Controlled magnetic survey on Geophysics tests sites of the Federal University of Paraná, Brazil: combining analytic signal and vertical integration for location of ferrous-based targets

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This paper was prepared for presentation during the 17th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, 16-19 August 2021.

Abstract

Magnetic data is often the best technique for investigating ferrous-based targets for engineering, geological, forensic or archeological issues. For this purpose, controlled buried objects may be helpful for field training, data filtering and depth estimative. We have done a terrestrial survey at the geophysics tests sites of the Federal University of Paraná, and experienced the 3D inversion of transformed magnetic data, by combining analytical signal and vertical integration. In this first approach, such unconventional input data provided reasonable target recovery, in spite of the smoothness given by the vertical integration. We conclude that ASVI and VIAS are likely affordable for application in near-surface investigations, at least for the detection of forensic or archeological targets.

Introduction

Magnetic survey has long been employed for several non-intrusive studies evolving all sorts of ferrous-based buried objects or obstructions, such as the detection of pipes, metal barrel, and buried weapons. Location and discrimination of such metallic objects are important for *i.e.*, civil construction purposes, investigation of archeological sites, or mapping of unexploded ordnance. In this way, geophysical controlled experiments have been used to explore the feasibility of detection of possible targets (*e.g.*, Cavancanti *et al.*, 2018; Canata *et al.*, 2020).

This research was developed at the controlled geophysics site of the Laboratory of Research in Applied Geophysics (LPGA), which is based in the Polytechnic Center campus of Federal University of Parana (Brazil). The studied area has about 240 m^2, and 27 artifacts for forensic and archeological studies.

A total of five ferrous-based targets were buried (about 0.30 and 0.37 m deep from the top): paint containers with varied metallic objects, metallic drum with varied metallic objects, a plastic drum with small-sized damaged firearms (<20 cm), an empty steel drum, and a wooden box with damaged rifles (Figure 1). Non-magnetic artifacts are fossils, t-shirt, fire extinguisher and ceramic vessels. Although the metallic composition of the fire extinguisher, this type of article is usually made by stainless steel. Therefore, we expect this target is not magnetically anomalous.

The geological background of the geophysical research site is composed by clayey sediments of the Guabirotuba Fm. (Bigarella *et al.*, 1961) over migmatites and gneiss from the Atuba Complex. Due to the clayey soil, sand was placed around some artifacts, in order to better understand the impact of those sedimentary backgrounds for GPR research (Canata, 2020, Canata *et al.*, 2020). However, for magnetic studies, the geophysical signal is unaffected by such soil changes.

Methods

Data acquisition and processing

The terrestrial magnetic records were acquired in 2019, supported by a two-person team with a nuclear precession or protons magnetometer sensor (GEM-Systems GSM-19T magnetometer, Gem Systems). Magnetic daily variation was measured in a base station (magnetometer ENVI-VLF MAG magnetometer, Scintrex). The data was line-to-line levelled using Oasis Montaj™ facilities, with final crossing errors between -10.71 and 12.97 nT of maximum error. The final dataset has 552.39 meters of leveled data, distributed as 34 lines and 8 tie-lines. Data files and processing report is being prepared and will be available soon at the LPGA website (http://www.lpga.ufpr.br/).

From the total magnetic anomaly, a first-degree polynomial surface was subtracted, in order to remove the regional magnetic signature. Such regional trend is interpreted as the magnetic influence from the next to the studied area (top left corner of the zoomed area on Figure 1). The resulting anomaly was applied for the reduced-to-pole (RTP; Baranov and Naudy, 1964), analytic signal amplitude (ASA, Nabighian, 1972, Roest *et al.*, 1992), and vertical integral (VI; Silva, 1996) filtering.

RTP and ASA filters were done in order to centering magnetic positive anomaly directly above the targets. For the RTP, we consider declination and inclination as -19.8º and -38.2, respectively, based on the International Geomagnetic Reference Model (IGRF). Beyond classical ASA filter, this filter was combined with vertical integral of the magnetic field, as illustrated in Paine *et al.* (2001): the vertical integral of the analytic signal (VIAS) and the analytic signal of vertical integral (ASVI).

