NGU Report 2001.031

Data Acquisition and Processing - Helicopter Geophysical Surveys, Östersund, Sweden

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REPORT

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Data Acquisition and Processing - Helicopter Geophysical Surveys, Östersund, Sweden

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Summary:

In December, 2000 and March, 2001, helicopter geophysical surveys were flown over three areas in the vicinity of Östersund, central Sweden. The purpose of the surveys was to provide geophysical information for mineral exploration. The data were collected and processed by Geological Survey of Norway (NGU). A combined total of about 2830 line-km of electromagnetic (EM), very low frequency EM (VLF), radiometric, and magnetic data were acquired using a nominal 200-m line spacing. The nominal flying height was 60 m above ground level (AGL), and lines were flown in alternating directions at headings of 45° and 225°. Noise levels were within survey specifications. All initial processing was carried out on a flight-by-flight basis. Magnetic data, consisting of total field measurements collected by a cesium vapor magnetometer, were corrected by removing diurnal variations as recorded at a magnetic base station at a heliport in Östersund. Radiometric data were reduced using three-channel processing according to procedures recommended by the International Atomic Energy Association. VLF data were reduced by removing a first-order trend along each line. EM data were leveled using data from frequent high altitude excursions above 300-m AGL. All final processed data, apart from VLF, were gridded using 50-m square cells. VLF grids have 100-m cells. Geophysical maps were produced at a scale of 1:50 000 for each of the three areas. This report covers aspects of data acquisition and processing.

Keywords: Geofysikk (Geophysics)	Radiometri (Radiometrics)	Magnetometri (Magnetometry)
Elektromagnetisk måling (Electromagnetic measurements)	Databehandling (Data processing)	Fagrapport (Technical report)

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1 INTRODUCTION

In December, 2000 and March, 2001, helicopter geophysical surveys were flown over three areas south of Östersund, Sweden. The three surveyed areas lie between longitudes 14°20′ E and 15°15′ E, and latitudes 62°10′ N and 63°05′ N (Fig. 1). The three areas denoted A, B, and C in this report represent surveys in the vicinity of Enstern, Lockne, and Hackås respectively (Fig. 1). The total area covered in the three surveys is 563 km^2, and the total distance flown was 2830 line-km. The distance flown and area covered in each survey area breaks down as follows: area A (Enstern)—865 line-km and 173 km^2, area B (Lockne)—495 line-km and 99 km^2, and area C (Hackås)—1470 line-km and 291 km^2. Electromagnetic (EM), radiometric, magnetic, and very low frequency electromagnetic (VLF) data were collected. The primary objective of the surveys was to provide geophysical information in order to enhance geological mapping.

2 SURVEY VARIABLES AND CONDITIONS

Strong wind can increase the noise level of airborne geophysical data. High winds were not frequent during the survey, but were encountered occasionally.

Magnetic data quality is excellent on all lines. Diurnal changes in the earth's magnetic field affect magnetic data. The base station magnetic field never indicated strong magnetic storm conditions during the surveys.

VLF data quality is generally good. VLF transmitters are controlled by naval defense authorities for communication with submarines, and their power output cannot be predicted or controlled during a survey.

Radiometric data can be negatively affected by atmospheric radon. However, in this survey radon contamination did not appear to be significant. The quality of the radiometric data is good. However, the resolution of the radiometric data has been decreased because of snow cover. Maps made from area A (Enstern) were constructed from data collected at two different times—in December 2000 and March 2001. The northern one-third of survey area A shows a visibly weaker radiometric response than the southern portion because the northern data were collected in March 2001 and the snow cover at this time was thicker than in December 2000.

Strong vertical temperature gradients can affect EM leveling because the temperature at the 300-m nulling altitude is different from the temperature when the EM sensors are only 30-m above ground level.

