MIRKO PETKOVIĆ
University of Belgrade, Faculty of Mining and Geology, Departman for geophysics, Serbia
mirkopetkovic.90@gmail.com

VESNA CVETKOV
University of Belgrade, Faculty of Mining and Geology, Departman for geophysics, Serbia

BRANISLAV SRETENOVIĆ
University of Belgrade, Faculty of Mining and Geology, Departman for geophysics, Serbia

902.3:621.317.444(497.11)"2013"
COBISS.SR-ID 219287052

Original research article
Received: January 24th 2015
Accepted: November 15th 2015

ADVANTAGES AND DISADVANTAGES OF A PARALLEL AND ZIGZAG METHOD OF ACQUISITION IN WALKING MODE IN MAGNETOMETRIC ARCHAEOLOGICAL RESEARCH

ABSTRACT

The occurrence of anomalies along traverses which are the subject of magnetic surveys in walking mode imposed the need to test different methods of acquisition and processing of magnetic data. For the testing polygon, the field above the previously identified archaeological anomaly in the archaeological site "Kremenite Njive" (Barajevo, Republic of Serbia) was used. An investigative polygon with dimensions of 25 x 25 m was used and the data was acquired using an Overhauser GSM-19GW (GEMLink) gradiometer, with and without the Global Positioning System. To obtain a regular data grid, the sampling was conducted at a 1s interval, and with a distance between the traverses of 1m. The traverses for this process were oriented in a north-south and east-west direction.

The best results or, more accurately, those with the absence of linear anomalies were observed when using the parallel method of acquisition, regardless of how the traverses were oriented compared to the magnetic meridian. This type of acquisition, except for clipping the peak of the gradient of the Earth's magnetic field, does not require additional data filtering. However, to reduce the time needed for field measurements, the zigzag mode is often applied which requires additional data processing such as: adjusting the traverses of the mean or median to a common value, decorrugation or the use of non-linear interpolation. Modern magnetometers (gradiometers) usually have a GPS system whose acquisition error level is significantly higher than that which is desirable in an archaeological survey. Therefore, it is better to use a total station to read the geographic coordinates of the investigation polygon where the magnetic measurements are acquired, rather than GPS which assigns uniformly-arranged coordinates along the x and y axes of the data.

KEYWORDS: MAGNETIC SURVEY, ZIGZAG AND PARALLEL ACQUISITION IN WALKING MODE, LINEAR ANOMALIES, ARCHAEOLOGY.

INTRODUCTION

The differences in the physical properties of the subsurface materials are the basic prerequisite for the application of geophysical methods to be successful.

The use of iron-based materials during human history allows for the successful application of magnetometry, which is now one of the leading choices of geophysical methods for archaeological reconnaissance.

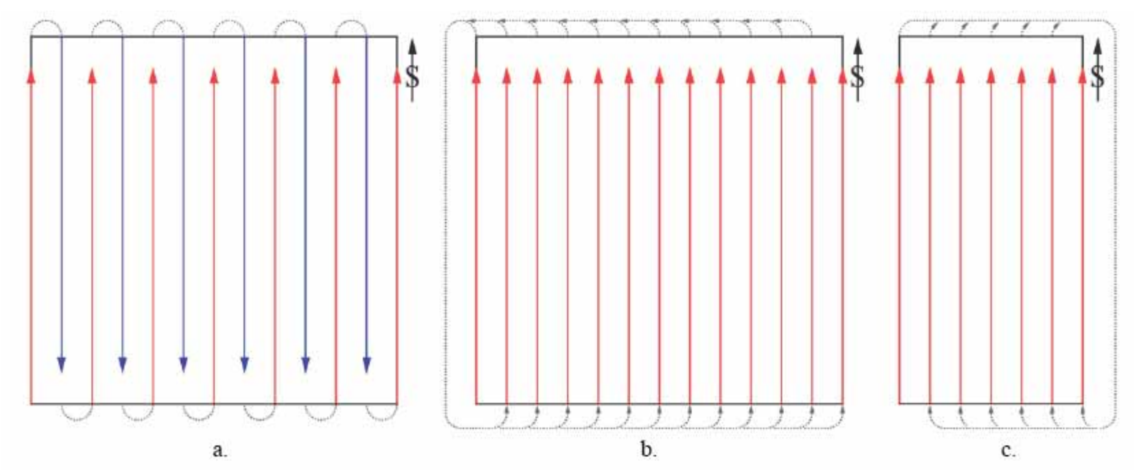

Fig. 1 Illustration of N-S orientation of traverses. Key: a. zigzag fashion; b. parallel fashion; c. mid-field in parallel fashion.

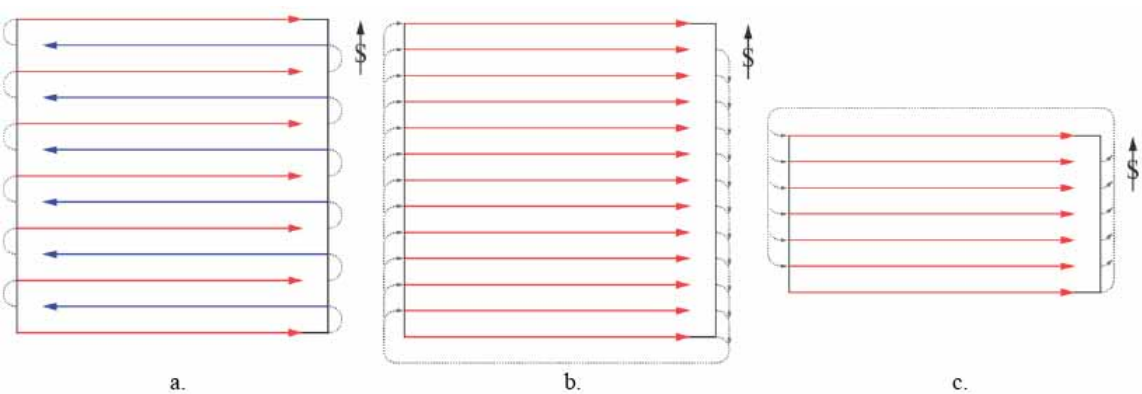

Fig. 2 Illustration of E-W orientation of traverses. Key as for Fig 1.

Besides iron-based materials, it is very important to have the presence of small amounts of magnetic minerals from the iron oxide and iron sulphide groups, either organic or inorganic in origin, which cause a difference in the magnetic susceptibility of archaeological objects and the environment that surrounds them.

The best responses to magnetic data are provided by materials that have been exposed to high temperatures, i.e. those that have acquired thermoremanent magnetisation.

The accuracy of a magnetic survey is directly related to the accuracy of the instruments used, and the development of instruments has kept up with developments in modern physics, resulting in present-day magnetometers that are accurate up to 0.02 nT.

One of the instruments with this degree of accuracy is the Overhauser GSM-19GW magnetometer from the Canadian company GEMLink, with a gradient tolerance up to 10,000 nT/m (Smekalova, Voss and Smekalov 2008).

Besides its high accuracy, an important advantage of this instrument is its ability to measure the gradient of Total Magnetic Intensity (TMI), which is achieved by using two identical probes. By measuring TMI on two coupled probes in the same time interval, allows the avoidance of variations of TMI in the base survey.

Also, another important function of the instrument is the data acquisition walking mode, which is characterised by performing automatic measurements based on a pre-defined time interval.

The time intervals for automatic sampling in walking mode that the instrument allows are from 0.2 to more than 60s (GSM-19 Instruction Manual 2008).

According to the theory of proton precession on which this instrument is based, the orientation of the probe in non-equatorial areas should not affect the data quality. However, a common occurrence during magnetic surveys is a linear anomaly along the traverses on which the acquisition has been made in the walking mode (McCullough 2007, Burks 2014).

In order to reach a proper conclusion as to what causes linear anomalies and how to avoid them, an investigative polygon with dimensions of 25 x 25 m was formed above the previously identified archaeological anomalies at the archaeological site "Kremenite Njive", near Barajevo, Republic of Serbia (Vasiljevic 2013). Here the data was collected with the gradiometer in walking mode, using several different procedures depending on the orientation of the traverses and a combination of with and without Global Positioning System (GPS).

The sampling time was set to 1 s and the distance between the traverses to 1 m in order to obtain a regular data grid with the same spacing between the points along the x and y directions.

