Magnetic and magneto-gradiometric surveying using a simulated unmanned aircraft system

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Summary

Carleton University and Sander Geophysics are developing an unmanned aircraft system (UAS) for aeromagnetic surveying. As an early indication of the performance to expect from the UAS, a simulated UAS (sUAS) was built. The sUAS is a T-shaped structure suspended beneath a helicopter which has the same magnetometers and sensor geometry as planned for the UAS. A test survey was conducted using the simulated UAS and the total magnetic intensity (TMI) data recorded were compared to that obtained during a conventional regional fixed-wing survey and a ground survey. Transverse magneto-gradiometric data were also recorded by the sUAS.

Introduction

In March 2010, a prototype unmanned aircraft system (UAS), the GeoSurv II, was unveiled at Carleton University, in Ottawa, Canada. The GeoSurv II (Figure 1) has been specifically designed for aeromagnetic surveying and was engineered to ensure low cost production and repairs (Samson et al. 2010). Some specific features include: a non-magnetic, all-composite airframe manufactured using innovative low cost composite manufacturing methods (Maley 2008, Mahendran 2010), the use of non-magnetic metal fasteners (aluminum, brass, austenitic stainless steel, titanium) in areas of high stress such as the landing gear, and the pairing of servos in order to lower electromagnetic noise generated during flight maneuvers. Another characteristic designed to enhance aeromagnetic surveying capabilities is the addition of a wingtip to wingtip horizontal magnetic gradiometer.

The application of gradiometry to aeromagnetic surveying was suggested in 1954 and has been in practice since 1965 (Hood and McClure 1965). The gradiometric aeromagnetic method provides several benefits including: the ability to remove diurnal variations, better discrimination between shallow and deep geological structures, and increased lateral resolution between geological formations that are in close proximity to each other (Hood and Teskey 1989). The integration of a horizontal gradiometer within the UAS provides the versatility of adding the observed transverse gradient to other magnetic datasets including the total magnetic intensity (TMI), the calculated longitudinal gradient, and the calculated vertical gradient. The addition of the transverse gradient will resolve geological detail in

Figure 1: UAS prototype GeoSurv II is a twim-boom pusher aircraft with a wingspan of 4.9 m. The yellow pods at the wingtips house the magnetometers which are separated by 4.67 m. The UAS is designed for a flight endurance of 8 hours at 30 m/s. The landing gear can be replaced with a track for use with a catapult to enable flying in remote locations that do not have airstrips.

the direction that is transverse to the flight direction (Hood and Teskey 1989).

Simulated Unmanned Aircraft System

While development of the GeoSurv II is continuing towards its first flight planned for spring 2011, a simulated UAS (sUAS) was built to make progress on aeromagnetic data acquisition. The sUAS is a T-shaped structure configured as a horizontal gradiometer with two cesium Geometrics G822A magnetometers spaced 4.67 m apart replicating both the wingspan and sensor geometry of the UAS (Figure 2). The sUAS is suspended 33 m beneath a helicopter to reduce the magnetic interference created by the aircraft to a negligible level. It records the Earth's magnetic field at the same resolution and altitude that the UAS is designed to achieve based on the topography and conditions of the area being surveyed. The goal of using the sUAS is to execute early tests indicative of the expected performance of the GeoSurv II.

Survey Area

The survey area, an 8.5 km^2 area in the Central Metasedimentary Belt of the Grenville Province, near Plevna, Ontario, was selected on the basis of its geological structure and relative remoteness from sources of cultural magnetic noise. The area was chosen in order to evaluate the resolution of the sUAS, and thereby to predict that of the UAS, and to determine to what extent low-altitude

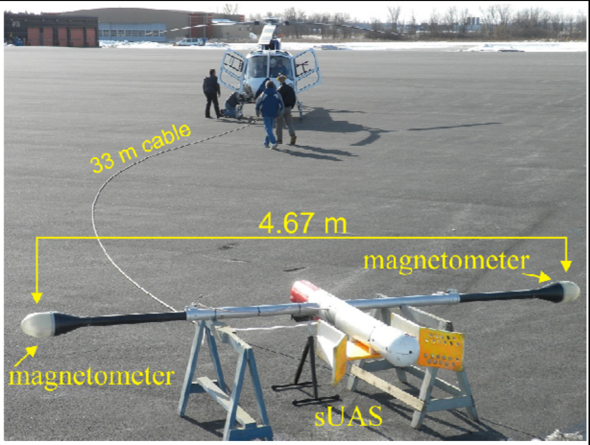

Figure 2: Heliported sUAS, a modified aeromagnetic bird with two cesium magnetometers laterally separated by 4.67 m. The sUAS was constructed for testing components such as the magnetometers, the magnetic gradiometer, and the obstacle detection and avoidance system. The center body is capable of housing instruments, and camera mounts have been added for bifocal video recording.

flying provides useful information towards the interpretation of the geological structure.

