuation

For determining height attenuation measurements were taken at a series of heights from 100 to 800 ft near Porvoo, Finland. This test line has been used for more than 25 years. Background and stripping corrections were applied and the attenuation was calculated using the logarithmic values of corrected Tot, K, U and Th, and flight altitude.

The attenuation coefficients were calculated as:

K	0.008089
U	0.005856
Th	0.006568
Total counts	0.006644

3.2.4 Concentration coefficients

The same Porvoo test line was used to determine the system sensitivities. This same line has been measured for more than 25 years using the same aircraft (OH-KOG). The sensitivity parameters have been applied yearly to the radiometric data measured. Comparisons have been made also between different areas measured during different years to find out the possible variations. The variations are mostly due to different methods used earlier for sensitivity determining, e.g. pads, runway. For the last few years the sensitivity parameters have varied by just a few percent.

All the corrections were made to the radiometric test flight data and the concentrations were compared to earlier measurements and new sensitivity parameters were calculated as:

K	0.00784	%K/(pulses/s)
U	0.0647	ppm eU/(pulses/s)
Th	0.1193	ppm eTh/(pulses/s)
TOT	0.09322	

3.2.5 Resolution of the spectrometer

The spectrometer resolution was measured with a Cs-137 source in Pori, Finland. Background was also measured and after a background correction, the Cs peak was measured and the FWHM determined. The FWHM is across 5.0 channels, each with an energy of 12.1 keV, which makes 60.5 keV. Thus we obtain a spectrometer resolution (R) of:

R = 100*60.5 keV/662 keV = 9.14 **%**

Individual crystals were measured at Helsinki-Vantaa airport. The downward looking spectra were stabilized using K-40 and the upward looking spectra with Cs-137. The results are given as Crystal Number with %Resolution in parentheses:

D1(7.4%), D2(11.0%), D3(7.5%), D4(6.1%), D5(5.3%), D6(5.9%), D7(5.9%), D8(5.4%), U13(9.5%), U14(7.9%)

D refers to downward and U to upward.

3.3 ELECTROMAGNETIC CALIBRATIONS

3.3.1 Coefficient Calibration

The calibration of the JAC AEM-05 system used in the survey is described by Hautaniemi et al. (2005) and Leväniemi et al. (2009). The EM calibration coefficients for 2009 were (1.668, 0.0) at 912 Hz, (1.826, 0.0) at 3005 Hz, (2.062, 0.0) at 11962 Hz and (2.195, 0.0) at 24510 Hz.

The EM system was calibrated by flying a test line over the sea (Gulf of Finland) prior to the 2009 survey season, at different heights from 25 to 100 m. The conductivity of the sea was measured by a CTD sensor at 4 different points along the test line, from the surface to the sea bottom. The conductivity of the sea was estimated by a model, which contains layers with a different conductivity for each layer.

The theoretical responses of the airborne EM to the model described above were calculated using the Leroi-air program developed by AMIRA. Non-linear optimization was used to obtain a best fit to a complex, scalar coefficient. The coefficients obtained at each frequency enables measured units to be converted to coupling ratios (Hs/Hp, meaning secondary over primary) in ppm (parts per million)

An example of the coefficient calculation (3005 Hz) is shown in Figures 8 and 9 below.

