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Helicopter-borne magnetic and radiometric geophysical survey in Kinsarvik, Ullensvang municipality, Hordaland

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- NGU -

REPORT

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Title:
Helicopter-borne magnetic and radiometric geophysical survey in Kinsarvik area, Ullensvang municipality, Hordaland.

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County: Hordaland		**Municipality:** Ullensvang	
Map-sheet name (M=1:250.000) Odda		**Map-sheet no. and -name (M=1:50.000)** 1315-I Ullensvang	
Deposit name and grid-reference: Kinasarvik UTM 32V 374800 E – 6696600 N		**Number of pages:** 24 **Map enclosures:**	**Price (NOK):** 100,-
Fieldwork carried out: July 17th and August 5th 2015	**Date of report:** 01.04.2016	**Project no.:** 353200	**Person responsible:** Jan S. Rønning

Summary:

NGU conducted an airborne magnetic and radiometric survey in Kinsarvik area in July and August 2015. The primary purpose of the survey was to see if there is uranium bearing bedrock in and next to Kinsarvik where there are great problems relates to high indoor radon concentrations.

This report describes and documents the acquisition, processing and visualization of recorded datasets. The geophysical survey results reported herein are from 400 line km, covering an area of 80 km^2.

A Scintrex CS-3 magnetometer in a towed bird and a 1024 channels RSX-5 spectrometer installed under the helicopter belly was used for data acquisition.

The survey was flown with 200 m line spacing, line direction 20^o (NNE - SSW) at an average speed of 50 km/h. The average terrain clearance was 62 m for the bird and 90 m for the spectrometer.

The collected data were processed at NGU using Geosoft Oasis Montaj software. Raw total magnetic field data were corrected for diurnal variation and leveled using standard micro-levelling algorithm.

Radiometric data were processed using standard procedures recommended by International Atomic Energy Association.

Data were gridded with the cell size of 50 x 50 m and presented as a shaded relief maps at the scale of 1:50.000.

Keywords:	Geophysics	Airborne
Magnetics	Radiometric	Uranium
		Technical Report

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1. INTRODUCTION

NGU (Geological Survey of Norway) conducted in July and August 2015 an airborne geophysical survey in Kinsarvik area, where the area flown is marked with a red line in Figure 1. The helicopter survey consists of 400 line-km of data, covering an area of 80 km^2 in Ullensvang municipality, Hordaland County. The primary purpose of the survey was to see if there is uranium bearing bedrock in and next to Kinsarvik where there are great problems relates to high indoor radon concentrations.

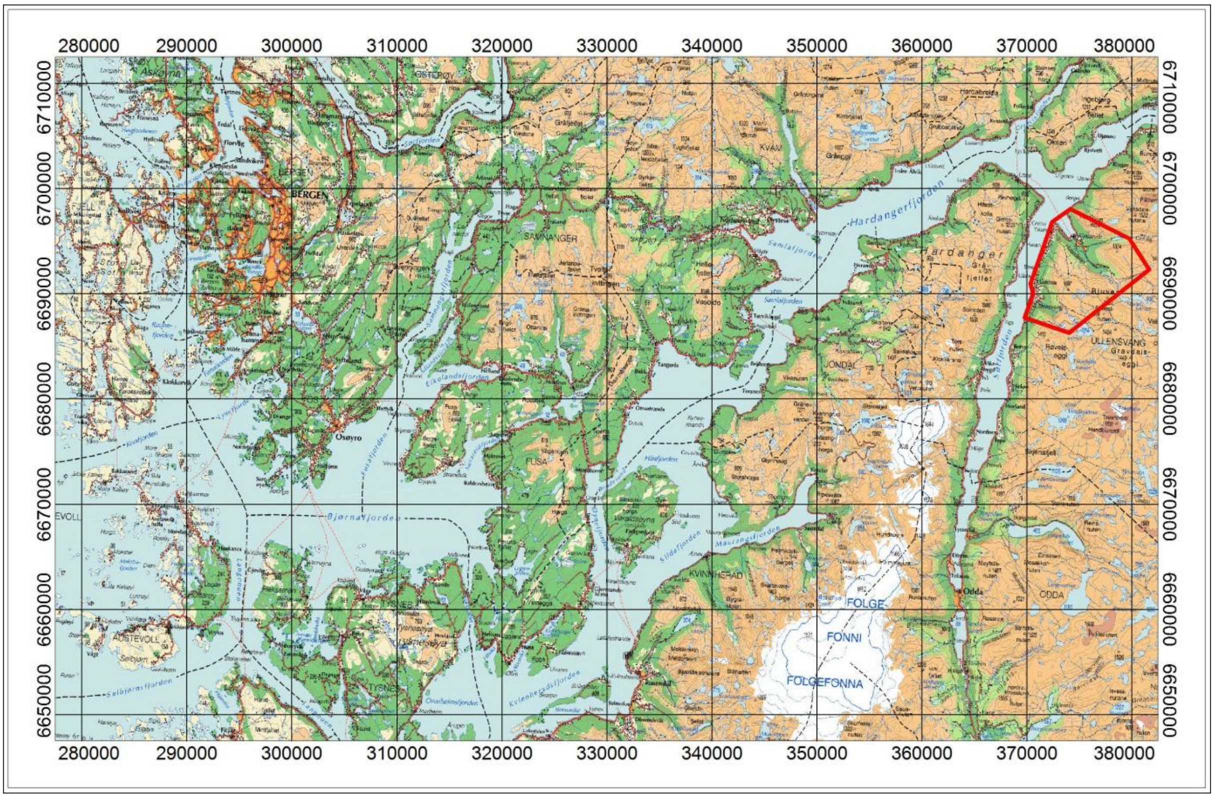

Figure 1: Kinsarvik survey area in Ullensvang municipality, Hordaland County.

The objective of the airborne geophysical survey was to obtain a dense high-resolution aero-magnetic and radiometric data set over the survey area to improve the understanding of the geology in the Kinsarvik area. The data can be used to map bedrock geology, contacts and structural features within the area, the potential of fracture zones, their geological settings and identify other areas of interest related to the radon issues in the area.

The survey incorporated the use of a high-sensitivity Cesium magnetometer, gamma-ray spectrometer and radar altimeter. A GPS navigation computer system with flight path indicators ensured accurate positioning of the geophysical data with respect to the World Geodetic System 1984 geodetic datum (WGS-84).

2. SURVEY SPECIFICATIONS

2.1 Airborne Survey Parameters

NGU used a helicopter survey system designed to obtain high detailed airborne magnetic data. The magnetic sensor was supplemented by one 1024 channel gamma-ray spectrometer with 16 liters downward and 4 liters upward crystal volume, which was used to map ground concentrations of Uranium, Thorium and Potassium.

The survey started July 17th, paused due to scheduled helicopter maintenance. The survey was later completed on August 5th, 2015. A Eurocopter AS350-B2 from helicopter company HeliScan AS was used during the survey (Figure 2). The survey lines were spaced 200 m apart, and oriented at a 20° azimuth in UTM zone 32V. Instrument operation was performed by Heliscan AS employees.

The magnetic sensor was housed in a single 1.8 meters long bird, which was supposed to fly at a constant altitude above the topographic surface. The Radiation Solutions RSX-5 gamma-ray spectrometer was installed under the belly of the helicopter, registering natural gamma ray radiation simultaneously with the acquisition of magnetic data.

Figure 2: Pilots with mag-bird in front of the helicopter used in survey.
(Photo by Mari Nymoen, Telen Newspaper, Notodden)

Rugged terrain and abrupt changes in topography affected the pilot's ability to 'drape' the terrain; therefore there are positive and negative variations in helicopter altitude with respect to the standard, which is defined as 60 m (200 ft), plus a height of obstacles (trees, power lines). The average altitude for the magnetometer in this survey was 62 m, and 90 m for the spectrometer.

The ground speed of the aircraft varied from 0 to 100 km/h depending on topography, wind direction and its magnitude. On average the ground speed during the whole survey was calculated to 50 km/h. Magnetic data was recorded at 0.2 second intervals resulting in 2.8 meters average point spacing, and spectrometry data was recorded every 1 second giving an average point spacing of 14 meters.

