Fixed-wing magnetic and radiometric survey of the Finnmark Region

for the

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1 INTRODUCTION

NOVATEM INC. was selected by the **GEOLOGICAL SURVEY OF NORWAY (NGU)** to carry out a high resolution airborne magnetic and spectrometric survey over the Finnmark in Northern Norway. The goal of this project is to provide geological input to the mapping of onshore-offshore structures and basement heat production, as well as geological mapping for planning of road and railroad tunnels and radon hazard applications. The campaign began on June 24th 2011 and end October 19th 2012.

The area flown is divided in two surveys areas: Finnmarksvidda named FRASW (Finnmark Region Airborne Survey West) and Lakselv-Kirkenes named FRASE (Finnmark Region Airborne Survey East). The entire project consisted of **141384** km linear distributed in **82584** km for FRASW and **58800** km for FRASE.

Two proprietary Piper Navajo PA31 aircrafts, equipped with a stinger and two wing-tip pods was used for this project. Taking into account the specific needs of the NGU, the use of three spectrometers RS500 in each aircraft was decided. Each aircraft was equipped with the following instrumentation:

- Three **Geometrics** G-823A Cesium optical vapour pumping magnetometers of the last generation, installed inside the stinger and inside the extensions of the wing-tip pods of each aircraft;
- Three **Radiation Solutions Inc**. (**RSI**) RS-500 Digital Airborne Gamma-Ray Spectrometers for the detection and measurement of low level radiation from naturally occurring sources. Each spectrometer includes 5 crystals RSX-5 detector: 16.72 litres (1024 in^3) NaI detector downward looking, plus a 4.18 litres (256 in^3) upward looking.
- A **NOVATEM** data-acquisition and compensator system unit, especially developed by **NOVATEM** for the Very High Resolution, based on the use of an inertial measurement unit and very robust inversion algorithms for the calculation of coefficients.
- An Inertial Measurement Unit (IMU) manufactured by **Honeywell**, providing the attitude angles of the aircraft (roll, pitch, yaw) in real time for both the compensation and the correction of the gradients;
- An orientation sensor (3DM) manufactured by **MicroStrain** , which incorporates 3 accelerometers and 3 magnetometers together, providing the attitude angles of the aircraft (roll, pitch, yaw) in real time for both the compensation and the correction of the gradients;
- A very high-resolution laser altimeter manufactured by **Optech**, integrated inside the rear of the aircraft. It measures the height of the aircraft above the ground with a precision of one centimetre, without calibration;
- A **TRA 4000** radar altimeter manufactured by **Free Flight Systems**, integrated below the aircraft, to measure the height of the aircraft above the ground when the clearance is too high for the laser (sharp valley);
- A double frequency **Novatel** Propack-V3 GPS providing an in real-time positioning with an accuracy of about one meter. The differential corrections are recomputed after the flights using the Waypoint GrafNav software to provide centimetre accuracy;
- A very efficient draping navigation system jointly developed by **Softnav** and **NOVATEM** to minimize the differences at the intersections of the flight lines and the control lines;

Two **GEM** systems magnetic base stations GSM19 and **Novatel** Propack-LBS base stations, for both magnetic temporal corrections and after flight differential positioning corrections.

All this instrumentation uses the latest technologies, both for measurements and processing:

- The compensation is based on the use of a high accuracy Inertial Measurement Unit (IMU), providing all the necessary information for the rigorous compensation of all the magnetic disturbances of the aircraft;

- The Piper Navajo proposed for this mission has been completely redesigned for the magnetic measurements of high resolution (by changing the magnetic components at the rear of the aircraft in particular).
- The data processing and Quality Controls as well as a presurvey reports were produced on the field (final maps and data processing were them produced in Montreal, Canada);
- Data processing and mapping were calculated by experienced geophysicists using the latest computer technology and state-of-the-art software;

NOVATEM is an active member of the International Airborne Geophysics Safety Association (**IAGSA**) and followed all its recommendations and guidelines.

This report describes the running of the operations during the survey, the equipment, the quality controls, and finally, the acquisition and processing of the data.

Figure 1 : Crew at Vigra Airport in 2011

2 SURVEY AREA DETAILS

2.1 SURVEY LOCATION

The FRAS project is located North of Norway as shown on the following figure

Figure 2 : Large scale location of the FRAS project in Norway

2.2 SURVEY BLOCKS PARAMETERS AND FLIGHT PATH

The survey parameters are summarized in the following tables.

Parameters	Specifications FRASW	Specifications FRASE
Traverse line spacing	200 m	200 m
Control line spacing	2 000 m	2 000 m
Traverse line direction	N 90	N 80
Control line direction	N 0	N 350
Magnetic sampling rate	10 Hz, 6.25 m at 225 km/h	10 Hz, 6.25 m at 225 km/h
Radiometric sampling rate	0.5 Hz, 31.25 m at 225 km/h	0.5 Hz, 31.25 m at 225 km/h
Nominal height of the drape	60 m	60 m

Table 1 : Flight parameters

2.2.1. FLIGHT HEIGHT ABOVE GROUND (DRAPED SURFACE)

The flights were carried out following a predetermined draped surface according to airborne survey standards. These surfaces were calculated following the recommendations of the Geological Survey of Canada, using software especially developed for that purpose, which uses the **NGU** Digital Terrain Model and took into account the specifications and the real load of each aircraft. The rate of climb of the **NOVATEM PA31** aircrafts is 1 220 ft./min (6.3 m/s) (101 m/km using a speed of 225 km/h). Every effort has been made to keep a constant altitude and fly the best drape surface as possible. However, some areas had to be flown at higher altitude over industries, antennas or even boats on the sea. By comparing the altitude flown with the drape surface calculated, we can easily locate these few areas.

The ground clearance was fixed at **60m** in order to cover the entire surface of the project. These parameters have been modified by the pilot, only judge of the flight safety, according to the local conditions of flight (proximity of the inhabited zones, power lines, industrial premises, steep sided valley, etc.). Moreover, the facility for the pilot to follow these parameters varies mainly according to the topography of the area as well as the jet streams. The tolerances, compared to the theoretical flight path, are fixed at +/-50 m in the horizontal plane, and +/-20 m on altitude, measured on a flight line over 5km.

2.2.2. AIR SPEED AND TOLERANCE

The aircraft mean airspeed is approximately **225 km/h** above flat topography. For safety reasons the speed may vary in areas of rugged terrain and/or strong wind. With a data-recording rate of 10 points per second (10 Hz), geophysical measurements are acquired approximately every **7 m** along the survey line. With a data-recording rate of 1 point per second (1 Hz), radiometric measurements are acquired approximately every **70 m** along the survey line. In order to improve the spatial resolution of these measurements, **NOVATEM** proposed to use three spectrometers to increase the number of counts per second and therefore to increase the data acquisition frequency to 2 Hz (to reduce the integration time to 0.5 second), and thus reduced the distance between the measurements to **35 m**.

2.2.3. FLIGHT PATH AND CUMULATED LINEAR KILOMETRES TO BE FLY

The following figure presents the limits of the final flight path using the coordinates provided by NGU in rectangular system WGS84, UTM 34N. Tables giving the complete coordinates of the vertices of the blocks are shown in Appendices. Geodetic parameters that were used for the plane positioning and all subsequent coordinate transformations are also presented in Appendices.

