geoconvention
Calgary • Canada • May 13-17 2019

High-Resolution UAV Magnetometry Surveys for Localizing Legacy/Abandoned Wells

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Summary

Advances in airborne magnetometry have been realized through reliably integrating unmanned aerial vehicle (UAV) platforms with light-weight, high-sensitivity magnetometer payloads. As such, UAV-borne aeromagnetic surveys can provide a more desirable balance between the two end-members of resolution and coverage attained using manned airborne and terrestrial magnetic surveys. This new data product is achieved as UAV platforms can safely traverse with magnetometer payloads at flight elevations closer to ground targets than manned airborne surveys, while also providing a higher rate of coverage over conventional terrestrial surveys. In July 2017, a UAV-borne aeromagnetic survey was conducted within the Shebandowan Greenstone Belt, northwest of Thunder Bay, Ontario, Canada, using a GEM Systems Inc. Potassium Vapour Magnetometer (GSMP-35U). A 2-D grid (~500m by ~700m) was flown at an approximate elevation of 40m, above the ground with a DJI-S900 multi-rotor UAV. In total, over 20 line-km's of UAV-borne aeromagnetic data was flown with a line spacing of 25m. The collected UAV-borne data was compared to a regional heliborne aeromagnetic survey flown at an elevation of approximately 85m above the terrain and a line spacing of 100m. This case study demonstrates that low flight elevation, UAV-borne aeromagnetic surveys can reliably collect industry standard magnetic measurements at an increased spatial resolution compared to manned airborne magnetic surveys. In addition, the ability to collect magnetic gradient observations has improved the interpretability of the targets significantly. In this study, the developed methodology is applied to accurately locate legacy/abandoned wells in a cost-effective manner. A series of forward models are developed to estimate the magnetic field produced by a set of subvertical stainless steel well casings buried near the surface. The field was calculated and sampled at different UAV flight elevations down to 10 metres above ground.

Introduction

Magnetic surveys passively sense the total magnetic intensity (TMI) and are regarded as one of the most cost effective and widely used geophysical methods (Everett, 2013). The traditional platforms used to collect total magnetic field data included high coverage, but low resolution manned airborne surveys and high resolution, but low coverage terrestrial surveys. The surveying design parameters of these two traditional platforms have remained fixed due to their physical constraints to a 2-D surveying space (manned airborne surveys at one flight elevation, terrestrial surveys on the ground). For regional manned airborne surveys, total magnetic field data are typically sensed at flight elevations of 100m or more above the ground for logistical and safety reasons. In contrast, for localized terrestrial surveys, total magnetic field data are collected via a field crew walking along the Earth's surface. As such, an observational gap in total magnetic field data has persisted extending from the ground up to an elevation of approximately 100m, where neither traditional platform can safely nor physically operate.

Within the past decade, the development of UAVs as a surveying platform has allowed for the collection of magnetic data within this prevailing observation gap. As such, UAV-borne magnetic surveys can exploit a higher rate of coverage than terrestrial magnetic surveys, ie. at speeds of

10 m/s (Cunningham, 2016), while also providing a higher resolution than manned airborne surveys, ie. 10m from the target surface (Walter et al., 2018). This new spatial and temporal scale can provide a more desirable balance between the existing two end-members of coverage and resolution in magnetic surveys, especially when looking for relatively small buried objects near the ground surface, such as legacy wells. There are four main reasons of this: (i) UAVs can fly relatively close to subsurface targets (~10m flight elevation) allowing for small variations in the magnetic field to be sensed (the benefit of terrestrial surveys), (ii) UAVs provide a relatively high rate of coverage (~10 m/s) increasing their efficiency per flight (the benefit of manned airborne surveys), (iii) UAVs can achieve a sub-metre data point density along flight lines and (iv) UAVs increase the safety of surveying personnel by removing the manned component of low elevation flight.