ASVI and VIAS are based on vertical integral filter. Accordingly, they have a tendency to smooth the magnetic

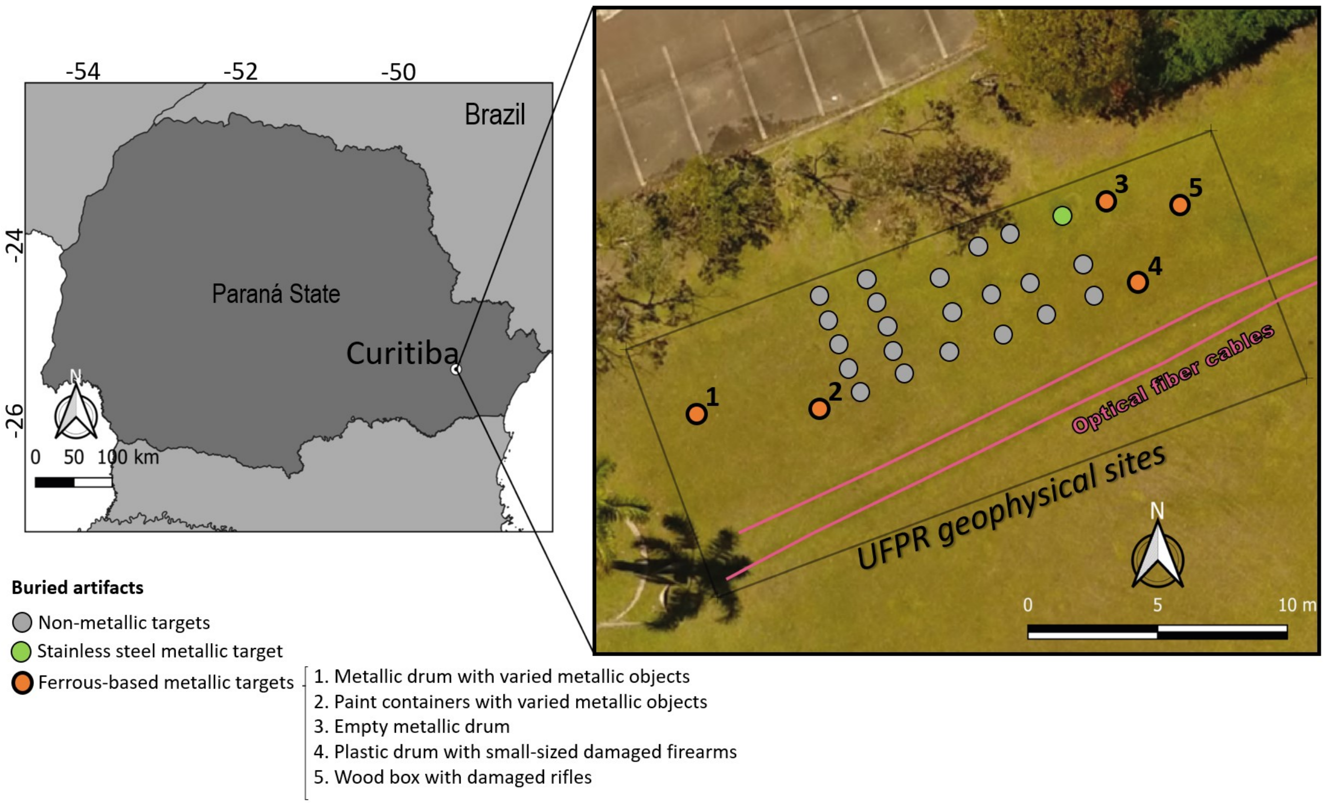

Figure 1 – Buried magnetic targets and other geophysics test sites at Polytechnic Center (UFPR), Curitiba, Paraná. Background image from http://www.campusmap.ufpr.br.

anomalies. On the other hand, it is based on ASA, which is a well-known technique used for map location of remnant magnetic sources. Application of ASA filter usually improves the similarity between the positive magnetic anomaly and the geometry of the target. Therefore, ASVI and VIAS can be appropriate for modelling remnant magnetic sources (Paine *et al.*, 2001).

3D modelling

Local 3D magnetic modeling was done in order to make in-depth investigations. Since the lack of discussion about ASVI and VIAS in literature, and general concerns about the applicability of transformed data for depth estimative, we take the opportunity to test ASVI and VIAS as the input data for 3D modelling.