DATA ACQUISITION IN ZIGZAG AND PARALLEL METHOD

Magnetometric data acquisition on traverses is usually performed in a zigzag or parallel fashion (David et al. 2008).

During the acquisitions of the three modes, traverses were oriented along a north-south direction. In the first case, the operator, at the end of the profile, made a semicircle and continued the measurement on the next adjacent profile in a zigzag fashion. Throughout the acquisition, the data was saved in the same file with the included GPS data. With this method of measurement, the adjacent traverses were reverse oriented (Figure 1.a.).

In the second mode of acquisition, the operator, after the completion of measuring each traverse, circumvented the test polygon, and on the next traverse entered on the same side as the previous one, in a parallel fashion. Using this type of acquisition, all profiles were oriented in the same direction (Figure 1.b.).

To accelerate the measurement, in the parallel third mode, it was started from a mid-field point. The operator, after the completion of measuring the traverse, circled around test polygon to the opposite side relative to the second measuring mode (Figure 1.c.).

In all three modes, the measurement was started from the same point, the south-west corner of test polygon.

Figure 1

After the completion of the first three methods of measurement, the same polygon traverses were reoriented by 90°, i.e. in an east-west direction and the next three measurements were performed in the same way as in the first three methods of measuring when the orientation was in a north-south direction (Figure 2). Just as with the north-south orientation, each individual measurement was also saved in the same file with the included GPS.

Figure 2

In the previously described measurements, all the data during the acquisition was stored in the same file, which does not allow for the processing of individual profiles.

To be able to process the individual traverses, the measurements were continued using the principle of "one traverse-one file". The traverses were oriented along a north-south direction and acquisitions conducted using the following three methods.

As with the first measurement, in this case, the data was sampled in a zigzag fashion. However, contrary to the first method, in this case, the data of each profile was stored in a separate file.

The last two methods of measurement were carried out on the eastern half of the polygon with the same orientation of profiles, and all the data

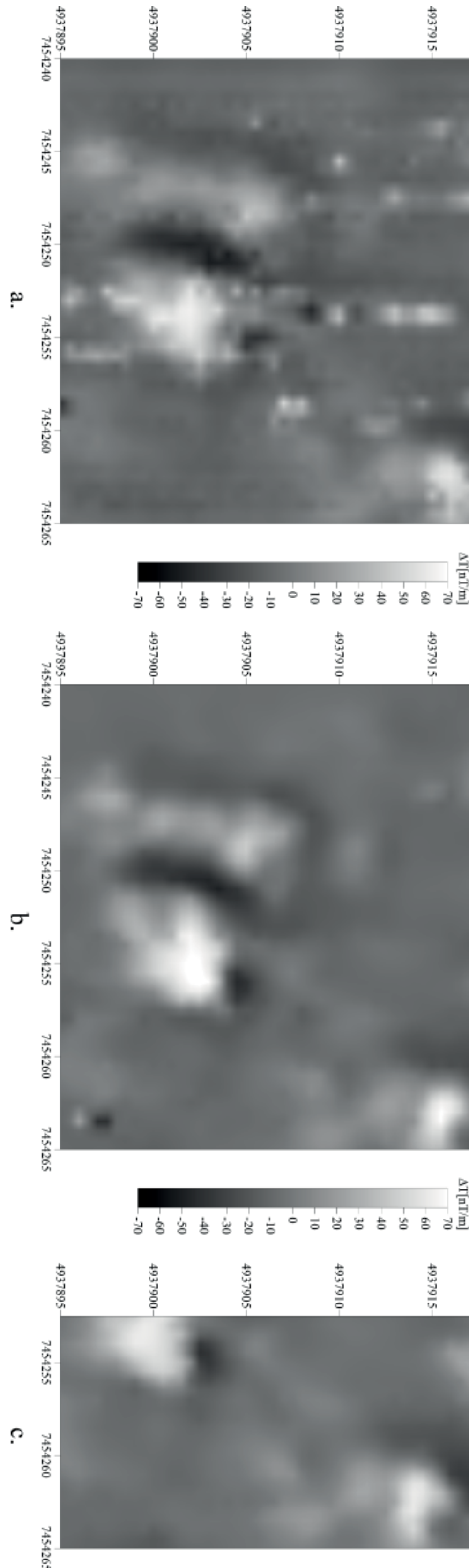

Fig. 3 Contour map of a vertical gradient of TMI in N-S orientation. Key as for Fig 1.

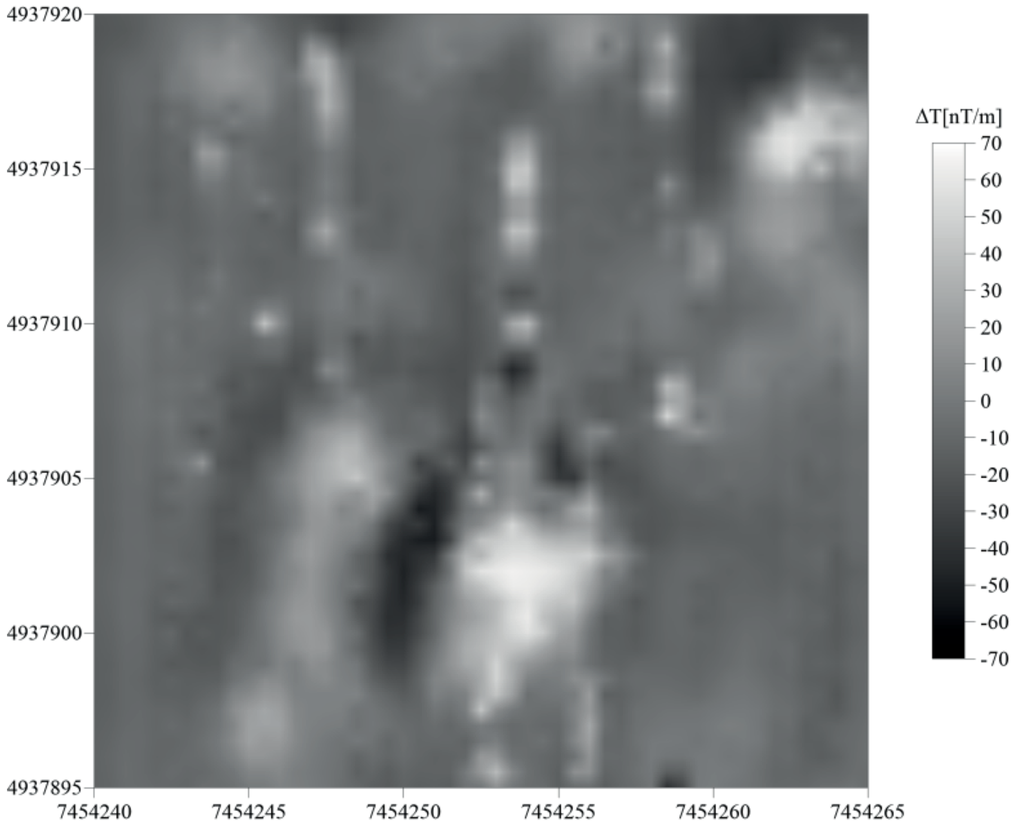

Fig. 3a Contour map of a vertical gradient of TMI in N-S orientation. Key as for Fig 1.