For the July 17th flights, the base magnetometer to monitor diurnal variations in the magnetic field was located near Voss Airport, UTM 32V 6725300 N, 363300 E. On August 5th the base station was placed at Kinsarvik, UTM 32V 6693700 N, 375500 E.

The GEM GSM-19 magnetic base-station data were recorded once every 3 seconds. The CPU clock of the magnetometer was synchronized through the built-in GPS receiver. Navigation system uses GPS/GLONASS satellite tracking systems to provide real-time WGS-84 coordinate locations for every second.

The accuracy achieved with no differential corrections is reported to be less than ± 5 m in the horizontal directions. The GPS receiver antenna was mounted externally to the cabin roof of the helicopter.

For quality control, the magnetic, radiometric, altitude and navigation data were monitored on two separate windows in the operator's display during flight while they were recorded in ASCII data streams to the acquisition PC hard disk drive.

2.2 Airborne survey instrumentation

Table 1: Instrument Specifications

Instrument	Producer / Model	Accuracy / Sensitivity	Sampling freq interval
Magnetometer	Scintrex Cs-3	2.5 nT / 0.002 nT	5 Hz
Base magnetometer	GEM GSM-19	0.1 nT	3 s
Gamma spectrometer	Radiation Solutions RSX-5	1024 ch's, 16 liters down, 4 liters up	1 Hz
Radar altimeter	Bendix/King KRA 405B	± 3 % 0 – 500 ft ± 5 % 500-2500 ft	1 Hz
Pressure/temperature	Honeywell PPT	± 0,03 % FS	1 Hz
Navigation	Topcon GPS-receiver	± 5 meter	1 Hz
Acquisition system	NGU custom software		

The magnetic and radiometric, altitude and navigation data were monitored on the operator's displays during flight while they were recorded to the PC hard disk drive. Spectrometry data were also recorded to internal hard drive of the spectrometer. The raw data files were backed up onto USB flash drive in the field.

2.3 Airborne Survey Logistics Summary

Traverse (survey) line spacing:	200 meters
Traverse line direction:	20° NNE-SSW
Nominal aircraft ground speed:	50 km/h
Average sensor terrain clearance Mag:	62 meters
Average sensor terrain clearance Rad:	90 meters

3. DATA PROCESSING AND PRESENTATION

All data were processed by Frode Ofstad at NGU. The ASCII raw data files were then loaded into separate Oasis Montaj databases and processed according to the descriptions in Appendix A1 and A2.

3.1 Magnetic total field data

At the first stage the magnetic data were visually inspected and spikes were removed manually. A two-fiducial lag filter and a non-linear filter were applied to eliminate short-period spikes. Then the data from basemag station were imported into the magnetic database. Diurnal variation channel was also inspected for spikes and spikes were removed manually. Typically, several corrections have to be applied to magnetic data before gridding, as described next.

Diurnal corrections

The temporal fluctuations in the magnetic field of the earth affect the total magnetic field readings recorded during the airborne survey. This is commonly referred to as the magnetic diurnal variation. These fluctuations can be effectively removed from the airborne magnetic dataset by using a stationary reference magnetometer that records the magnetic field of the earth simultaneously with the airborne sensor. Magnetic diurnals were within the standard NGU specifications during the entire survey (Rønning 2013).

Diurnal variations were measured with a GEM GSM-19 base magnetometer. The base station computer clock was continuously synchronized with GPS time. The recorded data are merged with the airborne data and the diurnal correction is applied according to equation (1).

$$\mathbf{B}_{Tc} = \mathbf{B}_T + \left(\overline{B}_B - \mathbf{B}_B\right), \tag{1}$$

where:

$\mathbf{B}_{Tc}$ = Corrected airborne total field readings

$\mathbf{B}_T$ = Airborne total field readings

$\overline{B}_B$ = Average datum base level

$\mathbf{B}_B$ = Base station readings

The average datum base level ($\overline{B}_B$) was set to 51000 nT for flights 1 and 2, when the base was located in Voss, and 50820 nT for flights 3 and 4, with the base in Kinsarvik. Using these values will bring all magnetic data to a common level. After basemag levelling, we added 176 nT to the final microlevelled data to ensure even distribution around zero before calculation of the magnetic derivatives.

Corrections for lag and heading

Neither a lag nor cloverleaf tests were performed before the survey. According to previous reports the lag between logged magnetic data and the corresponding navigational data was 1-2 fids. Translated to a distance it would be about 5 m – the value comparable with the precision of GPS.

Magnetic data processing, gridding and presentation

The total field magnetic anomaly data ($\mathbf{B}_{TA}$) were calculated from the diurnal corrected data ($\mathbf{B}_{Tc}$) after subtracting the IGRF for the surveyed area calculated for the data period (eq.2)

$$\mathbf{B}_{TA} = \mathbf{B}_{Tc} - IGRF \quad (2)$$

The total field anomaly data were split into lines and then gridded using a minimum curvature method with a grid cell size of 50 meters. This cell size is equal to one quarter of the 200m average line spacing. In order to remove small line-to-line levelling errors that were detected on the gridded magnetic anomaly data, the Geosoft Microlevelling technique was applied on the flight line based magnetic database. Then, the microlevelled channel was gridded using again a minimum curvature method with 50 m grid cell size.

The processing steps of magnetic data presented so far were performed on point basis. The following steps are performed on grid basis. The Horizontal and Vertical Gradient along with the Tilt Derivative of the total magnetic anomaly were calculated from the microlevelled total magnetic anomaly grid. The magnitude of the horizontal gradient was calculated according to equation (3)

$$HG = \sqrt{\left(\frac{\partial B_{TA}}{\partial x}\right)^2 + \left(\frac{\partial B_{TA}}{\partial y}\right)^2} \quad (3)$$

where $\mathbf{B}_{TA}$ is the microlevelled field. The vertical gradient (VG) was calculated by applying a vertical derivative convolution filter to the microlevelled $\mathbf{B}_{TA}$ field. The Tilt Derivative (TD) was calculated according to the equation (4)

$$\text{TD} = \text{atan}(\text{VG}/\text{HG}) \quad (4)$$

Magnetic data gridding and presentation

After the micro-levelling technique was applied to the magnetic data to remove small line-to-line levelling errors, a 5x5 grid cells convolution filter was passed over the final grid to smooth the grid image.

The Vertical Gradient, Horizontal Gradient and the Tilt Derivative of the total magnetic field were calculated from the resulting total magnetic field map. These signals transform the shape of the magnetic anomaly from any magnetic inclination to positive body-centered anomaly and it’s widely utilized for mapping of structures. A list of the produced maps is shown in Table 3.

3.2 Radiometric data

Airborne gamma-ray spectrometry measures the abundance of Potassium (K), Thorium (eTh), and Uranium (eU) in rocks and weathered materials by detecting gamma-rays emitted due to the natural radioelement decay of these elements. The data analysis method is based on the IAEA recommended method for U, Th and K (International Atomic Energy Agency, IAEA 1991, IAEA 2003). A short description of the individual processing steps of that methodology as adopted by NGU is given bellow.

Energy windows

The Gamma-ray spectra were initially reduced into standard energy windows corresponding to the individual radio-nuclides K, U and Th. Figure 3 shows an example of a Gamma-ray spectrum and the corresponding energy windows.

