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Testing of multi-coil FDEM sensors on a field model with magnetic susceptibility contrast

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Jörg Rühlmann *** and Jean Bourgeois ****

Key words: Electromagnetic induction sensor, Magnetic susceptibility, Coil orientation, Coil separation, Spatial sensitivity.

Introduction

The main advantage of frequency domain electromagnetic induction (FDEM) sensors is the simultaneous measurement of both electrical conductivity and magnetic susceptibility. Nevertheless, this sensor type is still not routinely used in geoarchaeological prospection (English Heritage, 2008). Although both the electrical conductivity and the magnetic susceptibility measurement has been related to electrical resistivity and magnetometer measurements respectively (Kvamme, 2006), these relationships are not always straightforward (Linford, 1998). The recent development of multiple coil instruments creates new opportunities for archaeological prospection (Simpson *et al.*, 2009) but at the same time complicates the interpretation of the different signal responses. (Tabbagh, 1986) investigated the response of different coil orientations to layered-earth and three-dimensional objects with theoretical modeling for a 1.5 m coil separation. But an exhaustive study with different sensor configurations on field models was not conducted until now. Our aim is to present different FDEM sensor measurements over an object with magnetic susceptibility contrast constructed in a test site, to evaluate the effect of the coil configuration. A fluxgate gradiometer survey was also conducted for comparison.

Experimental setup

The test site was located in Großbeeren, close to Berlin (Germany). The soil consisted mainly of glacial till deposits of coarse sand with a minor fraction of poorly sorted stones. Therefore, the soil electrical conductivity was in general very low (< 10 mS m^{-1}). The magnetic susceptibility was fairly uniform over the test field, with higher values in the topsoil. Several objects were dug in to act as models for typical archaeological features, but here only one will be discussed. This object had a rectangular shape of 5 m in length, 0.5 m width and 0.5 m depth; it represented wall remains below the plough layer. A trench was dug of 0.8 m depth (Fig. 1) and filled with basalt powder up to 0.3 m depth, after which the remaining 0.3 m was filled up with the original topsoil. The volumetric magnetic susceptibility (χ) of the soil profile and the basalt was measured with a handheld instrument (kappameter KT-6, SatisGeo). The basalt had a χ of 0.01 (SI), which was significantly higher than the soil χ (smaller than 0.001 SI).

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Two FDEM sensors were applied to test different coil configurations with a fixed transmitter frequency; the EM38-MK2 (Geonics Limited) and the DUALEM-21S (Dualem inc.). The former instrument has two coil separations of 0.5 and 1 m in horizontal coplanar (HCP) orientation or in vertical coplanar (VCP) orientation, if rotated 90 degrees. The latter sensor can measure two coil separations (1(.1) and 2(.1) m) in two coil orientations, HCP and perpendicular (PERP), or when rotated 90 degrees in VCP orientation (and NULL orientation). Both sensors record the in-phase as well as the quadrature-phase response (proportional to χ_a and σ_a respectively). The sensors were operated at 0.2 m height on a hand-pushed cart with a dGPS, parallel to the survey lines and perpendicular to the length of the trench. The in-line distance was maximally 0.1 m and the cross-line distance 0.5 m.

The magnetic gradiometer measurements were conducted with a Fluxgate FM18 (Geoscan Research) at 0.25 m in-line and 0.5 m cross-line distance on a fixed grid.

Results

The background value of the magnetic measurement was subtracted to be able to compare the magnitude of the object's response (Fig. 2). Three criteria were used to evaluate the different sensor responses: absolute magnitude, compactness and changing direction (resulting in positive and negative values). The responses to the magnetic object differed a great deal between the different sensor configurations. The 1.1 m PERP (Fig. 2a) and 2 m HCP (Fig. 2d) showed the strongest response and a compact, unidirectional pattern (the 2 m HCP had a slight negative dip outside the strong, positive response). The 1 m VCP configuration was not as strong, but was unidirectional and compact. Other configurations either suffered from low signal magnitude (Figs 2c, g and h), a wide anomaly (Figs. 2b and f) or a bidirectional response pattern (Figs 2b, c and f). The gradiometer anomaly was as expected very strong and with the typical bidirectional response. Based on these results, we concluded that the coil configuration of a FDEM sensor has a very large impact on the detection of small, magnetic contrasts.

