September 2014 C14104_NGU

AIRBORNE MAGNETIC AND RADIOMETRIC SURVEY
NORGES GEOLOGISKE UNDERSØKELSE (NGU)

CALIBRATION REPORT

TROMS - FINNMARK EAST REGION: TROFI-14 EAST
NORWAY 2014

www.novatem.com

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ABSTRACT

This calibration report compiled the test and calibration results performed during the operations. Results were digitally recorded and could be sent upon request from the client. All the results were GPS processed prior to calculation.

Part A and B contain calibration results obtain for PA31 C-FWNG and PA31 C-GJDD respectively. No equipment have been changes, modified or swapped during the whole survey period. The calibration tests involved the following instruments.

- Three **Geometrics** G-822A Cesium optical vapour pumping magnetometers of the last generation, installed inside the stinger and inside the extensions of the wing-tip pods of the 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 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 - LBS Plus GPS providing a 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;
- Due to the large scale of the survey and restraint access to islands, the installation of several base stations was problematic. However, one permanent base stations managed by the Tromsø Geophysical Observatory at University of Tromsø and one permanent base stations managed by IMAGE (International Monitor for Auroral Geomagnetism Effects) surrounding the survey area were also used to cover the entire survey area during the operation.

Data compilation and results analysis were done by Olivier Savignet, Eng., on behalf of **NOVATEM INC**.

Olivier Savignet, Eng. Physics

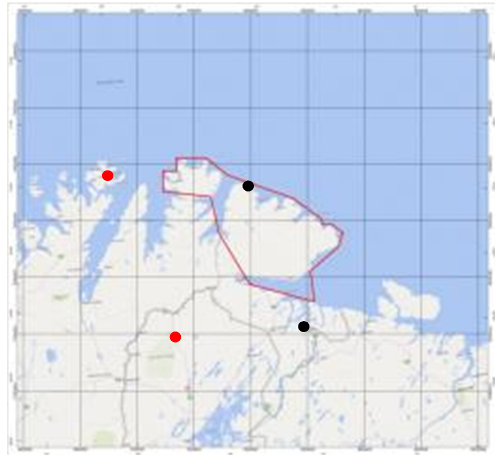
A. BASE STATIONS SYNCHRONISATION AND AIRCRAFTS CONSISTENCY

Date: 2014.07.15 - 2014.09.04

Location: Finnmark, NORWAY

Instrument: Magnetometer stations: GSM-19 Overhauser, **1Hz**
Magnetometers onboard: G-823 Cesium magnetometer, **10Hz**

Locations: FMI station: Kevo, NORWAY; 27.01 : 69.76
TGO station: Nordkapp, NORWAY; 25.79 : 71.09



Two Novatem base stations were installed at 2 locations during that period. The following table summarises the locations and the installation periods.

NAME	LOCATION	2014
Kirkenes	29.9529, 69.6989	Jul-Sep
Berlevåg	29.0267, 70.8670	Jul-Sep

Concurrent measurements of magnetic base station and aircraft magnetometer were done during the night of the 7th of February thru the 8th of February 2012. 500000 readings have been recorded. For processing, the magnetic base stations were interpolated in two dimensions in order to get the best estimation at the position of the aircraft. Preliminary results have been given only with the diurnal correction from the station 1.

According to the specification of the contract, maximum allowed diurnal variation is 100nT/h, 35 nT/10 min and 15 nT/2 min. Nevertheless, since there are only few weeks available to fly the whole project, and taking into account that the base stations installed cover a large area, making the diurnal correction very accurate, days with little activity have been considered valid. Note that the base stations on the following graphics have the same dynamic range, centred for each profiles. Thus, the axis scale on the left represents only Novatem station at Vigra.

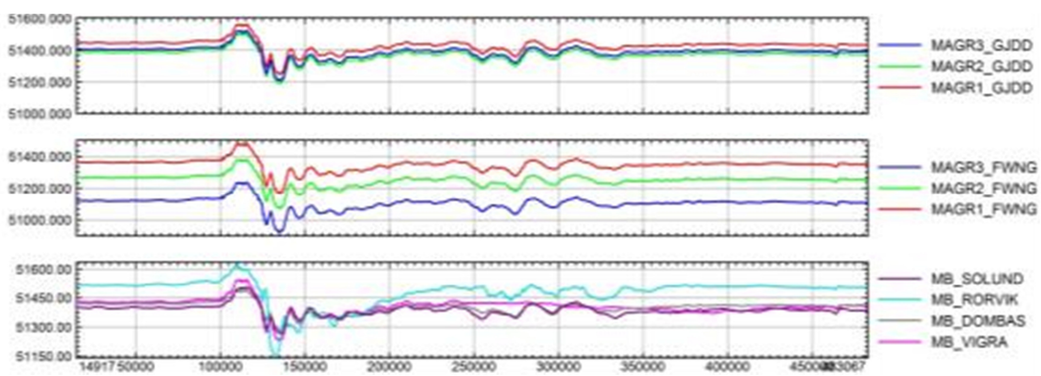


Figure 1: Magnetic base stations (MB) and aircrafts (C-GJDD, C-FWNG) synchronisation

CALIBRATION TESTS - C-FWNG

B. MAGNETOMETERS NOISE

Date: 2014.07.30

Location: Barents sea, Kirkenes NORWAY

Aircraft: PA31 **C-FWNG**

Instrument: Magnetometers: G-823 Cesium magnetometer, **10Hz**

Temperature: 10.3 °C at sea level

Pressure: 99.5 kPa at sea level

Height: 60 m following draped surface

Noise level is evaluated on a test line over a distance of 5 km. For convenience, the test line used during the survey and flown every flight was analysed for this purpose.

The graphic below shows the normalized fourth difference for each of the three magnetometers installed in the aircrafts. Requirement for the campaign is 0.1 units fourth difference, which is clearly above the three mounted magnetometers evaluated.

MAGR1, 2 and 3 represents left, right and tail total raw magnetic field respectively.

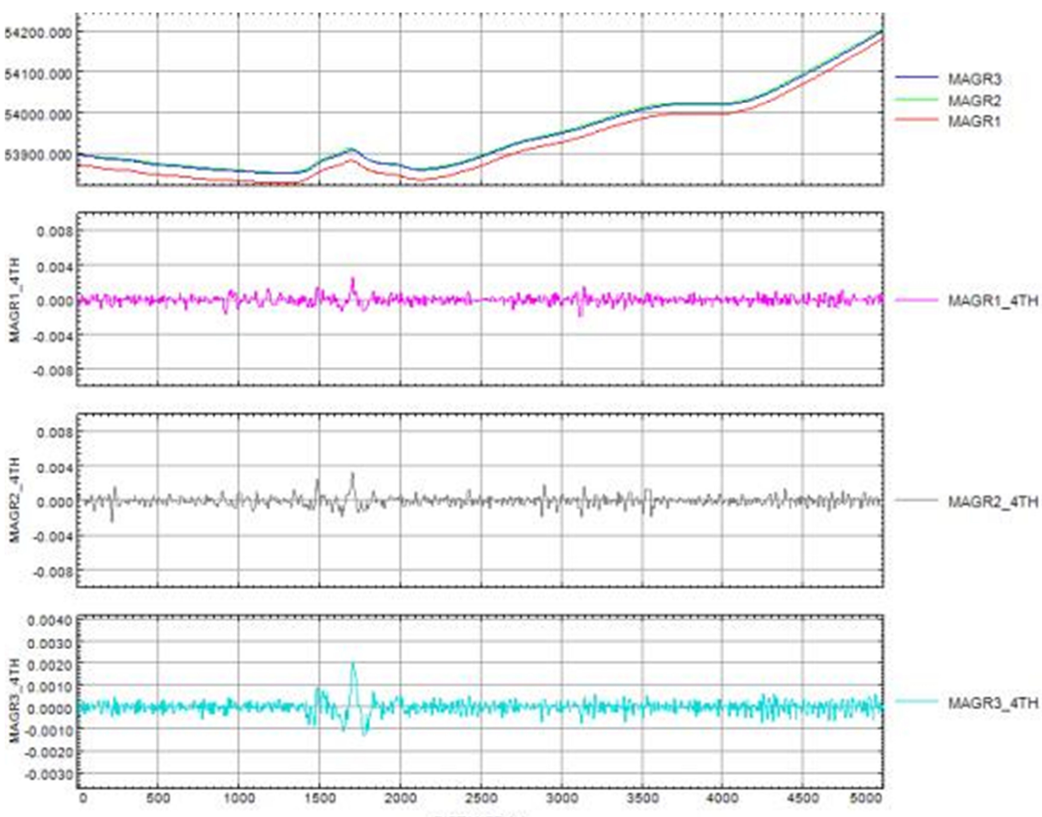


Figure 2 : Magnetometers 4th difference

novatem airborne geophysics

C. COMPENSATION BASED ON A PHYSICAL MODEL

Date: 2014.07.30

Location: North West of Kirkenes, NORWAY

Aircraft: PA31 **C-FWNG**

Instruments: Magnetometers onboard: G-823 Cesium magnetometer, **10Hz**
Orientation sensor (3DM), MicroStrain, **10Hz**

Temperature: 14.0 °C at sea level

Pressure: 100.0 kPa at sea level

Height: 1000 m

CALIBRATION FLIGHT (FOM)

In practice, the calibration flight follows a precise and reproducible geometry, called Figure of Merit (FOM) during which the aircraft describes successively three pitch oscillations (±5°), three roll oscillations (±10°) and three yaw oscillations (±5°) with a period of a few seconds. The four principal directions are described this way. The turns between each line are not taken into account for the calculation of the coefficients.

ESTIMATION OF THE COEFFICIENTS

The calculation of the coefficients is to determine the mathematical solution which minimizes the differences between the measured signals and those generated by the model. The disturbance field being described as a linear combination of the direction cosine and terrestrial field, the least square algorithm is particularly designated. The problems caused by the correlations between the columns of the matrix to inverse are easy to diagnose using the eigenvalues of the matrix. To do so, we calculate an index by submitting the ratio of the largest on the smallest eigenvalue. In practice, it is considered that this index should not exceed 10^3. In certain cases, we will be able to observe strong colinearities when certain variables are not used, such as the absence of eddy currents. An effective manner to solve this problem of multicollinearity consists in using the method known as regression ridge. In the case where the matrix is badly conditioned, then the coefficients have a variance much little than when a least square algorithm is used. The general idea is to shift the eigenvalues of the matrix by a small constant. Thus the largest eigenvalues, which have a real significance, are slightly modified, whereas the lowest eigenvalues - which cause problem at the inversion - are significantly modified. The implementation of the regression ridge thus allowed us to avoid the problems of numerical instability and to improve our algorithm.

RESULTS

The following figures show the results obtained by the calibration flights carried out at 1000m of altitude North West of Kirkenes in Norway.

Branch	TROFI
Line 1	N 0
Line 2	N 90
Line 3	N 180
Line 4	N 270

Table 1 : FOM line directions

Flying the calibration figures in the same directions as the survey flight lines, we optimize the coefficients for these directions, as they are the one we will use.

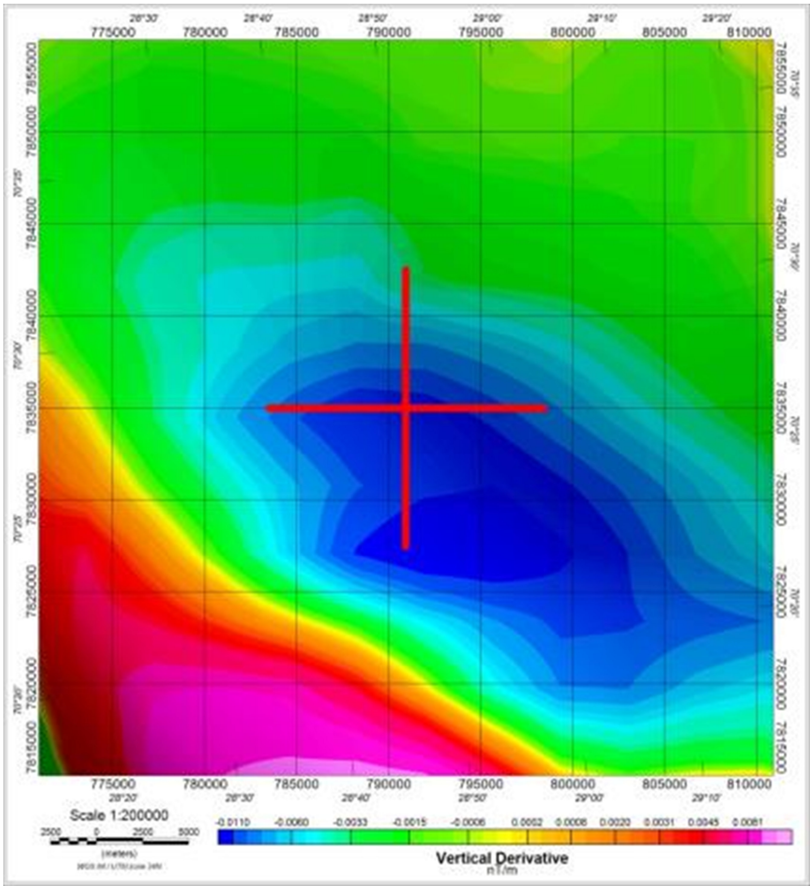


Figure 3 : Figure of merit over regional magnetic first vertical derivative

The figure of merit includes 4 lines (L1, L2, L3 and L4) flown at high altitude, in an area with a low vertical gradient, and following a figure in a clover shape. Each line is thus flown in the two directions in respect with the direction of the lines and tie-lines.

D. HEADING AND ABSOLUTE ACCURACY TEST

Date: N/A

Location: Bourget, Quebec, CANADA

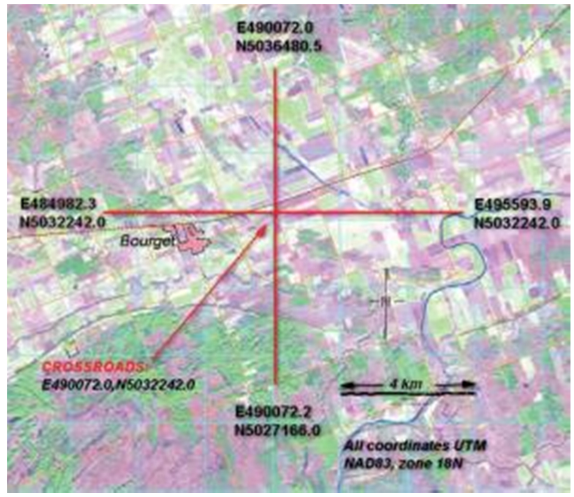
Aircraft: PA31 **C-FWNG**

Instrument: Magnetometers: G-823 Cesium magnetometer, **10Hz**

Temperature: N/A

Pressure: N/A

Height: N/A



This test is performed over an easily recognised point on the ground. The purpose is to ensure that aeromagnetic survey system measures the total field values with an absolute accuracy of 10nT or less after the aircraft has been compensated. The result from the test together with the FOM is also used to remove aircraft influence on magnetic data (heading error).

Analysis of the synchronisation tests and noise level of the magnetometers, chapter A and B of the present report, compile for each aircraft and all the test lines, shows clearly that both aircrafts have an absolute difference of less than 10nT.

Since the compensation also corrects the heading error, there is no need for an extra calibration on C-FWNG

E. TEST LINE AND QC TESTS

Date: 2014.07.16 – 2014.09.03

Location: Barents sea, Kirkenes NORWAY

Aircraft: PA31 **C-FWNG**

Instrument: Spectrometer, RSI RSX500, 50.16L down, 12.54L up, **2Hz**

Heights: 60 m following draped surface

During the survey, quality control is carried out by the project manager on site. Controls on the quality are integrated in the normal process of acquisition and start as soon as the flight path is established and end at the delivery of the final products.

A survey test lines is flown once every flight as a check on system sensitivity, the stability of the magnetometers and spectrometers, and finally to monitor the effect of soil moisture in the area, (Variation of thorium concentration less than 10% after corrections on every flight).

The extension of the test line is about 5 km. The measurement over the water is also used for the calibration of the gamma ray upward looking detector.

After each flight, the raw data are inspected to make sure that there are no missing data or corrupted data. Data are then saved on an independent and secure location. For each flight, the following controls are then carried out in priority, to ensure:

- The deviations on both sides of the flight lines (±50m over 5000m)
- The altitude deviations of the flight lines (60m above the drape surface over 3000m)
- Spacing between each measurement (225 km/h ± 25 km/h over 5000m)
- The diurnal drifts (100 nT/h, 35 nT/10min, 15 nT/2min)
- The noise level of the data (Mean 4th difference over 4000m less than 1.6)

Quality control maps are then issued in the Weekly Report and sent to the NGU representative every weekend of the project duration.