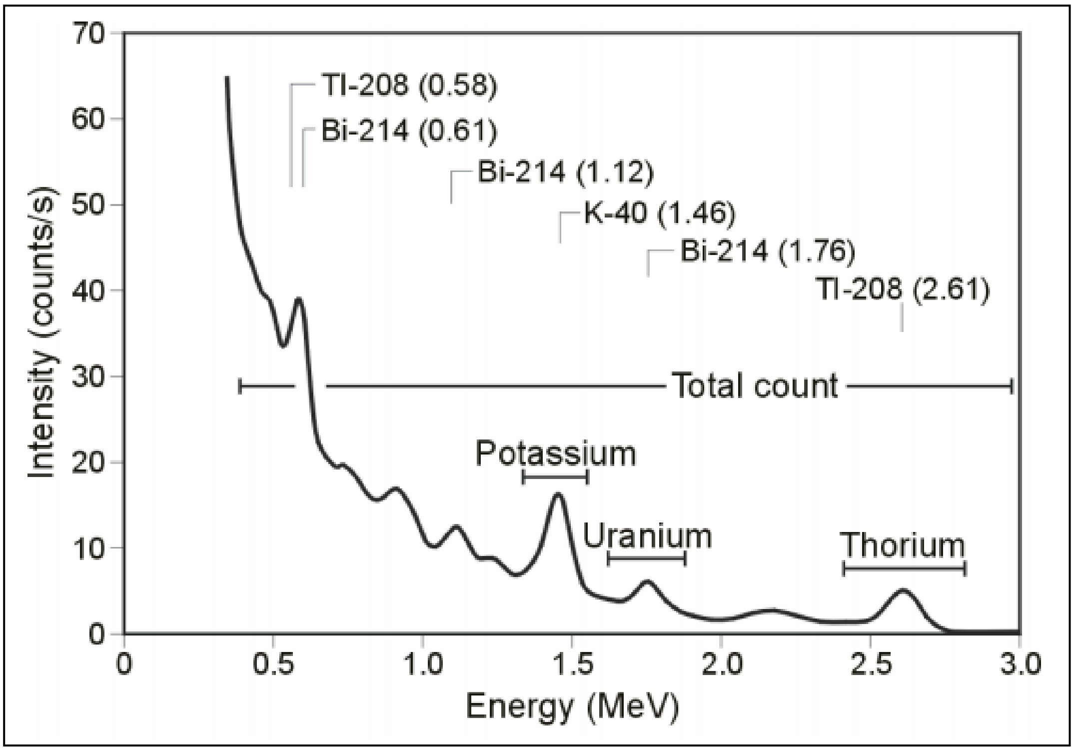

Figure 3: Gamma-ray spectrum with K, Th, U and Total count windows.

The RSX-5 is a 1024 channel system with a four downward looking and one upward looking detector, with a total crystal volume of 16 liters downward and 4 liters upward for cosmic corrections. The Gamma-ray spectrum of 0 to above 3000 keV is divided into 1024 channels, where each channel has a 3.0 keV range. Table 2 shows the channels and energies that were used for the reduction of the spectrum.

Table 2: Channel windows for the 1024 RSX-5 systems used in this survey

Spectrum	Cosmic	Total count	K	U	Th
Down	1022	134-934	454-521	551-617	801-934
Up	1022			551-617	
Energy, keV	>3000	407-2807	1367-1568	1658-1856	2408-2807
Peak, keV			1460	1765	2614
Peak channel			486	586	872

Live Time correction

The data were first corrected for live time. “Live time” is an expression of the relative period of time the instrument was able to register new pulses per sample interval. On the other hand “dead time” is an expression of the relative period of time the system was unable to register new pulses per sample interval. The relation between “dead” and “live time” is given by the equation (5)

$$\text{“Live time”} = \text{“Real time”} - \text{“Dead time”} \tag{5}$$

where the “real time” or “acquisition time” is the elapsed time over which the spectrum is accumulated.

The live time correction is applied to the total count, Potassium, Uranium, Thorium, upward Uranium and cosmic channels. The formula used to apply the correction is as follows:

$$C_{LT} = C_{RAW} \cdot \frac{1000000}{Live\ Time} \tag{6}$$

where C_{LT} is the live time corrected channel in counts per second, C_{RAW} is the raw channel data in counts per second and Live Time is in microseconds.

Cosmic and aircraft correction

Background radiation resulting from cosmic rays and aircraft contamination was removed from the Total Count, Potassium, Uranium, Thorium and Upward Uranium channels using the following formula:

$$C_{CA} = C_{LT} - (a_c + b_c \cdot C_{Cos}) \tag{7}$$

where C_{CA} is the cosmic and aircraft corrected channel, C_{LT} is the live time corrected channel a_c is the aircraft background for this channel, b_c is the cosmic stripping coefficient for this channel and C_{Cos} is the low pass filtered cosmic channel.

Radon correction

The upward detector method, as discussed in IAEA (1991), was applied to remove the effects of the atmospheric radon in the air below and around the helicopter. Usages of over-water measurements where there is no contribution from the ground, enabled the calculation of the coefficients a_c and b_c of the linear equations that relate the cosmic corrected counts per second of Uranium channel with total count, Potassium, Thorium and Uranium upward channels over water. Data over-land was used in conjunction with data over-water to calculate the a_1 and a_2 coefficients used in equation (8) for the determination of the Radon component in the downward uranium window:

$$Radon_U = \frac{Uup_{CA} - a_1 \cdot U_{CA} - a_2 \cdot Th_{CA} + a_2 \cdot b_{Th} - b_U}{a_U - a_1 - a_2 \cdot a_{Th}} \tag{8}$$

where $Radon_U$ is the radon component in the downward uranium window, Uup_{CA} is the filtered upward uranium, U_{CA} is the filtered Uranium, Th_{CA} is the filtered Thorium, a_1, a_2, a_U and a_{Th} are proportional factors and b_U an b_{Th} are constants determined experimentally.

The effects of Radon in the downward Uranium are removed by simply subtracting $Radon_U$ from U_{CA}. The effects of radon in the other channels are removed using the following formula:

$$C_{RC} = C_{CA} - (a_C \cdot Radon_U + b_C) \tag{9}$$

where C_{RC} is the Radon corrected channel, C_{CA} is the cosmic and aircraft corrected channel, $Radon_U$ is the Radon component in the downward uranium window, a_c is the proportionality factor and b_c is the constant determined experimentally for this channel from over-water data.

Compton Stripping

Potassium-, Uranium- and Thorium- Radon corrected channels are subjected to spectral overlap correction. Compton scattered gamma rays in the radio-nuclides energy windows were corrected by window stripping using Compton stripping coefficients determined from measurements on calibrations pads at the Geological Survey of Norway in Trondheim (for values see Appendix A2).

The stripping corrections are given by the following formulas:

$$A_1 = 1 - (g \cdot \gamma) - (\mathrm{a} \cdot \alpha) + (\mathrm{a} \cdot g \cdot \beta) - (b \cdot \beta) + (b \cdot \alpha \cdot \gamma) \tag{10}$$

$$U_{ST} = \frac{Th_{RC} \cdot ((g \cdot \beta) - \alpha) + U_{RC} \cdot (1 - b \cdot \beta) + K_{RC} \cdot ((b \cdot \alpha) - g)}{A_1} \tag{11}$$

$$Th_{ST} = \frac{Th_{RC} \cdot (1 - (g \cdot \gamma)) + U_{RC} \cdot (b \cdot \gamma - \mathrm{a}) + K_{RC} \cdot ((\mathrm{a} \cdot g) - b)}{A_1} \tag{12}$$

$$K_{ST} = \frac{Th_{RC} \cdot ((\alpha \cdot \gamma) - \beta) + U_{RC} \cdot ((\mathrm{a} \cdot \beta) - \gamma) + K_{RC} \cdot (1 - (\mathrm{a} \cdot \alpha))}{A_1} \tag{13}$$

where U_{RC}, Th_{RC}, K_{RC} are the radon corrected Uranium, Thorium and Potassium, and a, b, g, α, β, γ are Compton stripping coefficients.

Reduction to Standard Temperature and Pressure

The radar altimeter data were converted to effective height (H_{STP}) using the acquired temperature and pressure data, according to the expression:

$$H_{STP} = H \cdot \frac{273.15}{T + 273.15} \cdot \frac{P}{1013.25} \tag{14}$$

where H is the smoothed observed radar altitude in meters, T is the measured air temperature in degrees Celsius and P is the measured barometric pressure in millibars.

Height correction
Variations caused by changes in the aircraft altitude relative to the ground corrected to a nominal height of 60 m. Data recorded at the height above 150 m were considered as non-reliable and removed from processing. Total Count, Uranium, Thorium and Potassium stripped channels were subjected to height correction according to the equation:

$$C_{60m} = C_{ST} \cdot e^{C_{ht} \cdot (60 - H_{STP})} \qquad (15)$$

where C_{ST} is the stripped corrected channel, C_{ht} is the height attenuation factor for that channel and H_{STP} is the effective height.

