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Interpretation of high-resolution low-altitude helicopter magnetometer surveys over sites contaminated with unexploded ordnance

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ABSTRACT

Throughout the world, millions of acres of potentially productive land are contaminated with unexploded ordnance due to either past conflicts or to military training activities. Low-level helicopter magnetometry (HeliMag) is currently being used to rapidly survey large areas and identify regions that are potentially clear of hazardous munitions. One configuration currently in use comprises seven cesium vapor magnetometers, horizontally spaced 1.5 m apart and mounted on a boom several meters in front of a Bell 206L helicopter. Magnetometer data are collected at 400 Hz at altitudes as low as 1.5 m above the ground along transects spaced 7 meters apart. From this dense, high-resolution data, potential metallic targets as small as a 60 mm mortar are identified using manual and/or automatic target picking methods. The target picks are then used to estimate densities of potential contamination. 100% detection is generally not feasible, so that HeliMag is usually applied in a characterization rather than in a clearance mode. We describe a HeliMag survey collected over a UXO contaminated site at Yekau Lake, near Edmonton, Canada. The objective was to identify the location and extent of an 11.5 pound bomb target area at a former training range. The target density estimates derived from manual picks were strongly influenced by geology and clutter and did not reflect the underlying density of ordnance and ordnance related clutter. By fitting a dipole model to each target pick, and comparing it to the expected response of the target item, we could estimate the density of objects with similar size/shape to an 11.5 pound bomb. This analysis clearly identified an area of elevated contamination in the same region where 11.5 pound bombs were found during ground reconnaissance. In summary, the new methodology significantly improves the interpretability of HeliMag data when used for UXO site assessment.

1. Introduction

Unexploded ordnance (UXO) poses a significant public safety hazard in many parts of the world. UXOs occur on or near the surface and buried to depths of several meters. One source of UXOs is armed conflicts both old (World Wars I and II) and more recently in regions such as, the Middle East, Southeast Asia, Afghanistan, the Balkans, and parts of Africa. They are also a significant problem in countries such as Australia, Canada and the USA, where they are present in areas used for military training and firing ranges. For instance, it is estimated that 15 million acres of land in the USA are potentially contaminated by UXO with a cleanup time-frame in the decades and a staggering cost estimate, using existing technology, in the tens to hundreds of billions of dollars (Delaney and Etter, 2003).

In recent years, there has been a major effort to return large sections of potentially contaminated land over to productive use. Wide Area Assessment is a multi-tiered process whereby fixed-wing, helicopter and ground-based surveys are sequentially used to rapidly characterize large sites and locate areas of potential UXO contamination (Hodgson et al., 2004). Low-level helicopter magnetometer surveys are an important and integral part of this process. They allow large areas to be rapidly screened and are capable of detecting both surface and subsurface ferrous ordnance and ordnance-related scrap (such as shrapnel, ferrous target debris etc.).

In this paper we describe a helicopter magnetometry (HeliMag) survey conducted over a UXO contaminated site at Yekau Lake, near Edmonton, Canada. The objective was to identify the existence, location and extent of the bombing target used for training of airborne delivery of 11.5 pound bombs. In the first part of the paper we describe the HeliMag system we deployed. We then describe the Yekau Lake survey and the initial, standard, interpretation of that data. We then present a more advanced dipole-based analysis that allowed us to extract more informative results from the survey and that indicated the possible presence of an 11.5 pound bombing target.

2. HeliMag surveys for UXO detection

Buried UXO produces anomalies in the earth's magnetic field that are appropriately described by a dipolar model. This has been

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exploited by using target-fitting algorithms that accurately recover the location of the object, as well as its predicted depth, size and equivalent dipole orientation. This information aids greatly in site remediation by allowing development of an accurate, prioritized dig program (Nelson et al., 1998; Billings, 2004). These advanced data analysis techniques have been successfully deployed in support of UXO remediation activities using ground-based total-field magnetometer arrays that incorporate state-of-the-art global positioning systems (GPS). In an effort to expand this capability to include surveys over large tracts of land and over areas that may be unsuitable for vehicular towed systems, the HeliMag airborne UXO detection system was developed.

Airborne systems necessarily have greater sensor/target stand-off distances resulting in reduced resolution due to diminished anomaly amplitudes and spreading/overlapping of magnetic responses from adjacent sources. This effect is illustrated in Fig. 1 where we show a vertical cross section of the magnetic field taken in a north–south direction over a small (60 mm mortar) UXO item. We can see that the magnetic field at 0.25 m altitude has considerably more resolution than it does at altitudes greater than 1 m above ground level. The efficacy of airborne techniques juxtaposed with ground deployments is explained in more detail in Wright et al. (2003).