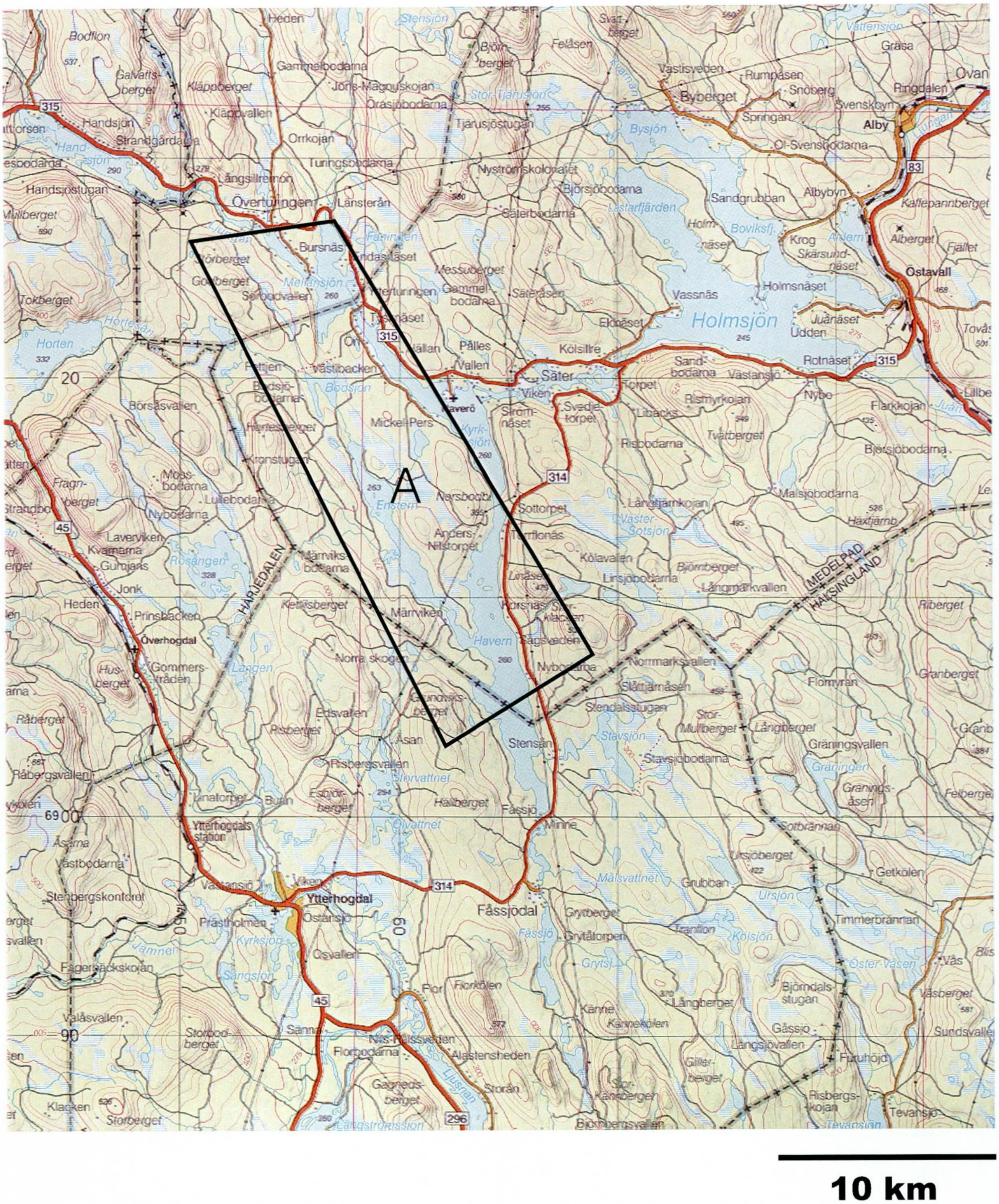

Figure 1. (A) Helicopter survey area 'A'--Enstern. The center of the area is roughly 90 km south of Östersund.