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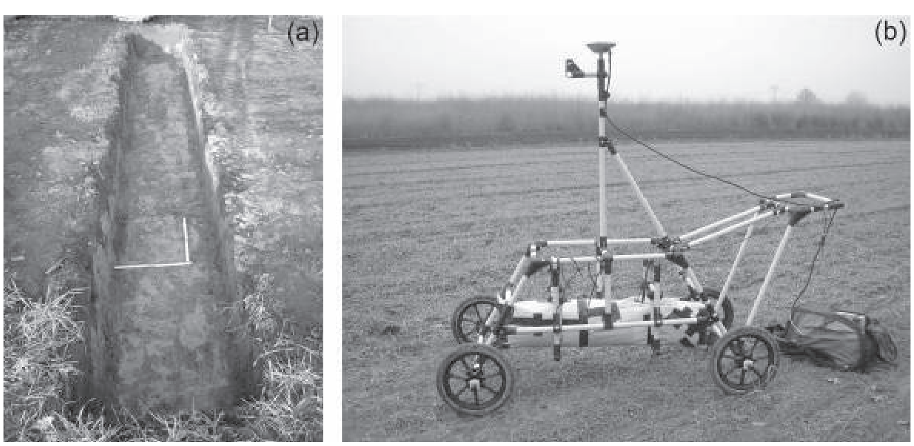

Figure 1: (a) Trench before filling up with basalt and topsoil. The length of the ruler is 0.4 m. (b) Non-metallic cart (made in the Institute of Geosciences, University of Potsdam) with the EM38-MK2 wrapped in plastic, a GPS-antenna above and a GPS and field computer in a backpack.

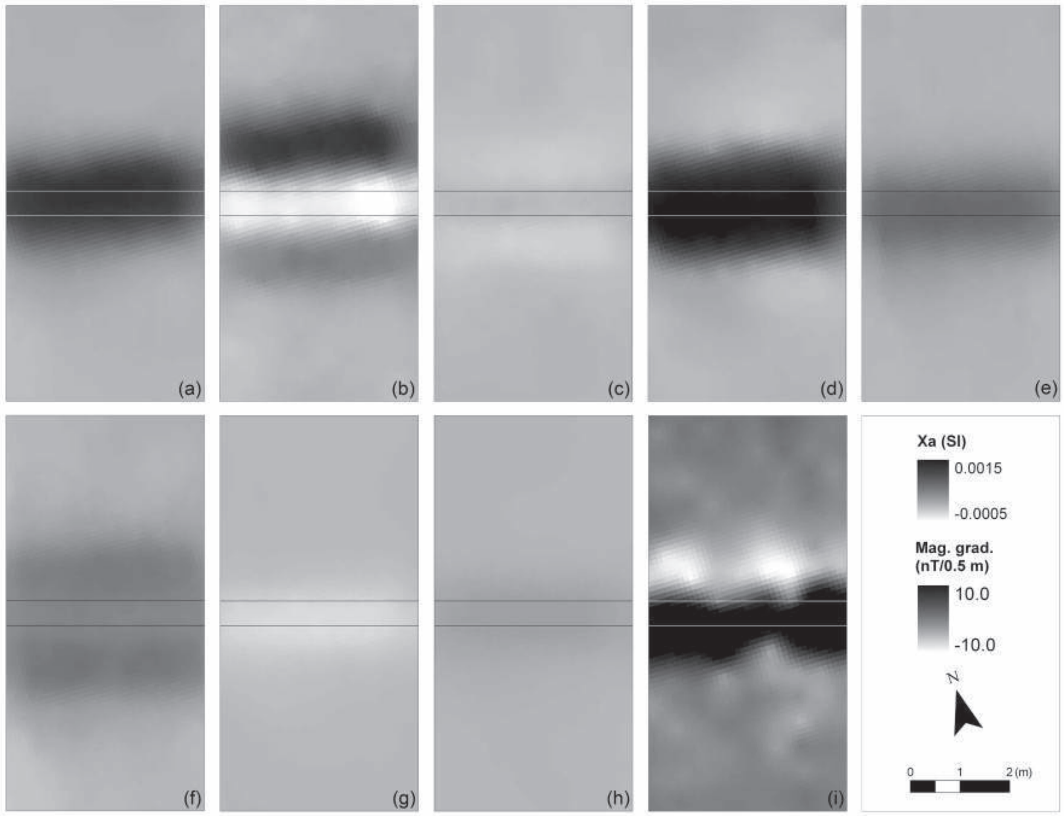

Figure 2: In-phase response of (a) 1.1 m PERP, (b) 2.1 m PERP, (c) 1 m HCP, (d) 2 m HCP, (e) 1 m VCP ,(f) 2 m VCP, (g) 0.5 m HCP, (h) 0.5 m VCP. (i) Fluxgate gradiometer.