Conversion to ground concentrations

Corrected count rates were converted to effective ground element concentrations using calibration values derived from calibration pads at the Geological Survey of Norway (see Appendix A2). The corrected data provide an estimate of the apparent surface concentrations of Potassium, Uranium and Thorium (K, eU and eTh).

Potassium concentration is expressed as a percentage, equivalent Uranium and Thorium as parts per million (ppm). Uranium and Thorium are described as equivalent" since their presence is inferred from gamma-ray radiation from daughter elements (^{214}Bi for Uranium, ^{208}Tl for Thorium). The concentration of the elements is calculated according to the following expressions

$$C_{CONC} = C_{60m} / C_{SENS\_60m} \qquad (16)$$

where C_{60m} is the height corrected channel, C_{SENS_60m} is experimentally determined sensitivity reduced to the nominal height (60m).

Spectrometry data gridding and presentation

Gamma-rays from Potassium, Thorium and Uranium emanate from the uppermost 30 to 40 centimeters of soil and rock in the crust (Minty, 1997). Variations in the concentrations of these radio-elements largely related to changes in the mineralogy and geochemistry of the Earth's surface.

The calculated ground concentrations of the three main natural radio-elements Potassium, Thorium and Uranium, along with total gamma-ray flux (Total Count) were microlevelled to remove small line-to-line levelling errors, a 5x5 cell convolution filter was applied to smooth the image, and then data were gridded using a minimum curvature method with a grid cell size of 50 meters.

A list of the maps is shown in Table 3. A list of the parameters used in the processing schemes is given in Appendix A2. For further reading regarding standard processing of airborne radiometric data, we recommend the publication from Minty et al. (1997).

4. PRODUCTS

Processed digital data from the survey are presented as:

1. Geosoft XYZ files: Kinsarvik_Mag.xyz, Kinsarvik_Rad.xyz.

2. Coloured maps (jpg) at the scale 1:50.000 available from NGU on request.

3. Geo-referenced tiff files (Geo-tiff).

Table 3: Maps in scale 1:50.000 available from NGU on request.

Map #	Name	Figure No
2015.056-01	Total Magnetic field Anomaly	4
2015.056-02	Magnetic Vertical Derivative	5
2015.056-03	Magnetic Horizontal Derivative	6
2015.056-04	Magnetic Tilt Derivative	7
2015.056-05	Uranium Ground Concentration	8
2015.056-06	Thorium Ground Concentration	9
2015.056-07	Potassium Ground Concentration	10
2015.056-08	Radiation Total Counts	11
2015.056-09	Ternary Image of Radiation Concentrations	12

Downscaled images of the maps are shown in figures 4 to 12.

5. REFERENCES

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Appendix A1: Description of magnetic data processing

Meaning of parameters is described in the referenced literature.

Processing flow:

- Quality control.
- Visual inspection of airborne data and manual spike removal
- Import basemag data to Geosoft database
- Inspection of basemag data and removal of spikes
- Correction of data for diurnal variation
- Splitting flight data by lines
- Gridding
- Micro-levelling
- 5x5 Convolution filter

Appendix A2: Description of radiometry data processing

Underlined processing stages are applied to the K, U, Th and TC windows.
Meaning of parameters is described in the referenced literature.

Processing flow:

- Quality control
- Airborne and cosmic correction (IAEA, 2003)

Used parameters: (From high altitude calibration flights at Frosta, May 2013)

Aircraft background counts:

K window	5.36
U window	1.43
Th window	0
Uup window	0.7
Total counts	42.73

Cosmic background counts (normalized to unit counts in the cosmic window):

K window	0.0570
U window	0.0467
Th window	0.0643
Uup window	0.0448
Total counts	1.0317

- Radon correction using upward detector method (IAEA, 2003)

Used parameters (determined from survey data over water and land):

a_u:	0.20268	b_u:	0.5444
a_{Th}:	0.59847	b_{Th}:	0
a_K:	2.61152	b_K:	0
a_{Tc}:	30.7332	b_{Tc}:	0
a_1:	0.034891	a_2:	0.017945

- Stripping correction (IAEA, 2003)
  Used parameters (from measurements on calibrations pads at the NGU in May 2013):

a	0.046856
b	0
g	0
alpha	0.30346
beta	0.47993
gamma	0.82316

- <u>Height correction to a height of 60 m</u>
  Used parameters (from high altitude calibration flights at Frosta in Jan 2014):
  Attenuation factors in 1/m:

K:	-0.009523
U:	-0.006687
Th:	-0.007394
TC:	-0.00773

- Converting counts at 60 m heights to element concentration on the ground
  Used parameters (determined from measurements on calibrations pads at the NGU in May 2013):
  Sensitivity (elements concentrations per count)::

K:	0.007458	%/counts
U:	0.08773	ppm/counts
Th:	0.15666	ppm/counts

<u>Microlevelling using Geosoft menu and smoothening by a convolution filtering</u>
Used parameters for microlevelling:

De-corrugation cutoff wavelength:	800 m
Cell size for gridding:	50 m
Naudy (1968) Filter length:	800 m