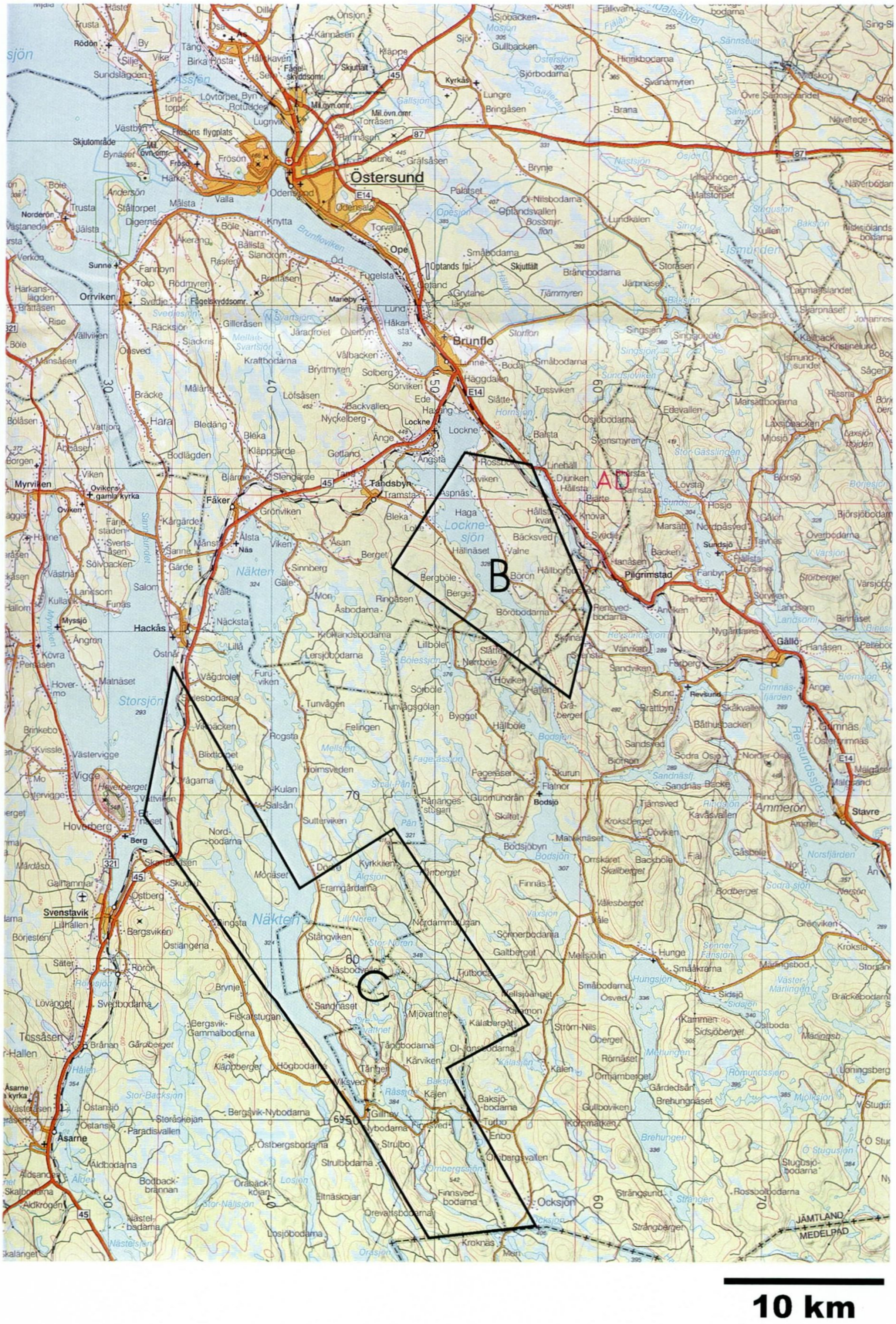

Figure 1. (B) Helicopter survey area 'B'--Lockne. (C) Helicopter survey area 'C'--Hackås.

The resolution of geophysical sensors decrease exponentially with flying height. To achieve the greatest possible resolution, the aircraft should be flown as low as is safely possible. The target flying height was 60 meters above ground level, and this height was achieved over level terrain. Flying heights were higher over power lines and densely inhabited areas. For safety reasons, i.e. because of poor natural light conditions in December, it was necessary to fly some lines in area A higher than 60 m, although still within project specifications.

3 DATA ACQUISITION

The survey aircraft was an Areospatiale Ecureuil SA 350 B-2. Flying speed was approximately 100 km per hour (28 meters per second). Flight lines over survey area were in directions 45°/225°. The radiometric sensors were mounted immediately beneath the helicopter. VLF sensors were suspended on a cable 10m beneath the helicopter. The 5-frequency EM system and the magnetometer were enclosed in a 6-m long 'bird' suspended by cable 30-m beneath the helicopter.

NGU personnel responsible for data acquisition were John Mogaard, Janusz Koziel, and Oddvar Blokkum.

3.1 Magnetic measurements

A Scintrex CS-2 cesium vapor magnetometer was used. The magnetometer resolution is 0.01 nT. Sampling rate was 10 measurements per second.

A Scintrex MP-3 proton precession magnetometer was located at a heliport in Östersund, and was used for base station measurements. The base station magnetometer was synchronized with the helicopter-borne magnetometer to ensure proper removal of diurnal magnetic changes from the helicopter magnetic measurements. The total magnetic field was digitally recorded during flights at a rate of 15 measurements per minute.

3.2 Radiometric measurements

The radiometric system, purchased from Exploranium, Ltd. of Canada, consists of four sodium iodide (NaI) crystals (model GPX-1024-256) having a total volume of 1024 cubic inches (16.78 liter). The NaI crystals are coupled to a 256 channel Exploranium GR820 gamma ray spectrometer. Registration rate is one per second. An upward looking crystal was used in this survey, and can if desired be used to correct for airborne radon contamination. The crystal package is mounted in a frame underneath the helicopter.

The spectrometer is an energy pulse height analyzer that sorts data into 256 channels according to energy magnitude. Every channel is 0.012 MeV wide. The full 256 channel spectrum was recorded. Windows constructed from selected groups of channels record the contributions of Potassium-40, Bismuth-214 (the daughter product of Uranium-238), and Thallium-208 (the daughter product of Thorium-232). These windows are labeled potassium, uranium, and thorium respectively. A fourth window—the total count window—measures gamma ray energy between 0.4 MeV and 3 MeV.

3.3 VLF-EM system

The VLF measurements were made with Totem-2A VLF receivers purchased from Hertz Industries, Ltd. of Canada. The three receivers are mounted orthogonally and measure fields in the direction of the flight line (in-line), normal to the flight direction (orthogonal), and vertical fields. The energy sources for VLF signals are powerful transmitters used by military organizations for communication with submarines. Their frequencies are in the range 15-30 kHz, depending on the individual transmitter. The VLF receivers are suspended 10 meters beneath the helicopter. Registration rate is five per second.

Good VLF targets are thin, shallow (a few tens of meters), near vertical conductors which are approximately on a line with one of the monitored VLF transmitters. For this survey, the primary VLF stations monitored were GBR (16 kHz, Rugby, England), used for in-line receiver measurements, and NAA (24 kHz, Cutler, Maine, USA), used for orthogonal receiver measurements. Other stations were used when either of these stations ceased transmission.