The survey area features a vertical similar fold composed of strongly magnetic metasedimentary rocks inter-bedded with magnetite bearing metavolcanic rocks. Within the similar fold, these two rock types are juxtaposed against weakly magnetic carbonate metasedimentary rocks (Easton 2006). The terrain in the area is characterized by forest covered steep hills, small lakes, and coniferous bogs.

Four magnetic data sets cover the survey area.

In 1983, a regional aeromagnetic survey conducted using a conventional fixed-wing aircraft flying at an altitude of 150 m and equipped with an optical cesium magnetometer, was able to delineate the geological fold with good detail (background of Figures 3 and 4) (Ontario Geological Survey 2003).

In February 2010, the area was surveyed with the sUAS suspended 50 m above ground. The sUAS survey was conducted at a speed of 30 m/s in order to simulate the speed of the UAS. It was flown along a conventional fixed-wing aircraft drape that was configured with a maximum climb gradient of 57.6 m/km (350 ft/NM) to account for the rapid variations in topography. During the sUAS survey, both the TMI and the traverse magnetic gradient were recorded simultaneously.

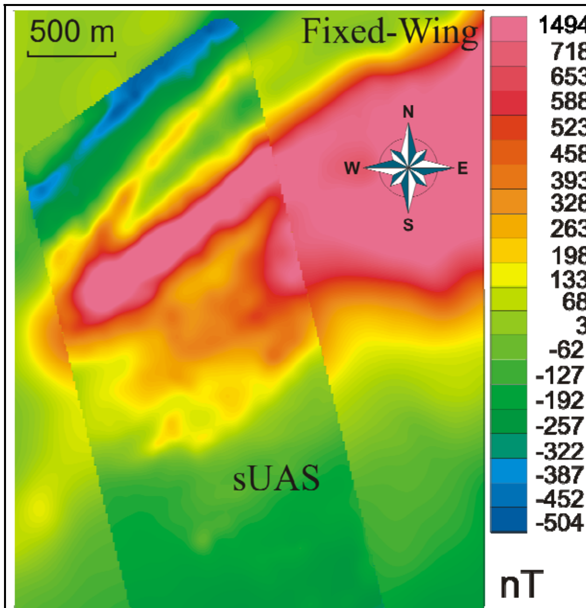

Figure 3. TMI map of the conventional fixed-wing survey data in the background and the sUAS data in the foreground. The fixed-wing survey was flown at an altitude of 150 m while the sUAS survey was flown at 50 m. The colour scale is the same as in Figure 4.

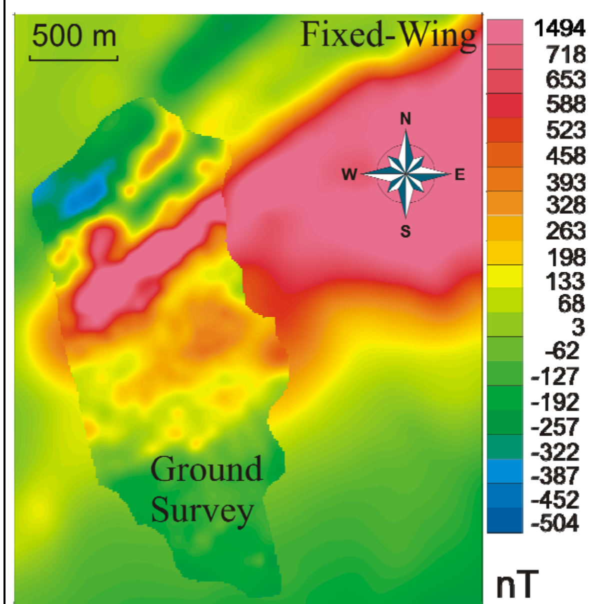

Figure 4: TMI map of the conventional fixed-wing survey data in the background and the ground survey, upward continued to 50 m, in the foreground.

A portion of the same area was also surveyed by a ground crew in February and November 2010 using a GSM-19 Overhauser walking magnetometer. The ground surveys were conducted in late fall and winter in order to obtain GPS coverage within the forest. The ground surveys do not cover all the area flown by the sUAS due to terrain access difficulties.

