Comparison of airborne magnetic and electromagnetic data from a bombing target  
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Summary

Airborne magnetic systems for mapping unexploded ordnance (UXO) and other shallow metals have been developed at Oak Ridge National Laboratory (ORNL) over the past five years. We have recently completed testing of a time-domain electromagnetic (EM) system to supplement the magnetic system for UXO investigations. The test was conducted at the Badlands Bombing Range (BBR) in South Dakota in September 2002. In this paper, we present a comparison of the magnetic and EM data from a bombing target within the BBR and suggest an approach for further integration of the two data sets, as well as opportunities for deploying this system for other types of surveys.

Introduction

UXO is a major environmental concern on former military test ranges as military bases have been scheduled for closure and re-development. By Department of Defense estimates, about 6 million hectares (15 million acres), are UXO-contaminated at 1500 sites in the United States alone (Bowers and Bidwell, 1999). Geophysical surveys, primarily magnetic or EM, play a key role in mapping ordnance locations for subsequent cleanup. For areas larger than a few hundred hectares, helicopter surveys can be an economic and time-efficient way to map ordnance, provided resolution is adequate to the task.

Since 1998, an ORNL-led team has focused on the development of low-flying helicopter geophysical systems for UXO detection, initially with magnetometry (Doll et al., 2001, Doll et al., 2002), and more recently with transient EM (Doll et al., in press, Beard et al., 2003) and magnetic vertical gradient systems (Gamey et al., 2003). The ORNL systems, collectively named the Oak Ridge Airborne Geophysical System (ORAGS) use multiple sensors to collect data at 1-3m above ground level with a density comparable to that of ground surveys. Instrumentation is housed in forebooms and sidebooms that are mounted directly to the helicopter (Figures 1, 2).

ORAGS-Arrowhead magnetic system

Our most advanced total field magnetometer system, the ORAGS-Arrowhead system (Figure 1) is an eight sensor system, with the magnetometers spaced 1.7 m apart. All data are recorded on a PC-based console that records the magnetic data at 1200 Hz sample rate and laser-derived altitude, GPS position, and a fluxgate magnetometer at lower sample rates. Raw data are downsampled to 120 Hz for processing. Navigation is directed by an Agnav RT-DGPS system with Racal satellite real-time correction. Aircraft position is recorded on the system console and updated by post-processing with a DGPS base station to provide 0.2m accuracy. An Ashtech ADU-2 GPS-based system is used to monitor the attitude of the system to provide accurate positioning for each sensor. Data are acquired at an airspeed of 30-50 knots, enabling full coverage of 300-600 acres per day on average during production surveys. Over areas of low vegetation and modest topography, typical survey altitudes average less than 2 m.

ORAGS-TEM System

The first helicopter EM system developed for UXO detection was a proof-of-concept system developed in cooperation with Geonics. This system, a two-receiver transient EM system based on the EM-61 described in
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detail in Doll et al. (in press), reliably detected medium to
large ordnance in a field trial at the former Badlands
Bombing Range (BBR) in South Dakota. Subsequent work
has aimed to improve on this design by using a larger
transmitter, by recording multiple time gates, and by
improvements in the electronics of the console. This led to
the development of the time domain system (ORAGS-
TEM). As shown in Figure 2, the system consists of a
transmitter loop wrapped around the outside of a
rectangular, 12 m x 3 m composite boom structure that is
attached to the underside of a Bell Long Ranger helicopter.
The transmitter coil may be arranged in a rectangular
geometry, or it may be affixed in a lobed configuration.
Two receiving channels are recorded with the current
system at 10.8 kHz sample rate. Test data were acquired at
base frequencies of 90 Hz and 270 Hz, although other base
frequencies can be used. Data can be stored at selected
time gates, or for the entire decay period. The ORAGS-
TEM was operated in two receiver configurations at BBR.
The ‘small coil’ configuration consists of multi-turn coils
measuring 23 cm x 60 cm mounted on a crossbeam
connecting the forward and rear transmitter booms, and
located 4 m from the helicopter centerline. The ‘large
loop’ configuration consists of a 2.7 m x 2.7 m single turn
loops affixed to the top and bottom of the outer part of the
boom assembly and crossbeam, and centered 4.9 m from
the centerline of the helicopter. For testing purposes, two
coils can be placed above one another for evaluation of
differencing methods.

The transmitter, receivers, and laser altimeter are integrated
via a console containing a PentiumIII-based computer, the
transmitter power supply, the transmitter driver board, and
a digital system control and acquisition board that governs
all system timing and performs digitization for EM receiver
coil outputs and auxiliary analog signals. The data from
the acquisition board, from GPS positioning, and from
altitude and attitude instrumentation are stored in a 60-
gigabyte hard disk

Field Demonstration

In September 2002, a field demonstration of the ORAGS-
Arrowhead and ORAGS-TEM systems was conducted at
the Badlands Bombing Range (BBR), South Dakota. Data
were acquired at a controlled test site (Beard et al, 2003),
and at one of the bombing targets on the BBR. A vertical
magnetic gradiometer system, the ORAGS-VG system was
also successfully demonstrated at BBR (Gamey et al.,
2003). In this paper, we are concerned only with the results
from the ORAGS-Arrowhead and ORAGS-TEM systems
at Bombing Target 1.