3.4 Electromagnetic system

The EM system used was the 5-frequency Hummingbird system made in Canada by Geotech, Ltd. The Hummingbird records data at a sampling rate of 40 measurements per second. It has two coil orientations—vertical coaxial (VCA) and horizontal coplanar (HCP). The VCA coils operate at 880 Hz and 7001 Hz. The HCP coils operate at 980 Hz, 6606 Hz, and 34133 Hz. The transmitter-receiver separation is 6 m for all frequencies. The manufacturer specified noise level for each frequency is 1-2 ppm. For the data in these surveys, this noise level appears accurate (Fig. 2).

3.5 Navigation, altimetry, and data logging

The navigation system used was an Ashtech G12 12 channel receiver with an RDS reference receiver connected to a laptop computer. GPS signals are corrected in real time using a correction signal in RDS format from Swedish Radio's P4 transmitter. Differential GPS is calculated using software from Seatex, and the data is transferred to the navigation console and data logger. Position accuracy using this system is better than 5 m.

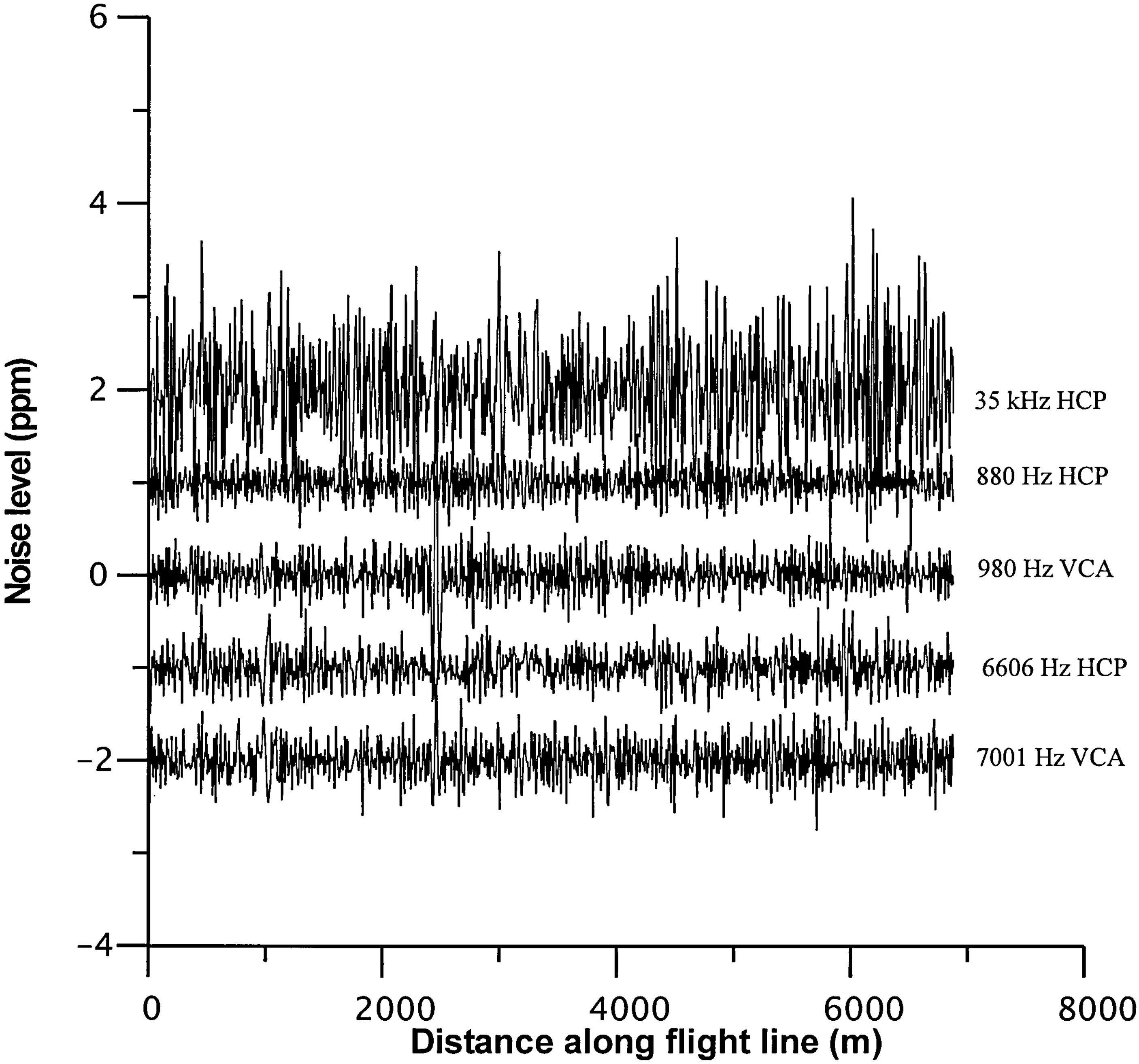

Fig. 2. EM noise levels. This shows the results of a 45-m high pass filter applied to all five frequencies from a section of a typical flight line. Curves have been offset from one another for better illustration.

The navigation console was a PNAV 2001 manufactured by the Picodas Group, Ltd. of Canada. Profile line data are entered into the console and the helicopter pilot can view the traces. The pilot can see his position with respect to these predefined lines and adjust accordingly.

The helicopter came with a King KRA-430 radar altimeter that measured height above ground level, and was recorded digitally and displayed before the pilot. The altimeter is accurate to 5 percent of the true flying height.