Detection of individual UXO targets is a function of the signal-to-noise ratio (S/N) of the magnetic response. The signal amplitude is extrinsic to the sensors and is a function of UXO size, orientation and offset distance. The intrinsic HeliMag noise is such that, at survey altitudes greater than 1 m, the dominant noise source is typically due to extrinsic factors such as local geology and/or anthropogenic clutter. This extrinsic noise is highly variable and ranges from less than 1 nT at some sites to several tens of nanoTesla at other sites (or even parts of the same site). Given the knowledge of local magnetic conditions and survey altitude limitations, we can predict the efficacy of the system for detection of various sized UXO targets. In Fig. 2 we show a series of graphs plotting nominal UXO caliber versus survey altitude for given detection thresholds. The latter is defined as the magnitude of the difference between the positive and negative lobes of the dipolar anomaly at the specified stand-off distance. This graph applies to the "worst-case" orientation, which has the long axis of the UXO oriented perpendicular to the ambient magnetic field. In this orientation, there is a large self-demagnetizing field which causes a large decrease in the net magnetization of the item. When the UXO is oriented with its low axis along the ambient field direction ("best-case" orientation), the self-demagnetizing field is smaller and the resulting net magnetization is larger (typically by a factor of five).

We use a Bell 206L series helicopter with an array of seven Geometrics 822A Cesium vapor total-field magnetometers housed in a Kevlar-reinforced composite resin boom. The sensor boom is mounted well forward of the helicopter to minimize interference from the aircraft rotor, engine and avionics (Fig. 3). The forward mounted design puts the boom in clear view of the pilot to allow precise, low-level flying in a safe manner. The magnetometers are evenly spaced at 1.5 m intervals. The data are logged at 400 Hz and de-sampled to 100 Hz after filtering of high frequency noise. The dominant intrinsic noise source is from the rotor-hub at a frequency of about 7.5 Hz and contributes peak-to-peak noise of between 1 and 3 nT (depending on the particular sensor and the helicopter

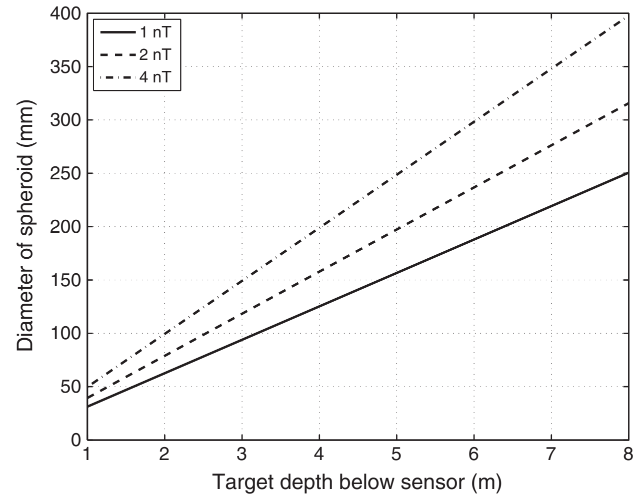

Fig. 2. Helimag survey planning tool showing minimum detected size as a function of sensor offset distance. The detection threshold is dictated by local magnetic conditions and survey altitude is dictated by site topographic and vegetation conditions. A prolate spheroid model with an aspect ratio of 3.5 was used to model the ordnance (Billings et al., 2006) and it was assumed to be in a "worst-case" orientation: long axis perpendicular to the ambient field.

Fig. 3. Bell 206L model helicopter collecting magnetometer data at Yekau Lake, Canada

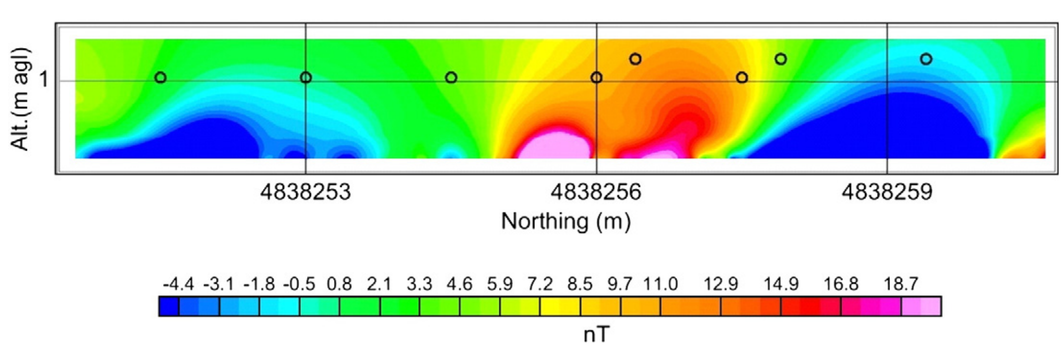

Fig. 1. North–south vertical cross section of the total magnetic field response due to an emplaced 60 mm mortar (centered at 4838256 N). Ground systems sample this field at 0.25 m AGL. The small circles represent Helimag measurement positions from two overlapping north–south survey passes. The cross section was obtained by upward continuation of the ground-based data.