Instances where magnetometer payloads have been integrated with a UAV platform for geophysical research are shown in the studies of Samson et al., 2010; Stoll, 2013; Cunningham et al., 2015; Parvar, 2016; and Walter et al., 2018. Recently, studies such as Adamson, 2016; and Hammack, 2018; have demonstrated the ability of UAV-borne aeromagnetic surveys to consistently detect legacy/abandoned wells and buried infrastructure. However, there are limited studies that directly compare high-resolution and low flight elevation UAV-borne magnetic data to manned airborne magnetic data flown over the same area. Within this realization, a case study was flown over a mineral exploration target to directly assess the achieved spatial resolution and data quality of a UAV-borne aeromagnetic survey, comparing the results with an airborne magnetic survey. In addition to the case study, buried wells were forward modeled to estimate the magnetic fields produced at UAV flight elevations between 10m and 100m above the ground (airborne flight elevation), allowing for a comparison to be drawn regarding the theoretical resolvability of legacy wells using these two methods.

Method

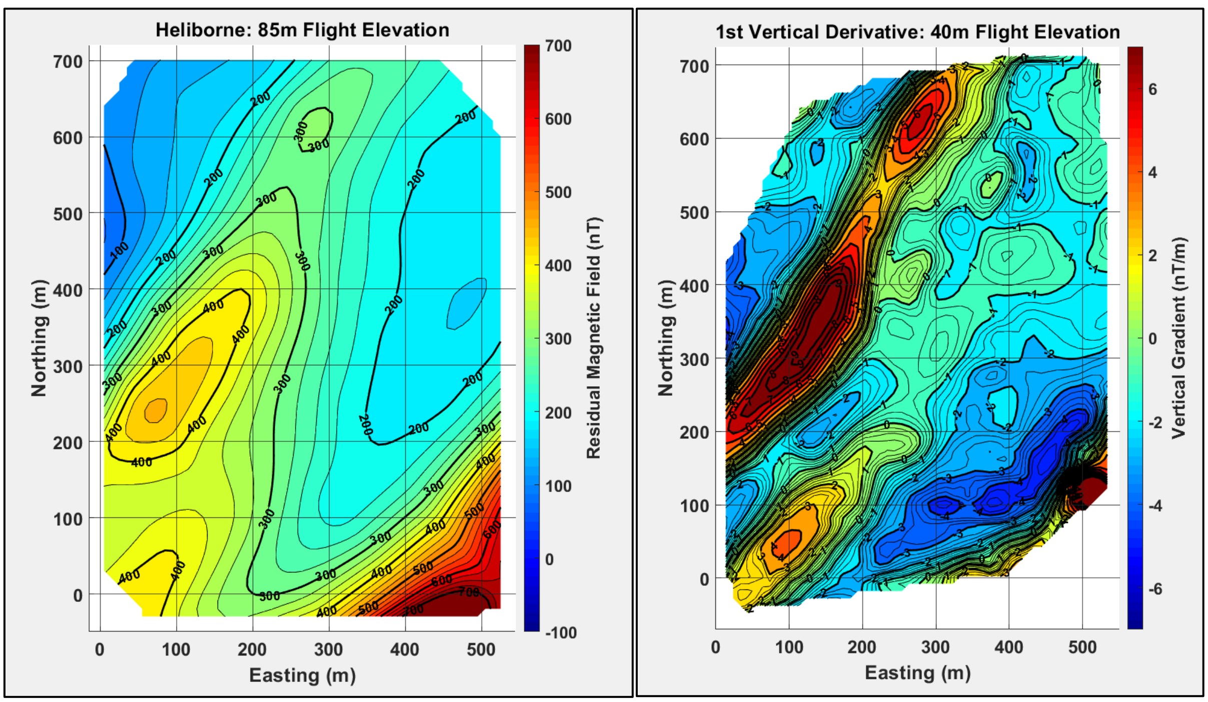
The platform used for the UAV-borne aeromagnetic case study was a DJI S900 heavy lift multi-rotor UAV as shown in Figure 1. Pre-programmed flights were conducted at a surveying speed of ~7.5 m/s along 700m long traverse lines. These twenty parallel traverse lines were flown with a 25m line spacing. Five flights were required to collect almost 20 line-km of magnetic data in an approximate 2-hour period. The magnetic sensor used during surveying was a GEM Systems Inc. GSMP-35U potassium vapour magnetometer composed of two main parts: (i) the magnetometer electrical console and (ii) the magnetometer sensor. The magnetometer electrical console was secured directly to the frame of the multi-rotor UAV. However, the magnetometer sensor head (used to measure the magnetic field) was semi-rigidly mounted (Walter et al., 2018) to the UAV and suspended 3 meters below the airframe. In addition to the main magnetometer payload, a data acquisition system was incorporated to collect and store the magnetic field and positional measurements. In total, the combined magnetometer payload, specialized mount and data acquisition system weighed ~2.2 kg. All on-board sensors collected data at or above 10 Hz resulting in an observation density of over one point per meter along the flight trajectory. Following acquisition, the data was processed to calculate the residual magnetic field in accordance to industry standards and plotted. The collected UAV-borne magnetic data was then compared to a manned airborne magnetic survey conducted at 85m flight elevation and a 100m line spacing. (Ontario Geological Survey GDS 1241, 2014).

