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## Magnetic surveying with UAV to fill the gap between ground and airborne magnetic surveys

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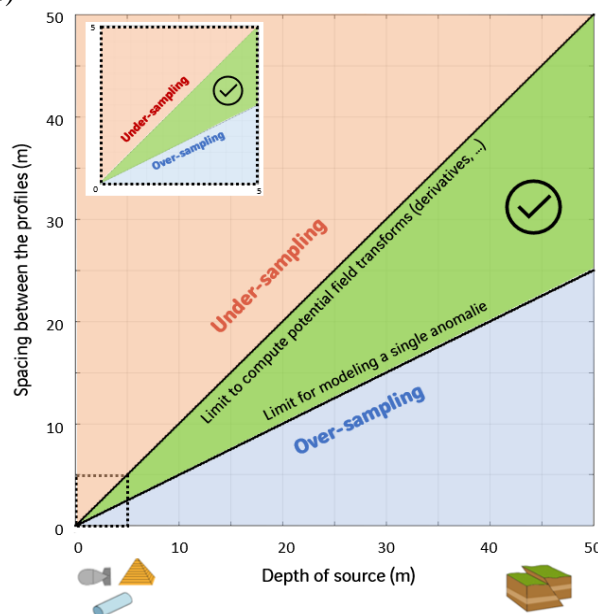
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## Magnetic surveying with UAV to fill the gap between ground and airborne magnetic surveys

### Introduction

The knowledge of the near surface is one of the key elements to achieve building projects, mining operations, investigating UXO risk, etc. Geophysical studies allow to characterizing underground physical properties, whatever the dimension or the purpose of the project (geological exploration for geothermal energy, mining, ...) or the location of anthropic objects (pipelines, Unexploded Ordnance, ...). Among the different geophysical methods, the magnetic method allows imaging objects from centimetres to kilometres in size. The magnetic method investigates the variations of the magnetic field intensity measured during prospecting campaigns. The advantage of this method is that it is passive, and the depth of investigation is not limited. The limits are related to the amplitude of the magnetization contrasts and their depths. Reid (1980) provided good parameters for magnetic survey design depending on the objective and the type of sensors used (gradiometry, total field). To properly map anomalies and compute potential field transforms, it is necessary that the spacing between the profiles is less than the distance between the sensor and the magnetic source. In addition, in the case of forward modelling of single anomalies, it is recommended that the spacing is equal to half the distance between the source and the sensor (Figure 1)



**Figure 1** Diagram built from the elements of Reid (1980) showing the spacing between profiles as a function of the source depth, in the context of the measurement of the magnetic field intensity.

In some cases, traditional aeromagnetic surveys do not provide sufficient resolution to characterize local anomalies and ground surveys cannot be achieved (access limitations, too large area,...). Over the last ten years, unmanned aerial vehicles (UAV) or unmanned aerial systems (UAS is a UAV and related equipment) have become efficient tools to fill the gap between ground surveys and fixed-wing or helicopter aeromagnetic surveys. UAV allows acquiring data from 1 to more than 100 m above the ground. In this study, we will present magnetic sensor integration, compensation of the magnetic effect of rotary-wing UAV and multiscale demonstrators (geology, building and UXO).