Finally, the following radiometric checks are performed every morning to ensure spectra constancy and are included in the Weekly Report:

- Stabilisation better than ±25 keV measured on the 2.62 MeV ^{208}Tl peak
- FWHM better than 200 keV measured on the 2.62 MeV ^{208}Tl peak
- Careful verification of each profile (and spectra) to spot spikes, jumps or interruptions in the readings
- Statistical calculation of the mean spectra for each line to insure potassium and thorium peak stability (drift less than 4 channels on the thorium peak)
- Correction and gridding of preliminary grids to evaluate data coherence and consistency.

F. COSMIC AND AIRCRAFT BACKGROUND CORRECTION

Date: 2014.09.02

Location: Barents Sea, Kirkenes NORWAY

Aircraft: PA31 **C-FWNG**

Instrument: Spectrometer, RSI RSX500, 50.16L down, 12.54L up, **2Hz**

Temperature: 15.1 °C at sea level

Pressure: 100.3 kPa at sea level

Heights: 1500m-3000m

To determine the cosmic and aircraft background, the spectrometer used records all incident particles above 3 MeV in the Cosmic channel. Steps are flown at 6 equidistant heights, from 1500m to 3000m and over the sea to reduce the presence of radon. Furthermore, in order to minimize statistical errors, each step is 17 km long and lasts around 4-5 minutes.

It was established that no radon contamination is notably apparent for which it would result in a breakdown of the linear relationship. Mean counts and linear relations of the cosmic radiations in the various spectral windows are represented below.

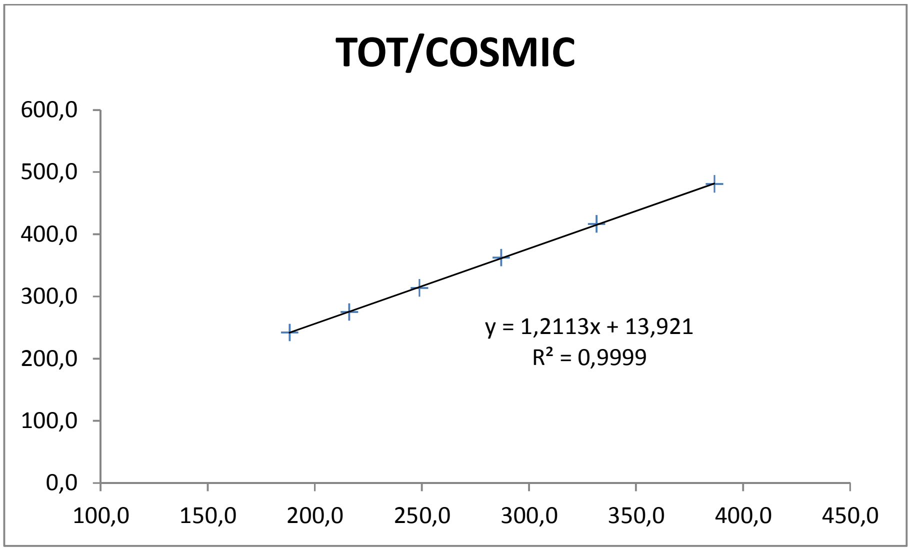
Altimeter (m)	Cosmic Dn	Cosmic Up	Total Count	Potassium	Uranium	Thorium	Cesium	Up Uranium
3000.8	188.2	50.8	242.1	21.3	10.1	10.4	46.5	2.5
2700.4	216.1	58.2	275.2	23.4	11.6	12.4	52.2	3.0
2399.7	248.7	67.6	314.0	25.4	13.8	14.4	58.9	3.5
2099.8	286.9	78.3	362.8	28.2	15.8	17.1	67.2	4.0
1800.5	331.5	91.1	416.6	31.5	18.6	20.2	75.5	4.9
1501.3	386.5	105.7	481.0	34.9	21.6	23.6	5.4	86.4

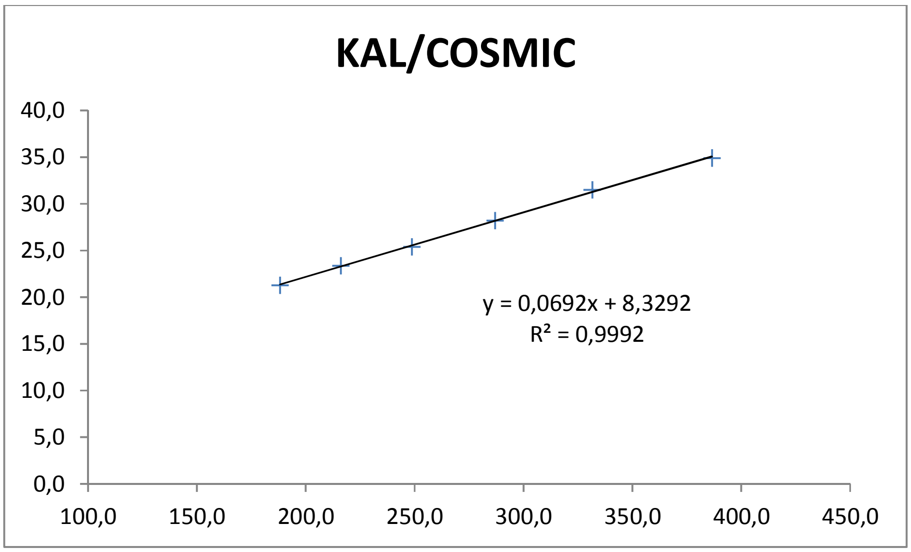
Table 2 : Steps averaged data

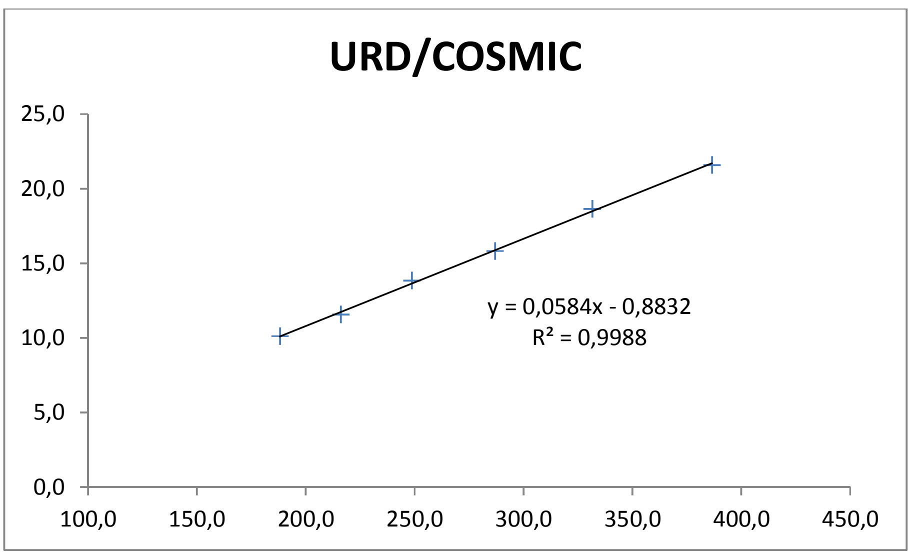
Background	Total Count	Potassium	Uranium	Thorium	Cesium	Up Uranium
Aircraft	13.9	8.33	-0.88	-2.07	8.67	-0.21
Cosmic	1.21	0.069	0.058	0.067	0.20	0.054

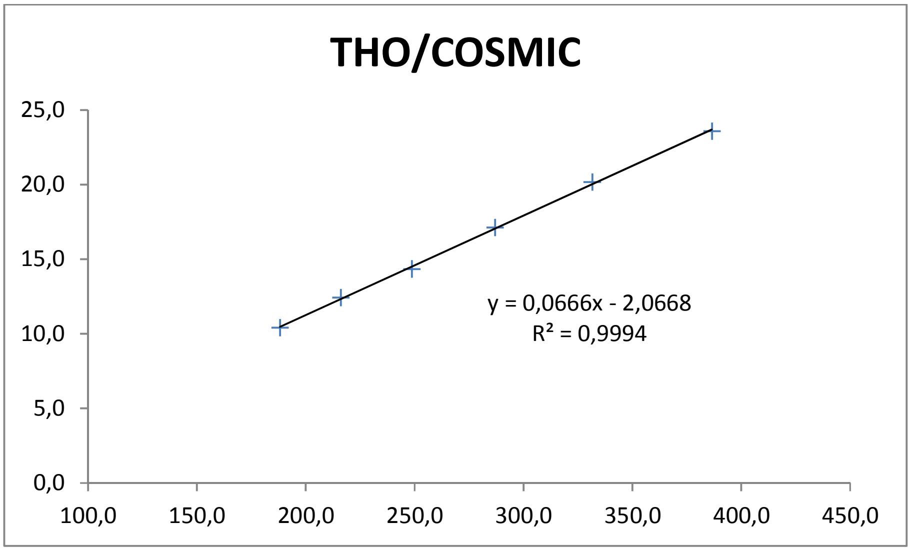
Table 3 : Cosmic & Aircraft background coefficients

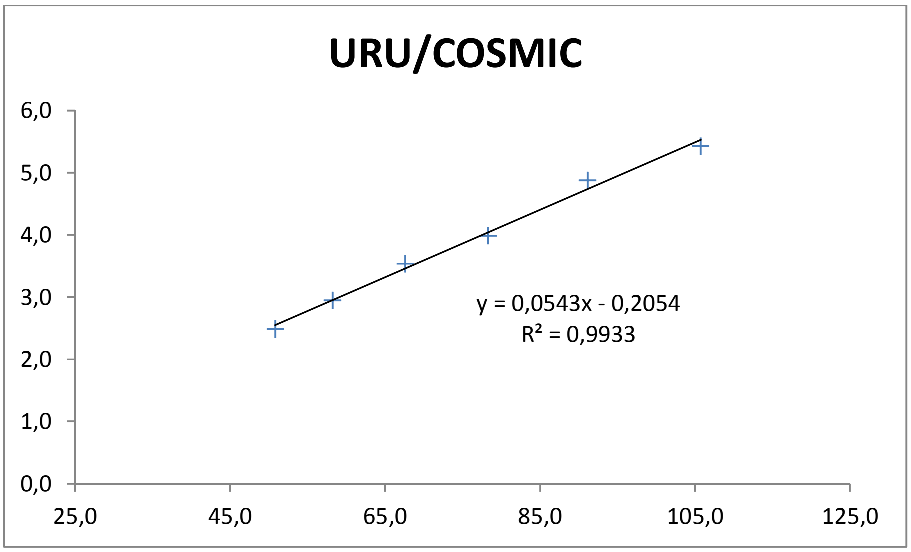
Notice that the coefficient of determination is remarkably high for every window. Lower coefficients would have been characteristic of the radon concentration variation in the air during the flight as the thorium window is less affected and the uranium and total count are closely correlated. However, the only effect of varying radon during the cosmic-ray calibration flights will be an unknown radon component which will be removed during radon processing, as it is demonstrated in *Grasty and Minty, AGSO 1995/60*.


TOT/COSMIC
600,0
500,0
400,0
300,0
200,0
100,0
0,0
100,0
150,0
200,0
250,0
300,0
350,0
400,0
450,0
y = 1,2113x + 13,921
R² = 0,9999


KAL/COSMIC
40,0
35,0
30,0
25,0
20,0
15,0
10,0
5,0
0,0
100,0
150,0
200,0
250,0
300,0
350,0
400,0
450,0
y = 0,0692x + 8,3292
R² = 0,9992


URD/COSMIC
25,0
20,0
15,0
10,0
5,0
0,0
100,0
150,0
200,0
250,0
300,0
350,0
400,0
450,0
y = 0,0584x - 0,8832
R² = 0,9988





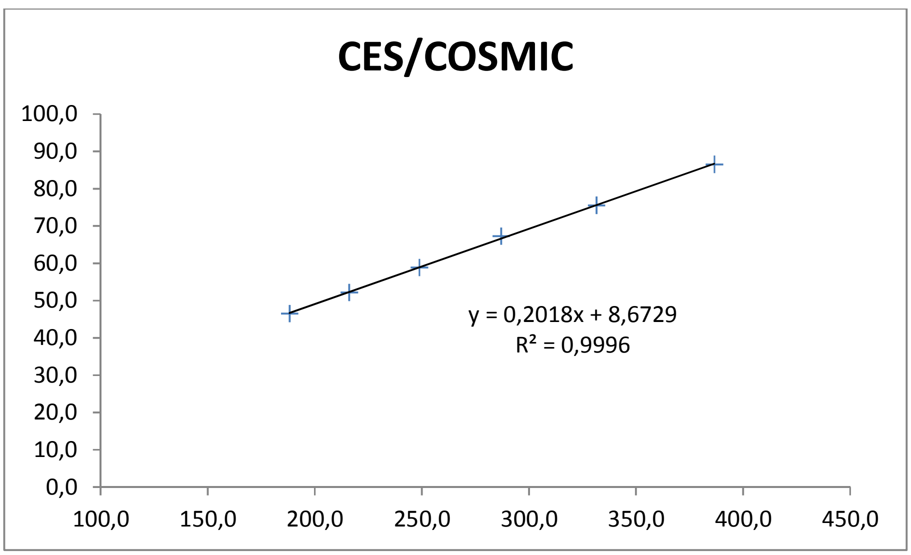


Figure 4 : Background corrections

G. UPWARD LOOKING DETECTOR CORRECTION COEFFICIENTS

Location: Barents Sea, Kirkenes NORWAY, 2014

Aircraft: PA31 **C-FWNG**

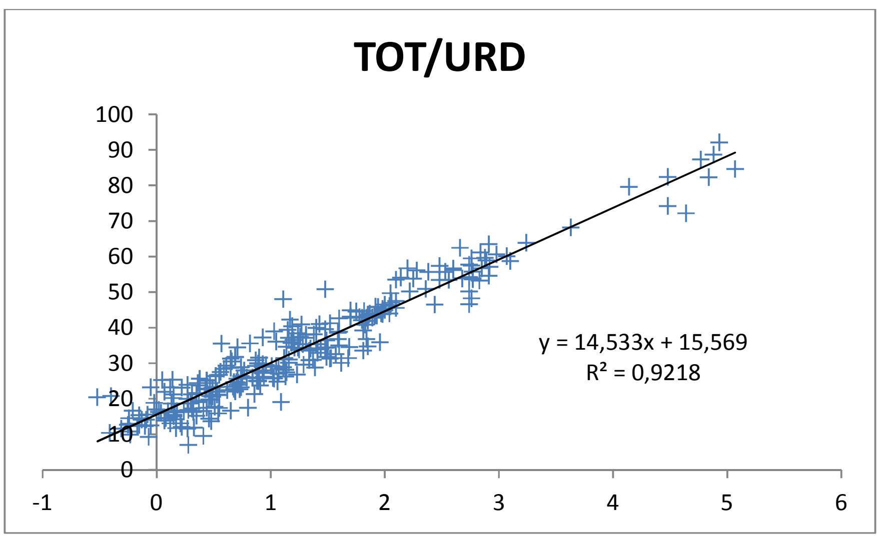
Instrument: Spectrometer: RSI RSX500, 50.16L down, 12.54L up, **2Hz**

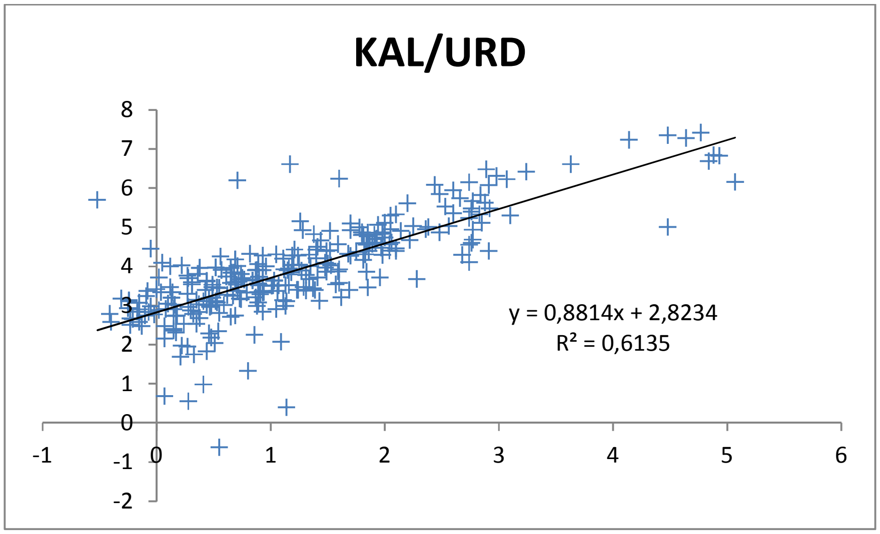
Flying Height: 60 m

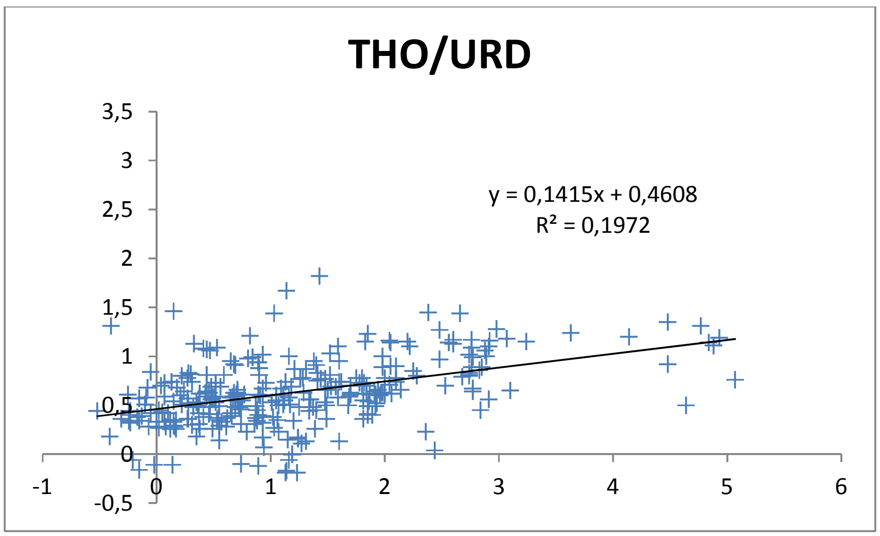
In order to determine the relationship between the upward and downward detector count rates for radon in the air, parts of flights over water at constant altitude, where there is no contribution from the ground, are used. Due to the scale of the survey, a considerable amount of data is recorded close to the area.