Figure 1. UAV platform, data acquisition system and semi-rigidly mounted potassium vapour magnetometer.

Based on the encouraging results of the UAV-borne aeromagnetic survey, the developed methodology and surveying parameters were applied within a forward modeling study to assess the resolvability of buried legacy wells. As such, forward modeling of the magnetic field, created by the buried well casings, was conducted within the interactive software IGMAS (Interactive Geophysical Modeling Assistant, Schmidt et al., 2010). Well spacing and geometry, surveying height above the ground and sampling intervals were all systematically varied within the modeling space. Identical subsurface geological models were used as a constant input parameter to generate the magnetic field models. These constant input parameters included a 500m by 500m area where 7, 20cm wide well casings (susceptibility of 10 SI) were systematically placed within a representative sandstone geological unit (-0.01 x 10^{-3} SI). For the model, remanent magnetization was not considered. The generated magnetic field and its gradients were calculated from the forward model between 10 and 100m above the ground.

Results

The residual magnetic field map produced from the heliborne aeromagnetic survey is presented in Figures 2. The UAV-borne 1st vertical derivative data is presented in Figure 3. The increased signal amplitude and resolution of the low flight elevation, UAV-borne aeromagnetic data was able to better define the two targeted trends within the area. From this UAV-borne survey an enhanced interpretation of the localized structures within the area was able to be concluded.



Figures 2 & 3. Aeromagnetic map produced from the regional heliborne survey conducted at an 85m flight elevation (left). UAV-borne 1st vertical derivative map valid at 40m above the ground (right) demonstrating an increase in spatial resolution and amplitude of the magnetic signal.

The synthetic total magnetic field profiles produced from forward modeling the magnetic field generated by 7 buried wells is presented in Figure 4. The upper plot of Figure 4 shows the magnetic field sampled at 80m above the ground (heliborne flight elevation), while the lower plot shows the magnetic field sampled at 10m above the ground (UAV flight elevation). As was observed within the case study, the UAV-borne aeromagnetic survey was able to provide a total magnetic field (black dashed line) and 1st vertical derivative (blue dashed line) profile with an increased signal amplitude and resolution, being closer to the targets. As such, individual wells spaced 20 - 100m apart are theoretically resolvable at a UAV-borne flight elevation of 10m.