In this work, we have applied the VOXI Earth Modeling, an Oasis Montaj^{TM} tool for geophysical inversion. The 3D inversion was done using a 0.52 mesh grid, and maximum of 5 meters depth. The intensity of the magnetic field was taken from the IGRF model (22609 nT).

Since VIAS and ASVI had centered the dipoles, it is assumed a polar-like magnetization for these anomalies (Paine *et al.*, 2001).

Results

The resulting magnetic maps are shown on Figure 2. The major features are two relatively high-amplitude anomalies to the west, and lower magnetically anomalies to the east. Concerning the five Fe-based targets, three distinguished anomalies are from paint containers with varied metallic objects and metallic drum with varied metallic objects (western part), and the group of damaged firearms (eastern part). From the sites with metallic drum and plastic drum with small firearms, they have lower amplitude response. At least in the 2D magnetic data, the steel drum could be recognized as a magnetic source, but the plastic drum with small firearms cannot be differentiated from other small-amplitude variations.

From the 3D inversion (Figure 3), the spatially distributed magnetic susceptibility has recovered anomalies related to four of the five targets as referred on Figure 1: painting containers (2), metallic drums (1 and 3) and the damaged rifles (5). There was no significant result for the target 4 in the 3D inversion. VIAS had higher magnetic amplitude, while amplitude in ASVI data is similar to the original magnetic anomaly an the calculated RTP.