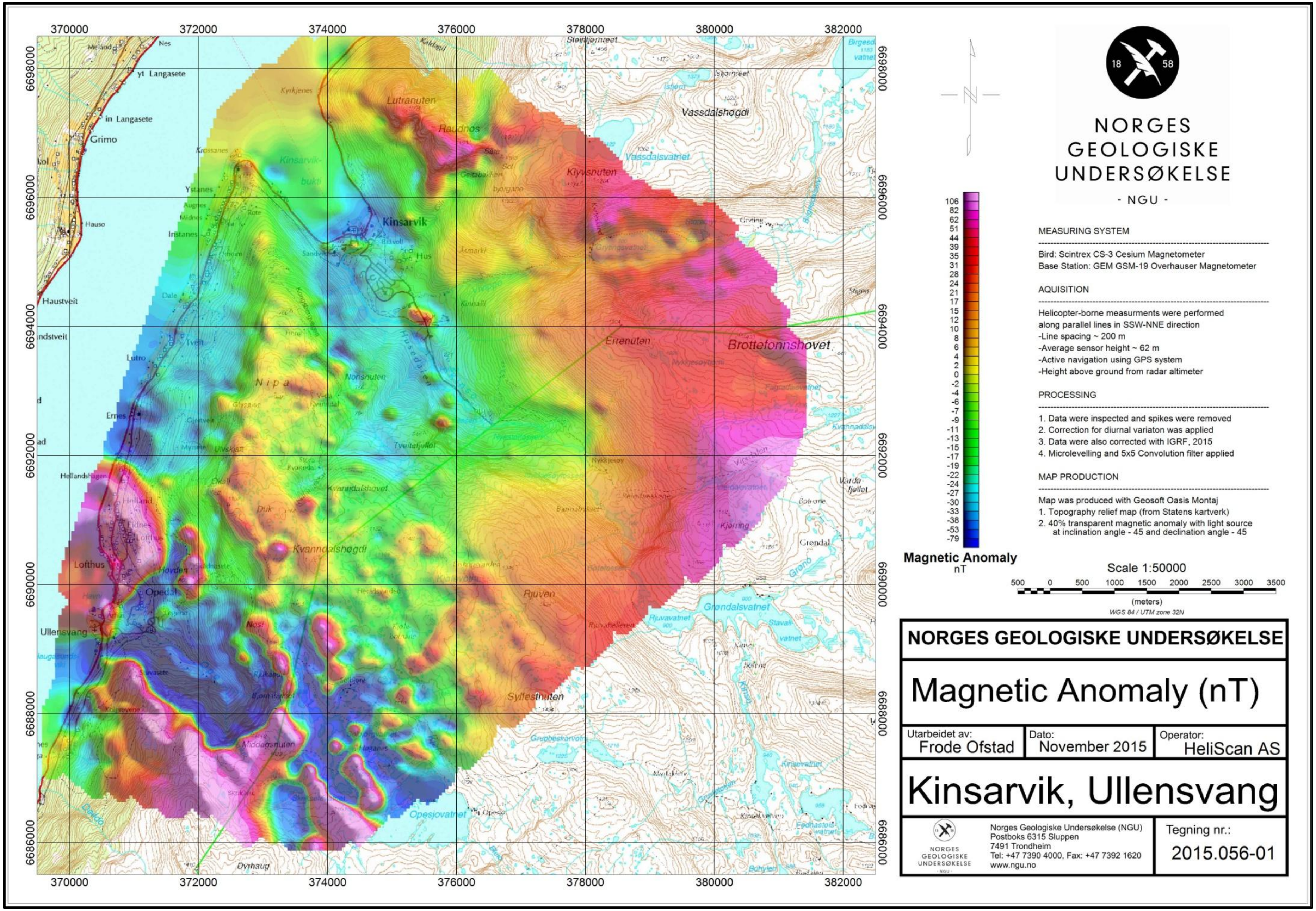

Figure 4: Magnetic Total Field Anomaly

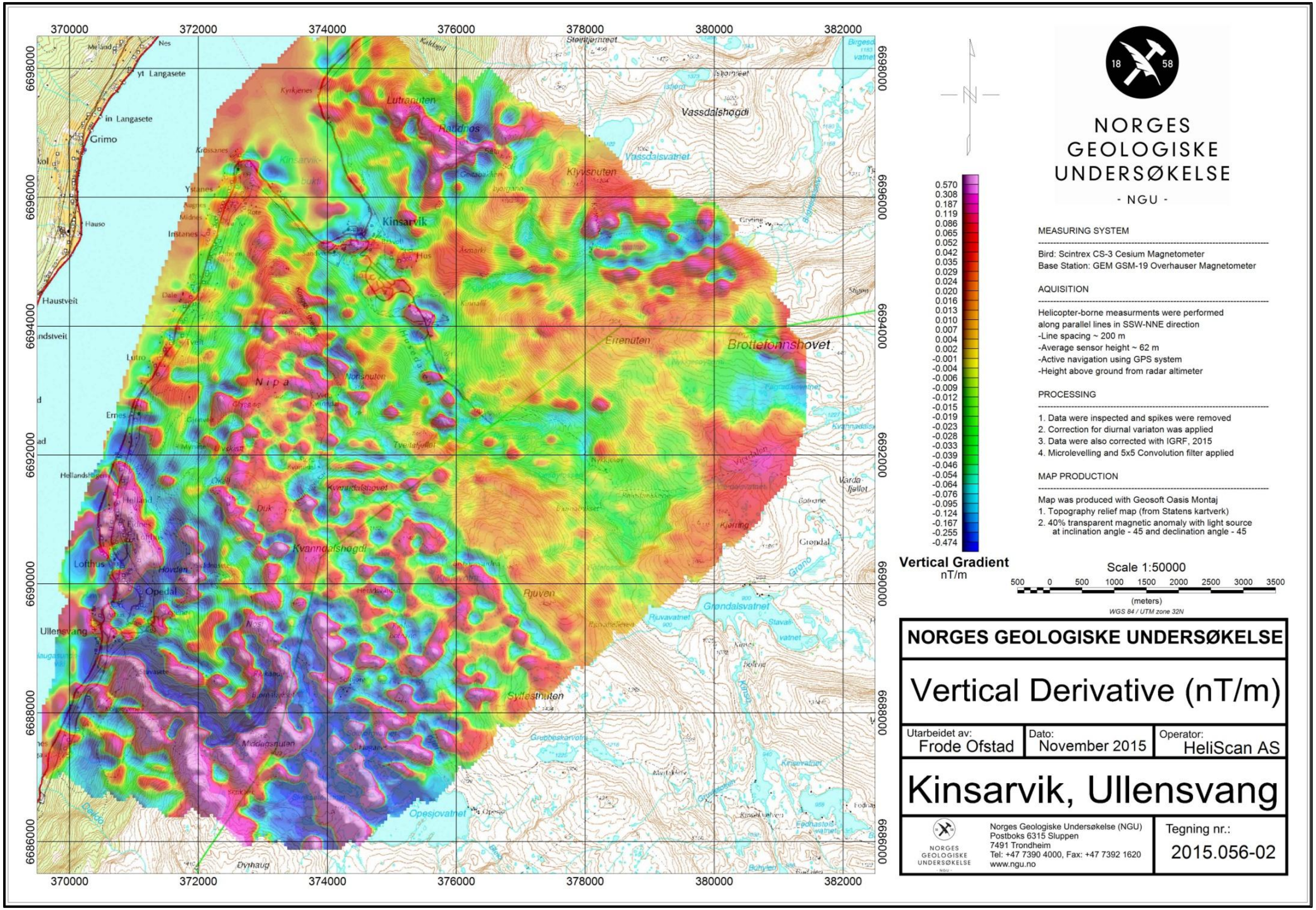

Figure 5: Magnetic Vertical Derivative

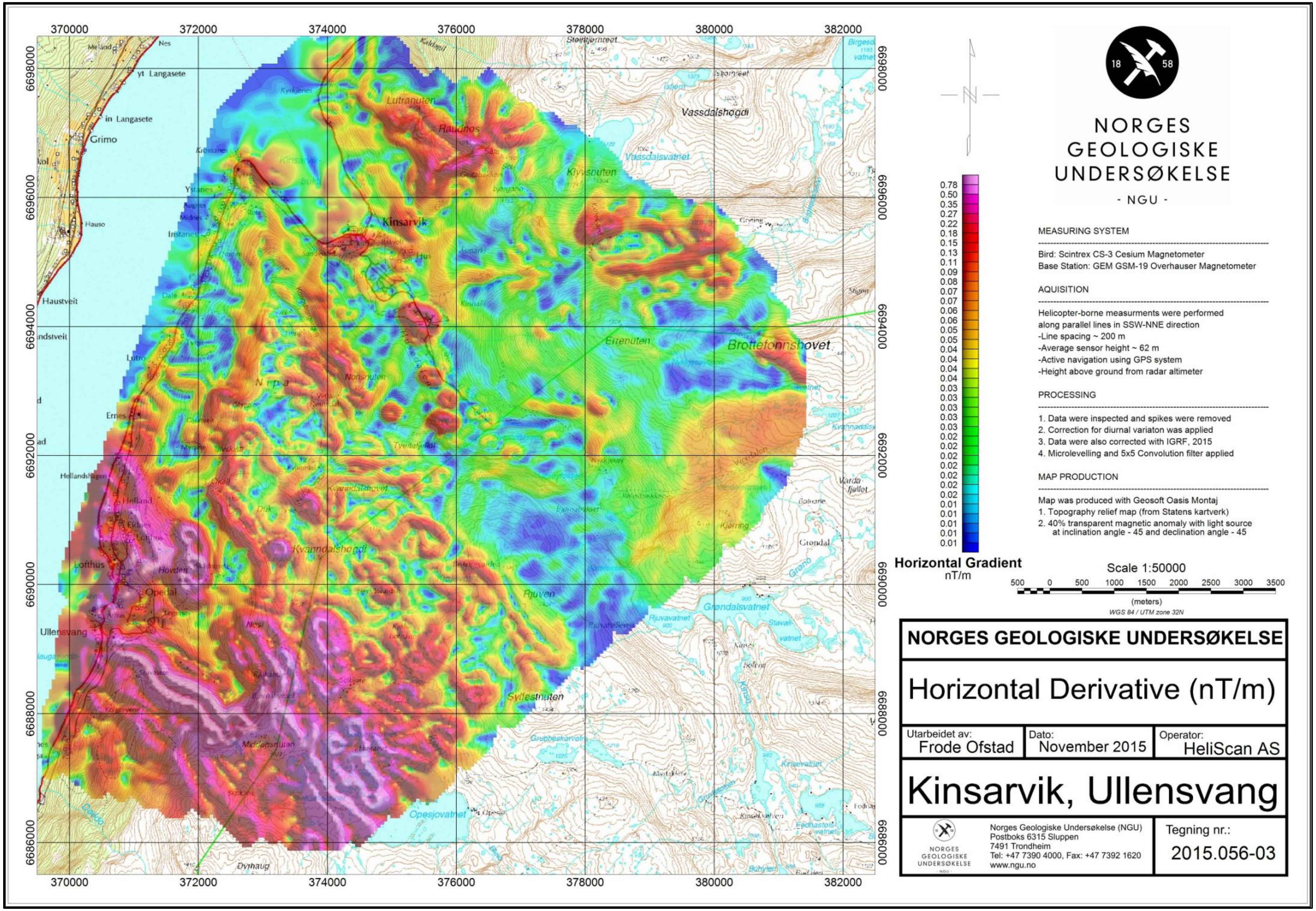