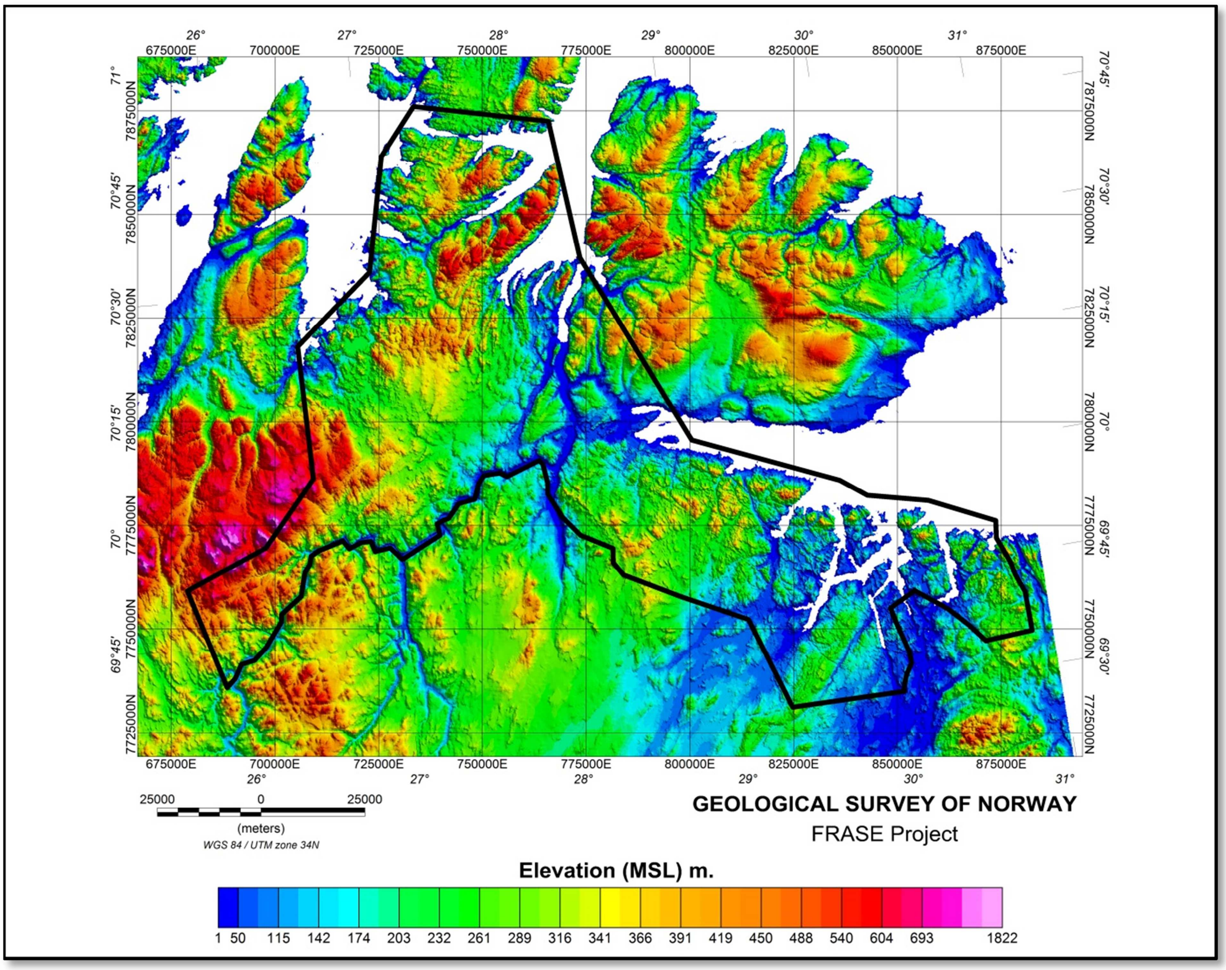

Figure 3 : Polygon to fly on FRASE project superimposed on elevation provided by NGU

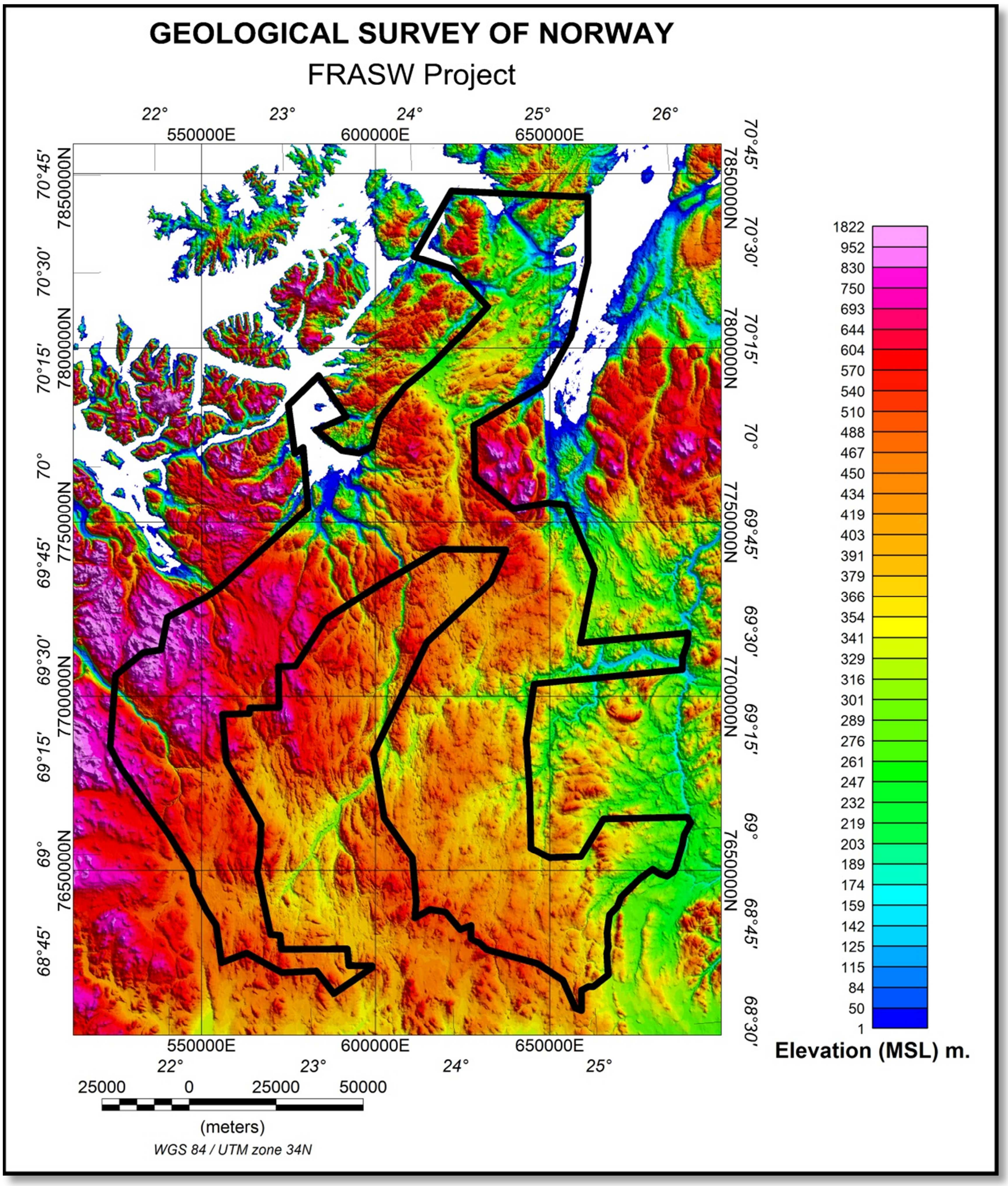

Figure 4 : Polygon to fly on FRASW project superimposed on elevation provided by NGU

3 LOGISTICS

3.1 GEOPHYSICS AND LOGISTICS SERVICES

NOVATEM provided the following services:

- Provision of the necessary qualified personnel required to complete the survey
- Supply of the technical equipment with spares necessary to fly the survey in an expeditious manner
- Supervision of the aircrafts and their crew
- Supply of the fuel and fuel transportation
- Pre-processing and quality control of the geophysical data on site
- Preparation and delivery to the client of all the final products specified in following paragraphs

The airborne geophysical survey was carried out by the personnel listed below. Acquisition, processing and presentation of data were done exclusively by employees of **NOVATEM.**

3.1.1 GEOPHYSICS CREW

Pascal Mouge, Ph. D.	Senior Geophysicist / Supervisor
Olivier Savignet, Eng	Project Director
Pierrick Chasseriau	Geophysicist / Project manager / QC & Data processor
Sébastien Jubelin	Operator / Maintenance of equipment

3.1.2 AIRCRAFT OPERATOR

NOVATEM aircrafts are operated by **AEROSCAN INC**. See details in Appendix K.

Mathieu Yanire	Chief Pilot and Manager of Flight Operations
Benoît Käppeli	Pilot-in-Command
Mathieu Fedotin	Pilot-in-Command
François Xavier Pinte	Pilot-in-Command
Xavier Pichot	Pilot-in-Command
Thomas Sornasse	Pilot-in-Command
Adalberto Coelho	AME
Luc Gagnon	AME
Olivier Moreau	AME

3.2 SURVEY SCHEDULE

The first tests and various equipment checks were carried out into the first week of October 2011. Production flights started on **June 25th, 2011** and finished on **October 19th, 2012**. Preliminary products were prepared in the field following the work progress.

All the steps of the survey were coordinated with the NGU representative in the field to satisfy its request. The time-table is detailed in the log books delivered weekly to the person in charge of the project at NGU.

The following timetable shows the progress on the FRAS project (both FRASW and FRASW), taking into account the 2.5 months where **NOVATEM** stopped his operation during winter.

	June 2011	July 2011	August 2011	Sept. 2011	October 2011	July 2012	August 2012	Sept. 2012
mobilisation & installation	x					x		
production &preliminary processing	x	x	x	x	x	x	x	x
Final processing								

	October 2012	November 2012	December 2012	January 2013	February 2013	March 2013	April 2013
mobilisation & installation							
production &preliminary processing	x						
Final processing			x	x	x	x	x

TABLE 2 : FRAS PROJECT TIMETABLE

3.3 PROJECT ORGANIZATION

The project had a large number of airports used for refuelling the aircrafts. Depending on which surveys were flown, the following airports were used:

- Alta Airport — IATA code: ALF;
  ICAO code: ENAT;
  (Lat, Long) = (69.9793, 23.3571)
- Hoeybuktmoen (Kirkenes) Airport — IATA code: KKN;
  ICAO code: ENKR;
  (Lat, Long) = (69.726, 29.8958)

Two more airports were available for safety reasons:

- Banak (Lakselv) Airport — IATA code: LKL;
  ICAO code: ENNA;
  (Lat, Long) = (70.0661, 24.975)
- Vadso Airport — IATA code: VDS;
  ICAO code: ENVD;
  (Lat, Long) = (70.0653, 29.8416)

NOVATEM was based near Kirkenes (FRASE) Airport and Alta (FRASW) airport where a local office, fully equipped to achieve the pre-processing (computers, printers, plotter rolls, phone, fax, communication with the aircraft, etc.), have been installed.