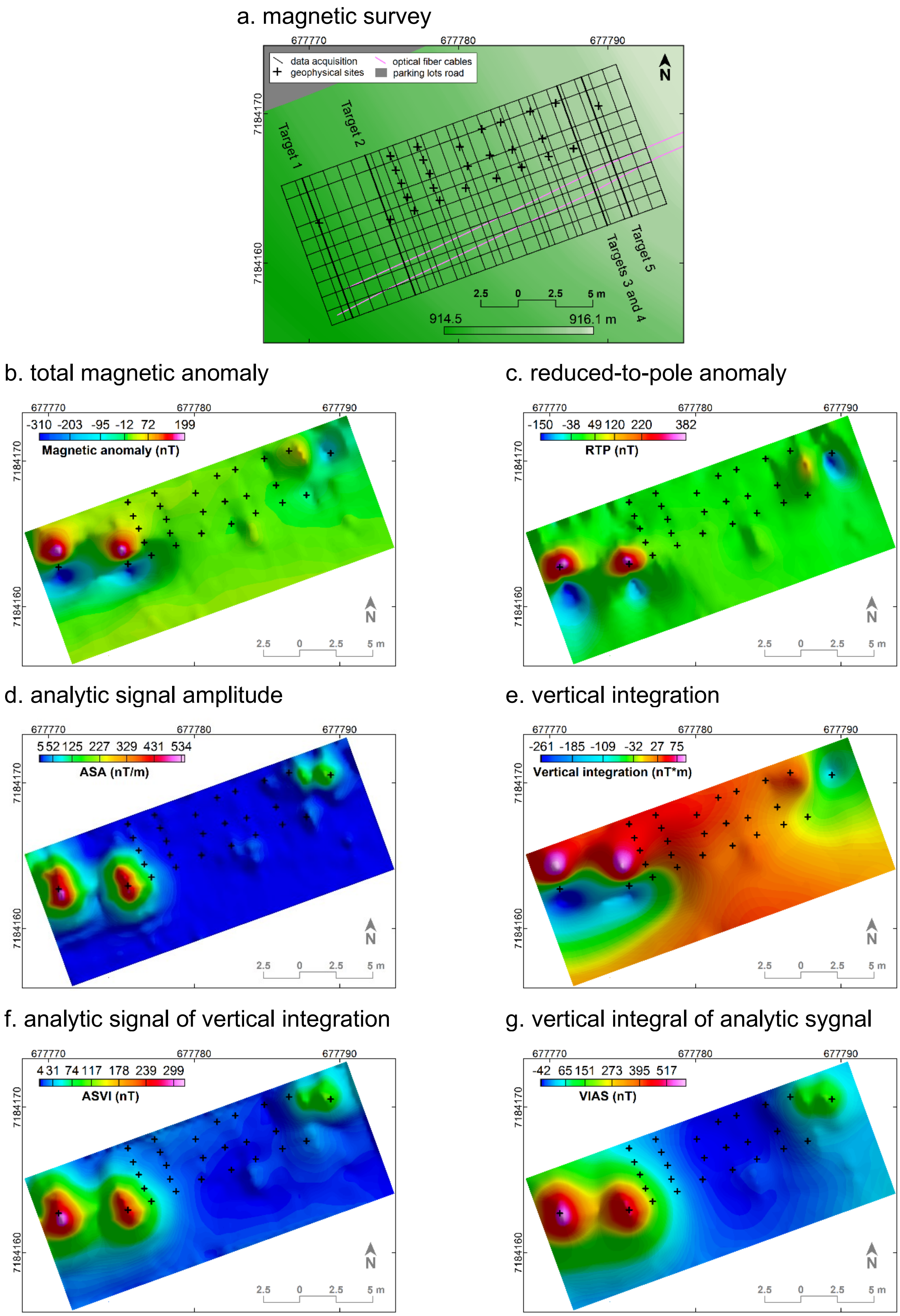

Figure 2 – Magnetic data maps.

Discussion

The two well-defined dipolar anomalies to the west are in accordance to the induced field in the Southern hemisphere. On the other hand, the eastern anomalous area has a sort of composite magnetic signature. From Figure 2, ASVI and ASA maps seem to better represents the five Fe-based targets.

In this first approach, we have noticed a reasonable depth estimative for sites 1, 2, 3 and 5 in the 3D inversion. From these sites, the best estimative was for the target 5 (Figure 3.d), and the less accurate estimative was the site 3 (Figure 3.c). In the case of the site 3, we have discussion on literature about limitations in the detection of the geometry of a thin metallic sheet (Eskola, 1993). On the other hand, since the top of the magnetic targets are about 30-35 cm from the surface, our Team is working on other modelling techniques in order to reach high-resolution models. Despite of that, the most relevant aspect of this study is to raise alternative techniques for location of magnetic targets. Also, ASVI and VIAS filters seems to be useful, for instance, for application in forensic and archeological studies.

It is important to point out that the smoothness given by the vertical integral increases the wavelength of the magnetic anomaly, in comparison to the RTP method. A potential consequence can be distortions on the source geometry and depth. However, VIAS and ASVI can be useful for defining complex geological bodies or strong remnant effects (Paine *et al.*, 2001). Also, a careful choosing of the integrated window may avoid the overestimation of depth, in case of individual magnetic sources.

Using the original data as the input for 3D modelling is always preferred, against a transformed magnetic data. However, entering raw magnetic anomaly require a good processing of the dipolar magnetic anomaly in order to provide good recovered depths. In the case of geological targets, the inversion technique must also consider possible effects of remanence from a unique or several sources. For this purpose, there are techniques for inversion of magnetic vector (*e.g.*, Ellis *et al.*, 2012). Nevertheless, ASVI and VIAS demonstrated a direct association between the positive magnetic anomaly on map and the high-magnetized estimated source in depth. It may simplify the understanding of the magnetic source geometry since the first steps of the magnetic interpretation. As a result, this study supports the application of this type of transformed magnetic data for near-surface targets in forensic and archeologic applications.

In summary, the remarkable advantages in using ASVI and VIAS are:

a) the general good centering of the anomaly above the target and modelling results, avoiding the assumption of non-remnant magnetic sources;

b) ASA and vertical integral filters are standardly applied for magnetic data, and therefore they are accessible for students and other professionals;

c) their results are suitable for using in inversion algorithms, especially as a first approach for unknown magnetic targets.

Conclusions

From this magnetic survey, we observe the perturbation in the total magnetic field caused by ferrous-based materials, which anomalies were modelled in tree-dimensions.

In this work, the controlled geophysical tests sites allowed the testing of in-depth investigation techniques. The integrated analytic signal and vertical integration filtering provides reasonable results on map and also as an input for depth estimative by 3D modelling. We conclude that ASVI and VIAS transformed data have potential applicability for estimation of near-surface magnetic targets, such as in forensic investigations.

The magnetic dataset acquired in the LPGA geophysical tests sites is a contribution for the scientific community, working as a free educational resource for students and society.

Acknowledgments

The authors would like to thank the Federal University of Paraná, CNPq and CAPES for their continuous support to our activities in the Laboratory for Research in Applied Geophysics. This research was partially supported by R.E. Canata’s fellowship from the Coordination for the Improvement of Higher Education Personnel, CAPES.