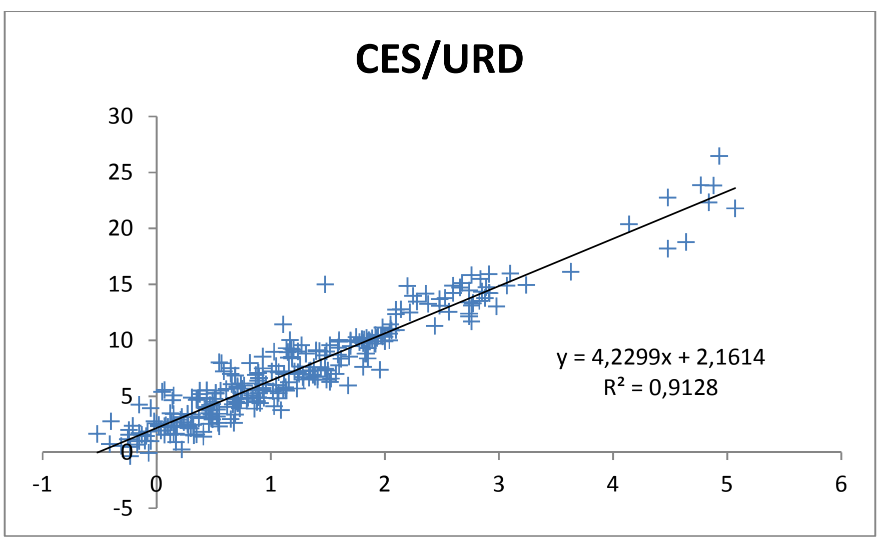
Prior to the analysis, aircraft background and cosmic component are removed and the dead time correction done. Since the cosmic and aircraft background calibration test leaded to highly reliable results, shown by the coefficients of determination R_2 in each window, we expect linear constants b_n to be close to zero. In addition, in order to minimize the statistical noise, only series over 10 valid counts are used. The results are presented in the following graphs.

Coefficients determined can have sometime a negative value. That can be explained by a variation of radon concentration during the calibration of the cosmic radiation. This unknown radon component is precisely removed by considering the given residual components at the time of the radon correction; results described in Grasty and Minty, AGSO 1995/60.




KAL/URD
y = 0,8814x + 2,8234
R² = 0,6135
8
7
6
5
4
3
2
1
0
-1
-2
-1
0
1
2
3
4
5
6


THO/URD
y = 0,1415x + 0,4608
R² = 0,1972
3,5
3
2,5
2
1,5
1
0,5
0
-0,5
-1
0
1
2
3
4
5
6


CES/URD
y = 4,2299x + 2,1614
R² = 0,9128
30
25
20
15
10
5
0
-5
-1
0
1
2
3
4
5
6

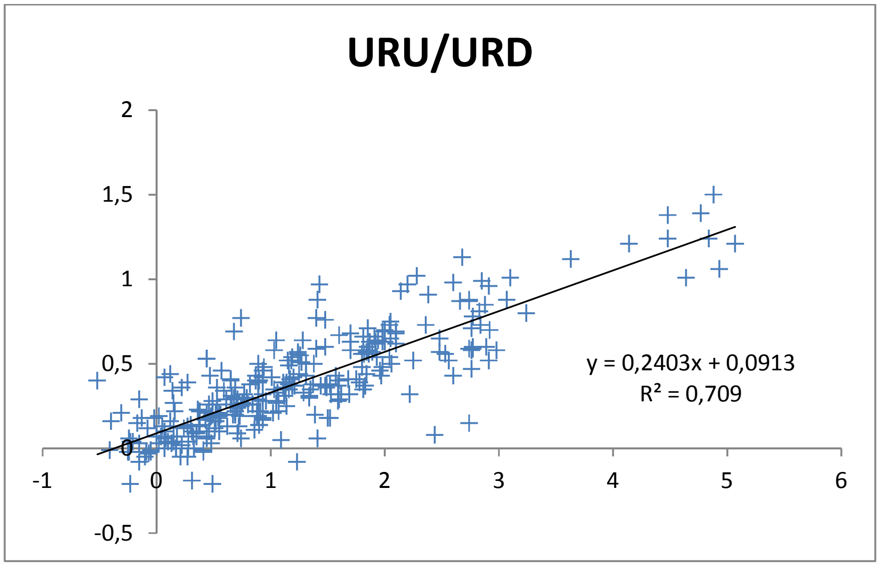


Figure 5 : Radon coefficients

The component of the upward detector count rate originating from the ground, u_g, will depend on the concentration of U an Th in the ground, as will the components of U and Th downward window count rates, U_g and Th_g, that originate from the ground. In order to minimize the statistical errors, the three components were calculated by subtracting flights above water present on TROFI-14 East at the values adjacent on the firm ground. Numerous sites have thus been evaluated on the block. Finally, from the series of calculated values of U_g, U_g and Th_g, the calibration factors, a_1 and a_2, are determined by the least squares method described in IAEA Technical reports series No.323.

a_1	a_2
0.035	0.025

H. PADS CALIBRATION

RADIATION SOLUTIONS INC

CALIBRATION SHEET

Instrument: **RSX-5**

Customer:	Novatem	Date:	May 4, 2011
Contact:	Pascal Mouge	Tech.:	GP
Console :	N/A	Job Order:	SO#1947
Detector 1:	5577	Customer PO	PO#Email
Detector 2:	N/A		

Channels: 1024 **ADC Offset:** N/A

	A1	A2	A3	A4	A5
High Voltages	683	680	680	701	704

Stripping Constant	"this system"	"normal"
Alpha	**0.272**	0.250
Beta	**0.404**	0.400
Gamma	**0.766**	0.810
a	**0.048**	0.060
b	**0.003**	0.000
g	**-0.002**	0.003

ROI#	Channel	IAEA Specification [keV]	Label
1	137-937	410-2810	Total Count
2	457-523	1370-1570	Potassium K
3	553-620	1660-1860	Uranium U
4	803-937	2410-2810	Thorium Th
5			
6			
7			
8	553-620	1660-1860	Uranium Upper U

Det#	Peak Cs	Cs FWHM		Peak Th	Th FWHM
A1	220.15	7.32		872.48	4.15
A2	220.00	7.52		872.35	4.24
A3	219.93	7.54		871.56	4.31
A4	219.00	7.40		872.06	4.14
Sum Dn	**219.76**	**7.48**		**872.13**	**4.20**
Sum Up	**218.88**	**7.81**		**871.32**	**4.40**

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RADIATION SOLUTIONS INC

CALIBRATION SHEET

Instrument: **RSX-5**

Customer:	Novatem	Date:	May 4, 2011
Contact:	Pascal Mouge	Tech.:	GP
Console :	N/A	Job Order:	SO#1947
Detector 1:	5578	Customer PO	PO#Email
Detector 2:	N/A		

Channels: 1024 **ADC Offset:** N/A

	A1	A2	A3	A4	A5
High Voltages	671	692	659	715	683

Stripping Constant	"this system"	"normal"
Alpha	**0.267**	0.250
Beta	**0.401**	0.400
Gamma	**0.764**	0.810
a	**0.047**	0.060
b	**-0.001**	0.000
g	**0.001**	0.003

ROI#	Channel	IAEA Specification [keV]	Label
1	137-937	410-2810	Total Count
2	457-523	1370-1570	Potassium K
3	553-620	1660-1860	Uranium U
4	803-937	2410-2810	Thorium Th
5			
6			
7			
8	553-620	1660-1860	Uranium Upper U

Det#	Peak Cs	Cs FWHM		Peak Th	Th FWHM
A1	219.86	7.15		872.88	4.06
A2	219.38	7.44		871.70	4.15
A3	219.67	7.36		872.60	4.01
A4	219.87	7.29		872.54	4.28
Sum Dn	**219.69**	**7.33**		**872.47**	**4.13**
Sum Up	**220.68**	**7.96**		**872.87**	**4.75**

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RADIATION SOLUTIONS INC

CALIBRATION SHEET

Instrument: **RSX- 5**

Customer:	Novatem	Date:	June 4, 2014
Contact:	Morten Skovgaard	Tech.:	Jim C
Console :	N/A	Job Order:	RMA# 10453
Detector 1:	5629	Customer PO	PO#
Detector 2:	N/A		

Channels: 1024 **ADC Offset:** N/A

	A1	A2	A3	A4	A5
High Voltages	642	672	657	624	738

Stripping Constant	"this system"	"normal"
Alpha	0.272	0.250
Beta	0.403	0.400
Gamma	0.753	0.810
a	0.051	0.060
b	-0.001	0.000
g	-0.001	0.003

ROI#	Channel	IAEA Specification [keV]	Label
1	137-937	410-2810	Total Count
2	457-523	1370-1570	Potassium K
3	553-620	1660-1860	Uranium U
4	803-937	2410-2810	Thorium Th
5			
6			
7			
8	553-620	1660-1860	Uranium Upper U

Det#	Peak Cs	Cs FWHM		Peak Th	Th FWHM
A1	219.86	7.39		872.80	4.07
A2	220.00	7.98		872.03	4.90
A3	219.66	7.96		872.42	5.07
A4	220.13	7.36		872.40	4.28
Sum Dn	**219.90**	**7.65**		**872.40**	**4.54**
Sum Up	**221.20**	**8.62**		**872.69**	**5.68**

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I. HEIGHT ATTENUATION & SENSITIVITY

Date: 2011.06.06

Location: Breckenridge, Quebec, CANADA

Aircraft: PA31 **C-FWNG**

Instruments: Spectrometer, RSI RSX500, 33.44L down, 8.36L up, **0.5Hz** 5629, 5577. 5578 Geological Survey of Canada, Portable spectrometer for ground measurements

Test Area: TC=54.94 nGy/h, K= 1.96%, eU= 1.55ppm, eTh= 8.20ppm

Temperature: 20°C at sea level

Pressure: 100.2 kPa at sea level

Height: 50-230m

The height attenuation & sensitivity is usually evaluated from an area of known concentration, which includes several records and statistics. Since there is no such area in Norway, data recorded separately for each spectrometer were added to recalculate TROFI-14 East coefficients, regarding the exact configuration in C-FWNG. Next tables show the results obtained.

Altimeter (m)	STP Corrected	Total Count	Potassium	Uranium	Thorium
49.21	46.69	1716.32	215.88	31.22	44.79
79.98	75.75	1393.44	166.02	26.88	36.43
108.65	102.88	1193.42	137.24	23.09	30.94
138.35	130.6	1046.54	114.83	21.80	26.31
167.01	157.21	931.69	98.00	20.43	24.20
197.98	185.96	799.27	80.51	18.60	20.04
227.44	212.61	695.59	70.48	16.93	18.34

Table 4 : Test Data (cps)

Altimeter (m)	STP Corrected	Total Count	Potassium	Uranium	Thorium
56.29	50.6	204.15	21.57	7.88	5.64
86.83	78.94	200.31	19.80	7.56	5.15
118.26	106.93	200.80	20.07	8.13	5.23
146.52	133.03	208.19	20.84	8.16	6.33
174.34	159.15	211.38	21.28	8.02	6.00
203.21	185.95	218.45	21.49	8.50	5.71
233.32	212.56	222.65	21.68	8.57	6.02

Table 5 : Background Data (cps)

α	β	γ	a	b	g
0.270	0.403	0.761	0.049	0.000	- 0.001

Table 6 : Stripping ratios

Total Count	Potassium	Uranium	Thorium
1512.17	194.31	23.34	39.15
1193.13	146.22	19.32	31.27
992.62	117.17	14.96	25.71
838.35	93.99	13.64	19.98
720.31	76.71	12.41	18.21
580.82	59.03	10.10	14.33
472.94	48.80	8.36	12.32

Table 7 : Background-Corrected & Stripped Counts (cps))

After dead time correction, mean count rates of all four windows are then corrected from the cosmic radiation, atmospheric radioactivity and aircraft background by subtracting adjacent values over water. STP corrected Compton stripping ratios are then applied to the count rates. The stripped count rates at each altitude are finally fitted to the exponential function to give the height attenuation coefficients. The following figure shows the curves for all four windows, determined from the test strip.

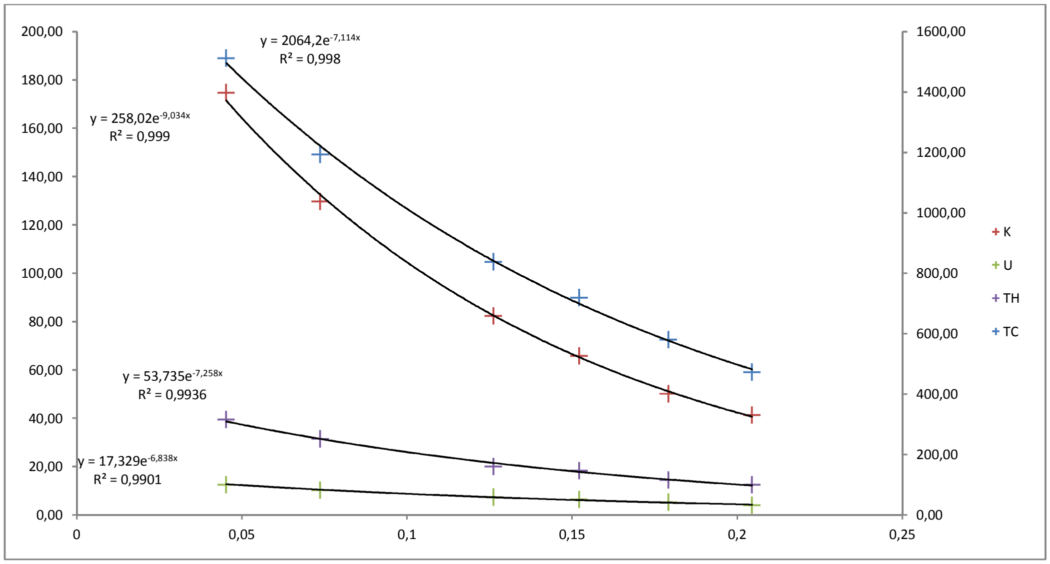


Figure 6 : Exponential height attenuation for all four windows

Broad source sensitivity for each window was calculated using concentration of the radioelement measured at ground level on the strip and for a final STP height of 120m. All the results are shown in the following table

	Total Count	Potassium	Uranium	Thorium
ATTENUATION	-0.00711 m^{-1}	-0.00903 m^{-1}	-0.00684 m^{-1}	-0.00726 m^{-1}
SENSITIVITY	16.0 cps/ nGy/h	44.5 cps/%	5.20 cps/ppm	2.74 cps/ppm

Table 8 : Attenuation coefficients & Sensitivity (120m)

J. PADS CALIBRATION, HEIGHT ATTENUATION & SENSITIVITY (MAN-MADE SOURCE)

Date: 2014.09.11

Location: Kirkenes Airport, NORWAY

Aircraft: PA31 **C-FWNG**

Instruments: Spectrometer RSI RSX500; 50.16L down, 12.54L up, 2**Hz**; S/N 5577, 5578, 5629

Temperature: 12.1 °C at sea level

Pressure: 102.1 kPa at sea level

^{137}Cs source: 163 kBq

The evaluation of natural radioelement unit spectra in the ^{137}Cs window, from the calibration pads and for the set of two spectrometers, gives the following sensitivities at ground level.

s_K	s_U	s_{Th}
0.619	4.801	3.372

Table 9 : Cesium stripping ratios

To derive the influence at different height in the ^{137}Cs window, plastic sheets of know density were placed underneath the detectors and above a cesium source of known activity to simulate the absorption of gamma rays in the air. By increasing the thickness of the material, the cesium attenuation coefficient is determined.