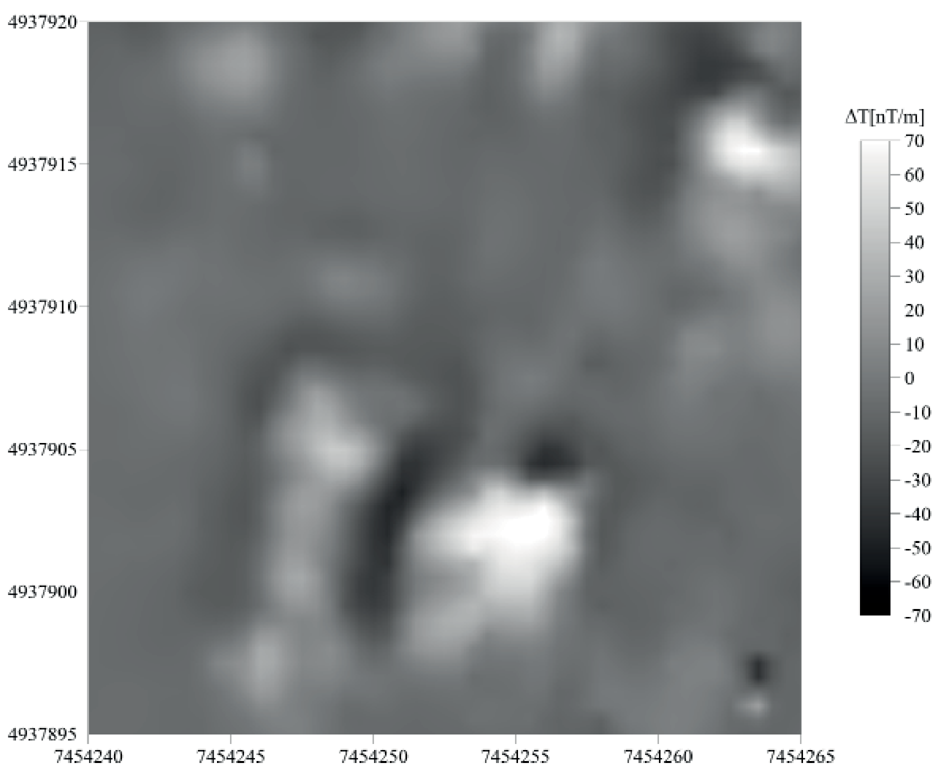

Fig. 3b Contour map of a vertical gradient of TMI in N-S orientation. Key as for Fig 1.

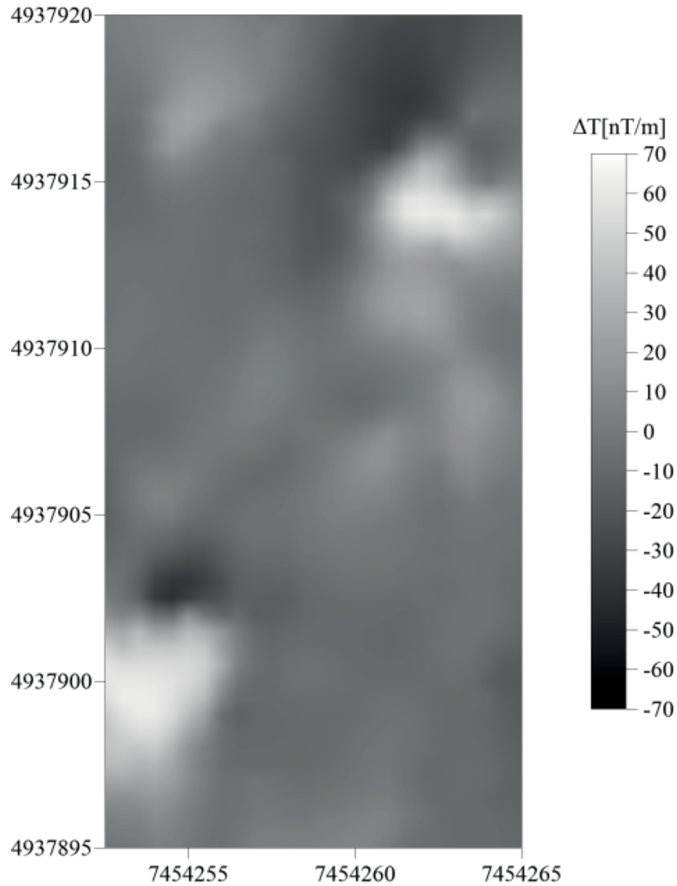

Fig. 3c Contour map of a vertical gradient of TMI in N-S orientation. Key as for Fig 1.

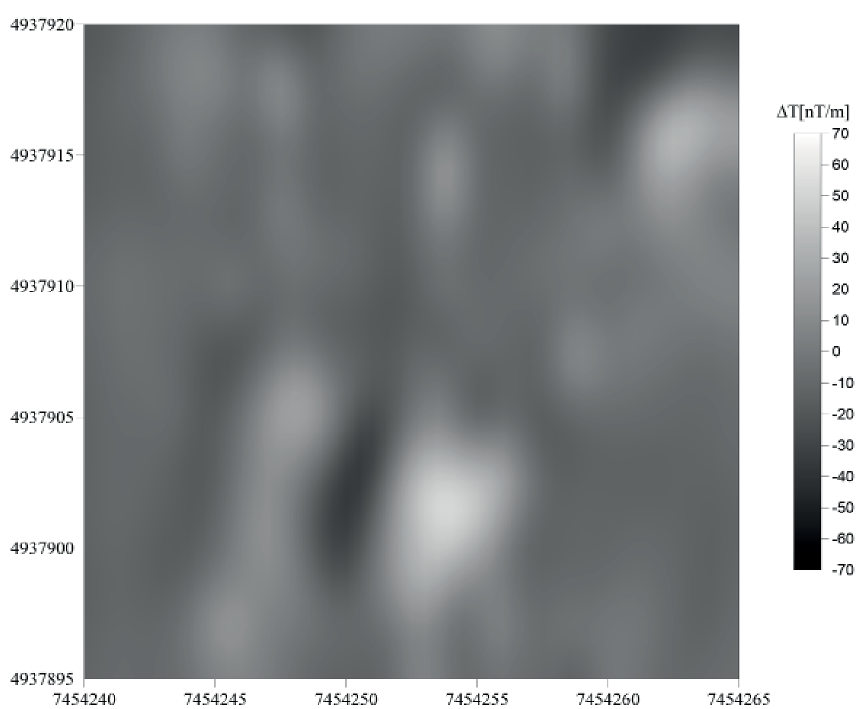

Fig. 4 Vertical gradient of TMI contour map of zigzag fashion in N-S orientation filtered by moving average filter in two directions.

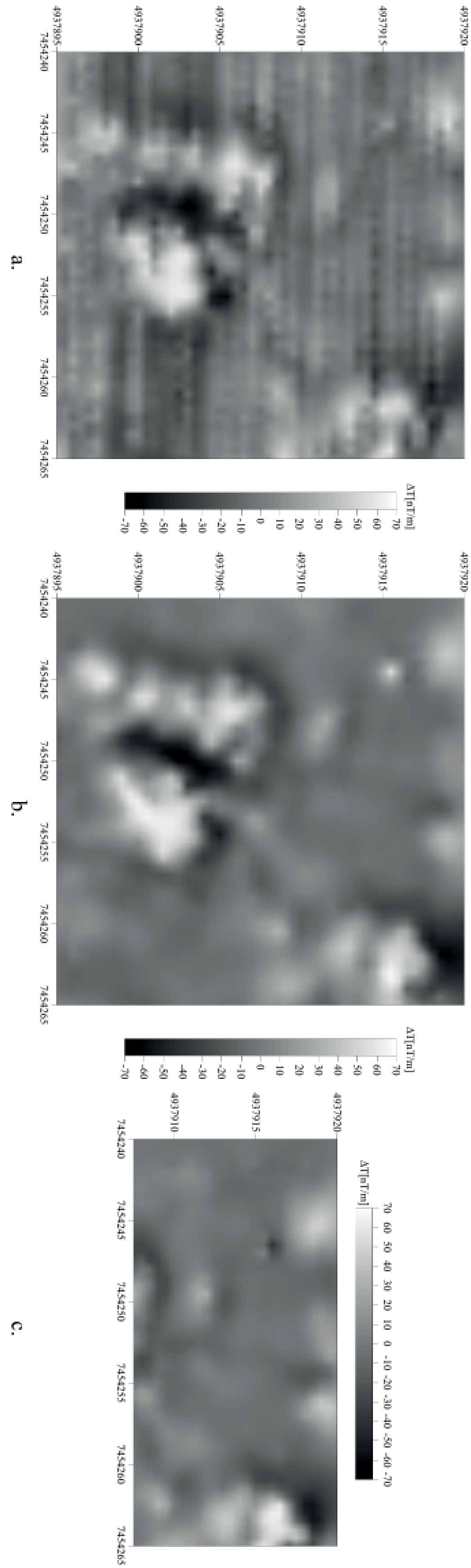

Fig. 5 Contour map of a vertical gradient of TMI in E-W orientation. Key as for Fig 1.