Figure 6: Magnetic Horizontal Derivative

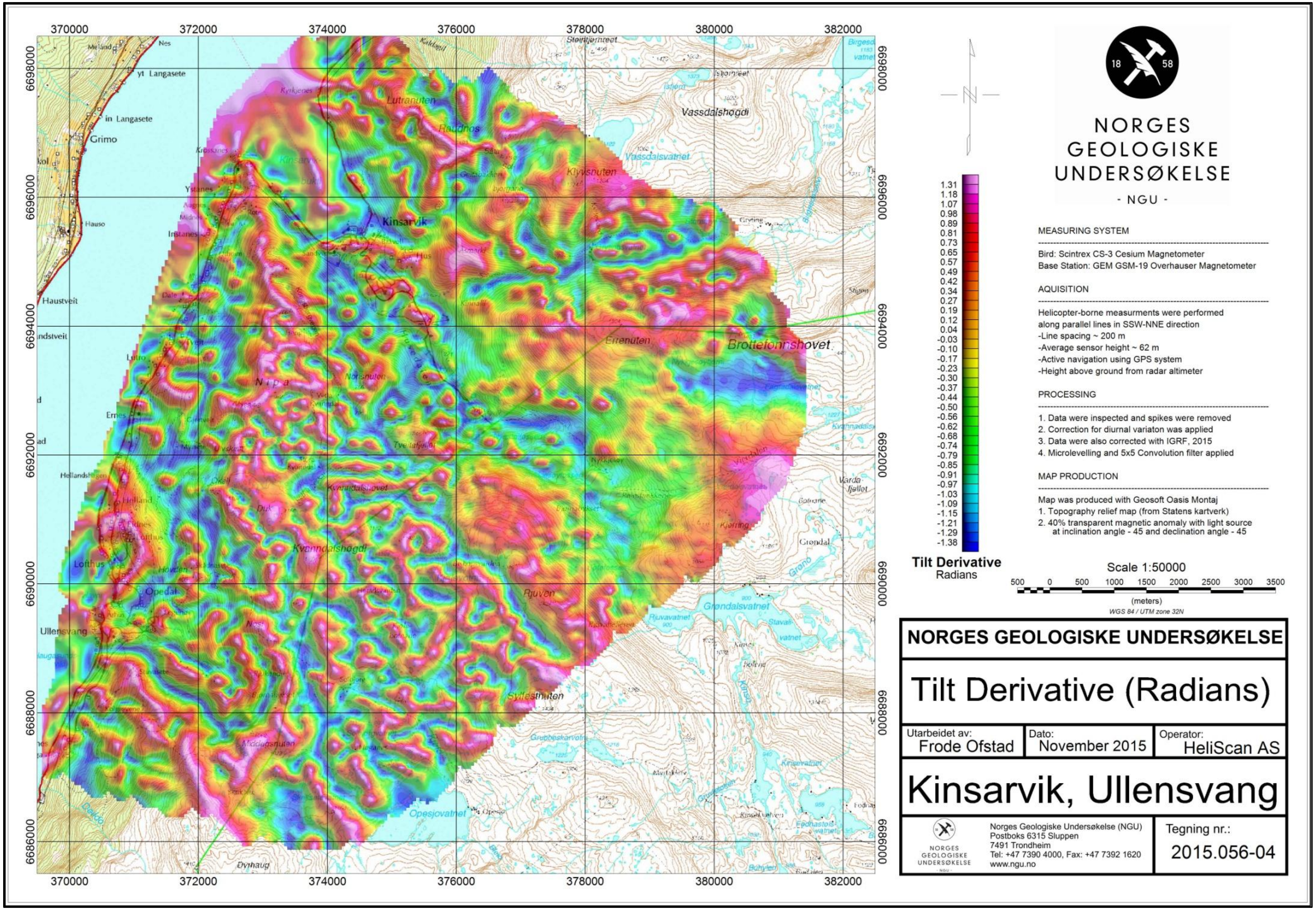

Figure 7: Magnetic Tilt Derivative

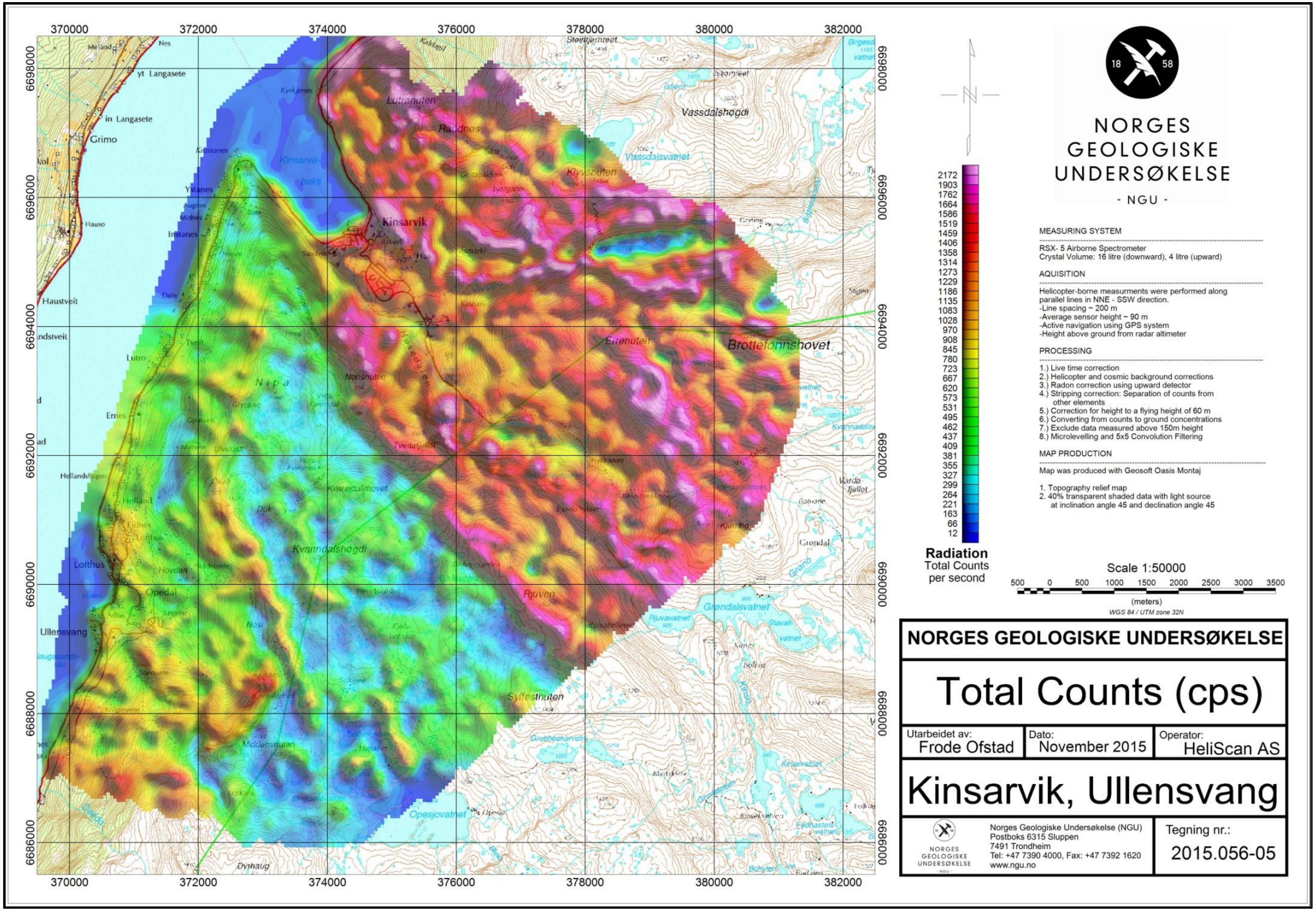

