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Processing and visualisation of data

Role of potential field derivatives in delineating buried archaeological ruins

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KEY-WORDS: total magnetic field, potential derivatives, tilt derivatives, analytical signal amplitude, total horizontal derivative, generalized derivative

Potential field derivative techniques are intensively used in various geophysical large-scale investigations. The current work applies some of these techniques to small-scale high-resolution surveys commonly conducted in archaeological prospection and environmental investigations. The techniques include: spatial orthogonal derivatives, analytical signal amplitude (ASA) (Nabighian 1972; Roest *et al.* 1992), total horizontal derivative (THDR) (Cordell and Grauch 1985; Phillips 2000), tilt angle derivative (TDR) (Miller and Singh 1994; Wijns *et al.* 2005), total horizontal derivative of TDR (TDR-THDR) (Verduzco *et al.* 2004), horizontal tilt angle (TDX) (Cooper and Cowan 2006), tilt angle of total horizontal derivative (TAHDR) (Ferreira *et al.* 2010; Cheyney 2012; Jacques *et al.* 2014), and generalized derivative operator (GDO) (Cooper and Cowan 2011).

A high-density total field magnetic survey was conducted at an ancient Egyptian archaeological site located in northeastern Sinai. The region is part of the old delta of the river Nile (Aziz *et al.* 2013). The chosen site was proposed by field archaeologists, aiming to delineate the eastern extension of the buried southern wall of Tjarou citadel (Abd El-Maksoud and Valbelle 2005). The citadel was erected mainly of mud brick, resulting in a low magnetic susceptibility contrast between the buried wall and the surrounding fill (Shendi and Aziz 2010).

A proton precession magnetometer was used to measure the total magnetic field. The instrument is also equipped with two sensors to measure the vertical gradient of the magnetic field. Three squared grids, covering an area of 20 m by 60 m, were laid out. The shortest side of the surveyed grids was parallel to the course of the wall: N80⁰ E. Traverses were surveyed perpendicularly to the wall azimuth, and were spaced 0.5 m apart. Measurements were recorded every

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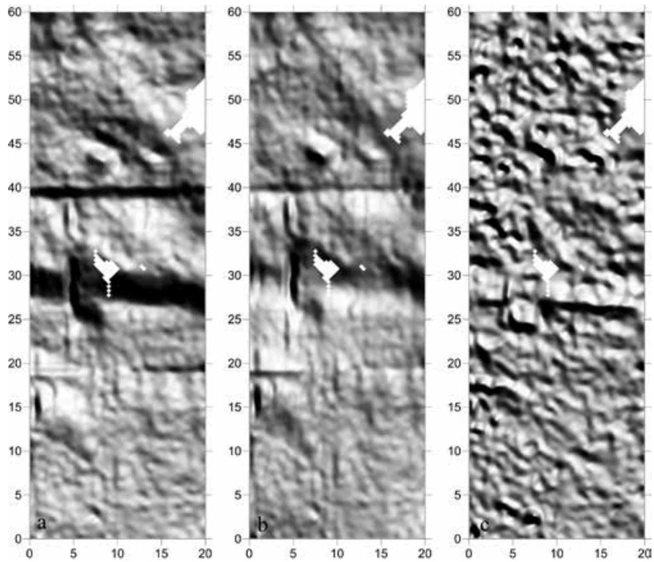

Fig. 1: a) Total magnetic field anomaly map; b) total magnetic field after reduction to the pole, c) actual vertical magnetic gradient measured in the field