4 SURVEY EQUIPMENT

Before beginning the survey, instrumentation were tested on the ground to ensure that the acquisition parameters were within the contract specifications. After completion of the survey, the equipment specifications were checked again.

During the data acquisition, quality controls were carried out on the data on a daily basis by the **NOVATEM**'s data processor to ensure that the quality remained within specifications.

4.1 AIRCRAFTS

In order to meet the **NGU** requirements, **NOVATEM** flown this survey using two Piper Navajo PA31 aircrafts, registered **C-FWNG** and **C-GJDD,** property of **NOVATEM**, equipped with a stinger and two wing-tip pods.

These aircrafts have been completely redesigned for the magnetic measurements of high resolution (by changing the magnetic components at the rear of the aircraft in particular). The aircrafts have been completely overhauled during the year preceding the survey (two new engines, two new propellers, etc.). The aircrafts thus had a potential far greater than the purposes of this survey and therefore required only low maintenance. Detailed specifications are provided in Appendices.

Figure 5 : Piper Navajo PA31 C-FWNG and C-GJDD aircrafts

Both aircrafts are equipped with Long Range Tanks (Nayak Nacelles fuel tanks – STC SA1305SW) for a provision of 7h of flight. Aircrafts were maintained on the Air Operators Certificate of **Aeroscan**, Canada, and approved by Transport Canada.

4.2 GAMMA RAY SPECTROMETERS

The SAS survey was flown using two airborne gamma ray spectrometers RSX-5 in each aircraft, manufactured by Radiations Solutions Inc. The RSX-5 detector consists of 4 x 4.18L NaI downward looking detector and 1 x 4.18L upward looking detector. <u>Thus a total of 33.44 litres downward looking and 8.36 litres upward looking was used (41.8 litres total).</u> Spectrometers were coupled to a PPT (Precision Pressure and Temperature) system which produces high quality analog signals for Digital analysis by the Advanced Digital Spectrometer (ADS) module.

The ADS module processes the incoming gamma ray pulses to produce a fully linearized 1024 channel spectrum for additional analysis with the RadAssist setup/support software. These spectra are fed by 1Mbps/sec RS-485 data connections to the DPU unit for summing and gain analysis. The ADS spectrometer achieves a very clean linearized spectrum, at very high throughput data rates and up to 10 per sec data sampling.

The console automatically adjusts the gain of the detectors to compensate for warm-up and aging drift effects. The system uses Natural Radioactive isotope present in all ground material to stabilize the system at start-up and maintain this gain automatically during system use with no user input required. Newly developed technology uses multiple peak stabilization for fast accurate gain stabilization typically 10-20 times faster than older systems. The RSX-5 spectrometer is self-calibrating and does not require daily source tests. The native system format is 1024 channels but the user can select operation in 256, 512 or 1024 channel spectral resolution as required to suit the application. Taking into account the need of the survey, **NOVATEM** proposed a 512 channel spectra for both downward and upward looking detectors.

The spectrometers were connected to their own pressure and temperature probe (Honeywell) having resolutions of 0.1 °C and 0.1 mbars. Each spectrometer were fully calibrated and tested at the manufacturer in May 2011.

4.3 MAGNETOMETERS

4.3.1 AIRBORNE MAGNETOMETERS

Three **Geometrics** G-823A Cesium Magnetometers, with a sampling rate of 10 measurements per second and an in-flight sensitivity < 0.0005 nT/□Hz and a heading error less than 0.15 nT over entire 360° polar and equatorial spin, was used. These magnetometers provide higher sensitivities and minimal heading errors.

SPECIFICATIONS	
Sampling rate	10 Hz
Accuracy	< 0.1 nT
Sensitivity	< 0.003 nT at 10 Hz
Resolution	0.0001nT
Dynamic range	20 000 at 100 000 nT
Heading error	± 0.15 nT

4.3.2 COMPENSATION

NOVATEM uses a proprietary compensator system developed especially for the Very High Resolution. **NOVATEM** compensator system was initially developed jointly with the Laboratory of Electronics, Technology and Instrumentation (LETI) of CEA in France. The first experiments were made in 2002. This compensator has since evolved. It notably includes for FWNG aircraft an Inertial Measurement Unit (IMU) and a 3DM orientation sensor for GJDD aircraft, which provides all the necessary information to recalculate the magnetic field components in a fixed reference system.

The magnetic noise of the aircraft (induced magnetization, permanent and eddy currents) are measured in real time and corrected during flights. Corrections can be repeated during the post-processing, particularly in order to test different sets of coefficients in particular when a new figure of merit is re-flown.

A flight calibration, along an accurate and reproducible geometry (FOM), is first performed at very high altitude, away from magnetic interference generated by the Earth's crust. A set of coefficients is then calculated by inversion, based on the physical magnetic disturbances model of the aircraft (the model is a linear combination of 18 terms, constructed from the cosine directors of the orientation angles and the Earth's field). These coefficients are then used to reconstruct the real-time magnetic field perturbations from the plane attitude angles provided by the IMU or the 3DM.

In addition to the components provided by a fluxgate magnetometer, Inertial Measurement Unit (IMU) or 3DM measurements are necessary for the Very High Resolution. A very small change in the orientation of the fluxgate axis generates a very strong variation of the magnetic measurement: for example, for a main magnetic field of 53,000 nT, a difference of 0.1 degree in the axis orientation results in a variation of amplitude of more than 100 nT. A positioning error of one axis, even small, thus results in a significant error, which causes anisotropy of the measurement. It is therefore impossible to make accurate compensation measurements with the only use of a vector magnetometer (fluxgate).

The compensation software uses the attitude angles provided by the IMU (and 3DM) and the magnetic components provided by a high-speed digital 3-axis fluxgate magnetometer and 24 bits analog to digital converter which specifications are resumed in the following table:

SPECIFICATIONS	
Magnetic noise	< 0.3 nT
Resolution	± 0.1 nT
Operating range	± 65 µT
Sampling rate	125 measurements/sec
Axis orthogonality	Better than ± 0.2º

4.3.3 BASE STATION MAGNETOMETER

Two **GEM** GSM19 base-stations recorded the diurnal variations were installed at fixed ground base stations (reference). The total magnetic field was recorded at a sample rate of 1 measurement per second.

SPECIFICATIONS	
Sampling rate	1 Hz
Accuracy	0.2 nT
Resolution	0.01 nT

Due to the large scale of the survey, restraint access to other infrastructure as power supply, the installation of two base stations was problematic for FRASW survey. However, two permanent base stations (Nordkapp & Sørøya) managed by the Tromsø Geophysical Observatory at University of Tromsø (geo.phys.uit.no) and three permanent base stations (Kilpisjärvi, Masi and Kevo) managed by IMAGE (International Monitor for Auroral Geomagnetism Effects) surrounding the survey area were also used to cover the entire survey area during all the survey operation.

For ensuring integrity of data, the base station near Alta (FRASW MAGBASE 1) was installed at the same location for both 2011 and 2012 surveys. Figure 5 shows typical installation of a base station in a quiet and secure environment.

Figure 6 shows locations of base stations installed by Novatem (yellow circles) and permanent base stations (orange circles) inside and around FRAS polygons.