The data logging system is an integral part of the Hummingbird electromagnetic system, manufactured by Geotech, Ltd. of Canada. Data is recorded both digitally and analog.

4 PROCESSING

The data were processed at the Geological Survey of Norway in Trondheim using Geosoft processing software (Geosoft, 1996) designed for NT operating systems. All maps, except VLF maps, were constructed from grids using a 50-m grid cell. The VLF maps used a 100-m grid cell. Obvious inaccuracies in navigation were manually removed from the data. The datum used was RT-90 and the projection the Swedish National Projection.

Total field magnetic data: The data were inspected flight-by-flight and any cultural anomalies were identified and manually removed. A base station correction was applied to each flight using corrections based on the diurnal measurements from the base magnetometer at the heliport. Extreme cold caused the malfunction of the magnetometer's electronic recording system during the final two flights in area A (Enstern) and on one flight in area B (Lockne). For these flights a diurnal correction was estimated using the analog record. The manually corrected magnetic data were not noticeably degraded in comparison to the digitally corrected data. The lines were gridded without further filtering.

Radiometric data: The Geosoft radiometric processing package (Geosoft, 1995) follows the three channel processing procedure outlined in International Atomic Energy Agency Technical Report No. 323 (IAEA, 1991). A narrow nonlinear filter was applied to the radiometric data to remove spikes and a low pass filter was applied to smooth the data slightly prior to further processing. Background radiation levels were estimated by flying background calibration lines over water, usually two per flight, and by analyzing flight lines passing over lakes. After background reduction, the data were corrected for spectral overlap using experimentally determined stripping ratios. The processed data are presented as ground concentrations of the uranium, potassium, and thorium, and as ground level total counts.

Atmospheric radon does not appear to have been a major source of data contamination in any of the flights.

VLF-EM data: Along each line of the raw VLF data channels - orthogonal and in-line receivers – a constant base level was estimated and removed, leaving lines containing residual anomalies. A single pass of a Hanning filter was applied to slightly smooth the residual grids. The maps from the gridded data show VLF anomalies from a receiver orthogonal to the flight direction, and anomalies from the receiver in-line with the flight direction. In general, the maximum of the VLF anomaly should be centered over the conductive structure causing the anomaly.

EM data: EM data were processed on a flight-by-flight basis. Zero levels and drift control for each frequency were obtained by frequent excursions above 300m AGL, usually at the end of each flight line. A nonlinear filter was applied to all EM data to remove data spikes resulting from sferics. Before levelling, all data were mildly low passed using a 45-m filter. Noise levels for all frequencies were within an envelope of 2 ppm, and the four lower frequencies usually had a noise level of about 1 ppm. This is confirmed by Figure 2, which shows the results of a 45-m high pass filter applied to a section of a typical flight line (Line 530, area B). Noise levels over 2 ppm occurred near powerlines. Levelled in-phase data at all frequencies show a few negative peaks. They occur on multiple frequencies and sometimes along adjacent flight lines. Dikes or other structures having high magnetic susceptibility may produce negatively oriented in-phase anomalies. A large magnetic structure in the central east portion of area C caused negative in phase anomalies over an area of about 8 km^2. Conductivity maps were computed for each frequency using least squares inversion and a homogeneous half space model. In most cases the inversion was performed on the in phase and the quadrature data combined. In instances where the quadrature data was clearly superior to the in phase data, the inversion was performed on the quadrature component only. Using the two vertical coaxial frequencies—980 Hz and 7001 Hz—conductances (conductivity x thickness) were computed for selected anomalies using a thin sheet model.

5 MAPS PRODUCED

All color maps were produced at a scale of 1:50 000, and presented with contours and in shaded-relief. Shading was from the northeast at 45° sun inclination above the horizon. The grid cell size for all maps besides VLF maps was 50 meters. VLF was gridded at 100 m to reduce the 'herringbone' effects.

In this report, samples of the data used to create the 1:50 000 scale maps are shown in Figures 3 through 6 (total magnetic field, 980 Hz EM conductivity, radiometric total counts, and VLF orthogonal, respectively). The figures are shown in color with shaded relief. Shading has been applied from the northeast at a 45° sun angle. Color figures show data, but are not exact copies of the maps that accompany this report.

A list of the 13 maps produced for each area is shown on page 3 of this report. These maps can be ordered from NGU either in digital form or as hard-copies.

6 ACKNOWLEDGMENTS

Maps shown in Figure 1 are scanned subsets from the Ôstersund Röda Kartan (Läntmateriverket, 1998).