Since the evaluation is kept at relatively low altitude, the equivalent height of air can be estimated as a ratio of density

$$eH = ntf\frac{\rho_p}{\rho_a}$$

Where: eH is the equivalent height of air (m)
n is the number of plastic sheet
t is the thickness of a plastic sheet (0.012 m)
f is the correction factor for the electron densities (1.133)
ρ_p is the density of plastic (950 kg/m^3)
ρ_a is the density of air at standard pressure and temperature (1.29 kg/m^3)

Here are presented the corrected data from the four standard radioelements as well as from the cesium window.

Total Count	Potassium	Uranium	Thorium
4404.00	-10.40	-1.73	1.31
4147.74	-14.46	0.02	0.49
3900.93	-11.99	-1.61	-0.25
3639.93	-15.74	-0.98	-0.73
3400.59	-17.45	-1.56	-2.63
3172.50	-20.78	-0.68	-3.20
2947.02	-19.37	-1.23	-2.43
2752.38	-21.98	0.50	-3.80
2533.65	-22.68	-2.99	-0.15
2349.09	-26.78	-0.47	-3.47
2161.71	-26.82	-3.45	-1.98
1968.00	-25.60	-2.74	-2.85
1810.95	-29.72	-4.55	-1.63
1609.26	-30.60	-4.25	-0.11
1459.80	-32.12	-2.71	-4.84

Table 10 : Natural radioelement Stripped Counts (cps))

Number of sheets	Equivalent Height	Cesium	Cesium background	Cesium corrected	Cesium stripped
0	0.50	4245	654	3591	3601.72
1	10.01	3955	654	3301	3308.35
2	20.03	3690	654	3037	3052.55
3	30.04	3443	654	2789	2805.98
4	40.05	3213	654	2559	2586.02
5	50.06	3010	654	2356	2382.65
6	60.08	2806	654	2152	2177.82
7	70.09	2638	654	1984	2007.91
8	80.1	2465	654	1811	1839.77
9	90.11	2317	654	1663	1693.78
10	100.13	2180	654	1526	1565.47
11	110.14	2032	654	1378	1416.86
12	120.15	1915	654	1261	1306.71
13	130.16	1771	654	1117	1156.30
14	140.18	1662	654	1008	1056.81

Table 11 : Cesium Stripped Counts (cps))

After dead time correction, mean count rates of each windows are then corrected from the cosmic radiation, atmospheric radioactivity and aircraft background by subtracting a background value measured just before and after the tests and without any source. STP corrected Compton stripping ratios are then applied to the natural radioelement count rates by using previously calculated stripping ratio for the cesium window. The stripped count rates at each altitude are finally fitted to the exponential function to give the height attenuation coefficient. The following figure shows the results for the cesium window.

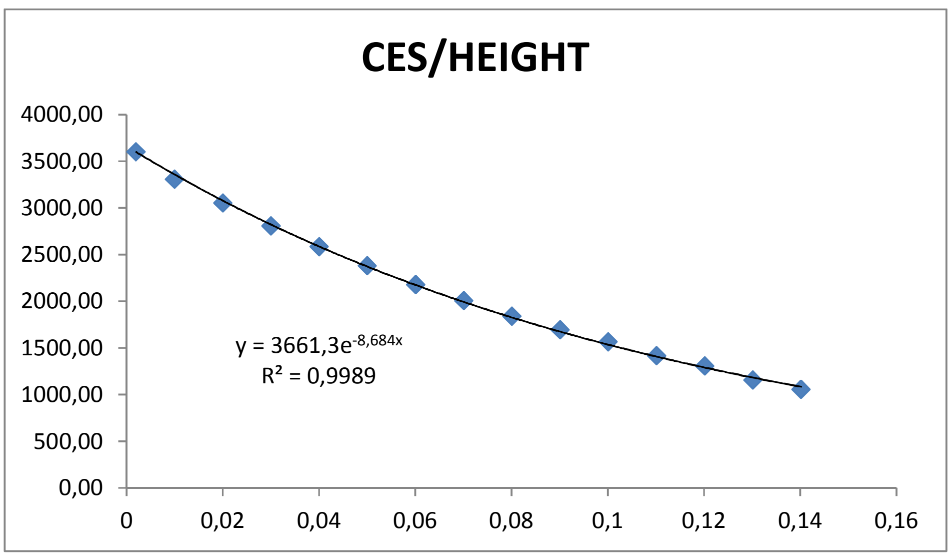
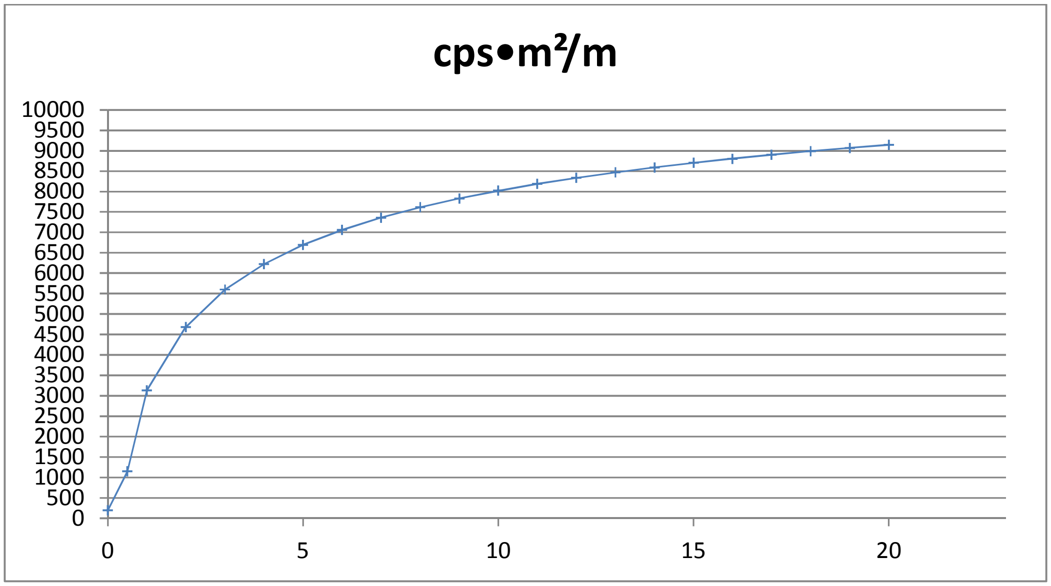


Figure 7 : Exponential height attenuation for the cesium window

In order to evaluate the equivalent ground concentration of a ^{137}Cs anomaly, we first modelled an infinite plane surface source. To create the model, several measurements at symmetrical angles and different distances from the aircraft were recorded for approximately 3 minutes each time. From the Cs source used, the model obtained at larger distances, out to 20 meters, is shown in the next figure. We can notice that the convergence approach 9 200 cps•m² in total. The source had an activity of 298.5 kBq at 21st March 1988. According to http://www.nist.gov/pml/data/halflife-html.cfm, the half life is 11018 days. The elapsed time from 21.3.88 to 26.08.14 is 9649 days which is 0.8757 half life, the activity is then 298.5 * (0.5)^(0.848) = 163 kBq. Knowing that the source activity is 163 kBq, the surface concentration can be estimated at 0.0177 kBq/m^2/cps.



Finally, broad source sensitivity for the cesium window is calculated using standard procedure, being the surface activity per counts of cesium calculated at ground level and brought to a final STP height of 120m. The results are shown in the following table.

	Cesium
ATTENUATION	-0.00868 m^{-1}
SENSITIVITY	19.9 cps / kBq/m^2

Table 12 : Attenuation coefficients & Sensitivity for cesium (120m)

K. LAG TEST

Date: 2012.02.15

Location: Flyplasstunnelen. Fv137
Vigra Airport. NORWAY

Aircraft: PA31 **C-FWNG**

Instrument: Magnetometers: G-823 Cesium magnetometer. **10Hz**

Heights: 60 m

Taking into account the spatial difference between the GPS antenna and the different magnetometers, the following results show that there is almost no time lag in the data records. Note that the spatial lag will be taking into account in the processing in order to replace each magnetometer in the space for gradient enhancement.

MAG 1 (Left wing tip pod)

LINE	HEADING (°)	YAW (°)	ALTITUDE (m)	TIME (HHMMSS)	X (m)	Y (m)	SPEED (m/s)	HIGH PASS FILTERED MAG (nT)
L1:0	70	60.32	64.79	143856.7	352159.7	6940220.8	58.9	51657.510
L2:0	250	245.78	62.95	144054.2	352151.4	6940221.2	61.7	51673.150

MEAN SPEED = 60.3 m/s
DISTANCE = 8.350 m
LAG = 0.069 sec

LINE	HEADING (°)	YAW (°)	ALTITUDE (m)	TIME (HHMMSS)	X (m)	Y (m)	SPEED (m/s)	HIGH PASS FILTERED MAG (nT)
L3:0	70	61.64	60.47	144312.6	352164.6	6940221.7	56.1	51694.060
L4:0	250	244.80	62.90	144523.1	352149.6	6940221.0	58.9	51671.060

MEAN SPEED = 57.5 m/s
DISTANCE = 14.996 m
LAG = 0.130 sec

LINE	HEADING (°)	YAW (°)	ALTITUDE (m)	TIME (HHMMSS)	X (m)	Y (m)	SPEED (m/s)	HIGH PASS FILTERED MAG (nT)
L5:0	68	71.61	276.038	71259.3	609880.28	7825645.32	64.17	1.086
L6:0	248	249.12	271.848	71534.5	609891.43	7825659.32	68.62	1.567

MEAN SPEED = 57.6 m/s
DISTANCE = 12.398 m
LAG = 0.108 sec

MAG 2 (Right wing tip pod)

LINE	HEADING (°)	YAW (°)	ALTITUDE (m)	TIME (HHMMSS)	X (m)	Y (m)	SPEED (m/s)	HIGH PASS FILTERED MAG (nT)
L1:0	70	60.32	64.79	143856.7	352159.7	6940220.8	58.9	51682.470
L2:0	250	245.78	62.95	144054.2	352151.4	6940221.2	61.7	51699.550

MEAN SPEED = 60.3 m/s
DISTANCE = 8.350 m
LAG = 0.069 sec

LINE	HEADING (°)	YAW (°)	ALTITUDE (m)	TIME (HHMMSS)	X (m)	Y (m)	SPEED (m/s)	HIGH PASS FILTERED MAG (nT)
L3:0	70	61.64	60.47	144312.6	352164.6	6940221.7	56.1	51710.720
L4:0	250	244.80	62.90	144523.1	352149.6	6940221.0	58.9	51697.300

MEAN SPEED = 57.5 m/s
DISTANCE = 14.996 m
LAG = 0.130 sec

LINE	HEADING (°)	YAW (°)	ALTITUDE (m)	TIME (HHMMSS)	X (m)	Y (m)	SPEED (m/s)	HIGH PASS FILTERED MAG (nT)
L5:0	70	61.19	61.92	144742.0	352165.0	6940220.6	56.7	51697.450
L6:0	250	244.48	64.26	144954.7	352153.8	6940215.2	58.6	51699.840

MEAN SPEED = 57.6 m/s
DISTANCE = 12.398 m
LAG = 0.108 sec

MAG 3 (Tail boom)

LINE	HEADING (°)	YAW (°)	ALTITUDE (m)	TIME (HHMMSS)	X (m)	Y (m)	SPEED (m/s)	HIGH PASS FILTERED MAG (nT)
L1:0	70	60.66	64.84	143856.9	352170.6	6940225.3	58.9	51687.020
L2:0	250	245.69	62.89	144054.3	352145.6	6940218.9	61.7	51700.870

MEAN SPEED = 60.3 m/s
DISTANCE = 25.767 m
LAG = 0.214 sec

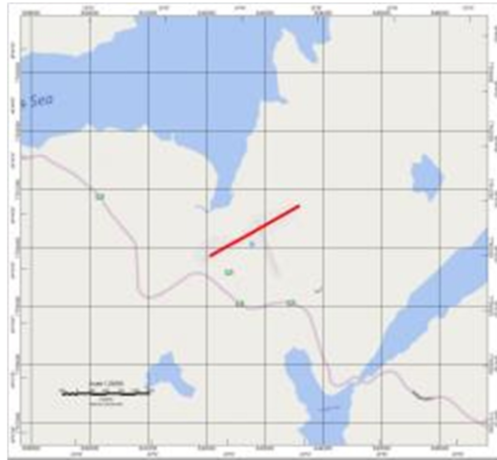
LINE	HEADING (°)	YAW (°)	ALTITUDE (m)	TIME (HHMMSS)	X (m)	Y (m)	SPEED (m/s)	HIGH PASS FILTERED MAG (nT)
L3:0	70	61.53	60.44	144312.7	352169.8	6940223.8	56.1	51718.830
L4:0	250	244.89	62.77	144523.2	352144.2	6940218.7	58.9	51701.230

MEAN SPEED = 57.5 m/s
DISTANCE = 26.113 m
LAG = 0.227 sec

LINE	HEADING (°)	YAW (°)	ALTITUDE (m)	TIME (HHMMSS)	X (m)	Y (m)	SPEED (m/s)	HIGH PASS FILTERED MAG (nT)
L5:0	70	61.23	61.93	144742.1	352170.2	6940222.8	56.9	51708.410
L6:0	250	244.53	64.23	144954.8	352148.4	6940213.0	58.6	51689.800

MEAN SPEED = 57.8 m/s
DISTANCE = 23.920 m
LAG = 0.207 sec

L. LASER AND RADAR CALIBRATION



Date: 2014.07.22

Location: Kirkenes airport (alt : 87 m) NORWAY

Aircraft: PA31 **C-FWNG**

Instrument: GPS receiver: Novatel Propak – LBS Plus. **10Hz**
Laser altimeter: Optech Sentinel 3100. **10Hz**
Radar altimeter: Free Flight TRA 4000. **10Hz**

Temperature: 21.7 °C at sea level

Pressure: 101.1 kPa at sea level

Heights: 40m-180m

To determine coefficients of calibration for the laser and radar altimeter, steps are flown at 6 different heights. from 40m to 180m and over the Alta airport strip in order to have a surface as flat as possible for the calibration. In order to minimize errors, each step is 2 km long.

The different altitudes recorded show a perfect linearity with the post processed GPS altitude. The airport altitude (87 m) was removed from the mean altitude recorded in order to evaluate the results. Finally, linear relations between the different altimeters are plotted below and calibration constants needed for processing are provided.