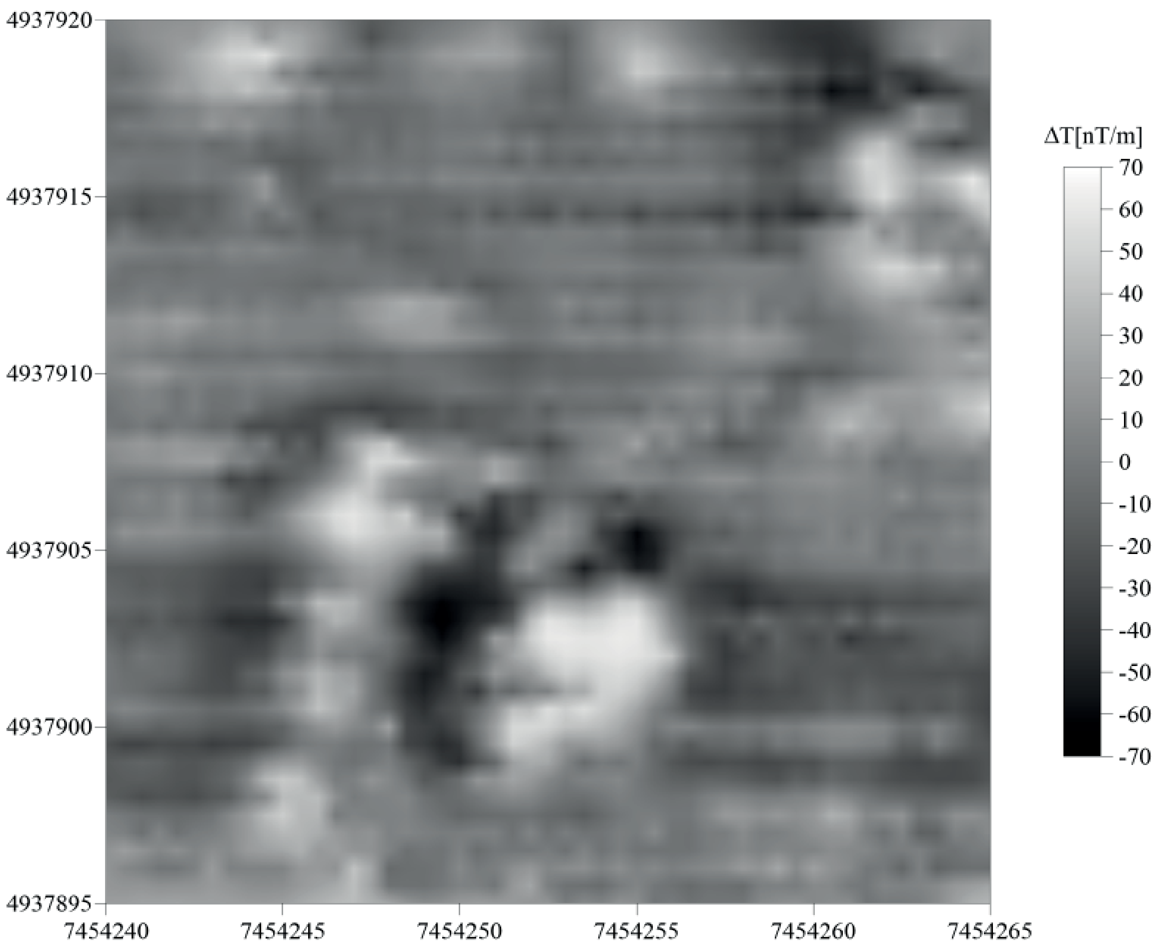

Fig. 5a Contour map of a vertical gradient of TMI in E-W orientation. Key as for Fig 1.

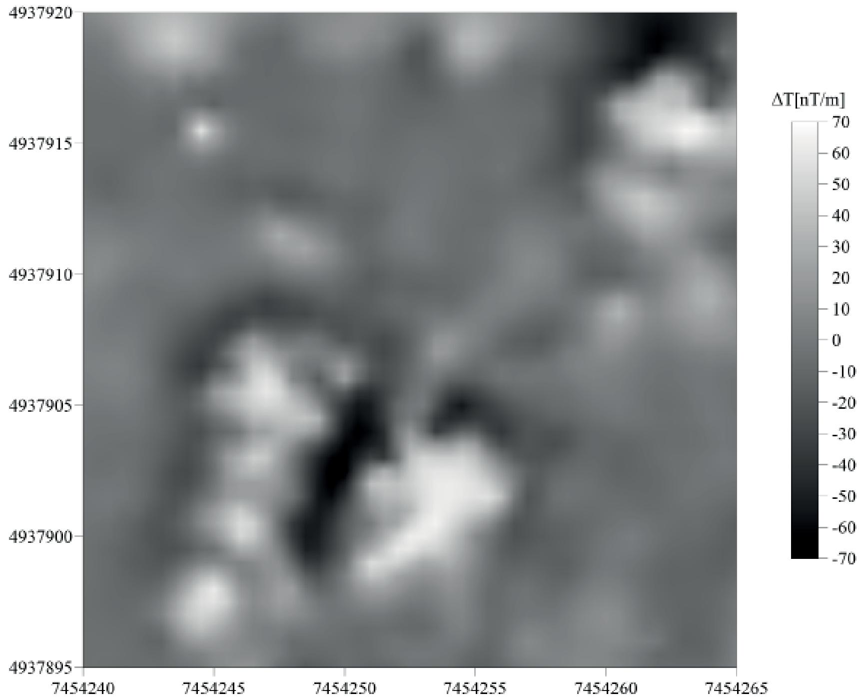

Fig. 5b Contour map of a vertical gradient of TMI in E-W orientation. Key as for Fig 1.

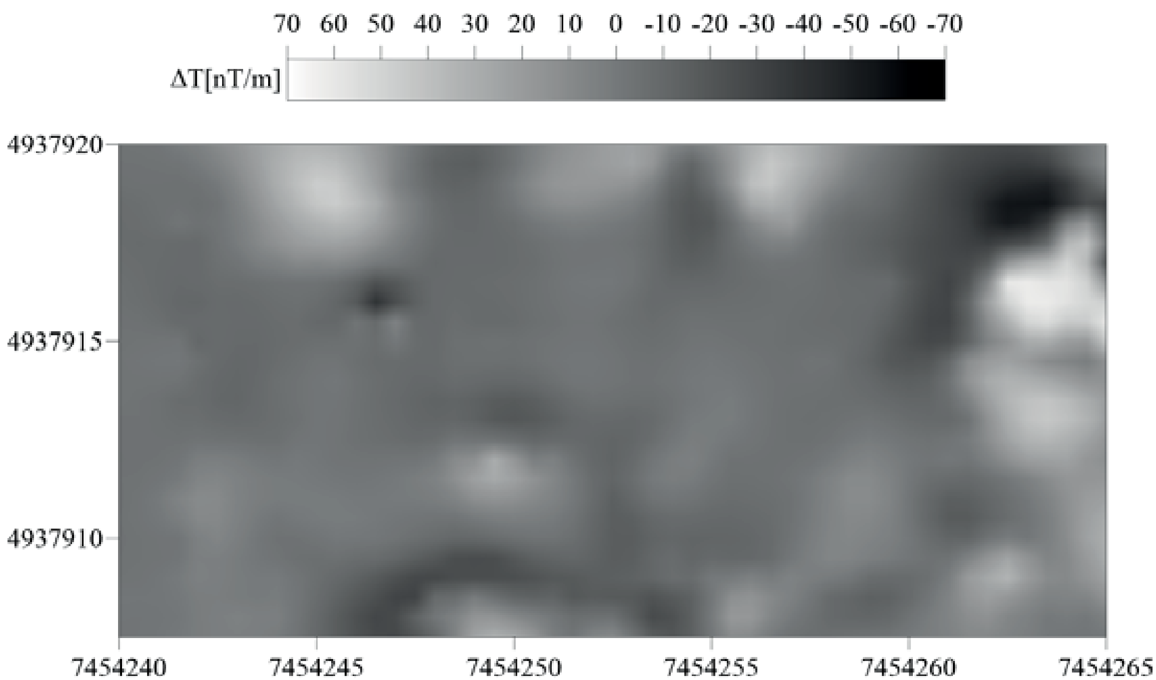

Fig. 5c Contour map of a vertical gradient of TMI in E-W orientation. Key as for Fig 1.

was collected when moving towards the north.

In the first case, the data was stored using 'one traverse - one file', with GPS coordinates, and in the second case it was stored without GPS coordinates.

Before and after the last three measurements, the geographical coordinates of the polygon corner points were taken.

DATA PROCESSING

After the completion of the acquisition, the data was prepared for software processing. In the first three cases, the data which had been acquired outside of the polygons was clipped from the database, and also the data whose value was outside a range of ± 70 nT/m. The data was arranged in a regular grid using Kriging's interpolation method (Isaaks and Srivastava 1989) and presented as a map of a vertical gradient of TMI (Figure 3).