Bombing Target 1 (Figure 3) was used for training
missions in World War II. As a result, most of the
ordnance at the site are M-38 100 lb sand-filled practice
bombs. These contain approximately 10-15 kg of ferrous
iron, but much smaller fragments are also found at the site
as well as smaller ordnance items. The target is marked
with a circular berm and crosshairs (Figure 3) that is 1.0-
1.5m in height. A barbed wire fence passes through the
center of the target with an east-west orientation (Figure 4).
Some of the ordnance items have been removed from the
northern side of the fence during evaluation of previous
mapping projects. To our knowledge, the area south of the
fence has not been excavated for UXO, although it is part
of a field and is routinely plowed.

Data were acquired with the ORAGS-Arrowhead
magnetometer system over Bombing Target 1 and
processed to yield an analytic signal map (Figure 5). The
berm of the target yields a magnetic anomaly in the
northern half of the map area. The barbed wire fence
produces a strong anomaly across the center of the target.

Figure 3. Aerial photograph of Bombing Target 1.

Figure 4. ORAGS-TEM near the fence at Bombing Target 1.
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A map of the second time gate from the ORAGS-TEM data for Bombing Target 1 is shown in Figure 6. This represents the first deployment of the ORAGS-TEM system at a UXO target. Our processing approach for these data is not yet fully developed, and we anticipate incorporating later time gates into subsequent processing streams. Visual inspection indicates a strong correlation between the magnetic anomalies in Figure 5 and the EM anomalies in Figure 6. It is noteworthy that the fence produces a double peak in the EM data and a slightly narrower single peak in the magnetic data. The target berm does not produce an EM anomaly, in contrast with the magnetic response.

Figure 7 shows anomalies that have been picked from the magnetic and EM data sets. All anomalies along the fence line have been excluded. Magnetic anomalies are shown as red circles, and EM anomalies are represented by blue triangles. In both cases, symbol size is proportional to the log of the signal amplitude. A threshold of 5nT/m was used for the magnetic data, and a threshold of 3mV was used for picking the EM data. A total of 324 magnetic anomalies and 104 EM anomalies were picked. Fewer than 10 EM anomalies in the area shown do not have corresponding magnetic anomalies.

Figure 5. Analytic signal map of a portion of Bombing Target 1 at BBR for data acquired with the ORAGS-Arrowhead system. Horizontal scale is in meters.

Figure 6. Airborne EM map of Bombing Target 1 using large loop receiver coils and 270 Hz base frequency with the ORAGS-TEM system. Horizontal scale is in meters.

Figure 7. Anomalies picked from the magnetic data (red circles) and EM data (blue triangles) for Bombing Target 1.
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Discussion

The magnetic data were picked at a threshold that corresponds to about three times as many anomalies as the EM data. Data from test sites indicates that intact M-38 ordnance will typically generate anomalies with magnitudes of 30 nT/m or larger for the parameters used in this survey. Most of the EM anomalies that were picked have corresponding magnetic anomalies that are 30 nT/m or larger, and thus could represent M-38s. Some EM anomalies without corresponding magnetic anomalies could correspond to non-ferrous metallic objects. A few large magnetic anomalies have no corresponding EM anomaly. In general, these can be attributed to altitude perturbations in one of the two data sets (low on magnetic or high on EM), orientation issues that reduce the EM response, or burial depth increases which have a greater effect on EM data than magnetic data. Data were collected with the small coil receiver configuration over a small portion of Bombing Target 1 and yielded improved signal-to-noise performance. However, the size of the small coil survey area was too small for a suitable comparison with magnetic results. Similarly, results from a lobed transmitter (Beard et al., 2003) have about twice the S/N of the large transmitter, but this configuration was not flown at Bombing Target 1.

Integration of EM and magnetic data sets can be used to aid in downselection of anomalies that have a high probability of association with UXO, as opposed to other types of metallic debris. We intend to verify these anomalies through excavation to develop improved methods for identifying UXO in airborne data sets, and thereby reduce the overall cost of remediation at these sites.

Conclusions

Results from the first deployment of the ORAGS-TEM airborne EM system at a UXO site are compared with magnetic data from the same site. These data demonstrate that airborne EM data can be acquired to supplement airborne magnetic data from UXO sites. Noise levels are presently higher in the EM data, but we expect that further improvements in hardware and processing methods will improve the sensitivity of the EM system.

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