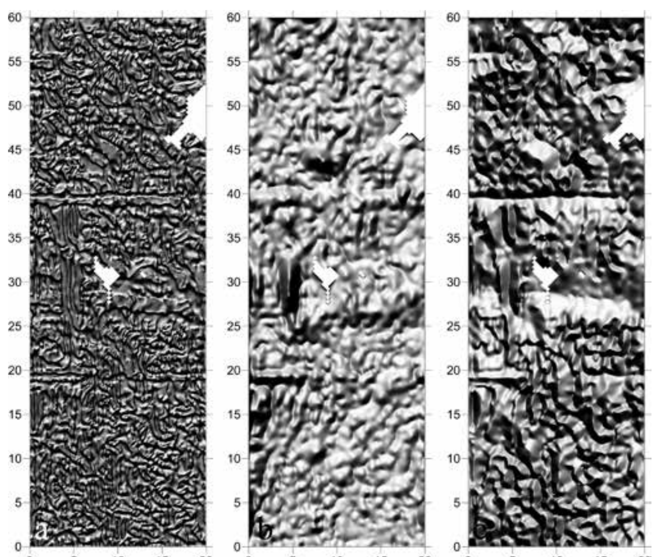

Fig. 2: a) Total horizontal derivative map $THDR = \left((\partial T/\partial x)^2 + (\partial T/\partial y)^2\right)^{1/2}$; b) analytical signal amplitude map $ASA = \left((\partial T/\partial x)^2 + (\partial T/\partial y)^2 + (\partial T/\partial z)^2\right)^{1/2}$, c) tilt angle derivative map $TDR = \cos^{-1}(THDR/ASA)$

0.5 m along each traverse. The acquired total magnetic field measurements were corrected for the effect of diurnal fluctuations of the Earth's magnetic field. The corrected data were reduced to the pole to eliminate the effect of the inclination and declination of the Earth's magnetic field. Oasis Montaj software was used to carry out the computation of derivatives and illustrate the results in black and white shaded relief maps (Figs 1, 2 and 3).

Examination of derivative mapping revealed more information about the buried sources of anomalies than those deduced from the original total magnetic map or the actual vertical gradient map. The spatial derivative map on the Y axis (northward) emphasizes the E–W azimuth of the wall. While both the orthogonal derivatives on the Y and Z axes showed that the buried wall had a higher magnetic susceptibility than its surroundings. THDR and ASA maps enhanced the edges of the subsurface magnetized bodies, and both were invariant with field inclination. Edge enhancement of the THDR map was approximately depth independent; while ASA enhanced the shallower and larger objects more than the deeper ones. Inflections of the TDR from positive, over the wall, passes through zero, over or near the edge, are superimposed by zero vertical derivative and maximum Y horizontal derivative. Negative horizontal Y derivative values are outside the source region. THDR contacts that overlie the analytical signal amplitudes ASA contacts indicate that the edges of the wall are vertically dipping. TDR-THDR and TAHDR show sharper delineation of the edges. GDO produces good horizontal locations for contacts and edges, independently of dip, inclination and depth. In addition, it is less susceptible to noise, and clarified other buried deeper and smaller walls, even if they have different runs, that is, not perpendicular to the direction of the surveyed traverses.

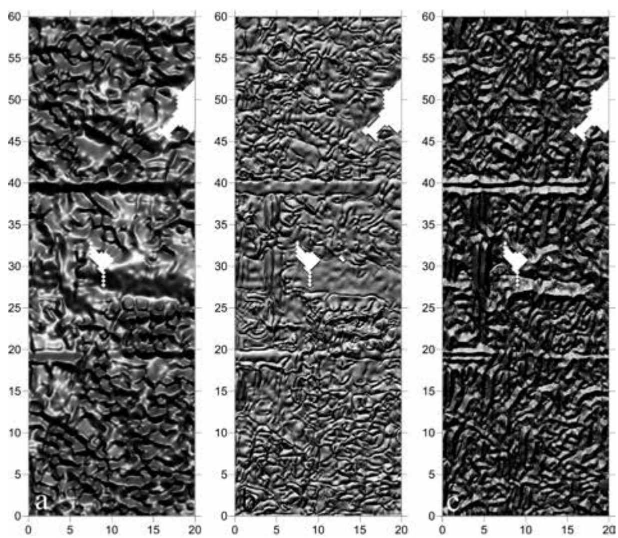

Fig.3: a) Generalized derivative operator $GDO = \frac{1}{ASA} * \left(\left(\frac{\partial T}{\partial x} \sin(\alpha) + \frac{\partial T}{\partial y} \cos(\alpha) \right) \cos(\beta) + \frac{\partial T}{\partial z} \sin \right.$, where α and β are the azimuth and the dip of the filter in the horizontal plane; b) total horizontal derivative of tilt angle $TDR\_THDR = \left((\partial TDR / \partial x)^2 + (\partial TDR / \partial y)^2 \right)^{1/2}$; c) tilt angle of total horizontal derivative $TAHDR = \tan^{-1}\left((\partial TDR / \partial z) / TDR\_THDR \right)$

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