GPS altitude	Adjusted GPS altitude (m)	Laser altitude (m)	Radar altitude (m)
130.91	43.91	44.72	43.93
151.30	64.30	65.15	64.85
182.01	95.01	95.81	96.19
210.94	123.94	124.83	125.95
241.56	154.56	155.35	158.12
271.09	184.09	185.02	188.96

Table 13: Radar calibration

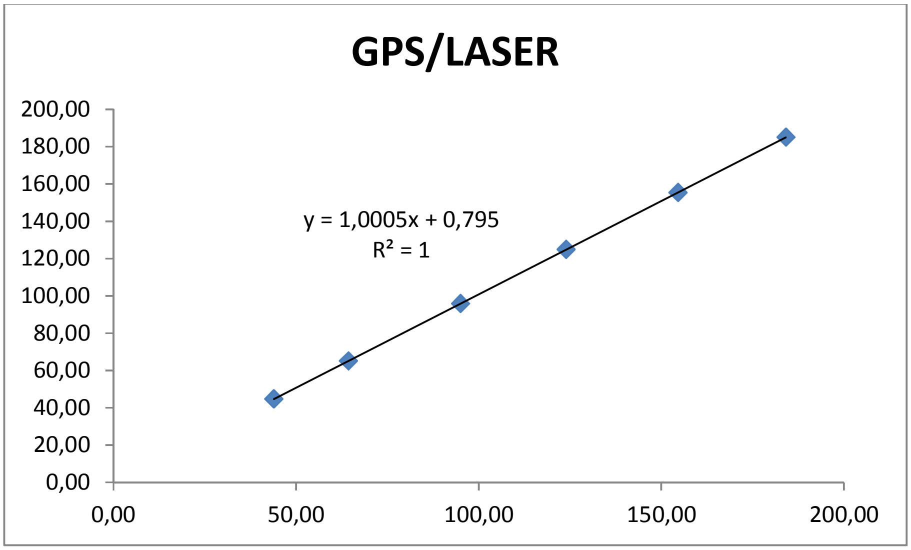


Figure 8 : Laser calibration

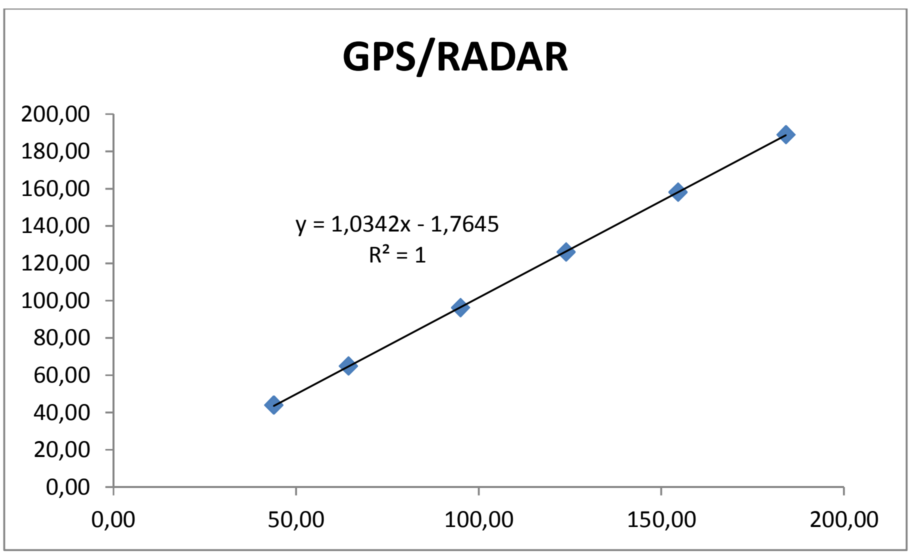


Figure 9 : Radar calibration

CALIBRATION TESTS - C-GJDD

B. MAGNETOMETERS NOISE

Date: 2014.07.30

Location: Barents sea, Kirkenes NORWAY

Aircraft: PA31 **C-GJDD**

Instrument: Magnetometers: G-823 Cesium magnetometer, **10Hz**

Temperature: 10.3 °C at sea level

Pressure: 99.5 kPa at sea level

Height: 60 m following draped surface

Noise level is evaluated on a test line over a distance of 5 km. For convenience, the test line used during the survey and flown every flight was analysed for this purpose.

The graphic below shows the normalized fourth difference for each of the three magnetometers installed in the aircrafts. Requirement for the campaign is 0.1 units fourth difference, which is clearly above the three mounted magnetometers evaluated.

MAGR1, 2 and 3 represents left, right and tail total raw magnetic field respectively.

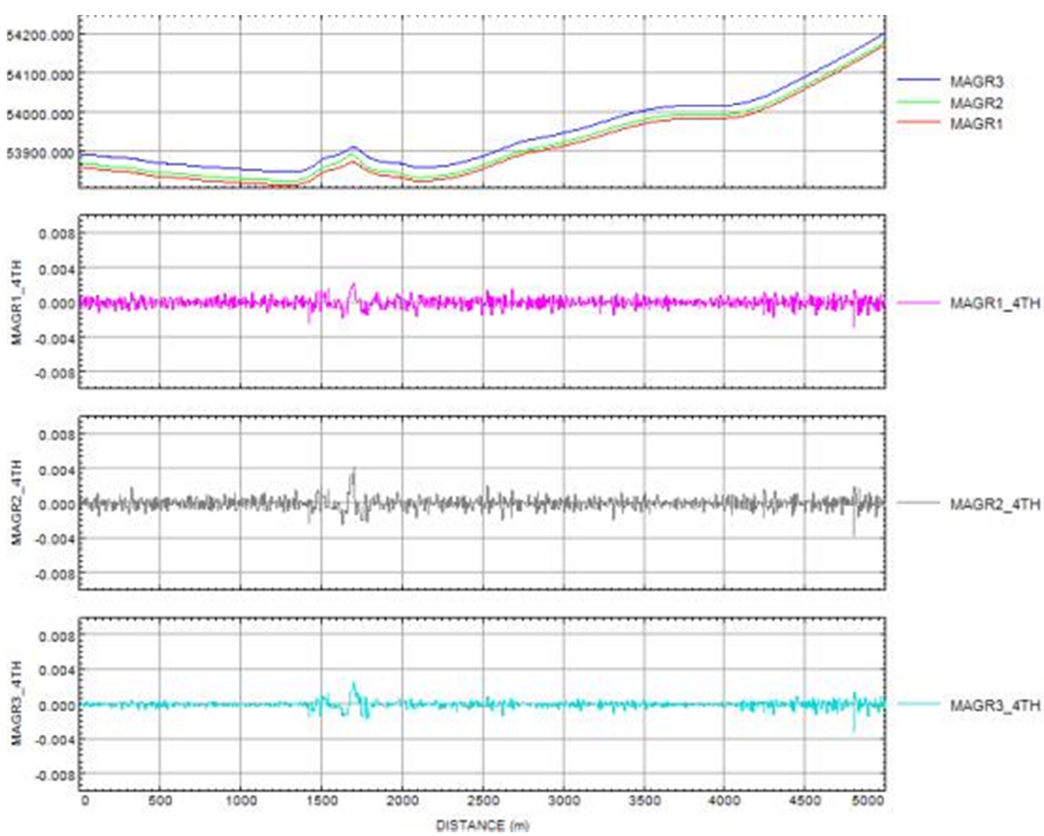


Figure 10 : Magnetometers 4th difference

C. COMPENSATION BASED ON A PHYSICAL MODEL

Date: 2014.07.30

Location: North West of Kirkenes, NORWAY

Aircraft: PA31 **C-GJDD**

Instruments: Magnetometers onboard: G-823 Cesium magnetometer, **10Hz**
Orientation sensor (3DM), MicroStrain, **10Hz**

Temperature: 14.6 °C at sea level

Pressure: 100.0 kPa at sea level

Height: 1000 m

CALIBRATION FLIGHT (FOM)

In practice, the calibration flight follows a precise and reproducible geometry, called Figure of Merit (FOM) during which the aircraft describes successively three pitch oscillations (±5°), three roll oscillations (±10°) and three yaw oscillations (±5°) with a period of a few seconds. The four principal directions are described this way. The turns between each line are not taken into account for the calculation of the coefficients.

ESTIMATION OF THE COEFFICIENTS

The calculation of the coefficients is to determine the mathematical solution which minimizes the differences between the measured signals and those generated by the model. The disturbance field being described as a linear combination of the direction cosine and terrestrial field, the least square algorithm is particularly designated. The problems caused by the correlations between the columns of the matrix to inverse are easy to diagnose using the eigenvalues of the matrix. To do so, we calculate an index by submitting the ratio of the largest on the smallest eigenvalue. In practice, it is considered that this index should not exceed 10^3. In certain cases, we will be able to observe strong colinearities when certain variables are not used, such as the absence of eddy currents. An effective manner to solve this problem of multicollinearity consists in using the method known as regression ridge. In the case where the matrix is badly conditioned, then the coefficients have a variance much little than when a least square algorithm is used. The general idea is to shift the eigenvalues of the matrix by a small constant. Thus the largest eigenvalues, which have a real significance, are slightly modified, whereas the lowest eigenvalues - which cause problem at the inversion - are significantly modified. The implementation of the regression ridge thus allowed us to avoid the problems of numerical instability and to improve our algorithm.

RESULTS

The following figures show the results obtained by the calibration flights carried out at 1000m of altitude North West of Kirkenes in Norway.

Branch	TROFI
Line 1	N 0
Line 2	N 90
Line 3	N 180
Line 4	N 270

Table 14 : FOM line directions

Flying the calibration figures in the same directions as the survey flight lines, we optimize the coefficients for these directions, as they are the one we will use.

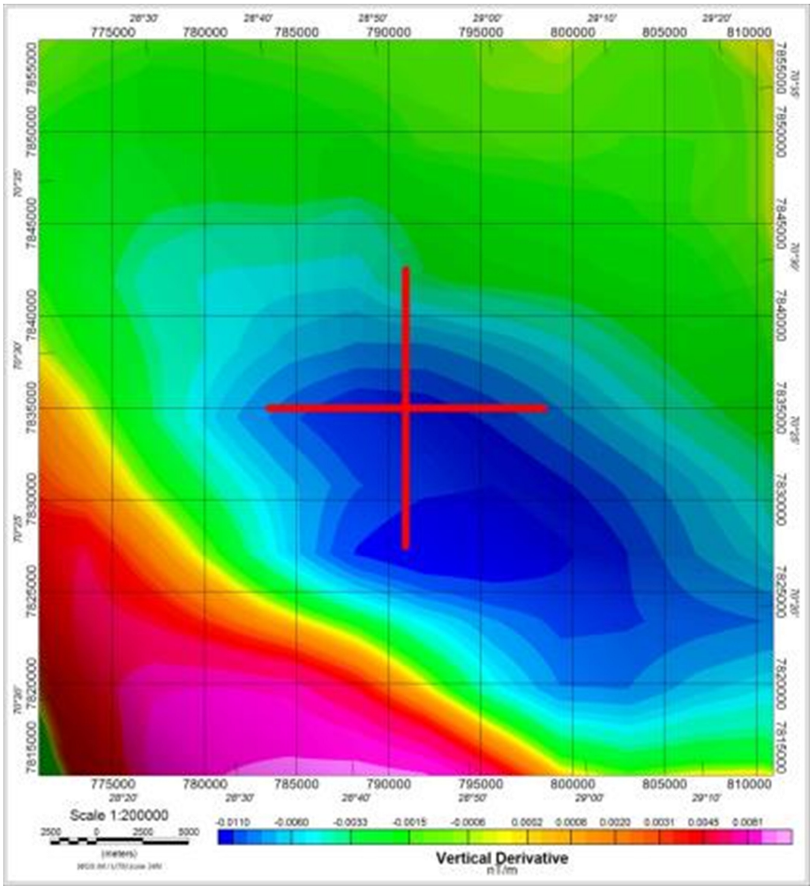
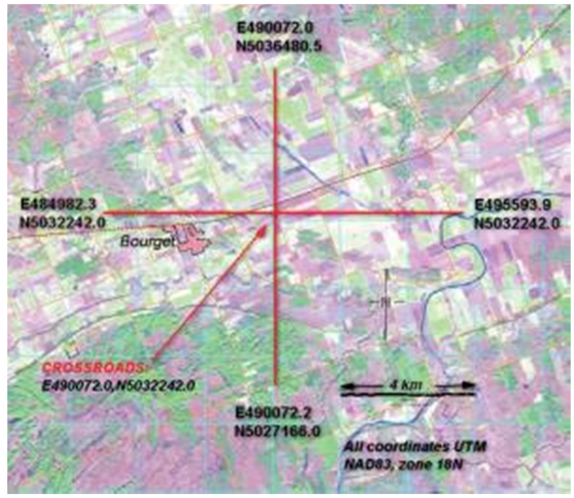


Figure 11 : Figure of merit over regional magnetic first vertical derivative

The figure of merit includes 4 lines (L1, L2, L3 and L4) flown at high altitude, in an area with a low vertical gradient, and following a figure in a clover shape. Each line is thus flown in the two directions in respect with the direction of the lines and tie-lines.

D. HEADING AND ABSOLUTE ACCURACY TEST



Date: N/A

Location: Bourget, Quebec, CANADA

Aircraft: PA31 **C-GJDD**

Instrument: Magnetometers: G-823 Cesium magnetometer, **10Hz**

Temperature: N/A

Pressure: N/A

Height: N/A

This test is performed over an easily recognised point on the ground. The purpose is to ensure that aeromagnetic survey system measures the total field values with an absolute accuracy of 10nT or less after the aircraft has been compensated. The result from the test together with the FOM is also used to remove aircraft influence on magnetic data (heading error).

Analysis of the synchronisation tests and noise level of the magnetometers, chapter A and B of the present report, compile for each aircraft and all the test lines, shows clearly that both aircrafts have an absolute difference of less than 10nT.

Since the compensation also corrects the heading error, there is no need for an extra calibration on C-GJDD.

E. TEST LINE AND QC TESTS

Date: 2014.07.29 – 2014.09.02

Location: Barents sea, Kirkenes NORWAY

Aircraft: PA31 **C-GJDD**

Instrument: Spectrometer, RSI RSX500, 50.16L down, 12.54L up, **2Hz**

Heights: 60 m following draped surface

During the survey, quality control is carried out by the project manager on site. Controls on the quality are integrated in the normal process of acquisition and start as soon as the flight path is established and end at the delivery of the final products.

A survey test lines is flown once every flight as a check on system sensitivity, the stability of the magnetometers and spectrometers, and finally to monitor the effect of soil moisture in the area, (Variation of thorium concentration less than 10% after corrections on every flight).

The extension of the test line is about 5 km. The measurement over the water is also used for the calibration of the gamma ray upward looking detector.

After each flight, the raw data are inspected to make sure that there are no missing data or corrupted data. Data are then saved on an independent and secure location. For each flight, the following controls are then carried out in priority, to ensure:

- The deviations on both sides of the flight lines (±50m over 5000m)
- The altitude deviations of the flight lines (60m above the drape surface over 3000m)
- Spacing between each measurement (225 km/h ± 25 km/h over 5000m)
- The diurnal drifts (100 nT/h, 35 nT/10min, 15 nT/2min)
- The noise level of the data (Mean 4th difference over 4000m less than 1.6)

Quality control maps are then issued in the Weekly Report and sent to the NGU representative every weekend of the project duration.

Finally, the following radiometric checks are performed every morning to ensure spectra constancy and are included in the Weekly Report:

- Stabilisation better than ±25 keV measured on the 2.62 MeV ^{208}Tl peak
- FWHM better than 200 keV measured on the 2.62 MeV ^{208}Tl peak
- Careful verification of each profile (and spectra) to spot spikes, jumps or interruptions in the readings
- Statistical calculation of the mean spectra for each line to insure potassium and thorium peak stability (drift less than 4 channels on the thorium peak)
- Correction and gridding of preliminary grids to evaluate data coherence and consistency.

F. COSMIC AND AIRCRAFT BACKGROUND CORRECTION

Date: 2014.09.02

Location: Barents Sea, Kirkenes NORWAY

Aircraft: PA31 **C-GJDD**

Instrument: Spectrometer, RSI RSX500, 50.16L down, 12.54L up, **2Hz**

Temperature: 15.1 °C at sea level

Pressure: 100.3 kPa at sea level

Heights: 1500m-3000m

To determine the cosmic and aircraft background, the spectrometer used records all incident particles above 3 MeV in the Cosmic channel. Steps are flown at 6 equidistant heights, from 1500m to 3000m and over the sea to reduce the presence of radon. Furthermore, in order to minimize statistical errors, each step is 17 km long and lasts around 4-5 minutes.

It was established that no radon contamination is notably apparent for which it would result in a breakdown of the linear relationship. Mean counts and linear relations of the cosmic radiations in the various spectral windows are represented below.