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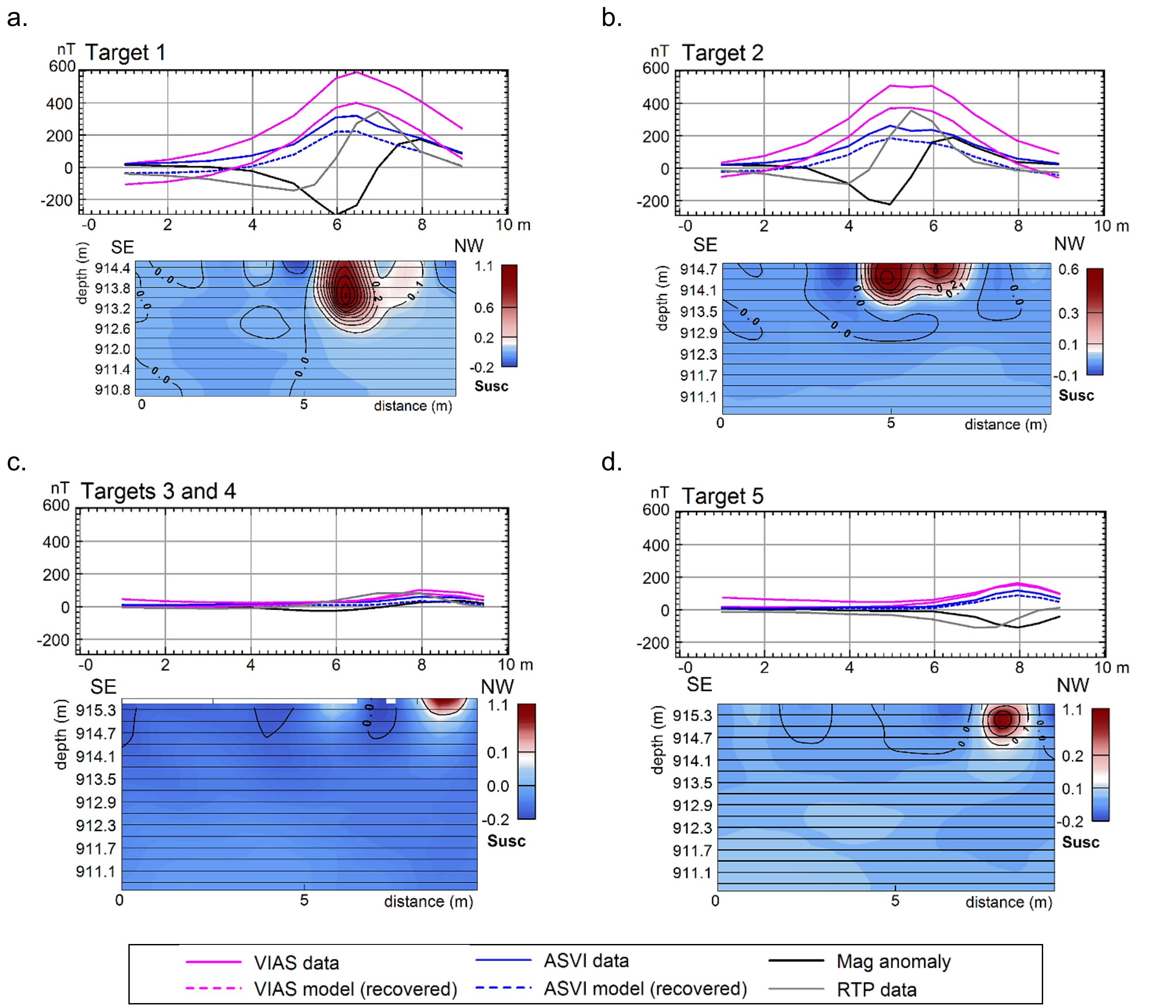

Figure 3 – 2D sections and profiles from the 3D inversion for the location of Fe-based targets. Graphics: results from 3D inversion of ASVI and VIAS, and curves from the total magnetic anomaly and RTP for comparison. Target locations as referred on Figure 1, and profiles as shown on Figure 2.a. 3D sections: the section above each profile was extracted from ASVI 3D solution (contrasting susceptibility); horizontal lines are 30 cm self-spaced in order to facilitate depth evaluation, concerning the distance from the surface to the top of metallic targets about 30-35 cm.