### Method

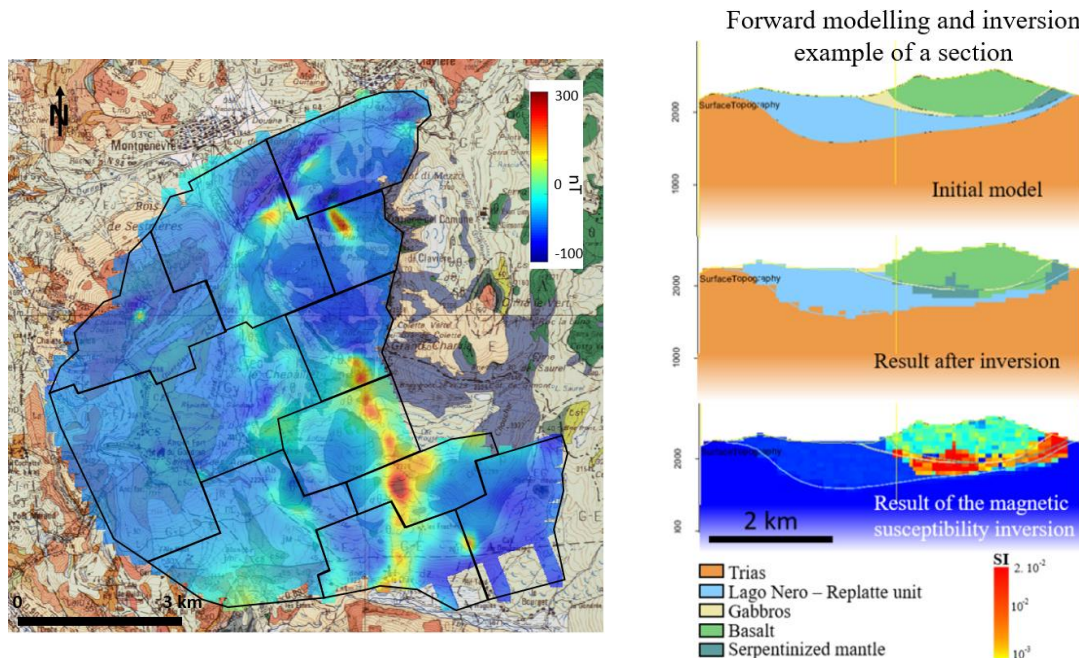
The study uses three components fluxgate magnetometers. Fluxgate vector magnetometers are cheap, lightweight, and low-consumption sensors. Fluxgates are relative magnetometers, so it is necessary to perform a correction of their measurements, i.e. calibrate the sensors. This procedure also allows compensate for the magnetic moment inherent to movements in the Earth magnetic field of magnetic

parts of the platform, such as connectors, motors, batteries, ... This procedure is the scalar calibration procedure (Le Maire et al., 2020; Munsch et al., 2007; Olsen et al., 2003).

## Examples

### At semi-regional scale, for geological modelling

In 2020, in the Alps, BRGM evaluated the feasibility of intermediate scale magnetic mapping in complex conditions, due to the altitude (> 1800 m), the strong topography variations and the weather conditions (negative temperatures, snow), with Terremys company. Despite these difficulties, which highlight the viability of UAV for semi-regional geophysical measurements, a survey of 20 square kilometers with 219 km of profiling was completed 100 m above ground level. Flight line spacing is 100 m above the ophiolitic basement and 200 m above the sedimentary units. Magnetic anomaly maps were computed after standard processing (e.g., calibration/compensation, temporal variation, and regional magnetic field corrections, leveling). Geological-scale cross-sections of the Chenaillet ophiolitic massif could be derived from direct and inverse 3D modelling of this UAV magnetic map.

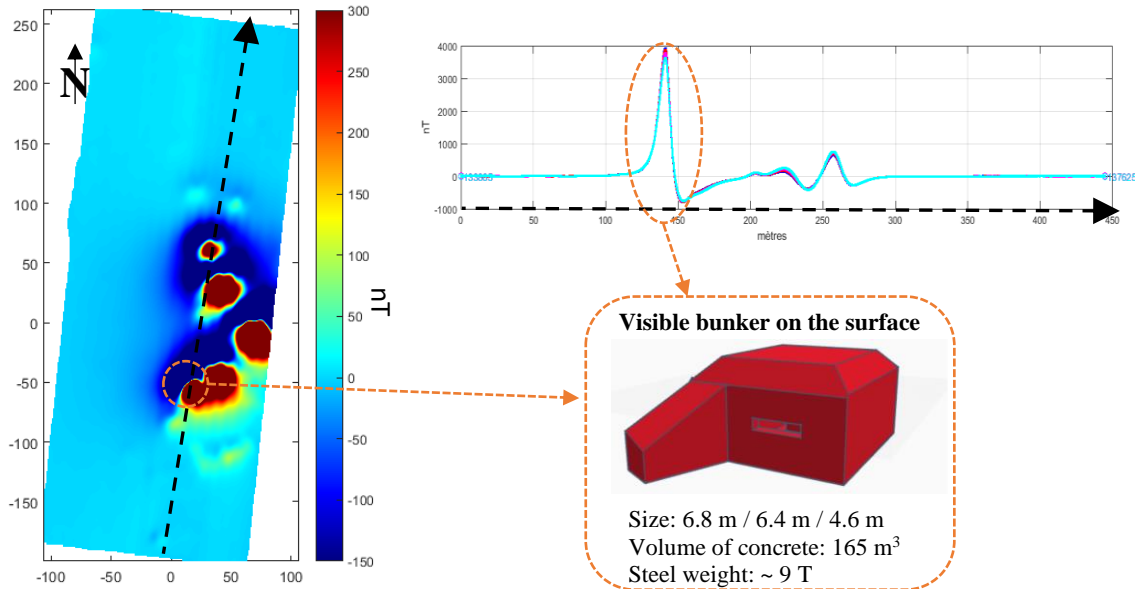


**Figure 2** In the left, the total magnetic intensity map and in the right, an example of forward magnetic modeling and inversion.