Figure 6 : typical installation of base station

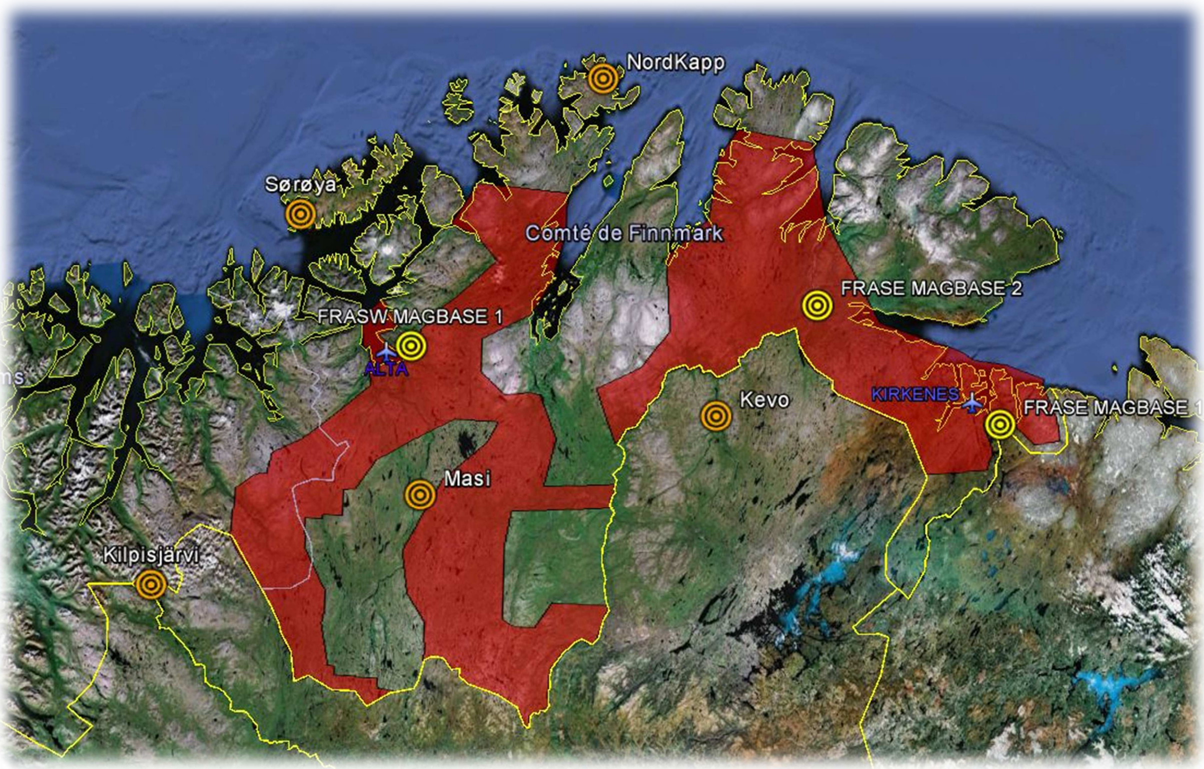

Figure 7 : Locations of base stations (orange=permanent base; yellow=Novatem base) inside and around FRASW & FRASE surveys

4.4 NAVIGATION

Figure 8 : Track-bar and navigation in flight

A double frequency **Novatel P**ropack-V3 GPS system providing the in-flight positioning with an accuracy of about one meter was used. The differential corrections were recomputed after the flights using the **Waypoint GrafNav** software to provide centimetre accuracy.

SPECIFICATIONS	
Sampling rate	10 Hz
WAAS L1/L2	10 cm
Reacquisition of L1 signal	0.5 s
Reacquisition of L2 signal	1 s
Time accuracy	20 ns

The following figures display the navigation during an approach procedure

and once the aircraft is on the line

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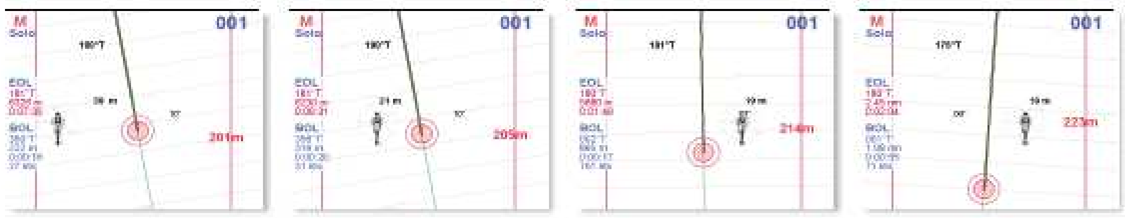

Figure 9 : NOVATEM's navigation software

4.5 GPS DIFFERENTIAL CORRECTION AND POST-FLIGHT

The **Novatel** Propack-V3 GPS dual frequency was used for real-time DGPS positioning. The receiver is coupled to the **Honeywell** Inertial Measurement Unit (IMU) in order to continue to provide real-time positioning with centimetre accuracy in case the GPS signal dilution is too high. The differential positions are finally restored after the flights using the **Novatel Waypoint GraftNav** software using data from a **Novatel** base station installed at the operation base.

4.6 ATTITUDE OF AIRCRAFTS

4.6.1 INERTIAL MEASUREMENTS ('INERTIAL MEASUREMENT UNIT')

A **Honeywell** HG 1700 AG62 Inertial Measurement Unit (IMU), is used to measure the attitude angles needed for compensation and correction of magnetic gradients. The three attitude angles (roll, pitch and yaw) are measured with very high sampling rate (between 100 and 600Hz) and synchronized at the same frequency as other measurements (10Hz). The IMU continues to provide real-time positioning with centimetre accuracy in case of loss of DGPS signal.

SPECIFICATIONS OF IMU	
Sampling rate	10 Hz (600Hz max)
Precision (pitch, roll, yaw)	0.001°

The **Honeywell** HG 1700 AG62 IMU is used following a security clearance agreement delivered by the Government of Canada according to the Canadian Controlled Goods Program.

4.6.2 ORIENTATION SENSOR (3DM)

A **MicroStrain** 3DM-GX1 sensor is used to measure the attitude angles needed for compensation and correction of magnetic gradients. The three attitude angles (roll, pitch and yaw) are measured with very high sampling rate (between 100 and 350Hz) and synchronized at the same frequency as other measurements (10Hz). The 3DM continues to provide real-time positioning with centimetre accuracy in case of loss of DGPS signal.

SPECIFICATIONS OF 3DM	
Sampling rate	10 Hz (350Hz max)
Precision (pitch, roll, yaw)	+/- 2°

4.7 RADAR ALTIMETER

The aircrafts were equipped with a TRA 4000 radar altimeter manufactured by Free Flight Systems, interfaced with an analog / digital board, to record the distance between the aircraft and the ground. The radar altimeter is calibrated by flying over a strip of known altitude (airport runway is preferred). Five heights surrounding the nominal height of the survey have been flown. A calibration curve is estimated by plotting the radar heights versus the GPS heights.

TECHNICAL SPECIFICATIONS	
Altitude range	-6 to 762 m
Altitude acuracy	±0.9 m for [0 , 30.48] m ±3% for [30.48 , 152.4] m ±5% above 152.4 m
Altitude ouput rate	25 Hz
Operating temperature	-55°C to +70°C
Input current	400 mA Max @ 28VDC

FLIGHT CONDITIONS	
Horizontal velocity	0 to 200 knots
Vertical velocity	0 to 20-25
Roll	0 to ± 20°
Pitch	0 to ± 20°

4.8 LASER ALTIMETER

An **Optech**'s ADM laser altimeter was mounted on each aircraft along with the GPS and the magnetic sensors for an accurate positioning of the measurements. The ground clearance was sampled 10 times per second with an accuracy of about one centimetre.

The ADM laser altimeter provides data accurate within 5 cm, with a resolution of 1 mm. The ADM uses last-pulse logic to measure through fog or snow. No calibration is required.

SPECIFICATIONS	
Sampling rate	10 Hz (100 Hz max)
Accuracy	1 cm
Resolution	1 mm
Colour	904 nm (IR)
Divergence	0.3º

4.9 DATA ACQUISITION AND RECORDING SYSTEM

The acquisition system developed jointly by **SOFTNAV** and **NOVATEM**, specifically for airborne geophysics surveys, is based on an onboard computer which records and synchronizes DGPS and magnetic data in real time. Data are saved on a backup disk after each flight. The following data are recorded:

- Flight number
- Line number
- Record number
- Day number from beginning of the year
- UTC Time
- WGS84 UTM 34N coordinates
- Quality factor (PDOP, etc.)
- Pitch, roll, yaw of the aircraft
- Radar and Laser altimeter
- Pressure and Temperature
- Total magnetic field (3 magnetometers)
- Components of the total magnetic field
- Full downward and upward radiometric spectra

Due to the high performance of the acquisition software, the instrumental delay of the acquisition system is in general less than 0.1s.

- The clock of the computer is adjusted then synchronized by the PPS signal and the GPS time of the Novatel receiver
- The precision is higher than 0.001 second (any latency is removed)
- The data coming from the different devices are processed independently and not sequentially

4.10 FIELD COMPUTER WORKSTATION

Over four dedicated PC-based field computer workstations are used in the field for purposes of checking geophysical data for quality control, calculating and displaying the navigation, producing preliminary maps and saving the digital data.

4.11 SAFETY AND CERTIFICATES

Installation of the survey equipment was done by qualified personnel. The aircraft installations are covered by Supplemental Type Certificates (STC) number LCA00500, LCA00216-PL2, LCA00216-MP2 and LCA00216-CD2 issued by Transport Canada.

4.12 SPARE PARTS

All the necessary spare parts and test instrumentation was stocked and available in the field during all the operation time.

5 CALIBRATION AND QUALITY CONTROLS

All instruments, including spares, were tested and calibrated prior or during the survey. Details and results of the different tests, used for the quality controls and data processing, are attached in the appendices.

Once a week, the **NOVATEM**'s Project Manager provided to the Client representative, all the relevant survey information including the date, flown lines number, start and end time of flight, segments, events, problems, etc on flight logs. These logs are also included in the appendices.