Figure 3

Although the instrument was only worn by one operator, linear anomalies were observed in the direction of acquisitions that blur or fleck other anomolies on the map and can lead to misinterpretation (Figure 3.a.). To eliminate this anomaly, a low-pass linear moving average decorrugation filtering process was applied to the data in two steps (Urquhart, 1988). In the first step, the data was filtered along the direction of the acquisition, and in the second step, the filtered data was filtered again, perpendicular to the direction of the acquisitions (Figure 4.).

Figure 4

What is important to note is that for the filter to be relevant, the data must be equally distributed along the x and y axes. If the data is sampled from an azimuth different from 0°, before applying the filter, the data needs to be rotated to the zero azimuths.

In the parallel acquisition to the north, there was no occurrence of linear anomalies along the direction of acquisitions and on this data, there was no need to apply the decorrugation filter and, after clipping the peaks, the data was ready for qualitative processing (Figure 3.b.).

Half of the field measured by the third method is shown in Figure 3.c. As in the previous measurement methods, there was no occurrence of linear anomalies along the direction of the acquisition.

Comparing Figure 3.b. with Figure 3.c, it can be determined that the data quality does not depend on which side the operator circles around the test polygon. Also, using a combination of the second and third mode of measurements, the time required for the data acquisition could be reduced.

As in the previous measurements, in the following three cases (the fourth, fifth and sixth) in the first step of processing, data outside the test polygon was clipped along with data whose gradient fell outside a range of ± 70 nT/m. The data was gridded using the same interpolation method and displayed as a map of the vertical gradient of TMI (Figure 5.).

Figure 5

In cases where data was sampled in a zigzag fashion, the linear anomalies appeared on the east-west profiles, which blur (fleck) other data, and for that reason it was necessary to apply decorrugation processing, as previously described (Figure 6.).

Figure 6

Comparing filtered and unfiltered data, it can be noticed that linear anomalies were removed from the vertical gradient of TMI map after filtering.

As in the case of orientating profiles in a north-south direction, with data sampled in the same direction, linear anomalies did not appear, so the data was suitable for further qualitative analysis, after having been clipped to the investigative area and the correct domain of gradient TMI.

The mid-field was measured in order to determine the data quality if the operator circumvents the test polygon on the same side each time, or if he circles around the polygon to the other half of the field from the opposite side. From the analysis of the maps shown in Figures 5.b. and 5.c. it can be concluded that there was no difference in the quality of data.

The acquisition of the last three measurements was carried out using the principle of "one traverse-one file" so that it would be possible to process the data as separate profiles. Also, with this method of measurement, all the data fell within the margins of the test polygon, so the processing step where the data was spatially limited, was omitted.

In the first step of processing, the peaks were clipped, i.e., where the gradient value of the TMI was outside the range of ± 70 nT/m, after which it was interpolated using the Kriging method (Figure 7.a.).

Figure 7

Although it was measured in the same polygon, the anomaly map shown in Figure 7.a is completely flecked.

Figure 7.b. shows the post map of the measured points which, in any case, does not describe the situation in the field This arrangement of the measured points is the result of the error of the GPS, i.e., when starting each new traverse, the GPS re-started its communication with the satellites (OEMV Family Installation and Operation User Manual, 2010). Taking into consideration the time required for the measurement of a traverse, an error of 2m can be regarded as a common error for each traverse. In the case when the distance between two adjacent profiles is 1 m (in archaeology the distance between two adjacent profiles is often less than 1m), this error can result in the complete flecking of the anomalies, such as in this case.

Expecting that the GPS error will lead to such a spatial distribution of the measured points, before and after the completion of the measurements with GPS, the geographic coordinates of the corner points of the investigation polygons were recorded. Taking the average value of the measured coordinates, the data is distributed regularly along the x or the y axis, and the map is shown as a vertical gradient of TMI (Figure 8.).

Figure 8

Linear anomalies along the direction of the acquisition entirely flack the main anomaly and can lead to a completely wrong interpretation (Figure 8.).

Considering that the data was collected using the principle of "one traverse-one file", each profile could be processed separately. The traverses were separated according to the direction of the acquisition, with one group categorised by traverses whose direction of the acquisition was pointed to the north, and the other group with the acquisition to the south. After separating the traverses by the direction of acquisition, the data was interpolated using the linear Kriging method and displayed as a gradient map of TMI, with the direction of the acquisition to the North (Figure 9.a.), and to the South (Figure 9.b.).

Figure 9

Taking into account the intensity of the vertical gradient of the two adjacent traverses, it can be concluded that the linear interpolation method leads to the linear anomalies along the direction of acquisition.

A decorrugation process using a low-pass moving average filter was applied to the data interpolated by the linear Kriging method (Figure 8.), in the direction of acquisition and in the direction perpendicular to the direction of acquisition (Figure 10.a.).

Figure 10

The same data was gridded using a nonlinear local polynomial method, and it was observed that there was an absence of linear anomalies, which supports the hypothesis that the process of linear interpolation causes anomalies along the traverses where the acquisition was performed (Figure 10.b.).

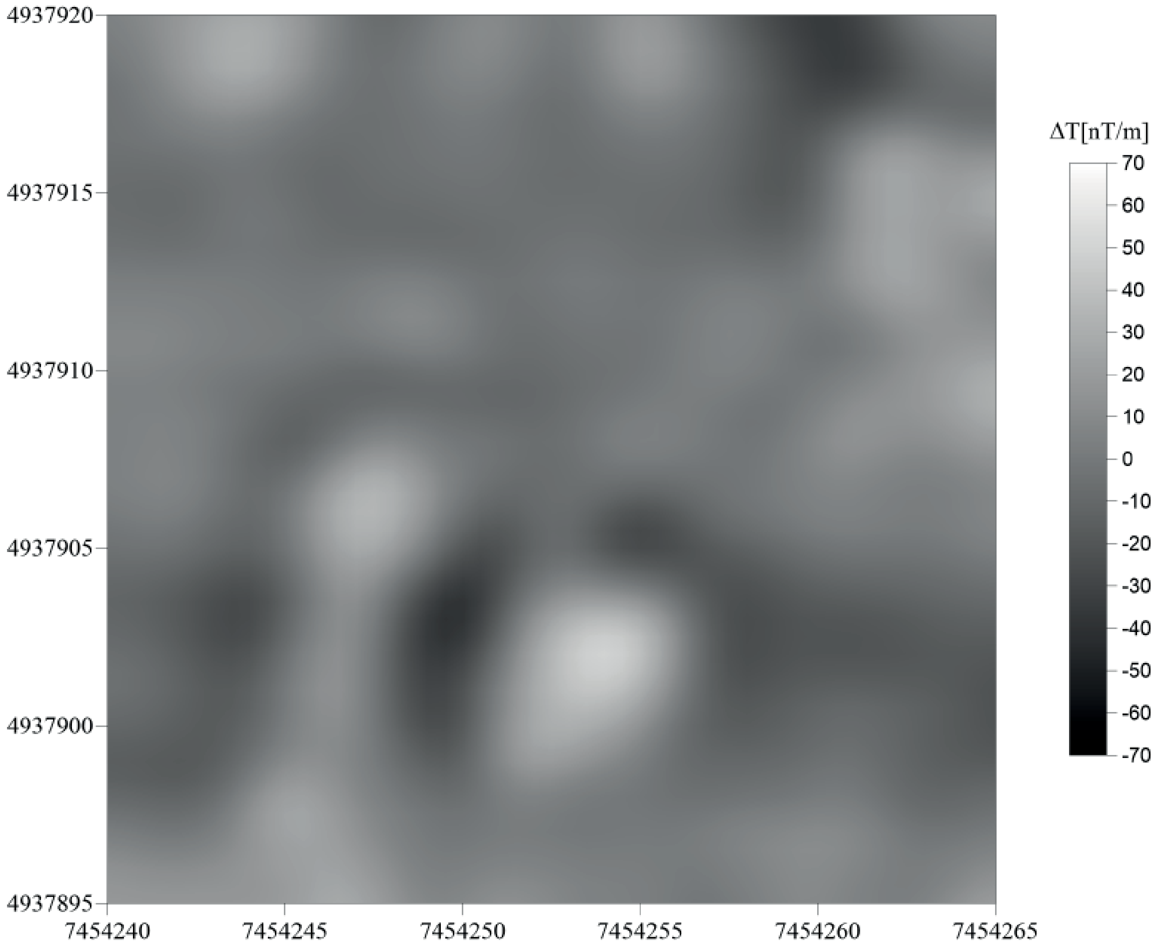

Fig. 6 Contour map of vertical gradient of TMI of zigzag fashion in E-W orientation filtered by moving average filter in two directions.