7 REFERENCES

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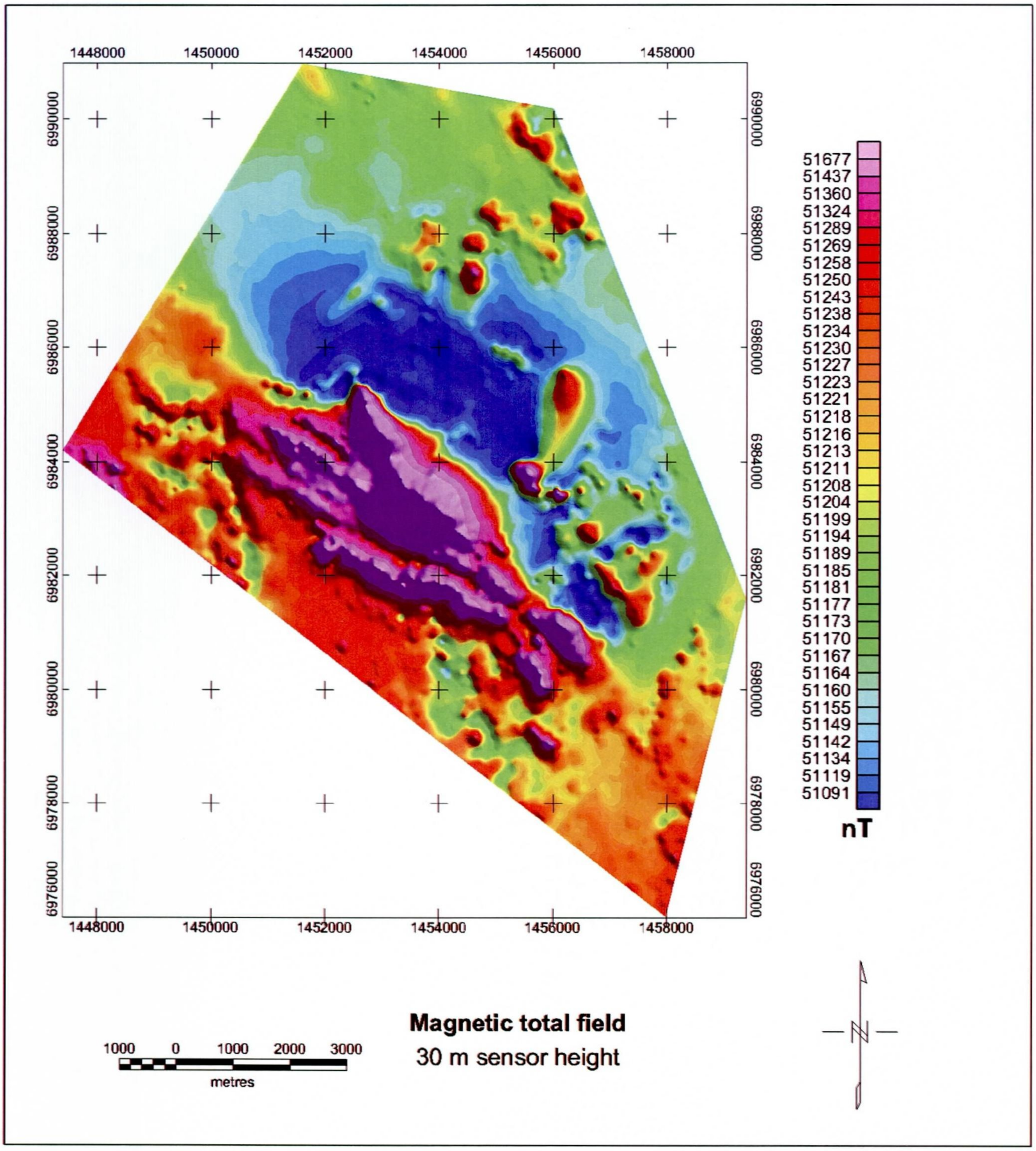

Figure 3. Sample magnetic data. Diurnally corrected total magnetic field, area B.