Quality controls are integrated in the normal survey procedures and commence from the establishment of the flight paths until the delivery of the data and reports to the client. Before the survey, the quality controls are applied in order to make sure that:

- The survey specifications are adequate for the targets
- The survey specifications are safe for the personnel and the equipment
- The navigation is safe considering the topography and the meteorological conditions
- The equipment and instruments are conform to the survey specifications (both for hardware and software)
- The spare parts and necessary instrumentation are available to perform the survey in an expeditious manner
- The aircraft maintenance facilities and spare parts are available

During the survey, the quality controls are applied by the Project Manager. In flight, the quality controls are computer-performed and the pilot stops the survey if the geophysical or/and aeronautical parameters don't meet the survey specifications. The data of the base-station are computer-controlled and the flights are stopped if the level of activity does not meet the survey specifications.

After each flight, the raw data are checked for quality and completeness and then securely stored. For each flight, the following controls are applied:

- Sample separation

- Flight path deviation
- Altitude deviation
- Data noise level

6 DATA PROCESSING

6.1 FLIGHT PATH RECOVERY

The successive GPS system positions delivered are firstly converted to UTM rectangular coordinates. Using the data of the reference station, the positions are recomputed using Waypoint software. A precision better than 20 cm is then obtained for the whole data set collected.

6.2 PROCESSING OF MAGNETIC DATA

The data collected in flight were edited daily and archived in *Geosoft Oasis Montaj* databases. Profiles were then plotted and controlled. Due to the spatial offset between the magnetic sensor and the GPS antenna, corrections are applied directly to the coordinates. First, the raw data are corrected for temporal variations (magnetic base station). Then, the directional variations due to the intrinsic heading error are removed. Using the vectorial information from the fluxgate magnetometers, magnetic measurements are corrected for perturbation due to the aircraft (compensation). Finally, a levelling is applied using the tie-lines in order to remove the residual errors caused by variation in the aircraft height.

6.2.1 DIURNAL CORRECTION

During FRASW survey, a permanent **NOVATEM** magnetic base station (Lat 70° 2'18.15"N; Long 23°33'26.79"E) was installed at 10 km North-East from Alta airport, far away from any potential man-made magnetic noise as reference. Base station location As FRASW survey has been flown during a period covering 2 years with demobilisation-mobilisation.

For FRASE survey, two base stations were installed. One was installed at local office (Lat 69°39'40.85"N; Long 30°12'29.89"E) at 15 km South-East from Kirkenes airport. The second one (Lat 70°10'24.03"N; Long 28°13'1.67"E) was installed in the middle of FRASE block at about 3 km South of Tana Bru in a very quiet place.

The data collected (1 Hz) at the base station were edited, archived in an ASCII file and then linearly interpolated to match the frequency of data acquisition. The base station being fixed to the ground and far away from any man-made magnetic interference, the variations recorded are precisely the temporal variations caused mainly by solar activity (diurnal variation, pulsation…).

Data from **Sørøya** and **Nordkapp** were downloaded from the Tromsø Geological Observatory website and for the whole duration of the survey. Data are 1 minute resolution (1/60 Hz). Data from **Masi**, **Kevo** and **Kilpisjärvi** were downloaded at 10 sec. resolution (1/10 Hz) from IMAGE website (http://www.geo.fmi.fi/image/index.html)

First, corrections were calculated after removing the local IGRF on each base station. The variations are then used to calculate a surface with a polynomial function taking into account the inverse distance of the aircrafts with each base station. Finally, the result, having spatiotemporal variation, is then subtracted from the value of the magnetic field measured in flight.

6.2.2 LAG CORRECTION

Residual errors of positioning are generated by the delay of time (lag) between the instant when the position is measured and its recording, generating a systematic offset in the position of the recorded magnetometer values, depending on the flight direction. The results of the lag tests carried out showed that the lag time between the geophysical data and the DGPS unit is not noticeable. The conception of the acquisition system, which separately assigns a “tag” to each instrument, renders the time lag negligible. Consequently no correction has been applied.

6.2.3 REMAINING CORRECTIONS

Another source of error, known as heading error**,** is intrinsic to optically pumped magnetometers: the absolute value of the magnetic field delivered by the magnetometer depends on the orientation of the sensor (position of the sensor compared to the surrounding magnetic field lines). This error - around ±0.3 nT for Caesium vapour optically pumped magnetometers – is a constant for a given direction (it may thus vary along a profile depending on the wind or the topography). Simple high altitude tests carried out prior to the survey enable us to determine these directional constants. The corrections obtained are applied to the data during processing.

6.2.4 COMPENSATION

The magnetic noise of the aircraft (permanent and induced magnetization, plus eddy currents) is measured in real time by the compensation system. Corrections are made in-flight as well as during the post-processing.

A calibration flight, following a precise and easily reproducible geometry (FOM), is first carried out at very high altitude, far from the magnetic disturbances generated by the Earth's crust. A set of coefficients is then calculated by inversion, using a physical model of the magnetic disturbances of the aircraft (the model is a linear combination of 18 terms, built from the cosine of the orientation angles and the terrestrial field). These coefficients are then used to rebuild in real time the field of the magnetic disturbances of the aircraft from the angles of attitude provided by the inertial measurements unit.

A very weak variation of the orientation of the axis of the fluxgate generates a very strong variation of measurement: thus for a field of 53.000 nT, a difference in orientation of 0.1º results in a variation of amplitude of more than 100 nT. A positioning error on one of the axes, even if very small, will result in an important error, which involves anisotropy in the measurement. It is thus impossible to make precise compensation using only a vectorial magnetometer as a fluxgate. On the other hand, very powerful inertial measurements units are now available and are able to measure the angles of attitude with a very high degree of accuracy.

The following figure illustrates the correlations between measurements of the magnetic field and the roll of the aircraft (principal disturbance component in the measurements), measured by the IMU. We can determine the correction of the variations of rolling using the data of the IMU. Rolling is the principal component of the noise due to the aircraft. In this case, the horizontal axis represents the time, indicated here in fiducials (0.1s). No filtering was applied to these data.

The use of an inertial measurement unit makes it possible to avoid all undesired filtering applied traditionally in real time compensation. Most commercial compensation systems apply a low-pass filtering of 0.9 Hz or 1.8 Hz - respectively more than 10 or 5 fiduces, to 0.1 Hz of acquisition – without any possibilities of modification, not allowing for high frequency acquisition and compensation.

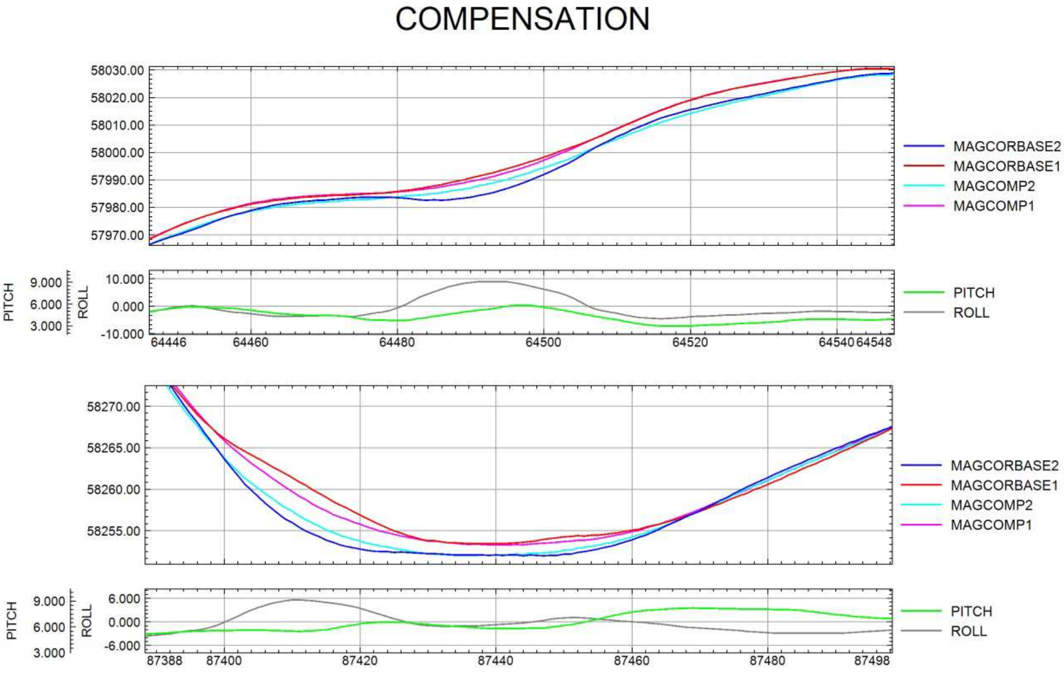

Figure 10 : Compensation example

- MAGCORBASE1 is the left total magnetic field, diurnal corrected
- MAGCORBASE2 is the right total magnetic field, diurnal corrected
- MAGCOMP1 is the left total magnetic field, compensated
- MAGCOMP2 is the right total magnetic field, compensated

We notice on figure, the differential effect of the plane (in first approximation, the plane behaves like a "dipole", most of the time asymmetrical compared to the axis of the plane, since it is oriented in the direction of the local magnetic field). This asymmetrical disturbance is entirely eliminated after compensation. On the other hand, the geological transverse gradient, which is reversed during the progress of the aircraft, is perfectly preserved being independent of the aircraft movement.