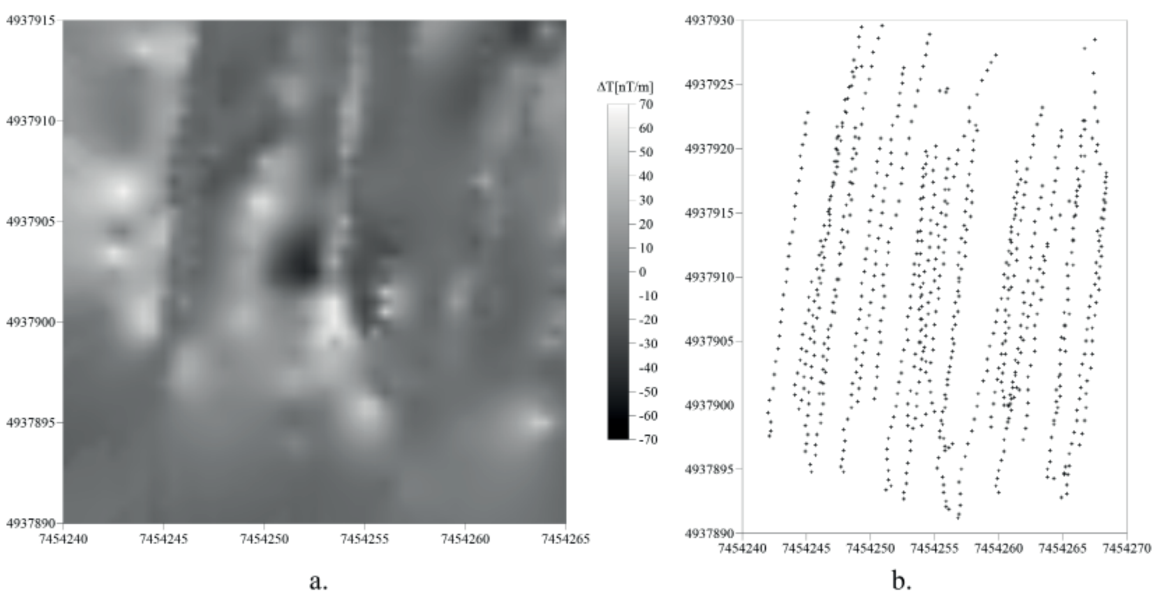

Fig. 7 a. Contour map of vertical gradient of TMI; b. post map of measuring data in zigzag fashion, N-S orientation, where data of each traverse were stored in a separate file.

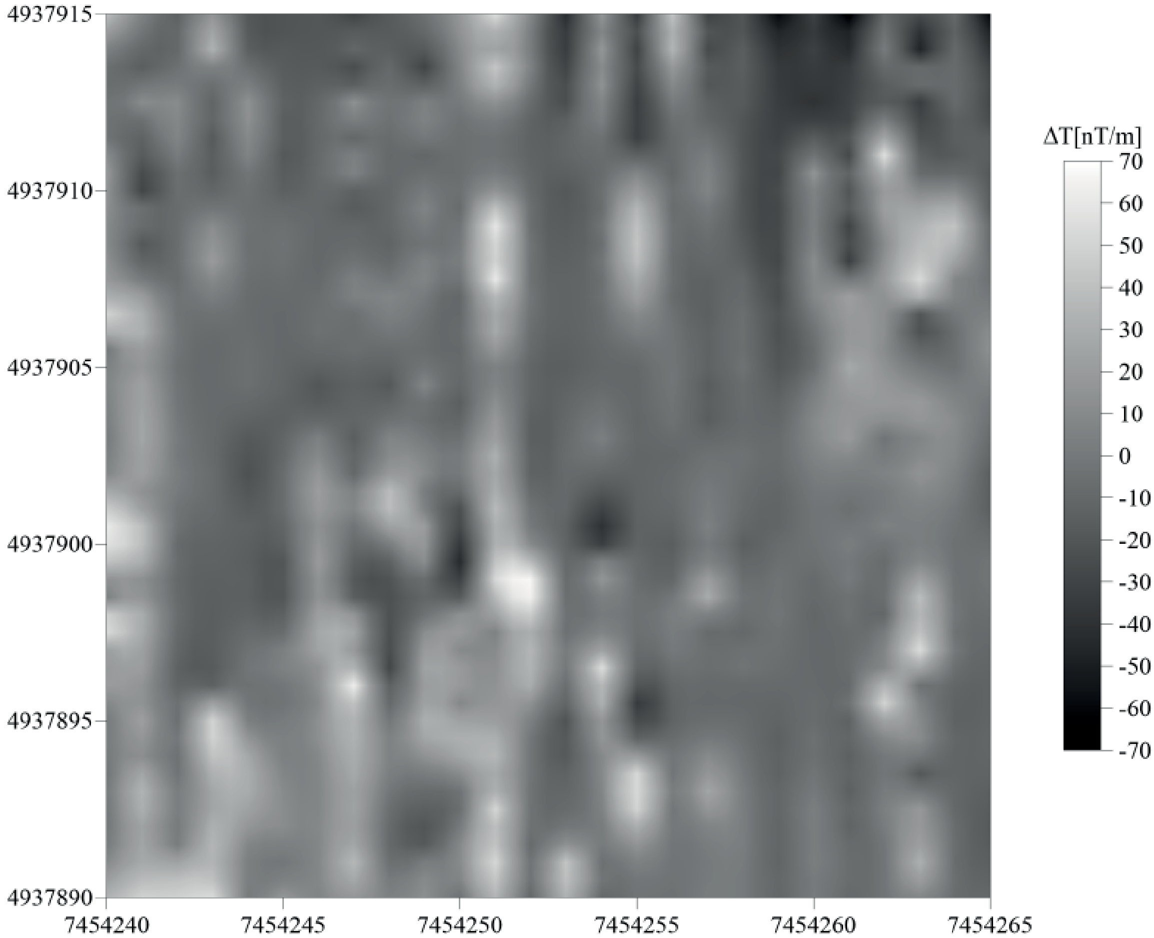

Fig. 8 Contour map shown in Figure 7.a. in relative coordinates.

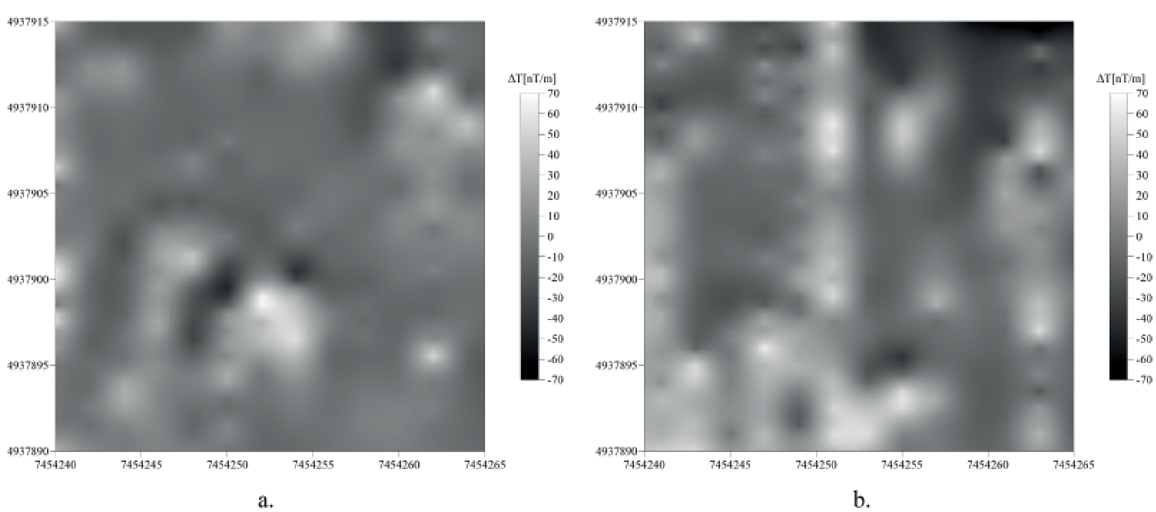

Fig. 9 Contour map of vertical gradient of TMI shown in Figure 8.
separated on the traverse orientation: a. to North; b. to South.