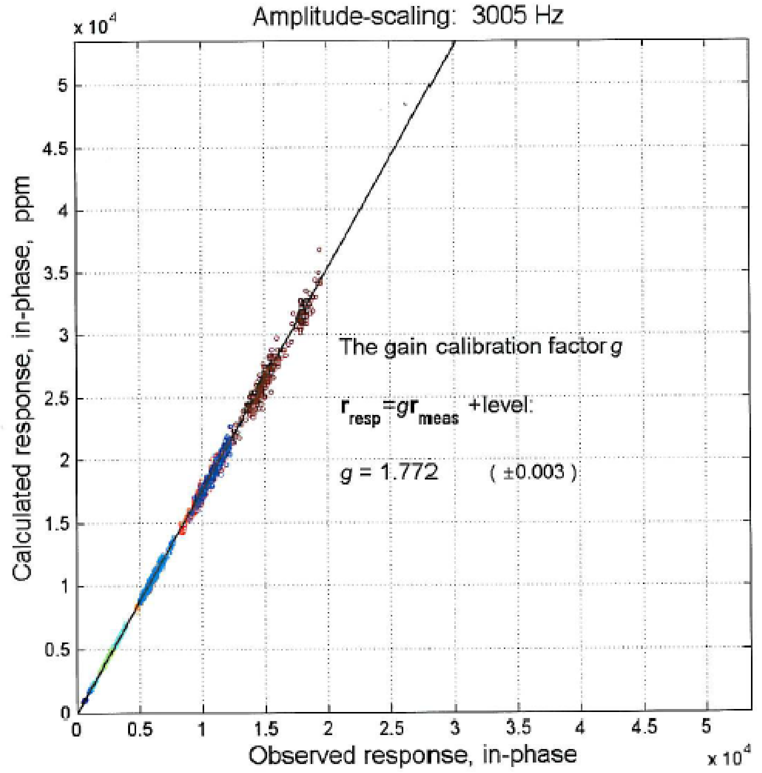


Figure 8. EM optimisation results for the Real component calibration at 3005 Hz.

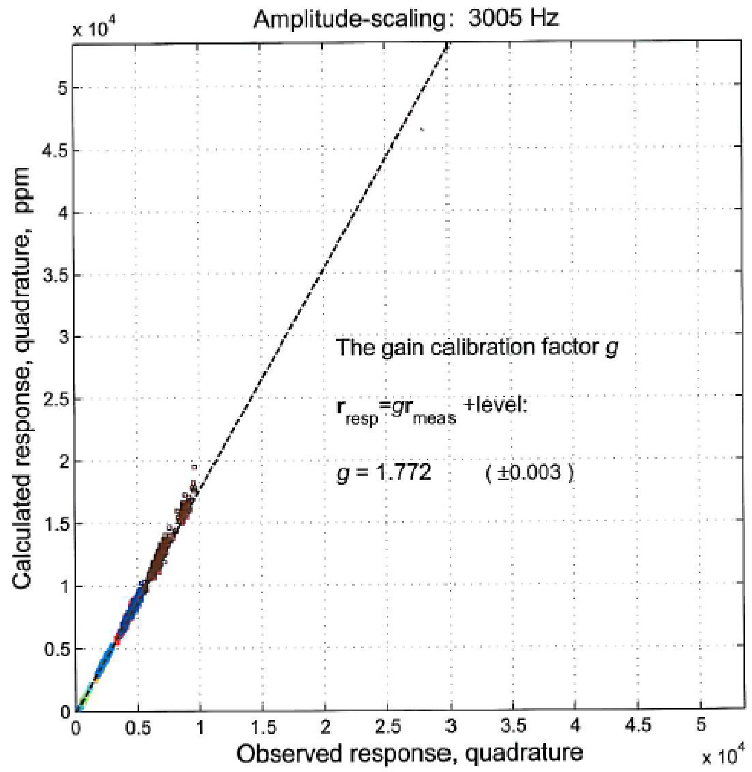


Figure 9. EM optimisation results for the Imaginary component calibration at 3005 Hz.

3.3.2 EM System orthogonality

The phase shift between in-phase (real) and quadrature (imaginary) components is checked and adjusted at the beginning and end of each survey flight. The test is undertaken at an 'out-of-ground-effect' elevation (e.g. >300 m) over the landmass (i.e. not over the sea). As the phase shift is 90 degrees, there should not be any trace in the quadrature component as an artificial signal is applied to in-phase component and vice versa. This procedure is done separately on each frequency to in-phase and quadrature components. At the end of each survey flight this same procedure is repeated to check for any possible phase drift during the flight. An example of the calibration pulses observed at the start of a flight is shown in Figure 10.