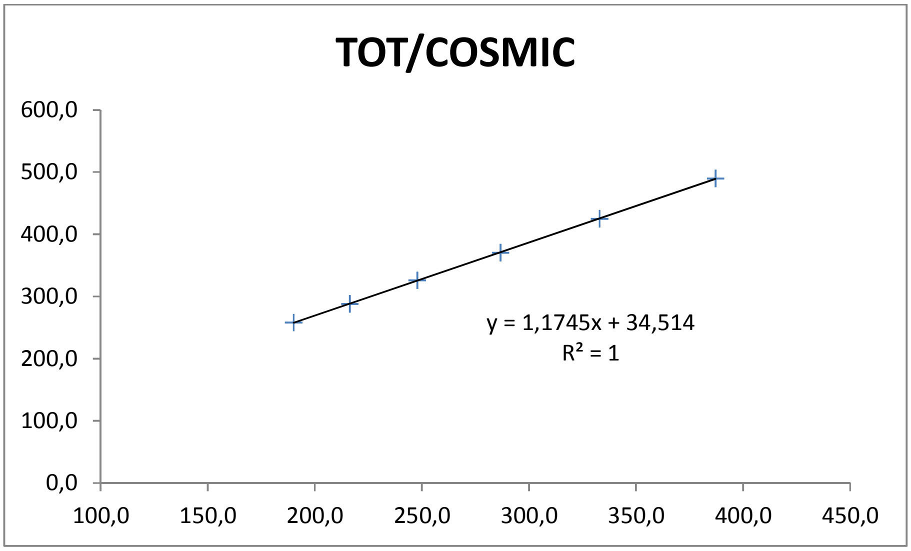
Altimeter (m)	Cosmic Dn	Cosmic Up	Total Count	Potassium	Uranium	Thorium	Cesium	Up Uranium
2999.7	190.1	51.5	258.2	23.2	10.6	10.3	2.8	50.4
2699.7	216.3	59.7	288.4	24.7	12.3	12.5	3.2	54.4
2399.3	247.7	68.4	325.9	27.5	13.8	14.2	3.7	61.2
2100.0	286.6	78.1	370.2	30.7	15.9	16.9	4.2	68.3
1800.0	332.9	90.7	425.1	33.4	18.5	20.0	4.8	77.6
1499.4	387.1	107.1	489.8	36.5	21.7	23.6	5.6	87.8

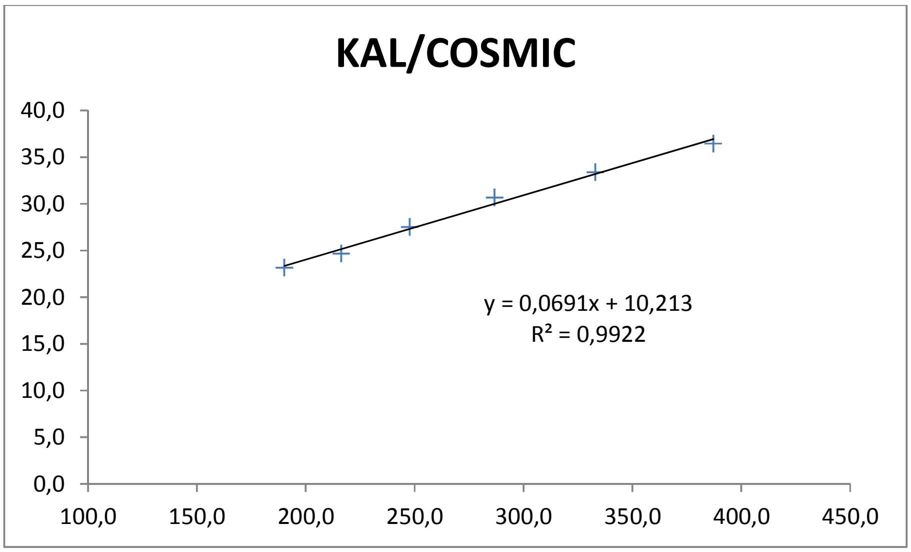
Table 15 : Steps averaged data

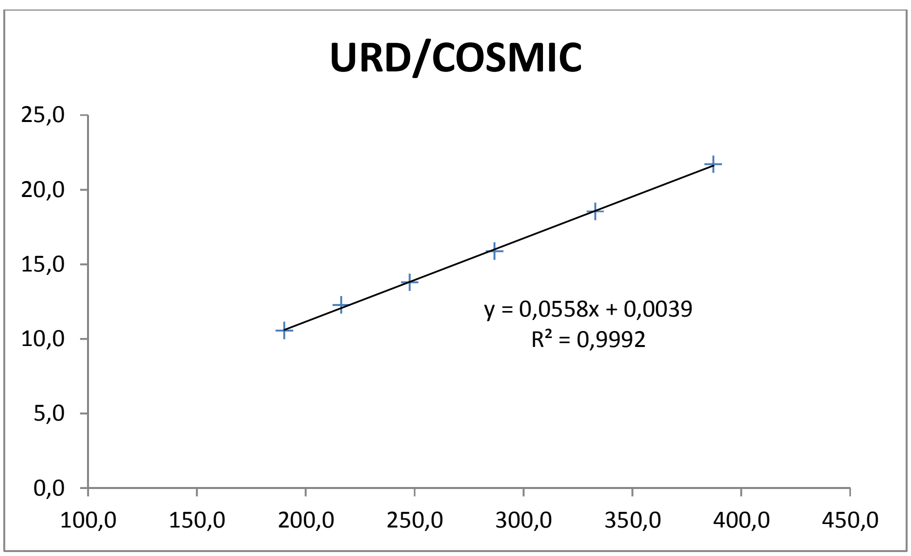
Background	Total Count	Potassium	Uranium	Thorium	Cesium	Up Uranium
Aircraft	34.5	10.2	0.00	-2.28	13.34	0.16
Cosmic	1.17	0.069	0.056	0.067	0.19	0.051

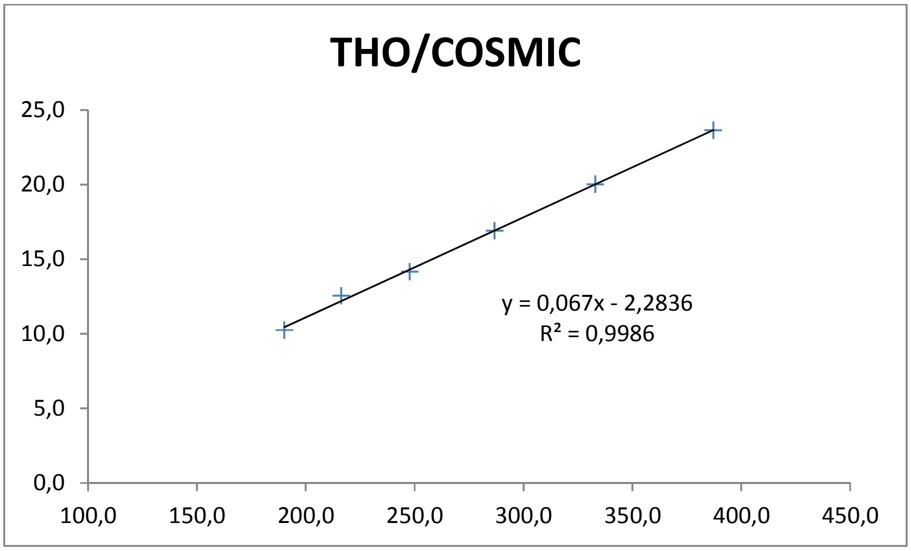
Table 16 : Cosmic & Aircraft background coefficients

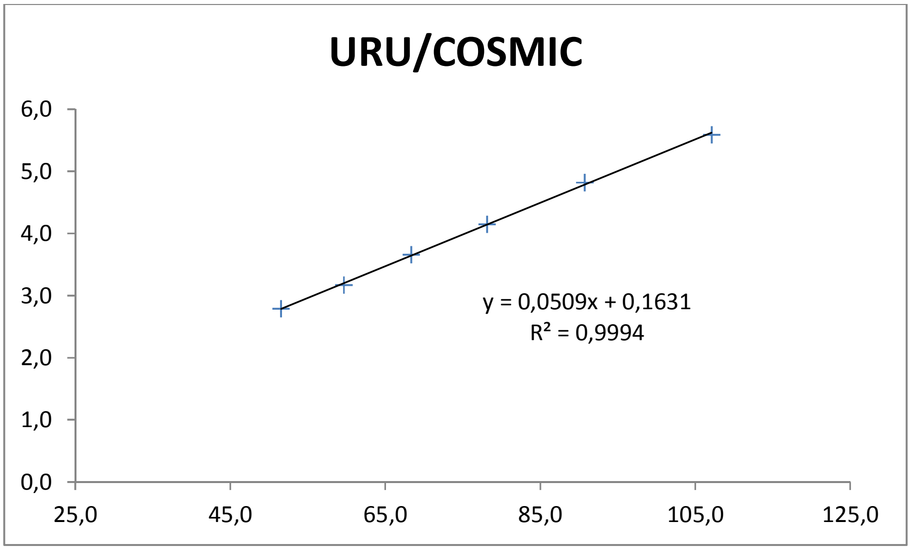
Notice that the coefficient of determination is remarkably high for every window. Lower coefficients would have been characteristic of the radon concentration variation in the air during the flight as the thorium window is less affected and the uranium and total count are closely correlated. However, the only effect of varying radon during the cosmic-ray calibration flights will be an unknown radon component which will be removed during radon processing, as it is demonstrated in *Grasty and Minty, AGSO 1995/60*.


TOT/COSMIC
600,0
500,0
400,0
300,0
200,0
100,0
0,0
100,0
150,0
200,0
250,0
300,0
350,0
400,0
450,0
y = 1,1745x + 34,514
R² = 1


KAL/COSMIC
40,0
35,0
30,0
25,0
20,0
15,0
10,0
5,0
0,0
100,0
150,0
200,0
250,0
300,0
350,0
400,0
450,0
y = 0,0691x + 10,213
R² = 0,9922


URD/COSMIC
25,0
20,0
15,0
10,0
5,0
0,0
100,0
150,0
200,0
250,0
300,0
350,0
400,0
450,0
y = 0,0558x + 0,0039
R² = 0,9992





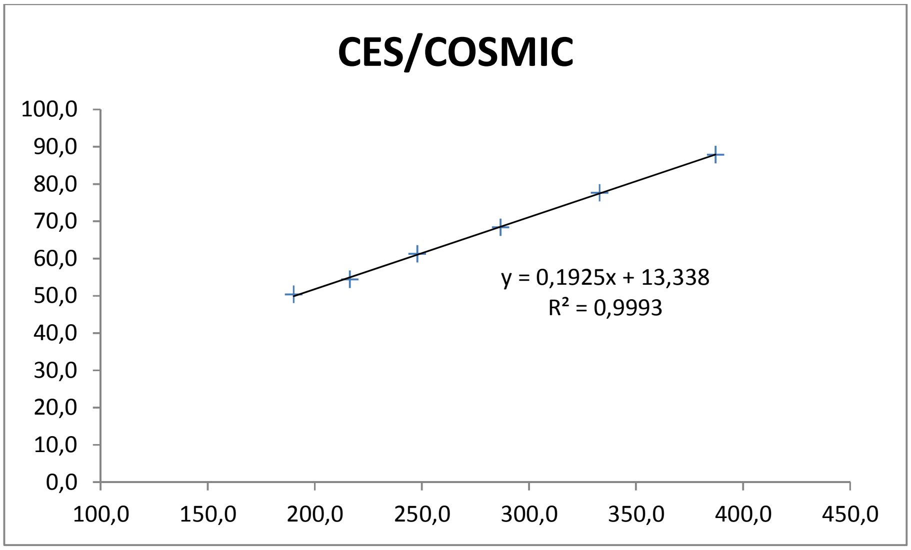


Figure 12 : Background corrections

G. UPWARD LOOKING DETECTOR CORRECTION COEFFICIENTS

Location: Barents Sea, Kirkenes NORWAY, 2014

Aircraft: PA31 **C-GJDD**

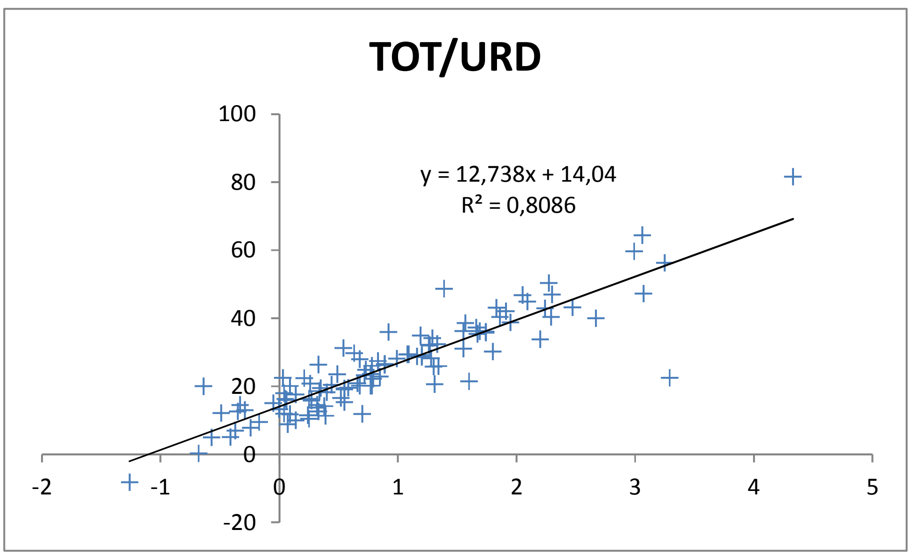
Instrument: Spectrometer: RSI RSX500, 50.16L down, 12.54L up, **2Hz**

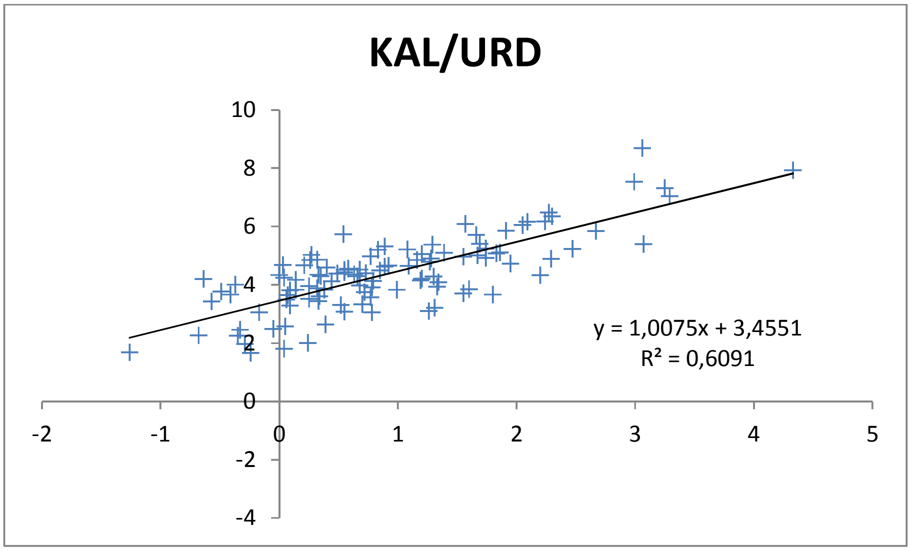
Flying Height: 60 m

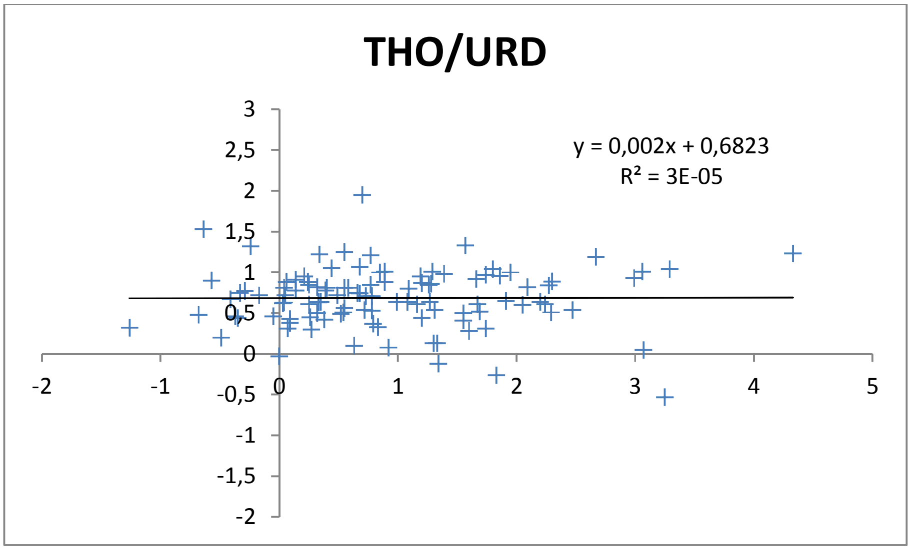
In order to determine the relationship between the upward and downward detector count rates for radon in the air, parts of flights over water at constant altitude, where there is no contribution from the ground, are used. Due to the scale of the survey, a considerable amount of data is recorded close to the area.