Figure 8: Radiation Total Counts

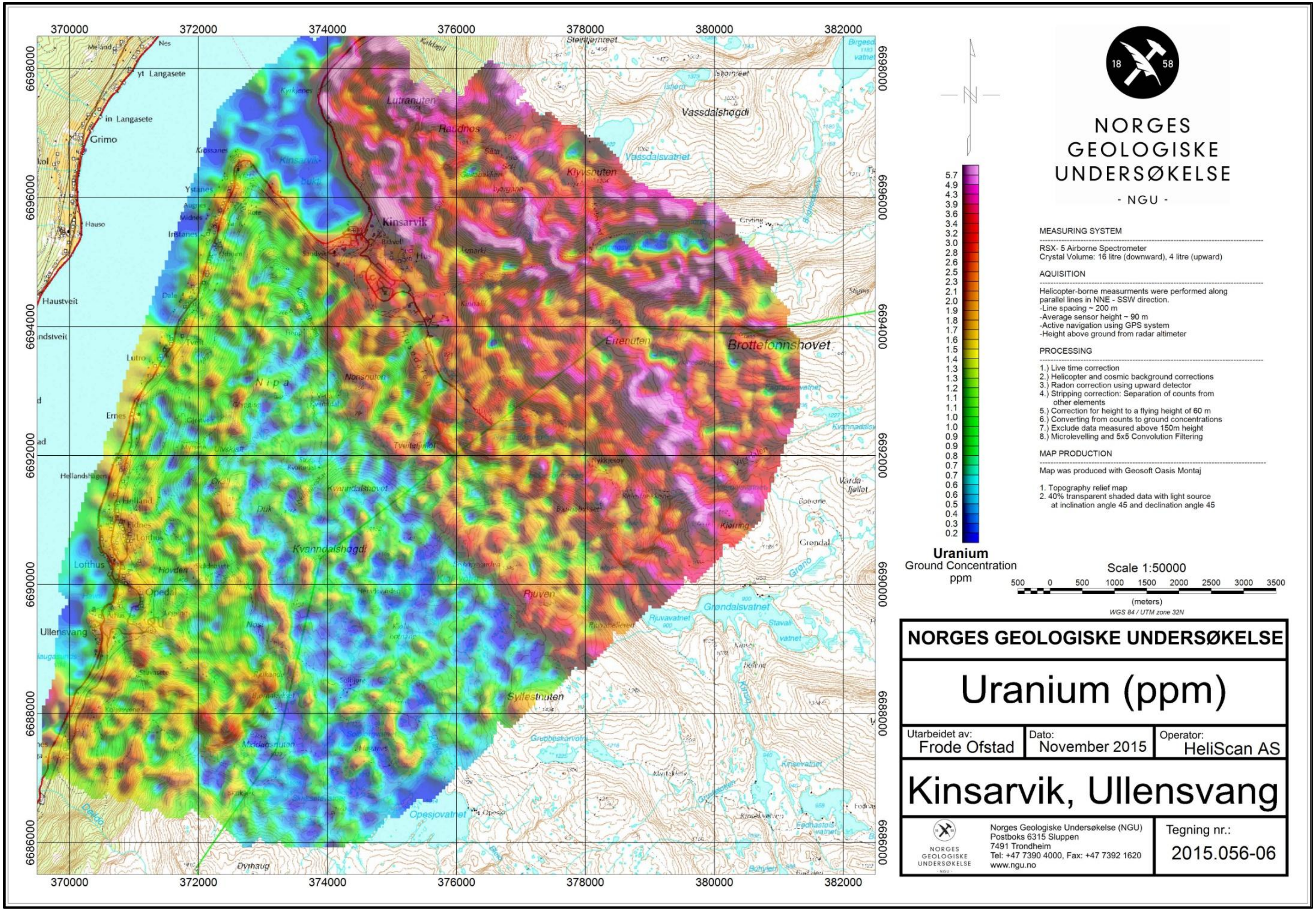

Figure 9: Uranium Ground Concentration

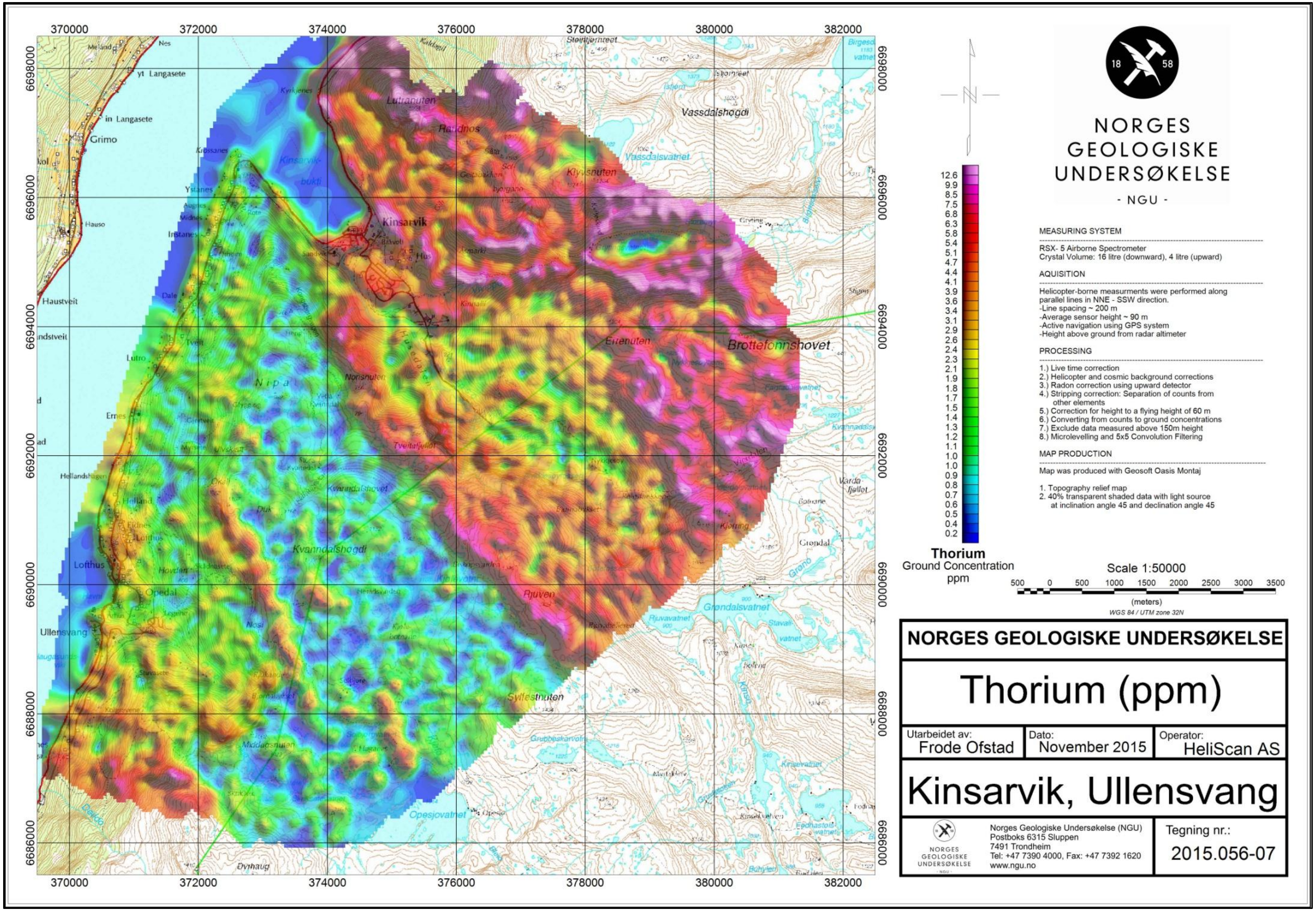

Figure 10: Thorium Ground Concentration