All 2010 surveys followed the same north-south traverse line heading and line spacing of 50 m. The sUAS survey flew control lines with a spacing of 300 m in order to apply leveling corrections to the data.

Total Magnetic Intensity

Figures 3 and 4 illustrate the increase in resolution gained from a decrease in altitude. A TMI map created from data gathered during the 1983 conventional fixed-wing survey flown at 150 m is compared, as a background, to a map created from the sUAS data in Figure 3. The fixed-wing survey is used again as a background in Figure 4, where a map created from the ground survey data is superimposed. The ground survey data in Figure 4 have been upward continued to 50 m to provide a direct comparison with the sUAS data, and to remove the cluttering effect of high frequencies that is common in ground surveys. The spatial offsets between the fixed-wing data and the two other more recent datasets are due to the introduction of GPS navigation which was unavailable in 1983.

The sUAS map from Figure 3 and the upward continued ground survey map from Figure 4 are similar. Both show a pronounced northeast trending magnetic high. The most notable difference is that, above this strong linear trend, the sUAS map reveals two additional linear northeast magnetic trends, one a high and the other a low, that are not visible on the other datasets.

Figure 5 is a sequence of upward-continued maps which illustrate the changes in frequency content in the ground magnetic data with increasing altitude. At ground level, the data exhibit sharp magnetic trends and many local bulls-eye anomalies that can be attributed to both signal and noise. Many of these bulls-eye anomalies are created from variations in measurements that are a byproduct of the walking ground method. They were exasperated due to the rugged nature of the terrain, the shallow depth to bedrock, and the high intensity and rapid variations of the magnetic field. Movements of the magnetometer, introduced despite best efforts, generated high frequency high amplitude variations, on the order of 20-30 nT, within the data. These variations were indistinguishable from incidents where the carrier tumbled or slipped and so this source of error could not be corrected despite having the time of each occurrence recorded. The widespread occurrence of these features and the ambiguity of their source complicate interpretation by

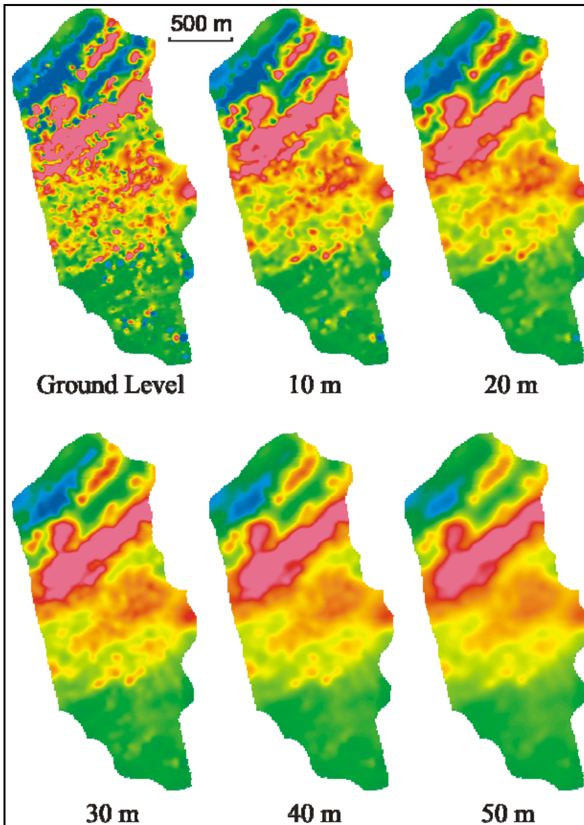

Figure 5. TMI ground survey maps that have been progressively upward continued from ground level to an altitude of 50 m in steps of 10 m. The colour scale is the same as in Figure 3.

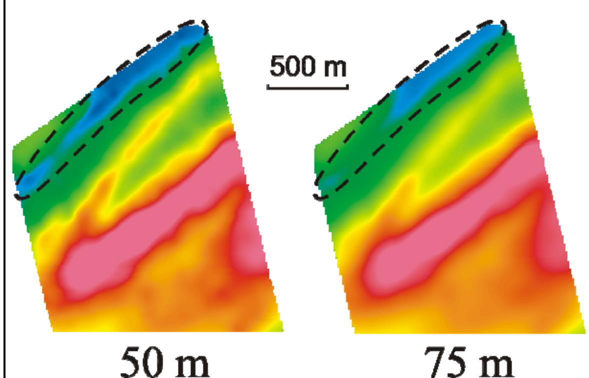

Figure 6: Detailed TMI maps of the sUAS data at 50 m altitude, and upward continued to 75 m altitude. Only the northern section of the survey area is shown. The magnetic valley, at the top of the map, is no longer identifiable as a linear trend at an altitude of 75 m. The colour scale is the same as in Figure 3.

cluttering the map. As altitude increases, the very high frequencies are attenuated to reveal deeper, more meaningful, magnetic trends.