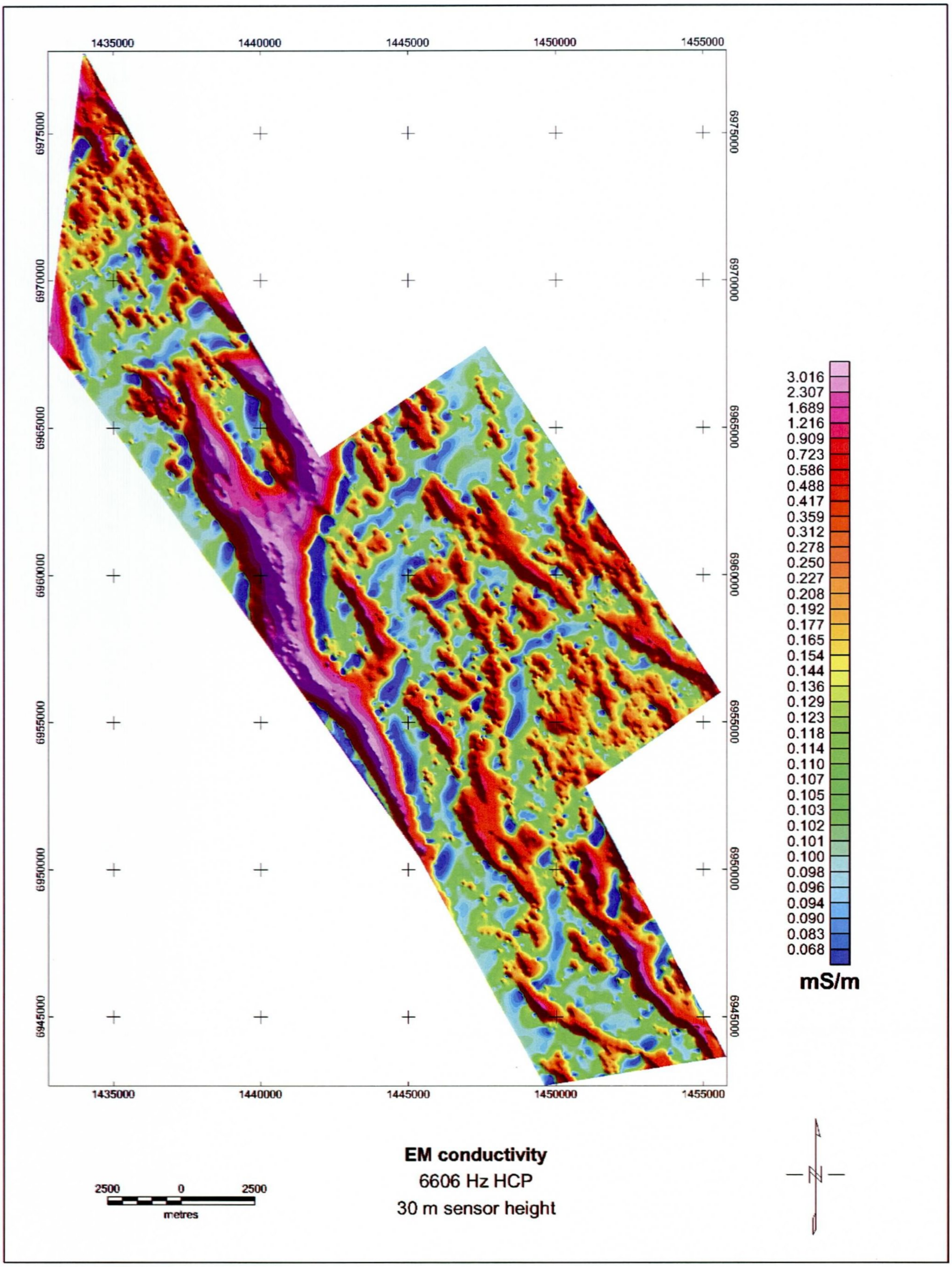

Figure 4. Sample conductivity data. EM conductivity from 6606 Hz HCP coil configuration, area C.