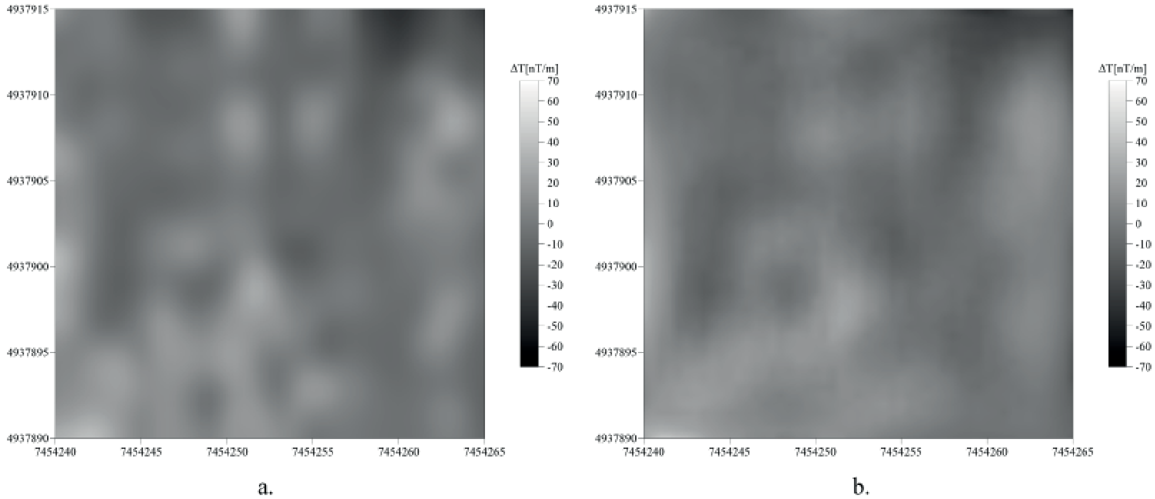

Figure 10. Contour map shown in Figure 8. a. Filtered by moving average filter in two direction; b. interpolated by nonlinear local polynomial method.

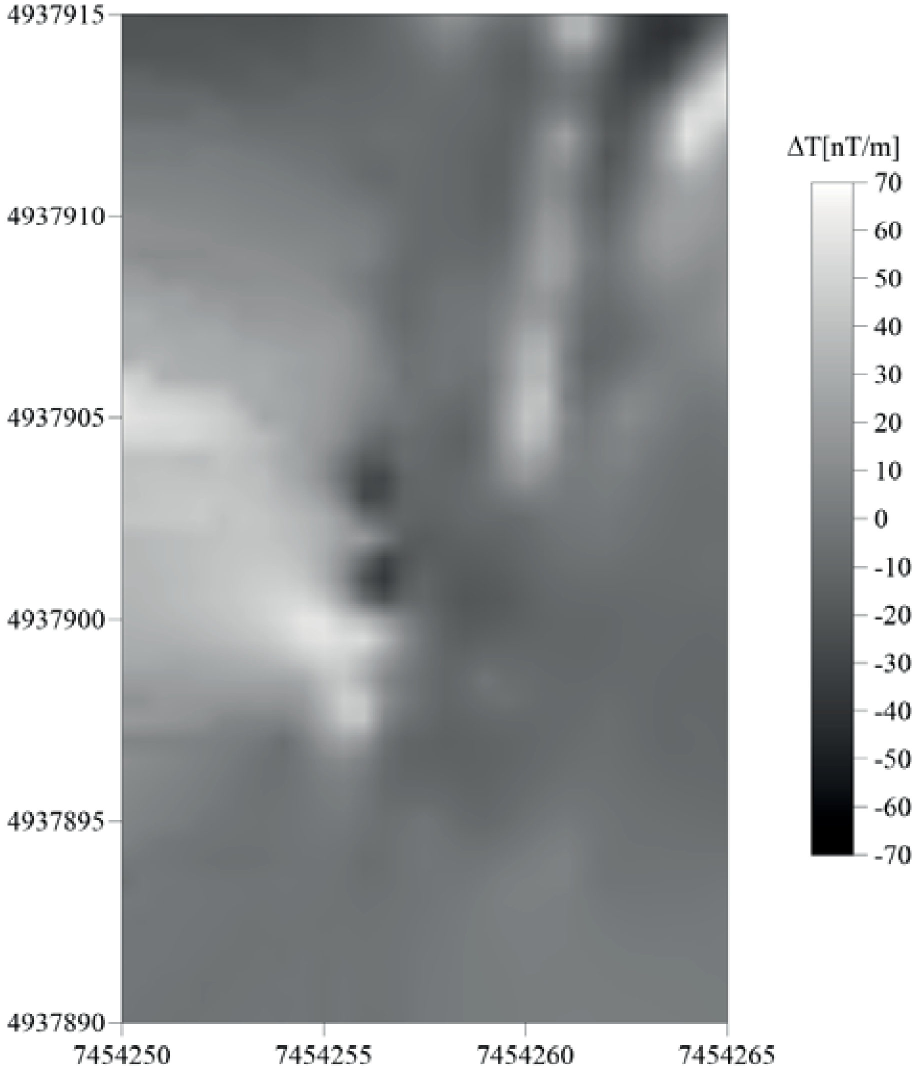

Fig. 11 Contour map of vertical gradient of TMI in last one case with flecked anomaly due to the large error of GPS.

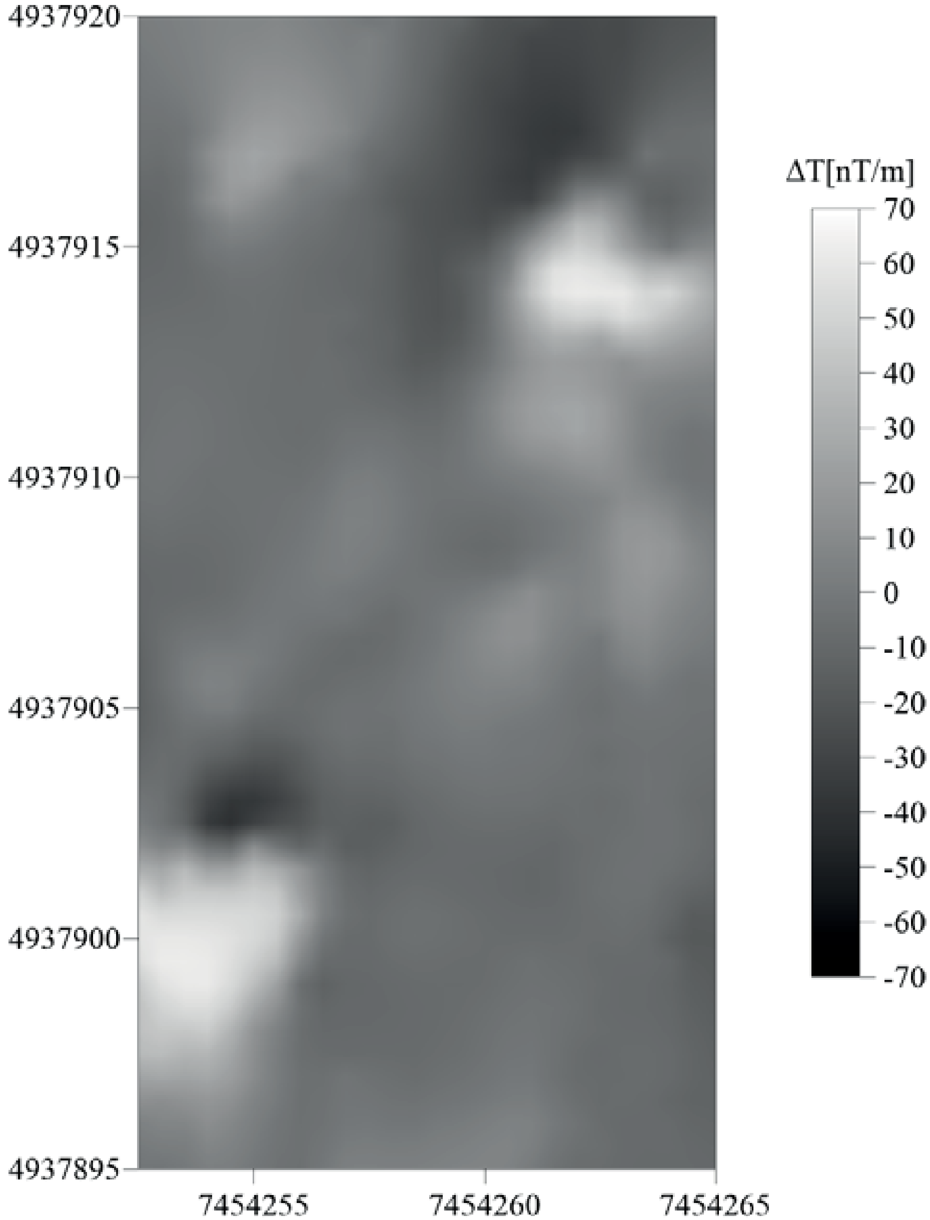

Fig. 12 Contour map of vertical gradient of TMI in last one case with relative coordinates.