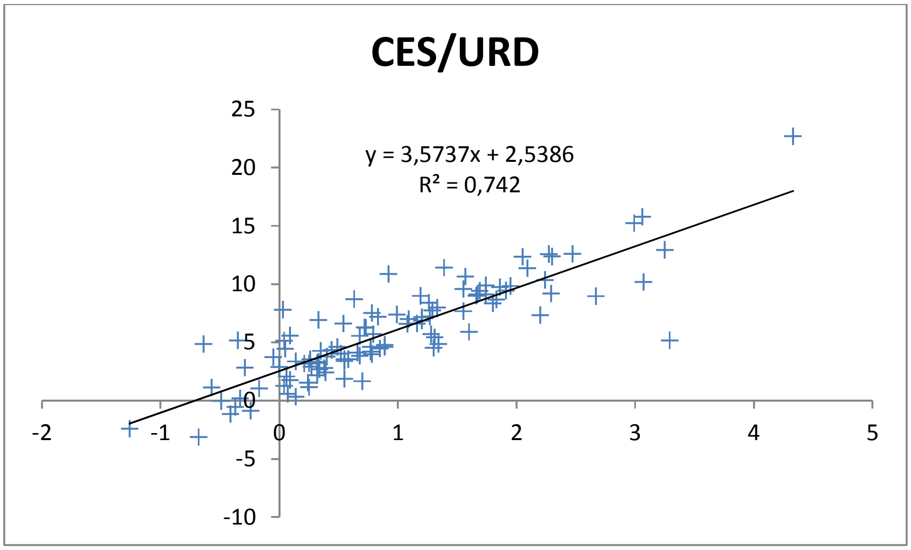
Prior to the analysis, aircraft background and cosmic component are removed and the dead time correction done. Since the cosmic and aircraft background calibration test leaded to highly reliable results, shown by the coefficients of determination R_2 in each window, we expect linear constants b_n to be close to zero. In addition, in order to minimize the statistical noise, only series over 10 valid counts are used. The results are presented in the following graphs.

Coefficients determined can have sometime a negative value. That can be explained by a variation of radon concentration during the calibration of the cosmic radiation. This unknown radon component is precisely removed by considering the given residual components at the time of the radon correction; results described in Grasty and Minty, AGSO 1995/60.




KAL/URD
y = 1,0075x + 3,4551
R² = 0,6091
10
8
6
4
2
0
-2
-4
-2
-1
0
1
2
3
4
5


THO/URD
y = 0,002x + 0,6823
R² = 3E-05
3
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
-2
-2
-1
0
1
2
3
4
5


CES/URD
y = 3,5737x + 2,5386
R² = 0,742
25
20
15
10
5
0
-5
-10
-2
-1
0
1
2
3
4
5

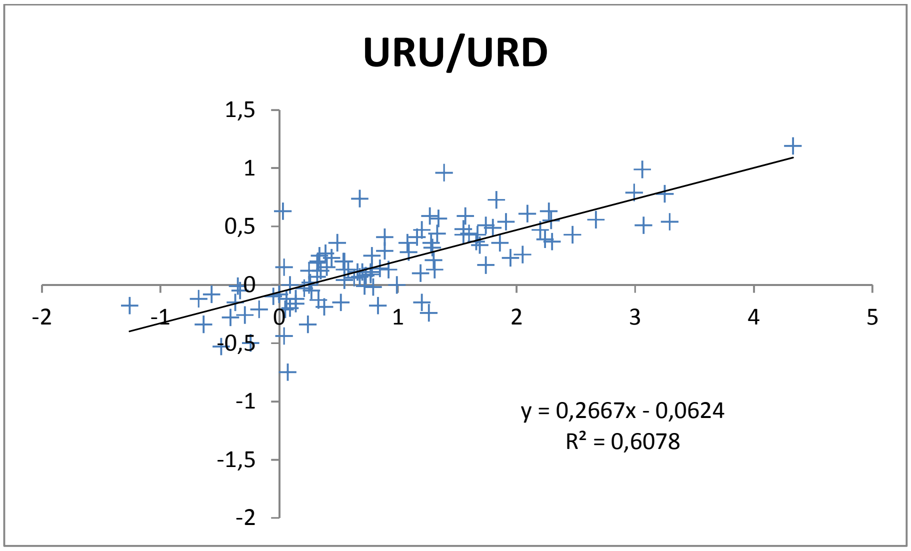


Figure 13 : Radon coefficients

The component of the upward detector count rate originating from the ground, u_g, will depend on the concentration of U an Th in the ground, as will the components of U and Th downward window count rates, U_g and Th_g, that originate from the ground. In order to minimize the statistical errors, the three components were calculated by subtracting flights above water present on TROFI-14 East at the values adjacent on the firm ground. Numerous sites have thus been evaluated on the block. Finally, from the series of calculated values of U_g, U_g and Th_g, the calibration factors, a_1 and a_2, are determined by the least squares method described in IAEA Technical reports series No.323.

a_1	a_2
0.035	0.025

H. PADS CALIBRATION

RADIATION SOLUTIONS INC

CALIBRATION SHEET

Instrument: **RSX-5**

Customer:	Novatem		Date:	May 24, 2011
Contact:	Pascal Mouge		Tech.:	GP
Console :	N/A		Job Order:	SO#1947
Detector 1:	5510		Customer PO	PO#Email
Detector 2:	N/A			

Channels: 1024 **ADC Offset:** N/A

	A1	A2	A3	A4	A5
High Voltages	635	675	649	640	704

Stripping Constant	"this system"	"normal"
Alpha	**0.273**	0.250
Beta	**0.401**	0.400
Gamma	**0.771**	0.810
a	**0.047**	0.060
b	**0.000**	0.000
g	**-0.001**	0.003

ROI#	Channel	IAEA Specification [keV]	Label
1	137-937	410-2810	Total Count
2	457-523	1370-1570	Potassium K
3	553-620	1660-1860	Uranium U
4	803-937	2410-2810	Thorium Th
5			
6			
7			
8	553-620	1660-1860	Uranium Upper U

Det#	Peak Cs	Cs FWHM		Peak Th	Th FWHM
A1	221.02	7.29		871.80	4.08
A2	221.07	7.32		871.65	4.20
A3	220.71	7.48		871.72	4.23
A4	221.04	7.23		872.28	4.08
Sum Dn	**220.96**	**7.33**		**871.86**	**4.14**
Sum Up	**221.56**	**7.46**		**872.41**	**4.26**

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novatem airborne geophysics

RADIATION SOLUTIONS INC

CALIBRATION SHEET

Instrument: **RSX-5**

Customer:	Novatem	Date:	July 20, 2011
Contact:	Jeremie Largeaud	Tech.:	GP
Console :	N/A	Job Order:	SO#9734
Detector 1:	5523	Customer PO	PO#
Detector 2:	N/A		

Channels: 1024 **ADC Offset:** N/A

	A1	A2	A3	A4	A5
High Voltages	714	705	725	704	693

Stripping Constant	"this system"	"normal"
Alpha	0.288	0.250
Beta	0.404	0.400
Gamma	0.775	0.810
a	0.051	0.060
b	0.003	0.000
g	0.002	0.003

ROI#	Channel	IAEA Specification [keV]	Label
1	137-937	410-2810	Total Count
2	457-523	1370-1570	Potassium K
3	553-620	1660-1860	Uranium U
4	803-937	2410-2810	Thorium Th
5			
6			
7			
8	553-620	1660-1860	Uranium Upper U

Det#	Peak Cs	Cs FWHM	Peak Th	Th FWHM
A1	220.84	8.37	872.30	4.91
A2	220.76	8.66	872.35	5.46
A3	221.26	8.45	872.12	5.22
A4	220.89	7.82	871.95	4.55
Sum Dn	220.94	8.30	872.10	5.06
Sum Up	221.19	9.70	871.12	6.56

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RADIATION SOLUTIONS INC

CALIBRATION SHEET

Instrument: **RSX- 5**

Customer:	Novatem	Date:	June 6, 2014
Contact:	Morten Skovgaard	Tech.:	Jim C
Console :	N/A	Job Order:	RMA# 10453
Detector 1:	5630	Customer PO	PO#
Detector 2:	N/A		

Channels: 1024 **ADC Offset:** N/A

	A1	A2	A3	A4	A5
High Voltages	643	647	647	655	644

Stripping Constant	"this system"	"normal"
Alpha	0.279	0.250
Beta	0.404	0.400
Gamma	0.766	0.810
a	0.042	0.060
b	0.000	0.000
g	0.003	0.003

ROI#	Channel	IAEA Specification [keV]	Label
1	137-937	410-2810	Total Count
2	457-523	1370-1570	Potassium K
3	553-620	1660-1860	Uranium U
4	803-937	2410-2810	Thorium Th
5			
6			
7			
8	553-620	1660-1860	Uranium Upper U

Det#	Peak Cs	Cs FWHM		Peak Th	Th FWHM
A1	220.04	7.89		871.78	4.81
A2	220.24	7.69		873.24	4.40
A3	220.05	7.59		872.37	4.62
A4	219.63	7.76		872.76	4.76
Sum Dn	**219.99**	**7.72**		**872.50**	**4.67**
Sum Up	**220.58**	**8.84**		**870.89**	**6.25**

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I. HEIGHT ATTENUATION & SENSITIVITY

Date: 2011.06.06

Location: Breckenridge, Quebec, CANADA

Aircraft: PA31 **C-GJDD**

Instruments: Spectrometer, RSI RSX500, 50.16L down, 12.54L up, **2Hz** 5629, 5630, 5523 Geological Survey of Canada, Portable spectrometer for ground measurements

Test Area: TC=54.94 nGy/h, K= 1.96%, eU= 1.55ppm, eTh= 8.20ppm

Temperature: 20°C at sea level

Pressure: 100.2 kPa at sea level

Height: 50-230m

The height attenuation & sensitivity is usually evaluated from an area of known concentration, which includes several records and statistics. Since there is no such area in Norway, data recorded separately for each spectrometer were added to recalculate TROFI-14 East coefficients, regarding the exact configuration in C-GJDD. Next tables show the results obtained

Altimeter (m)	STP Corrected	Total Count	Potassium	Uranium	Thorium
49.2	46.6	1709.87	212.58	32.01	44.09
80.86	70.5	1385.64	165.12	26.28	35.19
109.88	97.7	1166.42	132.13	22.88	28.83
139.57	121.9	1024.66	111.41	20.87	25.58
168.95	154.1	880.74	92.62	18.45	22.50
199.71	191.1	774.30	77.94	17.64	18.42
228.73	203.1	687.81	69.37	16.49	17.46

Table 17 : Test Data (cps)

Altimeter (m)	STP Corrected	Total Count	Potassium	Uranium	Thorium
55.89	52.8	210.41	21.76	6.27	4.56
86.93	75.8	202.49	20.00	6.35	4.83
117.65	104.6	208.18	21.34	7.46	4.00
145.36	126.9	209.59	20.51	6.73	5.22
174.74	159.4	208.93	20.92	7.87	5.93
204.55	195.8	217.35	21.96	8.46	4.50
233.39	207.3	225.99	22.86	7.55	5.74

Table 18 : Background Data (cps)

α	β	γ	a	b	g
0.280	0.403	0.771	0.047	0.001	0.001

Table 19 : Stripping ratios

Total Count	Potassium	Uranium	Thorium
1499.46	190.82	25.73	39.54
1183.15	145.13	19.94	30.37
958.24	110.79	15.42	24.83
815.07	90.90	14.13	20.35
671.81	71.70	10.58	16.57
556.95	55.98	9.18	13.92
461.82	46.51	8.94	11.72

Table 20 : Background-Corrected & Stripped Counts (cps))

After dead time correction, mean count rates of all four windows are then corrected from the cosmic radiation, atmospheric radioactivity and aircraft background by subtracting adjacent values over water. STP corrected Compton stripping ratios are then applied to the count rates. The stripped count rates at each altitude are finally fitted to the exponential function to give the height attenuation coefficients. The following figure shows the curves for all four windows, determined from the test strip.

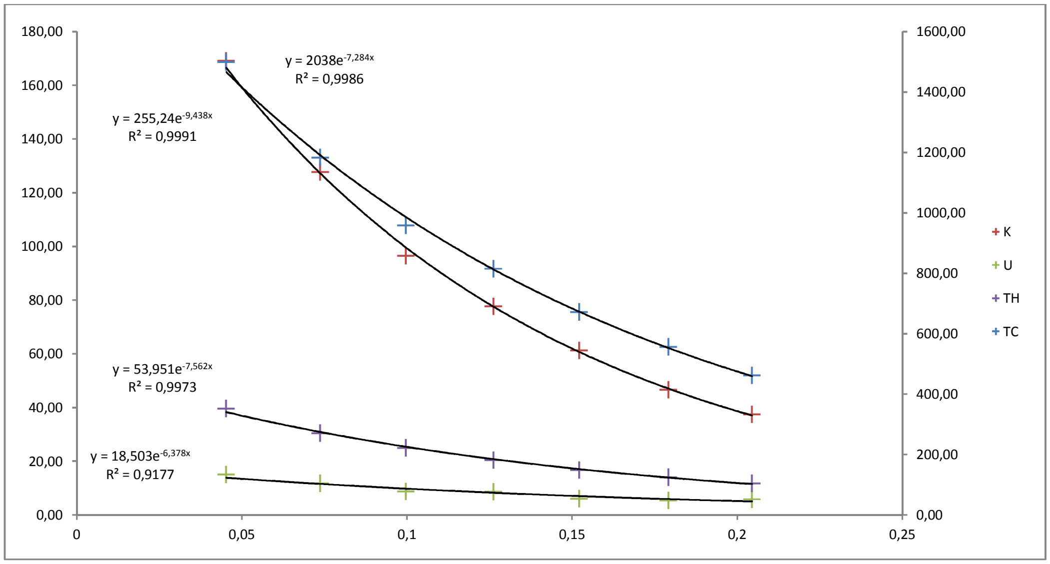


Figure 14 : Exponential height attenuation for all four windows

Broad source sensitivity for each window was calculated using concentration of the radioelement measured at ground level on the strip and for a final STP height of 120m. All the results are shown in the following table.

	Total Count	Potassium	Uranium	Thorium
ATTENUATION	-0.00728 m^{-1}	-0.00944 m^{-1}	-0.00638 m^{-1}	-0.00756 m^{-1}
SENSITIVITY	15.5 cps/ nGy/h	41.9 cps/%	5.5 cps/ppm	2.65 cps/ppm

Table 21 : Attenuation coefficients & Sensitivity (120m)

J. PADS CALIBRATION, HEIGHT ATTENUATION & SENSITIVITY (MAN-MADE SOURCE)

Date: 2014.08.26

Location: Kirkenes Airport, NORWAY

Aircraft: PA31 **C-GJDD**

Instruments: Spectrometer RSI RSX500; 50.16L down, 12.54L up, 2**Hz**; S/N 5510, 5523, 5630

Temperature: 13.9 °C at sea level

Pressure: 99.9 kPa at sea level

^{137}Cs source: 163 kBq

The evaluation of natural radioelement unit spectra in the ^{137}Cs window, from the calibration pads and for the set of two spectrometers, gives the following sensitivities at ground level.

s_K	s_U	s_{Th}
0.623	4.843	3.383

Table 22 : Cesium stripping ratios

To derive the influence at different height in the ^{137}Cs window, plastic sheets of know density were placed underneath the detectors and above a cesium source of known activity to simulate the absorption of gamma rays in the air. By increasing the thickness of the material, the cesium attenuation coefficient is determined.

Since the evaluation is kept at relatively low altitude, the equivalent height of air can be estimated as a ratio of density

$$eH = ntf\frac{\rho_p}{\rho_a}$$

Where: eH is the equivalent height of air (m)
n is the number of plastic sheet
t is the thickness of a plastic sheet (0.012 m)
f is the correction factor for the electron densities (1.133)
ρ_p is the density of plastic (950 kg/m^3)
ρ_a is the density of air at standard pressure and temperature (1.29 kg/m^3)

Here are presented the corrected data from the four standard radioelements as well as from the cesium window.