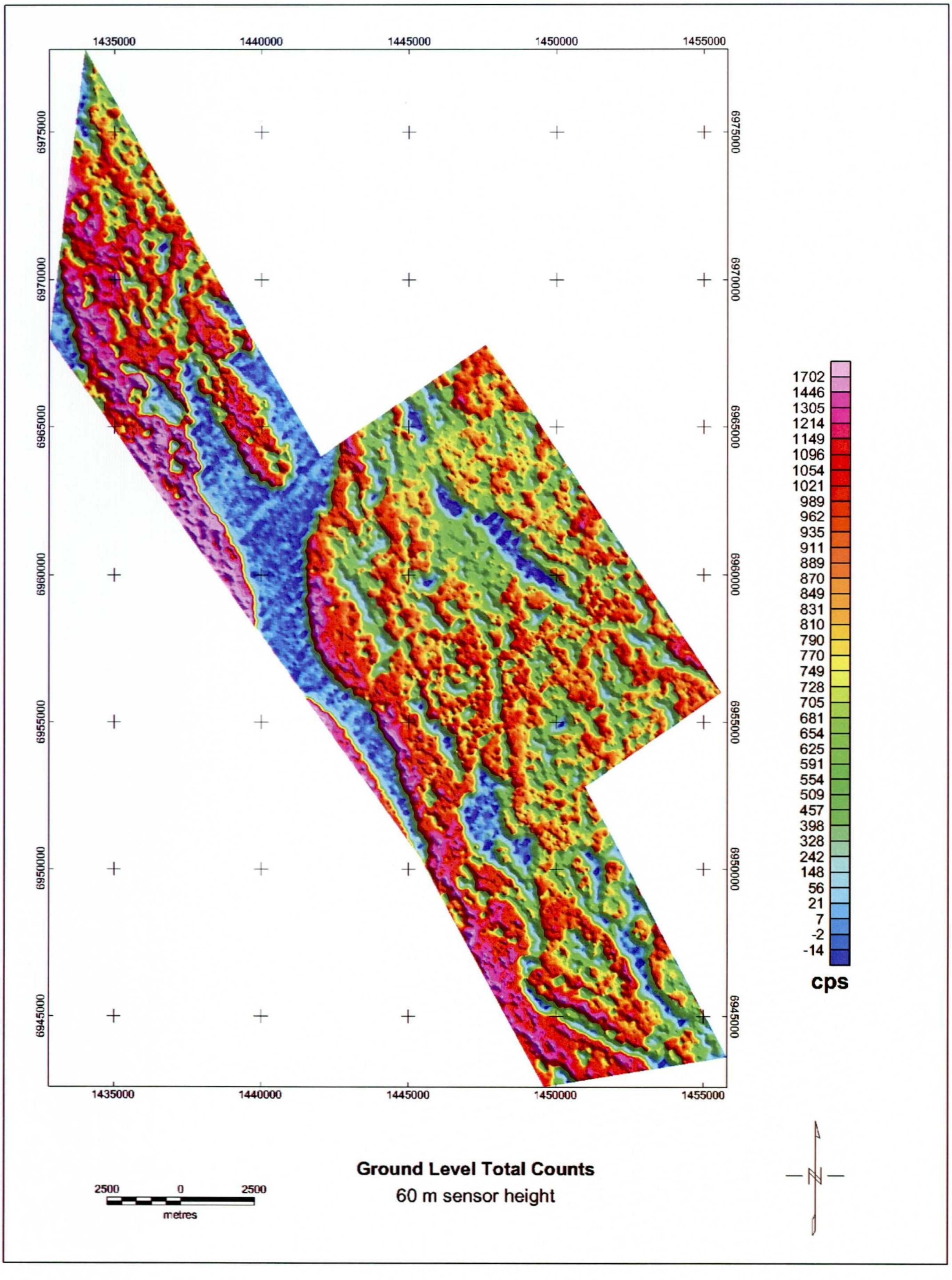

Figure 5. Sample radiometric data. Total counts adjusted to ground level, area C.

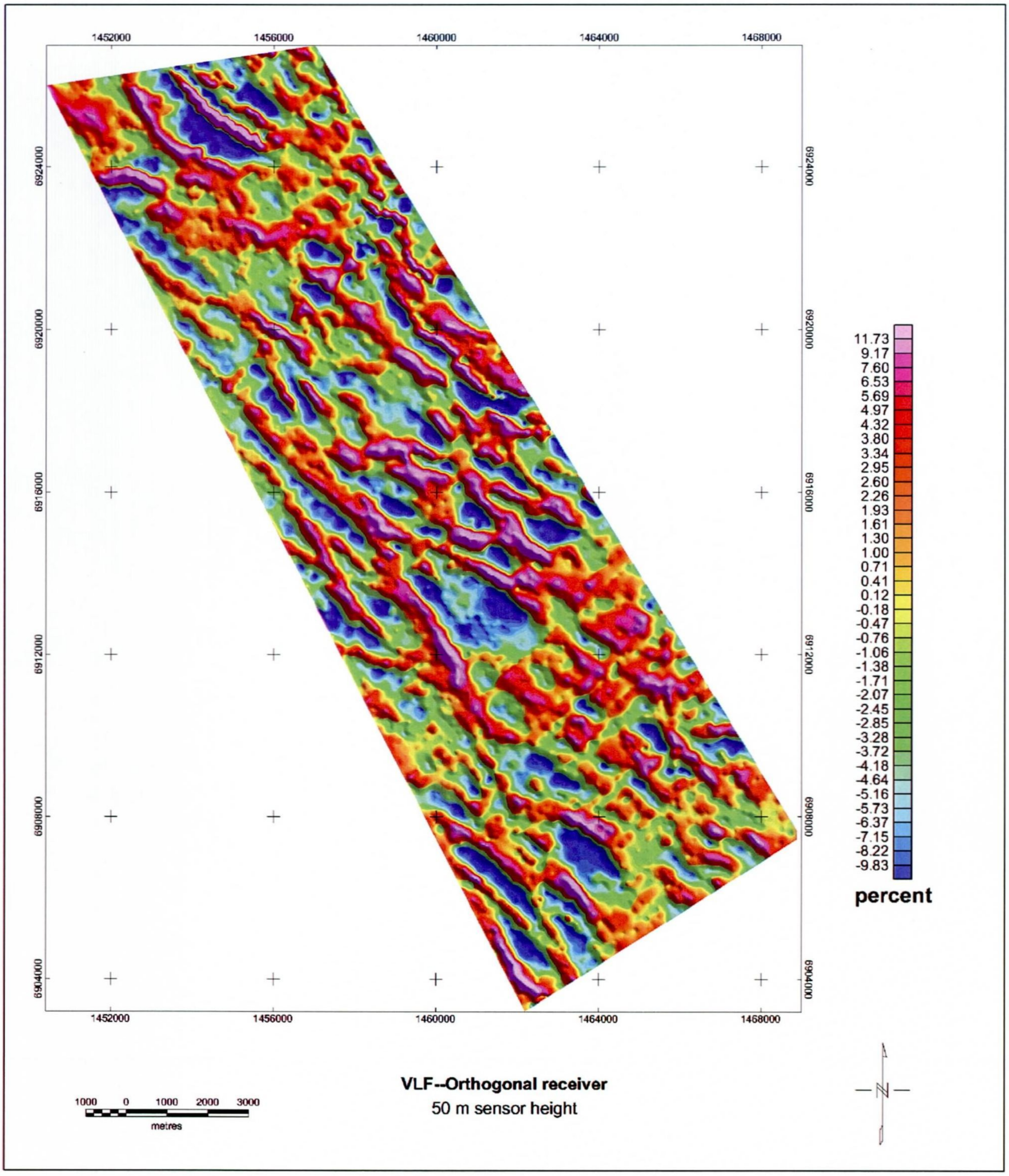

Figure 6. Sample VLF data. Percent change over background for receiver orthogonal to flight direction, area A.