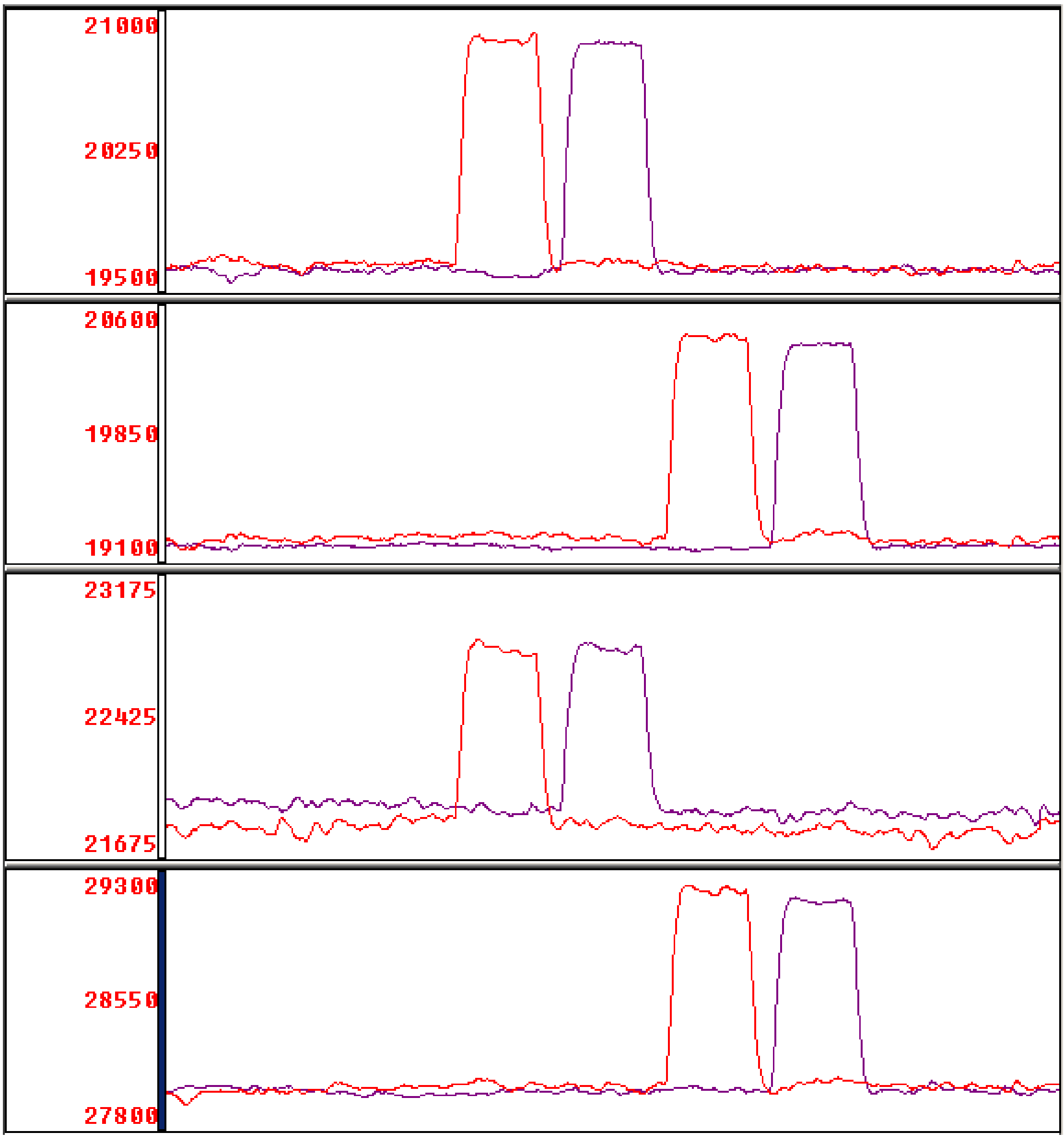


Figure 10. The orthogonality test for Real and Imaginary components of the Twin Otter EM configuration. Panels show the frequencies in increasing order from top to bottom with Real component in red and imaginary component in magenta.