6.2.5 Traditional magnetic levelling

A standard levelling procedure, based on the differences observed at the intersections between lines and tie-lines, was applied using *Oasis Montaj*™.

The correction was only carefully applied at the intersections where conditions permitted, with restricted tolerances on gradients and differences. An Akima interpolation was chosen to calculate the error channel.

6.2.6 Novatem's magnetic levelling

The preceding method is well adapted for fixed wing surveys, where the draped surface is relatively smooth. Even if the navigation seems close to the draped surface, local differences can appear which are generally well correlated with the top of the hills or the bottom of the valleys. The traditional methods of levelling fail, because the corrections are not as simple as a constant shift or a linear trend, but a local oscillation (local height variation). Moreover, the oscillation varies, according to topography, the relative speed of the plane, the direction of the wind, etc… And consequently the Spline function should vary locally.

The **Novatem**'s levelling method is based on a frequency approach in order to level only the frequencies measured at the points of intersection. Once the local variations to be levelled are identified, they are removed, and then added back once levelled. This is equivalent of removing a variable base level and making local corrections that will be added to the data. This procedure is not a micro levelling as defined by Geosoft because the corrections are only applied to a base level, without modifying the high frequencies.

Finally, the vertical gradient, calculated by convolution, makes it possible to bring the anomalies closer to the vertical axis of the sources. However, this technique reinforces the small wavelengths, and can create numerical artefacts.

6.3 GAMMA RAY SPECTROMETRY DATA PROCESSING

6.3.1 PRE-FILTERING

The pre-filtering applied to the data is detailed in the appendices, along with all the other subsequent filters required during the processing.

6.3.2 SPECTRAL ANALYSIS AND SMOOTHING USING THE NASVD TECHNIQUE

The stability of the spectra was checked, and no recalibration was necessary during the post-processing. No spectra stacking were applied to the raw data except for the calculation of the coefficients. On the other hand, principal component method (NASVD), which is more reliable, was used for spectrum restoration (smoothing), using Praga software from Geosoft.

6.3.3 LIVE TIME CORRECTION

Due to finite time required by the spectrometer to process counts from the detector, the counting time is less than half a second. RSX-5 detector pack has a very fast processing system which reduces dead time to an average of 1 ms. However, the spectrometer automatically records the system live time, which can be used to increase and normalize counts for a real second with the following formula

$$N_L = \frac{N_{NASVD}}{L}$$

Where: N_L is the live time corrected window (cps)
N_{NASVD} is the NASVD smoothed channel (cps)
L is the live time (sec)

6.3.4 COSMIC AND AIRCRAFT BACKGROUND REMOVAL

Variable cosmic radiation that reaches the Earth increases count rates in all spectral windows. The spectrometer used records a cosmic window with all incident particles above 3 MeV for which there is no such terrestrial gamma rays. Since the counts due to cosmic radiation in various windows is linearly related to the cosmic ray window, correction can be done using the linear function

$$N_{ac} = N_L - (a_N + b_N C)$$

Where: N_{ac} is the cosmic and aircraft background corrected channel (cps)
N_L is the live time corrected window (cps)
N is the stacked cosmic channel (cps)
a_N is the aircraft background for this channel
b_N is the cosmic coefficient for this channel

6.3.5 RADON REMOVAL

Since radon contamination is more significant in the Uranium window, due to its related energy level, an upward looking detector is used to monitor changes in the uranium window. The variation of radon background in the uranium window can then be evaluated with the following formula.

$$U_r = \frac{u_{ac} - a_1 U_{ac} - a_2 Th_{ac}}{a_u - a_1 - a_2 a_{Th}}$$

Where: U_r is the radon component in the downward U window (cps)
U_{ac} is the downward U corrected from cosmic and aircraft (cps)
u_{ac} is the upward U corrected from cosmic and aircraft (cps)
Th_{ac} is the downward Th corrected from cosmic and aircraft (cps)
a_u, a_{Th} are the upward/downward calibration factors for U and Th
a_1, a_2 are the upward/downward ground ratio for U and Th

Corrected upward and downward uranium count rates used in this formula were first highly filtered to reduce statistical noise. The method used follows the recommendations of IAEA Report #323.

The next step of the processing consists of determining the radon component in the other four windows using the following linear equations

$$u_r = a_u U_r + b_u$$

$$K_r = a_k U_r + b_k$$

$$Th_r = a_{Th} U_r + b_{Th}$$

$$TC_r = a_{TC} U_r + b_{TC}$$

Where: u_r is the radon component of the upward looking uranium
TC_r, K_r, U_r and Th_r are the radon components in the different downward looking windows
a, b are linearity coefficients

Finally, the count rates obtained are then subtracted from their respective window.

6.3.6 Reduction to Standard Temperature and Pressure (STP)

The laser altimeter is mainly used for height correction. Since the attenuating properties of the air are affected by its density, height must be corrected for the ambient temperature and pressure.

$$h_{STP} = h_{obs} \times \frac{273.15}{T + 273.15} \times \frac{P}{1013.25}$$

Where: h_{STP} is the equivalent height at STP (metres)
h_{obs} is the measured laser altimeter height (metres)
T is the air temperature (°C)
P is the barometric pressure (mbar)

6.3.7 Compton stripping correction

Compton stripping correction consists in removing the contribution of the other elements present in the spectral window of interest. After completion of background corrections, spectral overlap as to be removed. The stripping ratios used for it, given by the manufacturer and presented in Appendix D, are the ratios of the counts detected in one window to those in another window for pure sources of K, U and Th and are given by the manufacturer.

Owing to the scattering in the air, the stripping ratios increase with altitude and must first be corrected at STP elevation following the linear relation

$$\alpha_{STP} = \alpha + h_{STP} \times 0.00049[\text{m}^{-1}]$$

$$\beta_{STP} = \beta + h_{STP} \times 0.00065[\text{m}^{-1}]$$

$$\gamma_{STP} = \gamma + h_{STP} \times 0.00069[\text{m}^{-1}]$$

Where: α, β, γ are the Compton stripping coefficients
α_{STP}, β_{STP}, γ_{STP} are the STP corrected stripping coefficients
h_{STP} is the equivalent height at STP (metres)

Using the six stripping ratios, the background corrected count rates in the three windows can be stripped using the following formulas

$$K_{strip} = \frac{Th_{rc}(\alpha\gamma - \beta) + U_{rc}(\alpha\beta - \gamma) + K_{rc}(1 - a\alpha)}{1 - g\gamma - a(\gamma - gb) - b(\beta - \alpha\gamma)}$$

$$U_{strip} = \frac{Th_{rc}(g\beta - \alpha) + U_{rc}(1 - b\beta) + K_{rc}(b\alpha - g)}{1 - g\gamma - a(\gamma - gb) - b(\beta - \alpha\gamma)}$$

$$Th_{strip} = \frac{Th_{rc}(1 - g\gamma) + U_{rc}(b\gamma - a) + K_{rc}(ag - b)}{1 - g\gamma - a(\gamma - gb) - b(\beta - \alpha\gamma)}$$

6.3.8 Air Attenuation Correction

The correction for stripped count rates of the four windows are brought to a nominal survey altitude by the equation

$$N_{cor} = N_{strip} e^{\mu(H - h_{STP})}$$

Where: N_{cor} is the altitude corrected window count rates (cps)
N_{strip} is the stripped window count rates (cps)
μ is the attenuation coefficient (metres^{-1})
h_{STP} is the equivalent height at STP (metres)
H is the nominal survey altitude used as datum (metres)

The nominal survey altitude is specified in paragraph 2.2 of the present document. Due to steep valleys, aircrafts were sometimes too high to record sufficient data. For these reasons a threshold of 250 meters was applied in order to avoid creation of excessive noise in those areas.

6.3.9 Conversion to Radioelement Concentrations

The final step is to bring back the corrected window count rates into radioelement concentration value on the ground using the formula

$$eN = \frac{N_{cor}}{S}$$

Where: eN is the element concentration K (%) or the equivalent element concentration of U or Th (ppm)
N_{cor} is the altitude corrected window count rates (cps)
S is the broad source sensitivity for the window

The natural air absorption dose rate is finally determined using the previous calculated concentration and the following formula

$$E = 13.08 \times K + 5.43 \times eU + 2.69 \times eTh$$

Where: E is the absorption dose rate (nG/H)
K is the element concentration (%)
eU, eTh equivalent element concentration of U and Th (ppm)

6.3.10 Levelling

Radiometric data leveling is rarely efficient, since it is not continuous as the magnetic field is. However, it can be of great help if obstacle were in the path of the aircraft during a line. Height differences can be corrected with very good accuracy.