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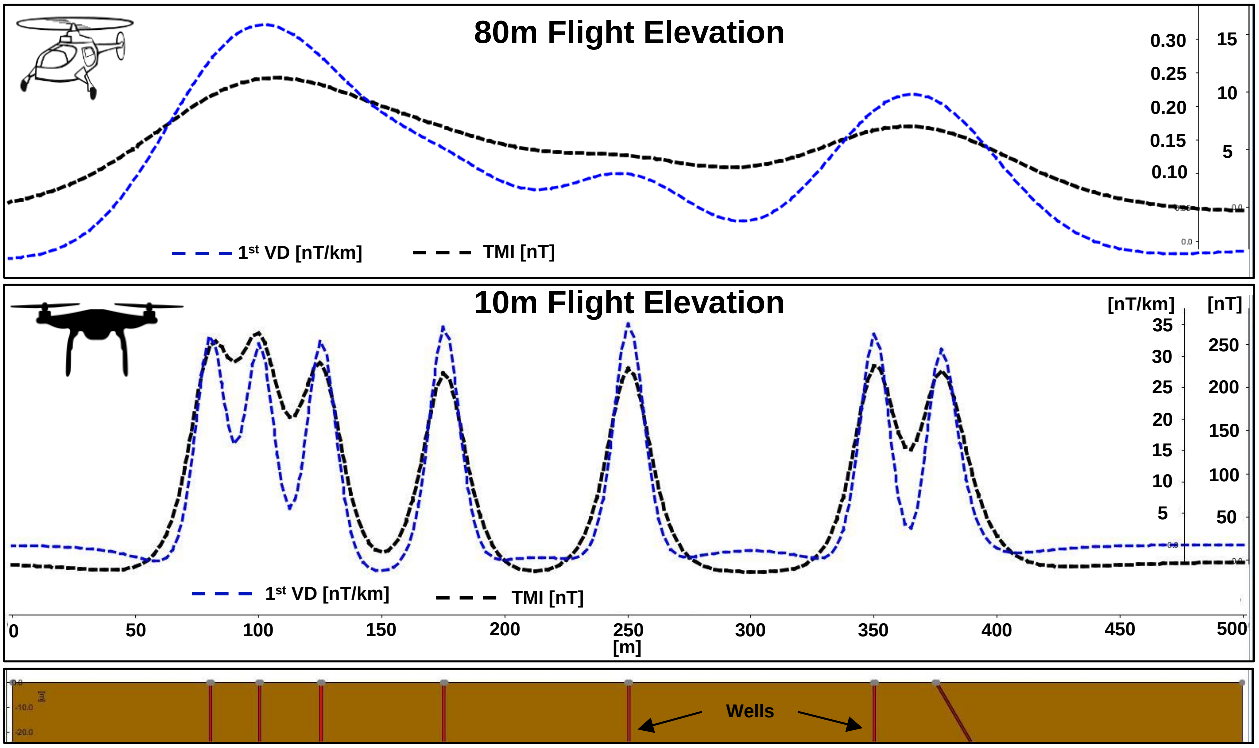

Figure 4. Synthetic aeromagnetic profiles produced by sampling the magnetic field at flight elevations of 80m – Heliborne (top) and 10m – UAV-borne (bottom) above 7 buried well casings (red) within IGMAS.

Conclusions

Within this study, a UAV-borne aeromagnetic survey flown at a height of 40m and a line spacing of 25m provided an increase in resolution and interpretability when compared to a manned aeromagnetic survey flown at 85m above the terrain and a line spacing of 100m. In addition, the UAV-borne magnetic survey increased the coverage rate when compared with a manned terrestrial survey. As such, the UAV-borne aeromagnetic survey demonstrated a practical balance between the existing coverage and resolution capabilities of both manned airborne and terrestrial magnetic surveys on a scale of ~1 km^2. Applying this proven method to an oil and gas application, the theoretically derived magnetic field generated by 7 well casings was forward modeled, demonstrating the ability of a UAV-borne aeromagnetic survey, conducted at a 10m flight elevation, to resolve individual wells. This contrasts the total magnetic field sensed at a flight elevation of 80m that was unable to detect the individual well anomalies. The proposed method will allow operators to design a magnetic survey that meets the resolvability requirement for localizing legacy wells, as well as contributing to decreased costs and increased safety.

Acknowledgements

The authors thank Sumac Geomatics Inc. for providing funding through a MITACS Accelerate Grant, piloting expertise and access to their facilities during the field campaign. NSERC (National Science and Engineering Research Counsel) is acknowledged for providing scholarships to CW. Kesselrun Resources Inc. is greatly acknowledged for providing access to their Huronian Property. GEM Systems Inc. is greatly acknowledged for providing a GSMP-35U potassium vapour magnetometer.

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