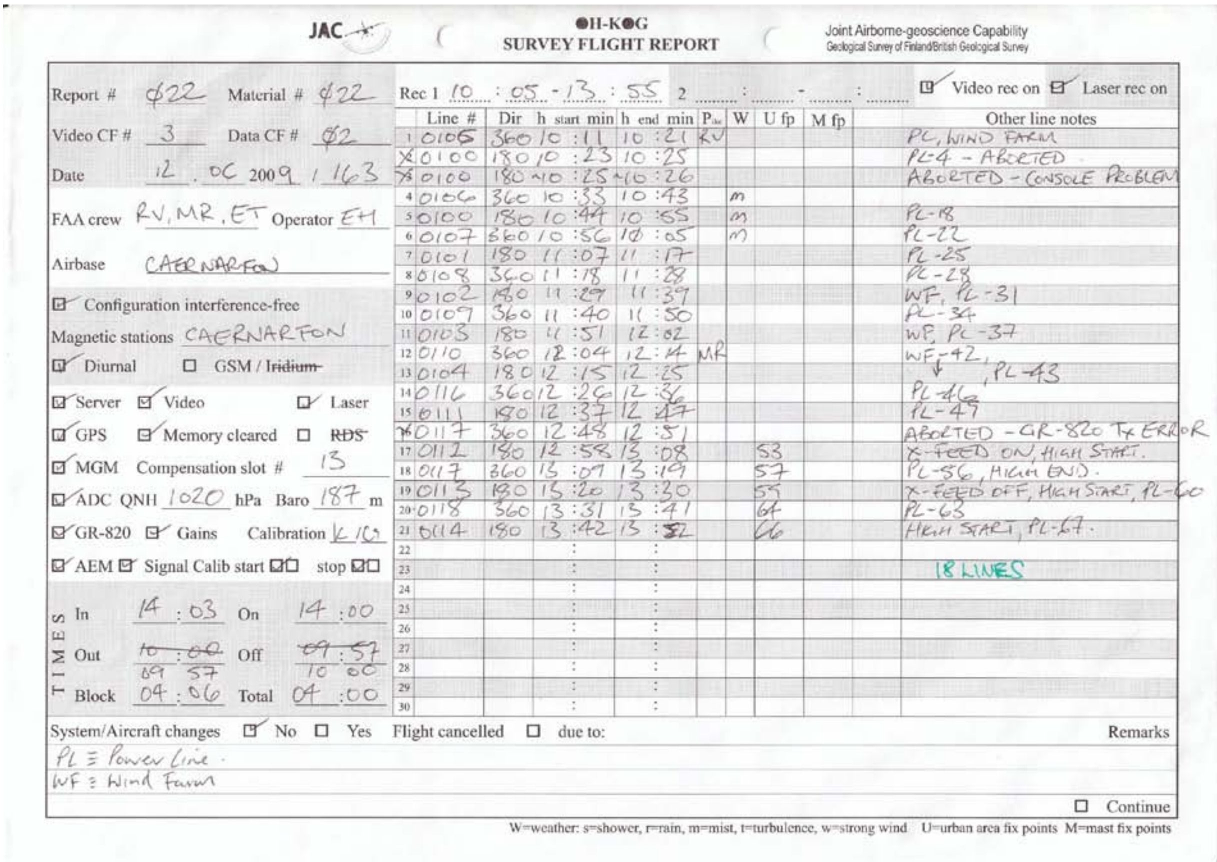
4 Data handling, QC procedures and Processing

The data handling and QC procedures used by the JAC are fully described by Hautaniemi et al. (2005).

The geophysical and avionic data acquired during each flight is monitored by a geophysical operator as shown in Figure 11. The geophysical operator monitors all the instruments and the data being acquired using a laptop computer. Each instrument is connected to a dedicated microprocessor. The microprocessor controls data transfer to a Local Area Network (LAN). A GPS-based synchronisation pulse is provided through the LAN at a frequency of 40 Hz.

Figure 11. Geophysical operator and main instrument rack on OH-KOG.

The operator is responsible for maintaining the flight logs, which summarise all the required parameters for each survey flight. An example log from flight 022 is shown in figure 12. Any noteworthy factors (e.g. urban fly-high conditions) and exceptions are digitally logged using a fixed-point (FP) number data channel that ties the operator’s notes to the recorded data stream. Fixed points also define on-line and off-line conditions.