Importantly, Figure 5 shows that, with respect to TMI for this terrain and geology, no new magnetic trends are obtained by lowering flight attitude below 50 m. If the sUAS survey had been conducted at a lower altitude, in the absence of a forest, then the higher resolution data obtained would not actually reveal previously unknown trends and may not contribute additional value to geological interpretation. If the sUAS survey had been conducted at a higher altitude, then important information would be lost, for example, the continuity of the linear anomaly circled in Figure 6.

Transverse Magnetic Gradient

The gradiometer configuration was tested during the sUAS survey in February 2010. The results, illustrated in Figure 7, show the transverse gradient which is calculated by dividing the distance between the magnetometers on each wingtip. The map highlights several linear magnetic trends striking to the northeast that were apparent on Figures 3 and 4. An additional trend, which was not visible on the TMI maps and is circled by a white line in Figure 7, resolves a magnetic high situated directly below the magnetic low identified by a black line in Figure 6. The trend is not well resolved as it strikes perpendicular to flight direction. The advantage of a transverse gradiometer is to resolve magnetic trends that are parallel to flight direction. Trends in this orientation are not visible in the mapped data.

In a survey conducted over a sedimentary basin with a depth in excess of 2 km using a similar transverse gradiometer system with a 3 m separation, other researchers found that the noise level often exceeded the signal when used over areas with weak magnetic gradients (Mushayandebvu and Davies 2006). As the magnetic gradients shown in Figure 7 are well defined and continuous, noise was not a problem in the case history presented here. The good performance of the sUAS gradiometer used in this study can be attributed to the larger sensor separation and the shallow depth to the bedrock. The depth to bedrock was observed to be less than 5 m except in areas where bogs, lakes, and small basins persist. The depth to bedrock in these areas is unknown.

Conclusions

The comparison between the different TMI maps presented confirms that an increase of resolution resulting from a substantial decrease in altitude will help to identify geologically significant magnetic trends. The case history also demonstrates that a UAS might be a viable alternative

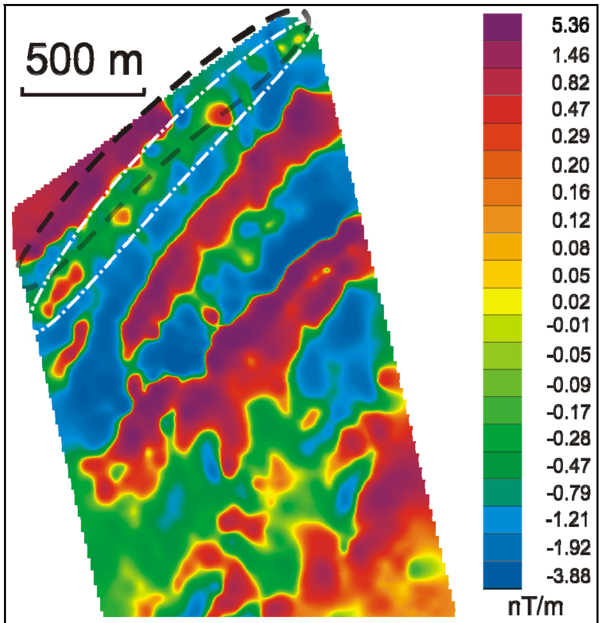

Figure 7: Transverse magnetic gradient measured using the sUAS at an altitude of 50m. The linear magnetic high trend highighted in white is not visible on the TMI maps shown in Figures 3 and 4.

to ground surveys in the delineation of subtle geological trends, like those associated with mineral exploration.

The map of the transverse magnetic gradient shows that a gradiometer configuration with a sensor separation of 4.6 m is sufficient to measure the magnetic gradient at an altitude of 50 m. Due to the absence of linear anomalies striking along the flight direction, further study is required in order to provide a more detailed analysis of the resolution capability of the gradiometer.

In conclusion, a UAS should be able to deliver more detailed magnetic data that will aid geological interpretation over conventional fixed-wing aircraft. Furthermore, the resolution capability of a UAS may be comparable to that of a ground survey, depending on the terrain and geology, and would be a cheaper, faster, and safer alternative.

Acknowledgements

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EDITED REFERENCES

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