To do so, the correction was only carefully applied on these specific intersections, with restricted tolerances on gradients and height differences. An Akima interpolation was chosen to calculate the error channel.

6.3.11 Filters Parameters for Spectrometry

The following table summarizes the different filters applied during the processing of the spectrometry data.

Correction	Parameter processed	Type of filter	Purpose
Pre-filtering	Laser altimeter	5 Points median on 10 Hz data resample at 1 HZ	Spikes removal
Pre-filtering	Cosmic Channel	15 points stacking	Reduction of statistical noise
Pre-filtering	Temperature Pressure	15 points median	Spikes removal
Pre-filtering	All nucleus ROIs	NONE	Smoothing
Radon removal	Corrected Up/Down	400 points median	Reduction of statistical noise
Spectrum restoration	All radioelement's concentration	NASVD with 7 eigenvectors for inverse transformation	Smoothing

7 DELIVERABLES

A digital version of the numerical data (databases), the maps and the report are archived on a DVD. One set is included with each report.

7.1 DIGITAL DATA

The databases are delivered in Geosoft format .GDB and ASCII format .XYZ. The structure and the format of the databases are described in the following table:
Note: All intermediate processing (correction) could also be provided to client upon request.

A. Magnetic database

Data	Description	Unit
FLIGHT	Flight No.	yyyymmddnn
LINE	Line or Tie-line number	
REC	Record No.	
X	UWGS84 coordinates UTM 32N	metres
Y	UWGS84 coordinates UTM 32N	metres
DAY	Day number from beginning of the year	Day
TIME	UTC time	HHMMSS
LONGITUDE	GPS Longitude WGS84	decimal degree
LATITUDE	GPS Latitude WGS84	decimal degree
ALTITUDE	GPS Altitude WGS84	meters asl
SPEED	Aircraft speed	meters /sec.
DRAPE	Theoretical Drape surface	meters
RALT	Radar altimeter	meters
LALT	Laser altimeter	meters
MAGR1	Raw magnetic measurements (Left wingtip pod)	nanoteslas
MAGR2	Raw magnetic measurements (Right wingtip pod)	nanoteslas
MAGR3	Raw magnetic measurements (Stinger)	nanoteslas
MAGCORB1	Diurnal corrected magnetic measurements (Left wingtip pod)	nanoteslas
MAGCORB2	Diurnal corrected magnetic measurements (Right wingtip pod)	nanoteslas
MAGCORB3	Diurnal corrected magnetic measurements (Stinger)	nanoteslas
MAGBF	Final magnetic base station re-sampled (10Hz)	nanoteslas
MAG1C	Compensated magnetic measurements (Left wingtip pod)	nanoteslas
MAG2C	Compensated magnetic measurements (Right wingtip pod)	nanoteslas
MAG3C	Compensated magnetic measurements (Stinger)	nanoteslas
MAG1ML	Levelled magnetic measurements (Left wingtip pod)	nanoteslas
MAG2ML	Levelled magnetic measurements (Right wingtip pod)	nanoteslas
MAG3ML	Levelled magnetic measurements (Stinger)	nanoteslas
IGRF	IGRF (International Geomagnetic Reference Field)	nanoteslas
VD_MAG	FFT vertical derivative of total magnetic field	nanoteslas/m
SRTM	Shuttle Radar Topography Mission	meters

Table 3 : Structure and format of the magnetic databases

B. Radiometric database

Data	Description	Unit
FLHT	Flight No.	
LINE	Line or Tie-line number	
REC	Record No.	
X	UWGS84 coordinates UTM 32N	metres
Y	UWGS84 coordinates UTM 32N	metres
DAY	Day number from beginning of the year	Day
TIME	UTC time	HHMMSS
LONGITUDE	GPS Longitude WGS84	decimal degree
LATITUDE	GPS Latitude WGS84	decimal degree
ALTITUDE	GPS Altitude WGS84	meters asl
SPEED	Aircraft speed	meters /sec.
DRAPE	Theoretical Drape surface	meters
RALT	Radar altimeter	metres
LALT	Laser altimeter	metres
DEM	Digital Model Elevation (altitude GPS – laser altimeter)	meters
BARO	Barometer	mbars
TEMP	Temperature	°C
DETDN	Numbers of detector in stable operating condition	
DETUP	Numbers of detector in stable operating condition	
SPEC_DN	Full downward spectrum	cps
SPEC_UP	Full upward spectrum	cps
SPEC_DN_NASVD	NASVD Full downward spectrum	cps
SPEC_UP_NASVD	NASVD Full upward spectrum	cps
RCCD	Raw cosmic count, downward-looking (>3MeV)	cps
RCCU	Raw cosmic count, upward-looking (>3MeV)	cps
RTOT	Raw total counts (0.40 – 2.81 MeV)	cps
RURD	Raw uranium counts, downward-looking (1.66 – 1.86 MeV)	cps
RKAL	Raw potassium counts (1.37 – 1.57 MeV)	cps
RTHO	Raw thorium counts (2.41 – 2.81 MeV)	cps
RURU	Raw uranium counts, upward-looking (1.66 – 1.86 MeV)	cps
LIVE	Live time	msec
TOT	Total radiation	nGy/h
KAL	Equivalent concentration of Potassium	%K
URA	Equivalent concentration of Uranium	ppm
THO	Equivalent concentration of Thorium	ppm
DOSE	Air absorbed dose rate from radionuclide concentrations	nGy/h

Table 4 : Structure and format of the radiometric databases

7.2 DIGITAL GRIDS

For convenience, the **NGU** will produce its own maps with the data and grids we provide. However, we include, with the digital data, colour shaded grids showing all the elementary products. The following table describes the grids included:

Grids (FRASW)	Grid name
Magnetic anomalies (Left wingtip pod)	FRASW_MAG1.grd
Magnetic anomalies (Right wingtip pod)	FRASW_MAG2.grd
Magnetic anomalies (Stinger)	FRASW_MAG3.grd
First vertical derivative	FRASW_VD_MAG.grd
Uranium equivalent	C11089_FRASW_URA
Thorium equivalent	C11089_FRASW_THO
Potassium equivalent	C11089_FRASW_KAL
Air absorbed dose rate (Total Count)	C11089_FRASW_TOT

Table 5 : Grids types and associated drawing numbers for FRASW survey

Grids (FRASE)	Grid name
Magnetic anomalies	C11089_FRASE_MAG
First vertical derivative	C11089_FRASE_VGRAD
Horizontal transverse gradient	C11089_FRASE_HGRAD
Uranium equivalent	C11089_FRASE_URA_FINAL
Thorium equivalent	C11089_FRASE_THO_FINAL
Potassium equivalent	C11089_FRASE_KAL_FINAL
Air absorbed dose rate (Total Count)	C11089_FRASE_TOT_FINAL

Table 6 : Grids types and associated drawing numbers for FRASE survey

8 ADVANCED PRODUCTS

Advanced data processing are available in order to help the interpretation. Extra charges will be calculated for each grid and map produced.

Advanced magnetics data processing:

- Gradient enhanced Total Field gridding
- Nelson levelling
- Integration
- Upward and downward controlled continuations
- Depth slicing
- Reduction to the Pole or Equator
- Directional filtering
- Analytical signal
- Depth estimation by Werner de-convolution using the measured gradients
- Depth estimation by Euler de-convolution using the measured gradients
- Modelling and inversion
- Interpretation

Data compilation:

Data compilation can be required to merge actual data with pre-existing surveys. Preliminary transformations are first required in order to bring each data set in a unique and coherent system. These processing include:

- Transformation of the projection coordinates
- Data transformations: re-sampling, controlled upward or downward continuations, etc.

- Merging of the coherent grids
- Mapping
- Etc. …

Special algorithms have been developed to perform a perfect continuity between the profiles.
The final data are delivery in a data base suitable for the client.

9 SUMMARY

An airborne magnetic and radiometric geophysical survey was flown for the **GEOLOGICAL SURVEY OF NORWAY (NGU)** during June 25th 2011 to October 19th 2012. The **FRAS project** was composed of two blocks called FRASW and FRASE in the Northern part of Norway.

As requested by **NGU**, the digital products consist of raw and final databases, metadata files and final grid files. The digital data are included on the attached DVD. The final products include digital grids which represent the magnetic anomalies, the first vertical derivative, Potassium equivalent concentration, Uranium equivalent concentration, Thorium equivalent concentration and Air absorbed dose rate derived from total count. All these grids have to be examined in conjunction with this report.

The recognition of the principal geological features detectable on the maps must be supplemented by a detailed campaign on site, as well as by complementary measurements every time a recognized body cannot be correlated with surface observations. The interpretation of the data sets requires a profound knowledge of the physical properties of the area, in their contemporary geological or cultural context. A field campaign including rock sampling is thus an essential step to get all the benefits of the maps enclosed with this report.

This report was written by Pierrick Chasseriau, PhD., was verified by Olivier Savignet, Eng. and Thibaut Astic, Jr. Eng. and approved by Pascal Mouge, PhD.