Total Count	Potassium	Uranium	Thorium
4205.97	-4.37	0.24	0.75
3910.14	-4.87	-0.02	1.24
3695.28	-1.35	-2.03	0.91
3468.54	-4.17	-1.56	1.52
3260.16	-4.83	-2.85	2.09
3035.85	-10.40	-1.58	-0.07
2838.09	-13.79	-0.84	0.20
2652.96	-14.09	-0.15	0.00
2450.07	-14.68	-1.40	0.13
2288.88	-16.74	-0.75	0.83
2122.62	-14.73	-1.64	0.70
1959.63	-14.21	-2.48	-0.21
1815.15	-17.65	-2.73	-1.36
1673.01	-18.31	-1.11	-1.99
1536.60	-18.97	-2.51	-0.16

Table 23 : Natural radioelement Stripped Counts (cps))

Number of sheets	Equivalent Height	Cesium	Cesium background	Cesium corrected	Cesium stripped
0	0.50	3842	445	3397	3395.97
1	10.01	3518	445	3073	3072.37
2	20.03	3289	445	2844	2851.91
3	30.04	3055	445	2610	2615.30
4	40.05	2850	445	2406	2415.39
5	50.06	2655	445	2210	2224.37
6	60.08	2480	445	2036	2047.73
7	70.09	2318	445	1873	1882.92
8	80.1	2155	445	1711	1726.10
9	90.11	2019	445	1574	1585.49
10	100.13	1895	445	1451	1465.49
11	110.14	1772	445	1327	1348.95
12	120.15	1665	445	1220	1249.10
13	130.16	1558	445	1114	1137.36
14	140.18	1461	445	1016	1040.76

Table 24 : Cesium Stripped Counts (cps))

After dead time correction, mean count rates of each windows are then corrected from the cosmic radiation, atmospheric radioactivity and aircraft background by subtracting a background value measured just before and after the tests and without any source, STP corrected Compton stripping ratios are then applied to the natural radioelement count rates by using previously calculated stripping ratio for the cesium window. The stripped count rates at each altitude are finally fitted to the exponential function to give the height attenuation coefficient. The following figure shows the results for the cesium window.

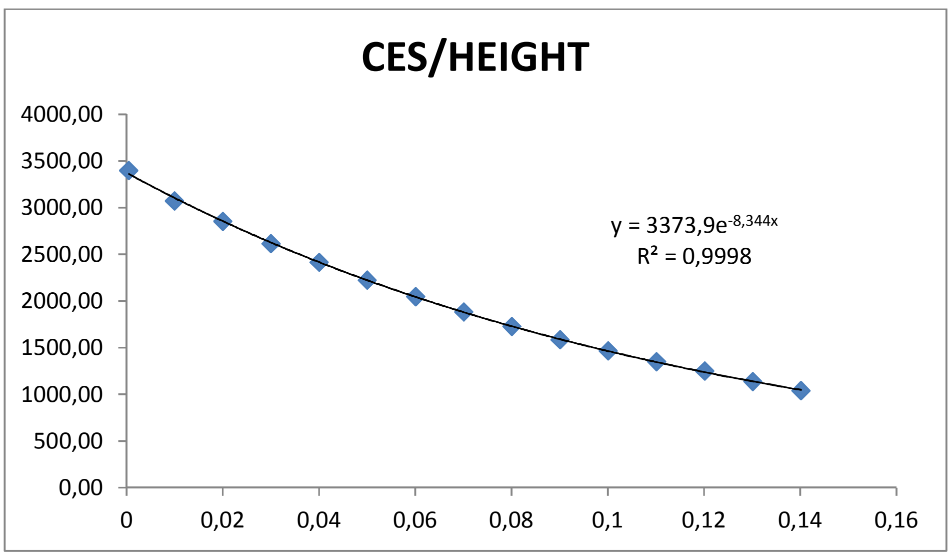
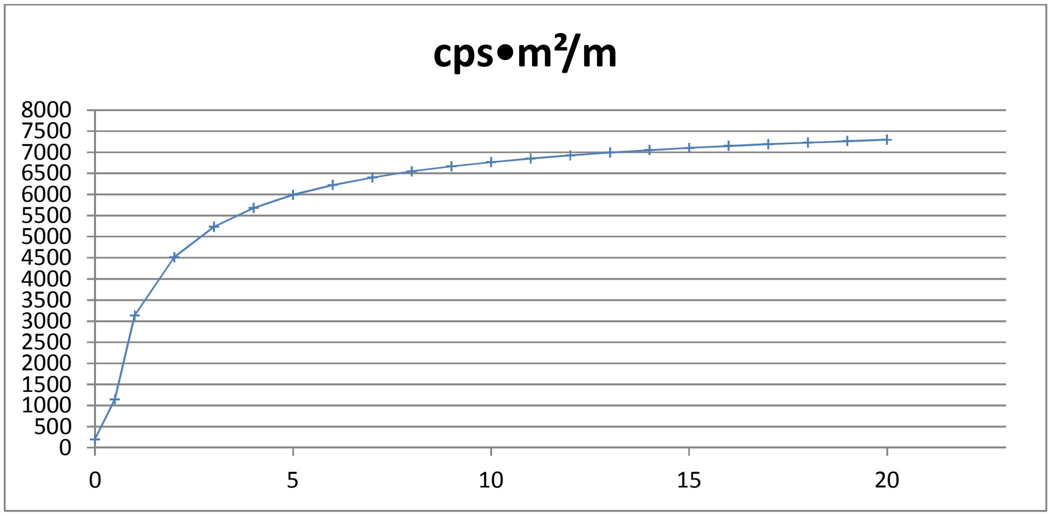


Figure 15 : Exponential height attenuation for the cesium window

In order to evaluate the equivalent ground concentration of a ^{137}Cs anomaly, we first modelled an infinite plane surface source. To create the model, several measurements at symmetrical angles and different distances from the aircraft were recorded for approximately 3 minutes each time. From the Cs source used, the model obtained at larger distances, out to 20 meters, is shown in the next figure. We can notice that the convergence approach 8 300 cps•m² in total. The source had an activity of 298.5 kBq at 21st March 1988. According to http://www.nist.gov/pml/data/halflife-html.cfm, the half life is 11018 days. The elapsed time from 21.3.88 to 26.08.14 is 9649 days which is 0.8757 half life, the activity is then 298.5 * (0.5)^(0.848) = 163 kBq. Knowing that the source activity is 163 kBq, the surface concentration can be estimated at 0.0196 kBq/m^2/cps.



Finally, broad source sensitivity for the cesium window is calculated using standard procedure, being the surface activity per counts of cesium calculated at ground level and brought to a final STP height of 120m. The results are shown in the following table.

	Cesium
ATTENUATION	-0.00835 m^{-1}
SENSITIVITY	18.7 cps / kBq/m^2

Table 25 : Attenuation coefficients & Sensitivity for cesium (120m)

K. LAG TEST

Date: 2012.02.15

Location: Flyplasstunnelen. Fv137
Vigra Airport. NORWAY

Aircraft: PA31 **C-GJDD**

Instrument: Magnetometers: G-823 Cesium magnetometer. **10Hz**

Heights: 60 m

Taking into account the spatial difference between the GPS antenna and the different magnetometers, the following results show that there is almost no time lag in the data records. Note that the spatial lag will be taking into account in the processing in order to replace each magnetometer in the space for gradient enhancement.

MAG 1 (Left wing tip pod)

LINE	HEADING (°)	YAW (°)	ALTITUDE (m)	TIME (HHMMSS)	X (m)	Y (m)	SPEED (m/s)	HIGH PASS FILTERED MAG (nT)
L1:0	70	223.40	60.67	150022.5	352157.6	6940221.2	61.4	51689.810
L2:0	250	176.60	61.40	150230.8	352156.3	6940221.6	62.8	51676.240

MEAN SPEED = 62.1 m/s
DISTANCE = 1.322 m
LAG = 0.011 sec

LINE	HEADING (°)	YAW (°)	ALTITUDE (m)	TIME (HHMMSS)	X (m)	Y (m)	SPEED (m/s)	HIGH PASS FILTERED MAG (nT)
L3:0	70	210.70	63.36	150517.3	352157.1	6940217.2	61.4	51674.050
L4:0	250	176.80	67.47	150723.5	352157.9	6940221.5	62.8	51634.440

MEAN SPEED = 62.1 m/s
DISTANCE = 4.368 m
LAG = 0.035 sec

LINE	HEADING (°)	YAW (°)	ALTITUDE (m)	TIME (HHMMSS)	X (m)	Y (m)	SPEED (m/s)	HIGH PASS FILTERED MAG (nT)
L5:0	70	212.70	65.61	150950.0	352159.1	6940216.8	63.3	51656.120
L6:0	250	172.30	64.98	151207.9	352155.1	6940221.4	60.6	51651.570

MEAN SPEED = 61.9 m/s
DISTANCE = 6.083 m
LAG = 0.049 sec

MAG 2 (Right wing tip pod)

LINE	HEADING (°)	YAW (°)	ALTITUDE (m)	TIME (HHMMSS)	X (m)	Y (m)	SPEED (m/s)	HIGH PASS FILTERED MAG (nT)
L1:0	70	223.40	60.67	150022.5	352157.6	6940221.2	61.4	51696.560
L2:0	250	176.60	61.40	150230.8	352156.3	6940221.6	62.8	51692.240

MEAN SPEED = 62.1 m/s
DISTANCE = 1.322 m
LAG = 0.011 sec

LINE	HEADING (°)	YAW (°)	ALTITUDE (m)	TIME (HHMMSS)	X (m)	Y (m)	SPEED (m/s)	HIGH PASS FILTERED MAG (nT)
L3:0	70	210.70	63.36	150517.3	352157.1	6940217.2	61.4	51666.260
L4:0	250	176.80	67.47	150723.5	352157.9	6940221.5	62.8	51655.930

MEAN SPEED = 62.1 m/s

DISTANCE = 4.368 m

LAG = 0.035 sec

LINE	HEADING (°)	YAW (°)	ALTITUDE (m)	TIME (HHMMSS)	X (m)	Y (m)	SPEED (m/s)	HIGH PASS FILTERED MAG (nT)
L5:0	70	212.70	65.61	150950.0	352159.1	6940216.8	63.3	51649.860
L6:0	250	172.30	64.98	151207.9	352155.1	6940221.4	60.6	51665.630

MEAN SPEED = 61.9 m/s

DISTANCE = 6.083 m

LAG = 0.049 sec

MAG 3 (Tail boom)

LINE	HEADING (°)	YAW (°)	ALTITUDE (m)	TIME (HHMMSS)	X (m)	Y (m)	SPEED (m/s)	HIGH PASS FILTERED MAG (nT)
L1:0	70	223.30	60.82	150022.7	352168.9	6940225.9	61.4	51718.670
L2:0	250	176.60	61.36	150230.9	352150.5	6940219.2	62.8	51710.760

MEAN SPEED = 62.1 m/s

DISTANCE = 19.582 m

LAG = 0.158 sec

LINE	HEADING (°)	YAW (°)	ALTITUDE (m)	TIME (HHMMSS)	X (m)	Y (m)	SPEED (m/s)	HIGH PASS FILTERED MAG (nT)
L3:0	70	210.60	63.32	150517.5	352168.4	6940221.9	61.4	51696.240
L4:0	250	176.80	67.55	150723.7	352146.3	6940216.7	62.8	51670.020

MEAN SPEED = 62.1 m/s

DISTANCE = 22.772 m

LAG = 0.183 sec

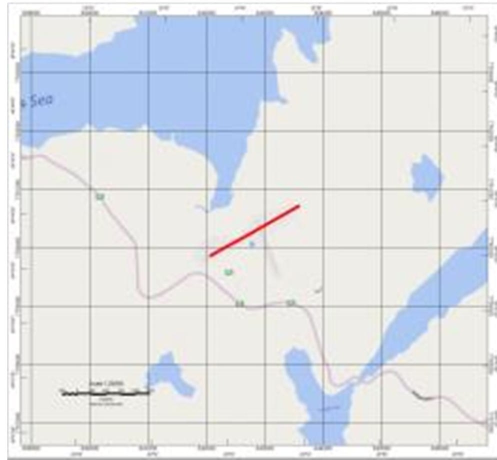
LINE	HEADING (°)	YAW (°)	ALTITUDE (m)	TIME (HHMMSS)	X (m)	Y (m)	SPEED (m/s)	HIGH PASS FILTERED MAG (nT)
L5:0	70	212.80	65.54	150950.2	352170.7	6940221.7	63.3	51678.350
L6:0	250	172.30	64.93	151208.0	352149.5	6940219.1	60.8	51685.630

MEAN SPEED = 62.1 m/s

DISTANCE = 21.418 m

LAG = 0.172 sec

L. LASER AND RADAR CALIBRATION



Date: 2014.07.22

Location: Kirkenes airport (alt : 87 m) NORWAY

Aircraft: PA31 **C-GJDD**

Instrument: GPS receiver: Novatel Propak – LBS Plus. **10Hz**
Laser altimeter: Optech Sentinel 3100. **10Hz**
Radar altimeter: Free Flight TRA 4000. **10Hz**

Temperature: 12.3 °C at sea level

Pressure: 100.3 kPa at sea level

Heights: 40m-180m

To determine coefficients of calibration for the laser and radar altimeter, steps are flown at 6 different heights. from 40m to 180m and over the Alta airport strip in order to have a surface as flat as possible for the calibration. In order to minimize errors, each step is 2 km long.

The different altitudes recorded show a perfect linearity with the post processed GPS altitude. The airport altitude (87 m) was removed from the mean altitude recorded in order to evaluate the results. Finally, linear relations between the different altimeters are plotted below and calibration constants needed for processing are provided.

GPS altitude	Adjusted GPS altitude (m)	Laser altitude (m)	Radar altitude (m)
125.81	38.81	40.10	38.85
147.19	60.19	61.49	60.57
n/a	n/a	n/a	n/a
207.37	120.37	121.89	121.95
237.16	150.16	151.86	152.00
267.32	180.32	182.23	183.75

Table 26: Radar calibration

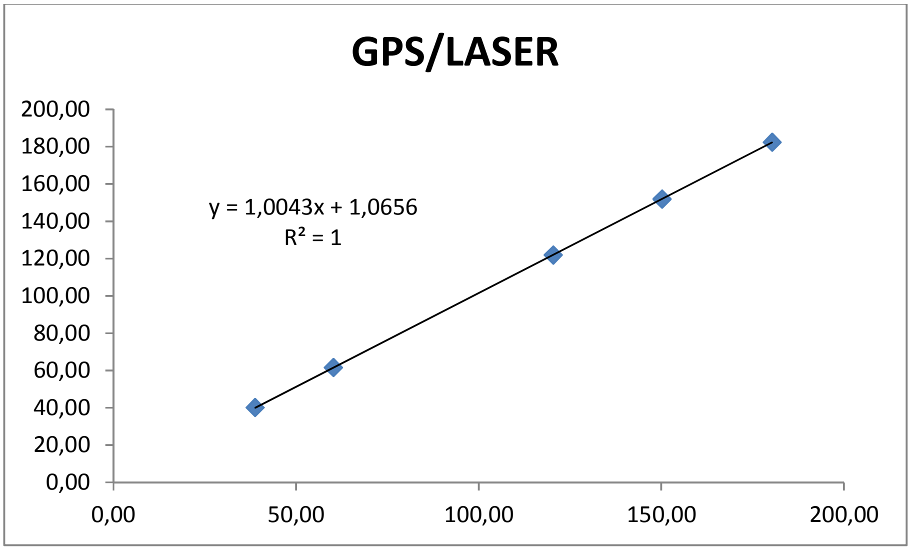


Figure 16 : Laser calibration

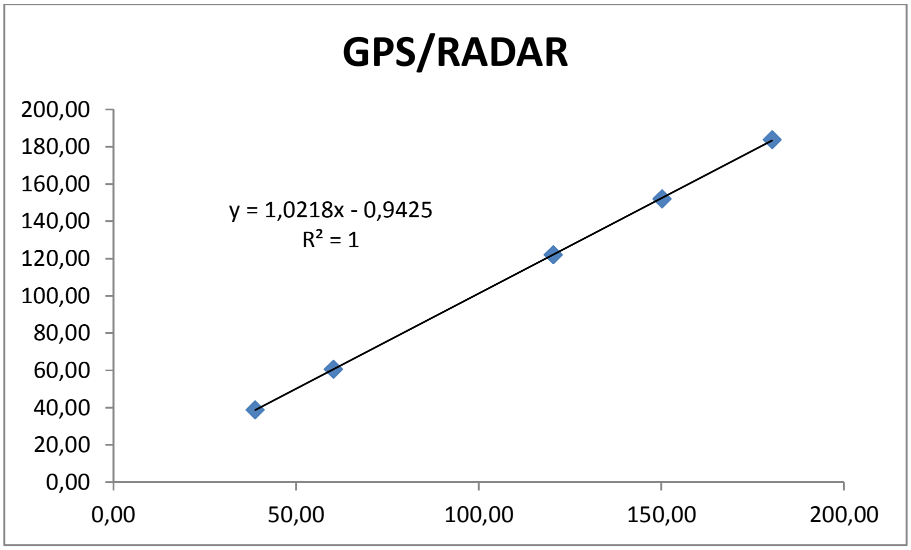


Figure 17 : Radar calibration