### At intermediate scale, for the detection of building remains

In 2022, BRGM and CARDEM conducted a project in a littoral beach and the dune context. In the area, the variation of the topography is *c.a.* 25 m. A survey of 8 ha with 20 km of profiling was completed 7 m above ground level. In the study area, only one bunker is visible on the surface.

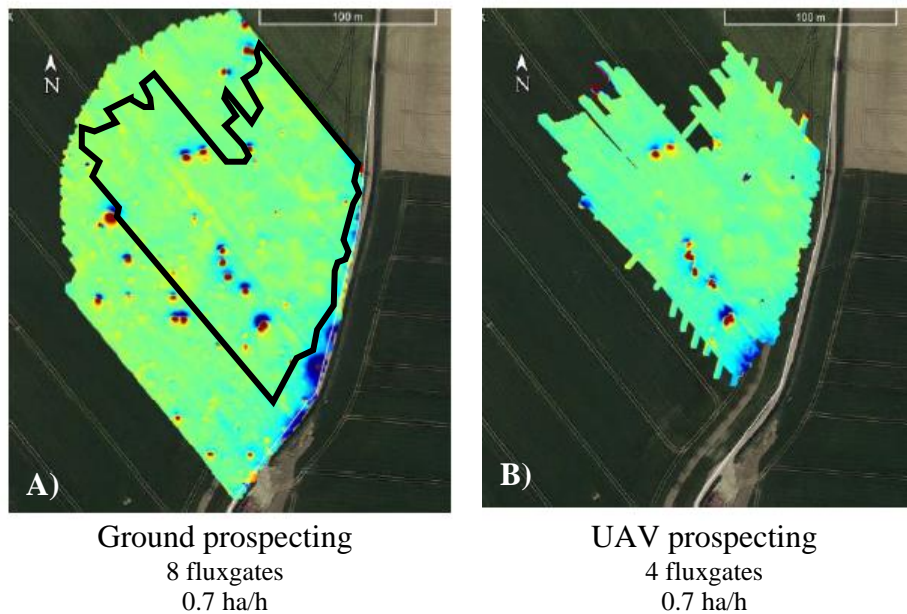
In the total magnetic intensity map, we observe 5 dipolar anomalies of high intensity. One of these anomalies is correlated on the surface with the presence of a bunker (Orange circle, Figure 3). For the other 4 anomalies, after forward modelling and comparison with other magnetic maps over bunkers, the presence of 4 buried bunkers with different sizes can be hypothesized. Other lower amplitude anomalies and right angle oriented towards the northeast anomaly are visible. These structures are certainly from the same period.



**Figure 3** Total magnetic intensity map and profile and the location of the only visible bunker in the study area.

#### At local scale, for UXO detection

In 2019, CARDEM and ITES (Institut Terre et Environment de Strasbourg) conducted a pilot project in the farm field for UXO cleaning. In the area, two magnetic surveys were carried out. A ground survey with a mean height of 0.80 m AGL, and an UAV survey with a height of 1.50 m AGL (because there were agricultural crops). For the ground prospection, 8 fluxgates were attached at 50 cm spacing. For the UAV acquisition, 4 fluxgates were surveyed at 50 cm spacing in front of a DJI M210 RTK UAV. Figure 4 displays the magnetic anomaly maps obtained during the ground survey (Figure 4A) and with the UAV (Figure 4B). Both surveys are very consistent, they were produced grossly at the same speed but the ground survey required bare soils.



**Figure 4** Maps of the total magnetic intensity from -40 to 40 nT, for the ground prospecting (left) and with the UAV (right).

## Conclusions

Fluxgate magnetic measurements with a rotary-wing UAV have reached industry standards and fill the gap between ground magnetic mapping and aeromagnetism. This low-cost and rugged geophysical prospecting tool has now proven its efficiency and versatility, allowing fast, precise and efficient magnetic mapping from local to semi-regional scales, in demanding field conditions of access, topography, vegetation, ...

## Acknowledgment

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