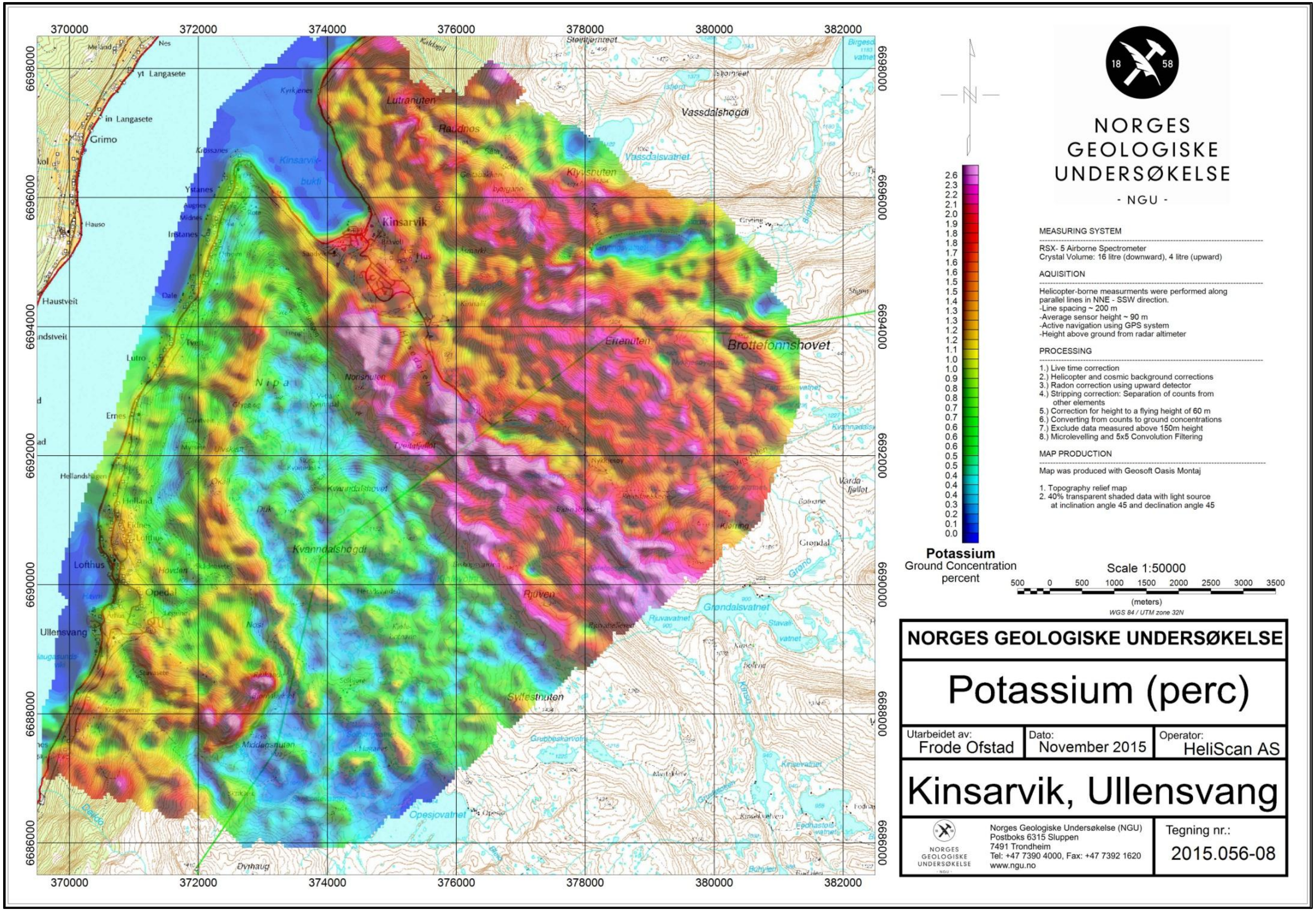

Figure 11: Potassium Ground Concentration

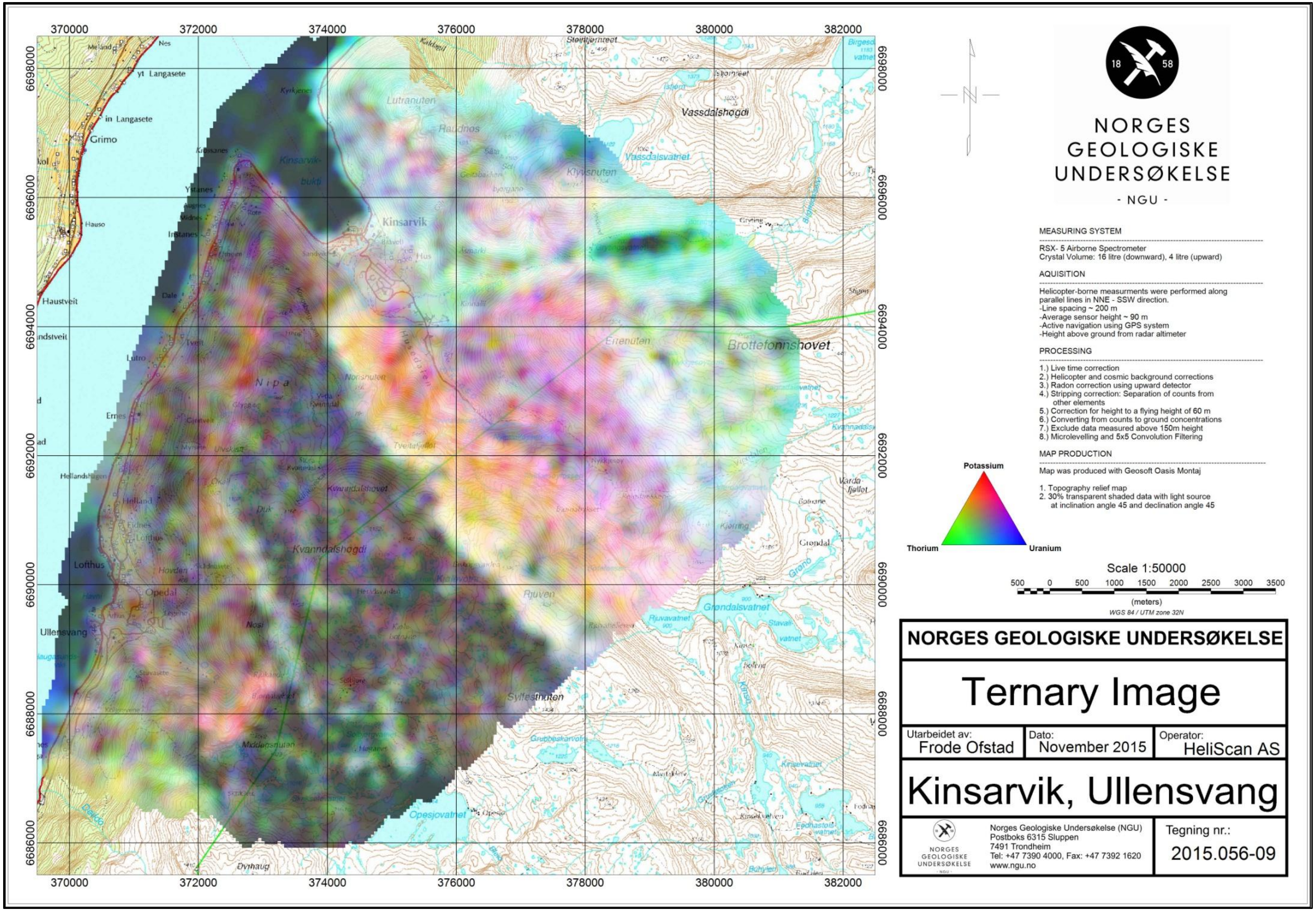

Figure 12: Ternary Image of Radiation Concentrations