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Pierrick Chasseriau, Ph.D. project manager

Pascal Mouge, Ph. D. President

APPENDICES

APPENDIX A: SURVEY GEODETIC PARAMETERS

The table below presents the geodetic parameters used for the projection plane positioning. These parameters were applied in all subsequent coordinate transformations.

Local Datum transform:	WGS 84 World
Ellipsoid:	WGS 84
Projection:	UTM
Zone:	34N
Lat0, Lon0,	0, 21
False Easting:	500 000
False Northing:	0
Scale factor:	0.9996
Major Axis, Inverse flattening, Prime Meridian	6378137, 298.25722, 0

Table 7 : Geodetic parameters

The following tables summarize the construction parameters of the grids:

Type of elements	FLOAT
Separation between two points along X, in m	50
Separation between two points along Y, in m	50
Number of points along X	4073
Number of points along Y	2893
Origin of the grid:	X = 678900 Y= 7731350
Azimuth	0

Table 8 : Magnetic grids parameters of FRASE

Type of elements	FLOAT
Separation between two points along X, in m	50
Separation between two points along Y, in m	50
Number of points along X	4107
Number of points along Y	2904
Origin of the grid:	X = 678000 Y= 7731100
Azimuth	0

Table 9 : Radiometric grids parameters of FRASE

Type of elements	FLOAT
Separation between two points along X, in m	100
Separation between two points along Y, in m	100
Number of points along X	1669
Number of points along Y	2348
Origin of the grid:	X = 523700 Y= 7610000
Azimuth	0

Table 10 : Magnetic grids parameters of FRASW

Type of elements	FLOAT
Separation between two points along X, in m	50
Separation between two points along Y, in m	50
Number of points along X	3334
Number of points along Y	4690
Origin of the grid:	X = 523800 Y= 7610200
Azimuth	0

Table 11 : Radiometric grids parameters of FRASW

APPENDIX B: COORDINATES OF THE VERTICES OF BLOCKS

World Geodetic System 1984, WGS84
In coordinates for the Universal Transverse Mercator (UTM, zone 34N)

vertex	X (Easting)	Y (Northing)	vertex	X (Easting)	Y (Northing)	vertex	X (Easting)	Y (Northing)
1	697782	7769511	26	853401	7741823	51	739783	7772646
2	709254	7786232	27	852210	7739025	52	730686	7766783
3	705468	7818140	28	851700	7736381	53	727763	7769587
4	722831	7836040	29	851700	7735000	54	724148	7768704
5	725635	7863953	30	824749	7731229	55	723110	7771162
6	733380	7876079	31	814081	7752302	56	720879	7770893
7	765864	7872495	32	798058	7757696	57	717918	7769356
8	773497	7839555	33	784003	7763063	58	716380	7771277
9	800473	7795632	34	781531	7766040	59	710656	7768882
10	836067	7785927	35	781491	7769479	60	708689	7767589
11	842747	7782287	36	773624	7772630	61	708402	7765562
12	857405	7781057	37	769260	7776992	62	707207	7763610
13	873673	7776160	38	765770	7782556	63	706361	7757851
14	873822	7772023	39	765715	7785195	64	701613	7753488
15	877293	7766151	40	764538	7789885	65	701536	7751606
16	878391	7763164	41	763682	7790714	66	697868	7745463
17	880779	7759026	42	755875	7786802	67	695071	7742442
18	882472	7749672	43	754147	7787660	68	691962	7741462
19	871311	7747171	44	750294	7787044	69	690474	7738101
20	867234	7750932	45	749112	7785163	70	688503	7735880
21	862125	7754899	46	748150	7781383	71	678914	7759161
22	854141	7759263	47	744286	7780276	72	697782	7769511
23	848369	7755060	48	741841	7776696			
24	849898	7751094	49	740347	7776111			
25	852801	7744621	50	739110	7775389			

Table 12 : Coordinates of FRASE project

vertex	X (Easting)	Y (Northing)	vertex	X (Easting)	Y (Northing)	vertex	X (Easting)	Y (Northing)
1	686117	7650821	41	572313	7696872	81	590318	7770607
2	685582	7649562	42	563876	7696724	82	595344	7769837
3	683679	7648320	43	563779	7695136	83	599100	7771674
4	681589	7648935	44	556045	7694848	84	601114	7779704
5	679530	7650311	45	557168	7681347	85	608341	7788886
6	675868	7647627	46	567125	7663411	86	615759	7794957
7	670403	7642175	47	566902	7654803	87	625948	7805208
8	669443	7639636	48	565999	7649574	88	632187	7811982
9	667186	7637297	49	569875	7631636	89	622060	7822687
10	666478	7632039	50	572659	7631354	90	610962	7826347
11	666766	7627887	51	572915	7627312	91	621804	7845121
12	666376	7626072	52	591918	7627341	92	660954	7843368
13	666777	7619925	53	592329	7622588	93	660961	7824579
14	662532	7616566	54	599006	7622485	94	656130	7803525
15	661113	7616613	55	598903	7621920	95	648522	7789579
16	659135	7615528	56	588015	7614577	96	628166	7777764
17	659132	7609786	57	583020	7621063	97	628608	7763037
18	657372	7610397	58	573079	7620586	98	639497	7753887
19	653790	7618407	59	563038	7626219	99	649687	7755600
20	646550	7623198	60	555792	7623435	100	654820	7754960
21	631868	7627192	61	554246	7634318	101	662852	7736292
22	629955	7629005	62	551507	7638410	102	658773	7715384
23	627419	7630293	63	547728	7645764	103	689652	7718200
24	627458	7634210	64	547269	7649545	104	689521	7715063
25	624373	7633002	65	540582	7660503	105	688131	7711397
26	620086	7638062	66	527064	7679171	106	688032	7707784
27	615684	7638822	67	523814	7685452	107	645550	7703606
28	611320	7636332	68	525297	7706142	108	643285	7687594
29	611696	7641093	69	533296	7712597	109	644316	7672696
30	610595	7653558	70	538386	7713396	110	644572	7656403
31	602469	7665039	71	540229	7722588	111	649957	7653682
32	599407	7683625	72	551547	7728571	112	658975	7653957
33	614773	7715537	73	555372	7731221	113	665506	7664833
34	633160	7732846	74	580653	7754065	114	689452	7665280
35	637427	7742079	75	579180	7771421	115	690460	7663772
36	618548	7742263	76	576825	7769656	116	688548	7660173
37	600941	7731897	77	574943	7783665	117	688113	7657416
38	585597	7722068	78	583647	7792077	118	686117	7650821
39	577028	7708794	79	591625	7780330			
40	572163	7708594	80	582922	7776414			

Table 13 : Coordinates of FRASW project

APPENDIX C: AIRCRAFTS SPECIFICATIONS

Model	Registration	Capacity	Fuel per hour	Range	Survey speed	Stall speed
PA31-310	C-FWNG	183 gallons + 2 x 26 gallons	25 - 32 gal/h	7h +	120 kts (220 km/h)	60 kts (112 km/h)
PA31-310	C-GJDD	183 gallons + 2 x 26 gallons	25 - 32 gal/h	7h +	120 kts (220 km/h)	60 kts (112 km/h)

Table 14: Novatem Piper PA31 Navajo aircrafts and specifications

Figure 11: NOVATEM Piper PA31 Navajo, registered *C-FWNG*

General:

- **Crew:** one pilot
- **Capacity:** 6+2 passengers
- **Length:** 32 ft 7.5 in (9.95 m) + stinger (+ 4m)
- **Wingspan**: 40 ft 8 in (12.40 m) + wingtip pods (2x 1.5m)
- **Height:** 13 ft (3.96 m)
- **Wing surface:** 229 ft² (21 m²)
- **Wing profile**: NACA 2412
- **Empty weight:** 3 759 lb. (1 709 kg)
- **Gross weight**: 36 500 lb. (2 900 kg)
- **Engines:** 2 × Lycoming Motors TIO-540-A2B, 2 x 310 hp (2 x 230 kW)

Performances:

- **Max speed**: 188 kts (348 km/h)
- **Endurance**: 7h + reserve
- **Service ceiling**: 24 000 ft (7 400 m)
- **Rate of climb**: 1 220 ft/min (6.3 m/s) (101 m/km using a speed of 225 km/h)

Features:

- Airworthiness Certified
- New engines
- New blades
- IFR equipped
- Long Range
- Garmin 340 Audio Panel
- Garmin 430 GPS/Comm
- King KR87 ADF
- King KT76A Transponder
- King KY96A Comm
- King KN62A DME
- NSD HIS Compass system
- Altimatic 3 autopilot
- Janitrol Ceramic heater
- Vortex Generator
- Full Deice with new boots
- Hot Windshield
- Avionics Master Switch
- Heavy duty Cleveland Brakes
- Co-Pilot instruments
- Wing lockers

APPENDIX D: DIGITAL DATA
APPENDIX E: CALIBRATION REPORT