JAC

●H-K●G
SURVEY FLIGHT REPORT

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

Report # ф22 Material # ф22
Video CF # 3 Data CF # ф2
Date 12 . OC 2009 / 163
FAA crew RV, MR, ET Operator EH
Airbase CAERNARFON
☑ Configuration interference-free
Magnetic stations CAERNARFON
☑ Diurnal ☐ GSM / ~~Iridium~~
☑ Server ☑ Video ☑ Laser
☑ GPS ☑ Memory cleared ☐ ~~RDS~~
☑ MGM Compensation slot # 13
☑ ADC QNH 1020 hPa Baro 187 m
☑ GR-820 ☑ Gains Calibration ✓/✓
☑ AEM ☑ Signal Calib start ☑☐ stop ☑☐

TIMES
In 14 : 03 On 14 : 00
Out ~~10 : 00~~ 09 57 Off ~~09 : 57~~ 10 00
Block 04 : 06 Total 04 : 00

Rec 1 10 : 05 - 13 : 55 2 : - :
☑ Video rec on ☑ Laser rec on

#	Line #	Dir	h start	min	h end	min	P	W	U fp	M fp	Other line notes
1	0106	360	10	11	10	21	RV				PL, WIND FARM
~~2~~	0100	180	10	23	10	25					PL-4 - ABORTED
~~3~~	0100	180	~10	25	~10	26					ABORTED - CONSOLE PROBLEM
4	0106	360	10	33	10	43		m			
5	0100	180	10	44	10	55		m			PL-18
6	0107	360	10	56	11	05		m			PL-22
7	0101	180	11	07	11	17					PL-25
8	0108	360	11	18	11	28					PL-28
9	0102	180	11	29	11	39					WF, PL-31
10	0109	360	11	40	11	50					PL-34
11	0103	180	11	51	12	02					WF, PL-37
12	0110	360	12	04	12	14	MR				WF-42,
13	0104	180	12	15	12	25					↓ , PL-43
14	0116	360	12	26	12	36					PL-46
15	0111	180	12	37	12	47					PL-49
~~16~~	0117	360	12	48	12	51					ABORTED - GR-820 Tx ERROR
17	0112	180	12	58	13	08			53		X-FEED ON, HIGH START.
18	0117	360	13	09	13	19			57		PL-56, HIGH END.
19	0113	180	13	20	13	30			59		X-FEED OFF, HIGH START, PL-60
20	0118	360	13	31	13	41			64		PL-63
21	0114	180	13	42	13	52			66		HIGH START, PL-67.
22											
23											18 LINES
24											
25											
26											
27											
28											
29											
30											

System/Aircraft changes ☑ No ☐ Yes Flight cancelled ☐ due to: Remarks
PL = Power Line.
WF = Wind Farm
☐ Continue

W=weather: s=shower, r=rain, m=mist, t=turbulence, w=strong wind U=urban area fix points M=mast fix points

Figure 12. Operators log for Flight 022.

4.1 QC AND FIELD PROCESSING

The basic processing of the recorded data is undertaken immediately after each flight and before the start of the next flight.

In the first stage the data is examined for any apparent errors such as file corruption or significant data errors. An example of this is shown below. After this, the data profiles are examined more carefully. Standard processing and QC involves the use of fourth differences in the magnetic and electromagnetic channels. The appearance, quality and noise levels of all data components together with EM calibrations, drift levels and noise peaks are examined.