The last two measurements were carried out with the intention of displaying the differences in the data processed with GPS and its relative coordinates. However, the same problem occurred as in the previous measurement, such that as a result of the large GPS error and after linear interpolation, the main anomaly was completely flecked (Figure 11.). For this data, instead of GPS coordinates, relative coordinates were assigned along the x and y axes and interpolated using the Kriging interpolation method (Figure 12.).

Figure 11

Considering that the acquisition was carried out from the same mid-field, and in the same direction, it is logical to obtain the same map of the vertical gradient of TMI (Figure 12.).

Figure 12

When a magnetometric survey for archaeology involves high-resolution data and, despite the high accuracy of the instrument, it is desirable to have the polygon coordinates measured using an absolute station. Also, if large areas are to be explored, it is desirable to divide them into a series of smaller exploration polygons with margin lengths not exceeding 25 m.

CONCLUSION

The linear interpolation method is the most common choice of interpolative methods for the processing of magnetometric data for archaeology.

However, linear anomalies often appear along the traverse with interpolation. A common processing method is to adjust the individual traverse to the mean or median value (David and other, 2008). In order to simplify the technique, traverses are usually adjusted to a zero mean or median value. During the processing of data from the "Kremenite Njive" fields, this technique proved to be unsuccessful. The reason is most likely that this technique has a favourable impact on data with a smaller gradient along the traverse. Much better data is obtained using a decorrugation filter, i.e., data filtered by a low-pass linear moving average filter, in two steps, in the direction of acquisition and in the direction perpendicular to the direction of acquisition. Also, the absence of linear anomalies is observed using the non-linear interpolation method. In this case, the local polynomial method proved to be the best.

In order to avoid linear anomalies it is necessary to apply a parallel method of data acquisition in the walking mode. Instead of forming separate files, it is recommended that all data be stored in one. In order to be able to individually process the traverses, and to control the data, it is necessary to separate the files by using a software tool during the acquisitions.

Some companies whose gradiometers are specialised for archaeological research resolve the problem of the zigzag method of acquisition by using the instrument's software. Before the start of the acquisition process, the operator sets the direction and the method of acquisition. The instrument's software then prepares the data collected in the zigzag method for further computer processing, treating them as if they were collected using a parallel method.

Linear anomalies can be avoided by combining two instruments, one measuring the even, and the other the odd traverses in the parallel acquisition method.

Despite the high accuracy that global navigation systems offer, it is advisable to use absolute stations. Current commercial navigation systems do not satisfy the accuracy required by archaeological research. In addition, their accuracy is directly affected by the environment and the weather.

BIBLIOGRAPHY

Burks, J. 2014
Geophysical Survey at Ohio Earthworks: updating Nineteenth Centure Maps and Filling the "Empty" Spaces, *Archaeological Prospection* 21: 5-13.

David, A., Linford, N. and Linford, P. 2008
Geophysical survey in archaeological field evaluation, *Archaeological Prospection* 16: 139-140.

GSM-19 v 7.0 Instruction Manual. 2008
GEM Systems, Inc. Advanced Magnetometers.

Isaaks, E. and Srivastava, M. 1989
An Introduction to Applied Geostatistics, New York: Oxford University Press.

McCullough, R. 2007
Geophysical survey and limited test exvatinos to locate the Hargrove Cemetery on a land parcel in the Patoka River National Wildlife Refuge and management Area near Oakland City, Gibson Country, Indiana, Ph.D Tessis, Indiana University.

Smekalova T.N., Voss O. and Smekalov S.L. 2008
Magnetic surveying in archaeology. More than 10 years of using the Overhauser GSM-19 gradiometer, *2nd revised edition*, St. Petersburg: Publishing House of the Polytechnical University.

Urquhart, T. 1988
Decorrugation of enhanced magnetic field maps, *58th Annual International Meeting*, Society of Exploration Geophysicists, Expanded Abstracts: 371-372.

Vasiljević, I. 2013
Definisanje arheoloških objekata na lokalitetu Kremenite njive primenom geofizičkih ispitivanja, Master rad, Rudarsko-geološki fakultet, Univerzitet u Beogradu.

REZIME

PREDNOSTI I MANE PARALELNOG I CIK-CAK POSTUPKA AKVIZICIJE U HODAJUĆEM MODU PRI MAGNETOMETRIJSIM ISPITIVANJIMA U ARHEOLOGIJI

KLJUČNE REČI: MAGNETOMATRIJSKA ISPITIVANJA, CIK - CAK I PARALELNA AKVIZICIJA U HODAJUĆEM MODU, LINEARNE ANOMALIJE, ARHEOLOGIJA.

Korišćenje materijala izrađenih od gvožđa tokom ljudske istorije omogućilo je uspešnu primenu magnetometrije za arheološko rekognosciranje. Pored gvozdenih materijala, veoma je bitno prisustvo male količine magnetičnih minerala iz grupe gvožđe-oksida i gvožđe-sulfida, organskog ili neorganskog porekla, koji prouzrokuju razliku u magnetskoj susceptibilnosti arheoloških objekata i sredine koja ih okružuje.

Tačnost magnetometrijskih istraživanja je u direktnoj vezi sa tačnošću instrumenata, a jedan od instrumenata sa osjetljivošću od 0,02 nT je magnetometar *Overhauser GSM-19G* kanadske firme *GEM-Link*. Prema teoriji protonske precesije, na čijim je fizičkim osnovama zasnovan ovaj instrument, orijentacija sonde u vanekvatorijalnim područjima ne bi trebalo da utiče na kvalitet podataka. Pri magnetometrijskim merenjima, hodajućim načinom uzorkovanja, uočena je pojava linijskih anomalija duž profila. Da bi se došlo do adekvatnog zaključka šta prouzrokuje ove linijske anomalija i kako ih prevazići, na ranije ispitanom arheološkom lokalitetu Kremenite Njive (u blizini Barajeva, Republika Srbija), formiran je istražni poligon dimenzija 25 x 25 m. Akvizicija je obavljena gradiometrom, hodajućim načinom uzorkovanja, korišćenjem različitih postupaka merenja u zavisnosti od orijentacije profila u odnosu na magnetski meridijan u kombinaciji sa i bez *Global Positioning System*-a (GPS).

Linearni metod interpolacije je najčešći izbor

interpolacije pri obradi magnetometrijskih podataka za potrebe arheologije. Uz ovu interpolaciju često idu i linijske anomalije duž profila. Najčešće se prevazilaze svođenjem pojedinačnih profila na srednju ili medijalnu vrednost. Prilikom obrade podataka sa prostora Kremenite Njive ova tehnika se pokazala kao neuspešna. Mnogo bolji podaci su dobijeni primenom dekorugacije tj. filtriranjem uskopojasnim linearnim filterom *moving average* u pravcu akvizicije i u pravcu upravnom na pravac akvizicije. Uočeno je da se upotrebom nelinearne interpolacije mogu izbeći linijske anomalije duž profila. Na istražnom poligonu najboljim se pokazao *local polynomial* metod intertpolacije.

Ukoliko se žele izbeći linijske anomalije u hodajućem modu akvizicije potrebno je primeniti paralelan postupak akvizicije podataka u hodajućem modu uz korišćenje apsolutne geodetske stanice, jer trenutni komercijalni navigacioni sistemi ne zadovoljavaju tačnost koja je neophodna za arheološka istraživanja.