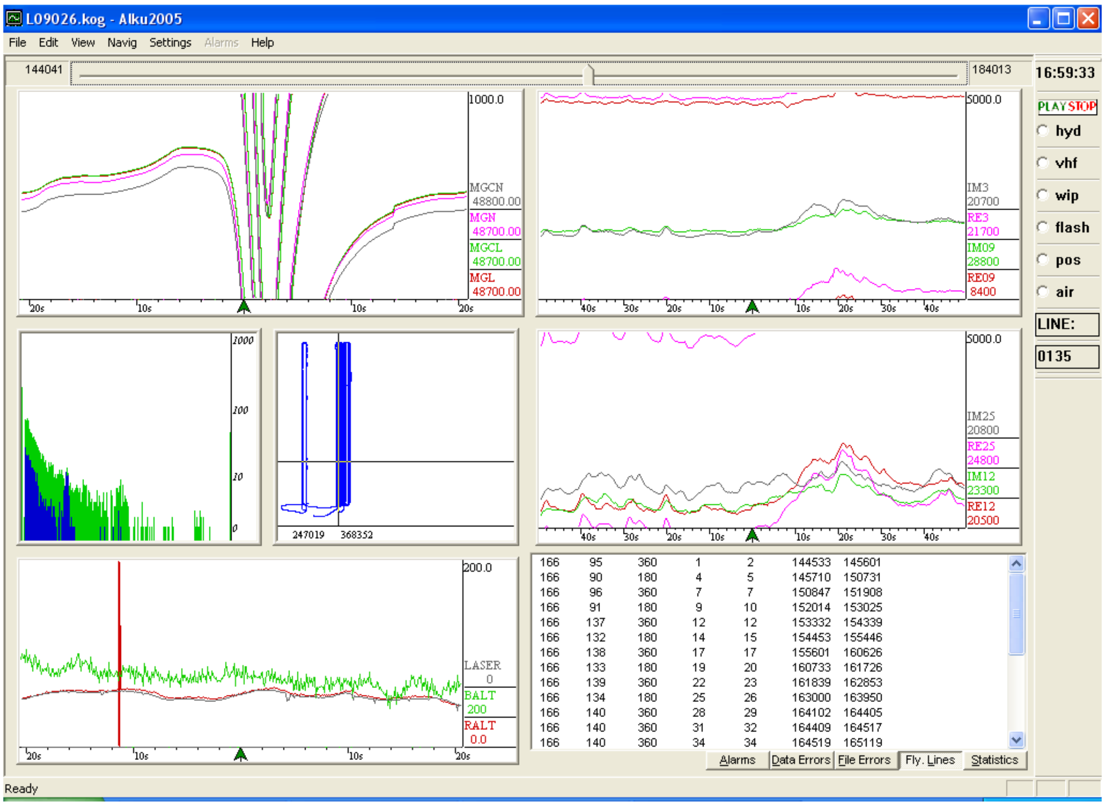


Figure 13. Example of the initial QC using ALKU2000 (Flight 026)

Base station magnetic and GPS data are also checked. For magnetic data this means comparing the recorded data against specification conditions for reflights. The GPS data are checked for any recording gaps or low-quality data.

Although the final levelling of the EM data is performed after the whole area has been surveyed, preliminary levelling is carried out at this stage. This initial levelling step, carried out in the field, is important in that it allows for a greater degree of QC on the EM coupling ratios acquired.

After all these processing steps, further programs are then applied for the calibration and the application of methodological corrections to the geophysical data. These procedures provide an initial, but still preliminary, set of text files (termed .xyz) for each flight and for each of the three geophysical data sets. These data sets are finally assembled into a Geosoft database for further QC assessments according to those required by the survey specifications.

The outcome of the application of the procedures mentioned above, together with the DGPS corrections, result in flight-line by flight-line xyz text files for each geophysical parameter. These are transferred to Geosoft databases where further QC control is applied. Altitude deviation is checked statistically and also by plotting colour profiles. The line paths are compared to the specified line paths and the flight path deviation is analysed. Sampling intervals and survey speed are also checked.

Average radiometric spectra and the main energy windows are plotted for each line. This allows an assessment of any spectral drift. Spectral stability and overall functioning of the spectrometer is controlled during the survey in real-time (geophysical operator), together with the initial QC and line-based spectral inspection.

Processed data for each successive flight are appended to the survey area databases. Geophysical parameters, errors and noise levels of all measurements are examined on a line-by-line basis. Geophysical parameters are also interpolated to grids and examined. All these grids are preliminary but they form useful updated summaries of the behaviour of the survey data.

4.2 FINAL PROCESSING

Final processing of all the data is carried out only after all survey lines have been acquired and accepted. The final processing does not form part of this logistics report. The procedures applied to the data are described by Hautaniemi et al. (2005). The final levelled EM data are then used to calculate apparent resistivity and depth according to a half-space model (Hautaniemi et al., 2005, Leväniemi et al., 2009).

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