Merging scalar magnetometer and fluxgate gradiometer data – an alternative method

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Abstract
Combining the records of different types of magnetometers to one magnetogram can be onerous. We introduce an alternative way to merge magnetograms of diverse magnetometers. The application of a high-pass filter on scalar magnetometer data resembles gradiometer data. This can be a fast and easy way to merge scalar magnetometer and fluxgate gradiometer data.

Keywords
fluxgate gradiometer; high-pass filter; magnetogram; scalar magnetometer

Introduction

The circumstances of campaigns or field work may require the use of a scalar magnetometer and a gradiometer on the same survey area in adjacent segments, for example, when a large survey area is to be investigated in a short time, as was the case with our project in Fara (Hahn et al. 2022). However, the different designs of the magnetometers measure different components or quantities of the magnetic flux density of an anomaly. Specifically, a scalar magnetometer measures the total-field anomaly, the projection of the anomalous anomaly onto the geomagnetic field vector, while a single axis gradiometer measures the difference of the anomaly's component at the lower and upper fluxgate sensor. Therefore, the instruments produce different visual outputs. This can be disturbing or distracting during archaeo-geophysical interpretation. To obtain comparable readings of both instruments, the correct physical approach involves

- a transformation of the scalar magnetometer data from the total-field anomaly to the vertical component of the anomaly
- adjusting these data to one fluxgate gradiometer sensor height and computing a signal for a virtual second sensor through upwards or downward continuation
- calculating the difference between these two data sets

In the following, we discuss a more simple way to combine scalar magnetometer and fluxgate gradiometer output to a visually uniform magnetogram.

Materials and methods

The magnetometer survey from the 2018 Fara campaign, the results of which we show here, was conducted with scalar magnetometers in duo-sensor configuration, a Scintrex Smartmag SM4G-special magnetometer and a Geometrics G-858 magnetometer, and with a fluxgate gradiometer, a Foerster Ferex instrument. For the total-field anomaly data, the data processing involves the correction of the diurnal variation including the subtraction of a reference value. Knowing that a fluxgate gradiometer measurement has an intrinsic high-pass filter (HPF) effect (Schmidt 2008) inspired the approach to merge the high-pass filtered scalar magnetometer data with the fluxgate data as a quick, time-efficient and simple method in comparison to the above-mentioned exact method. The mean value of the individual data sets of the segments is set to zero before the merging. We used the “Geoplot” (Geoscan Research) “HPF” command on the total-field anomaly data with different radii for the image HPF.

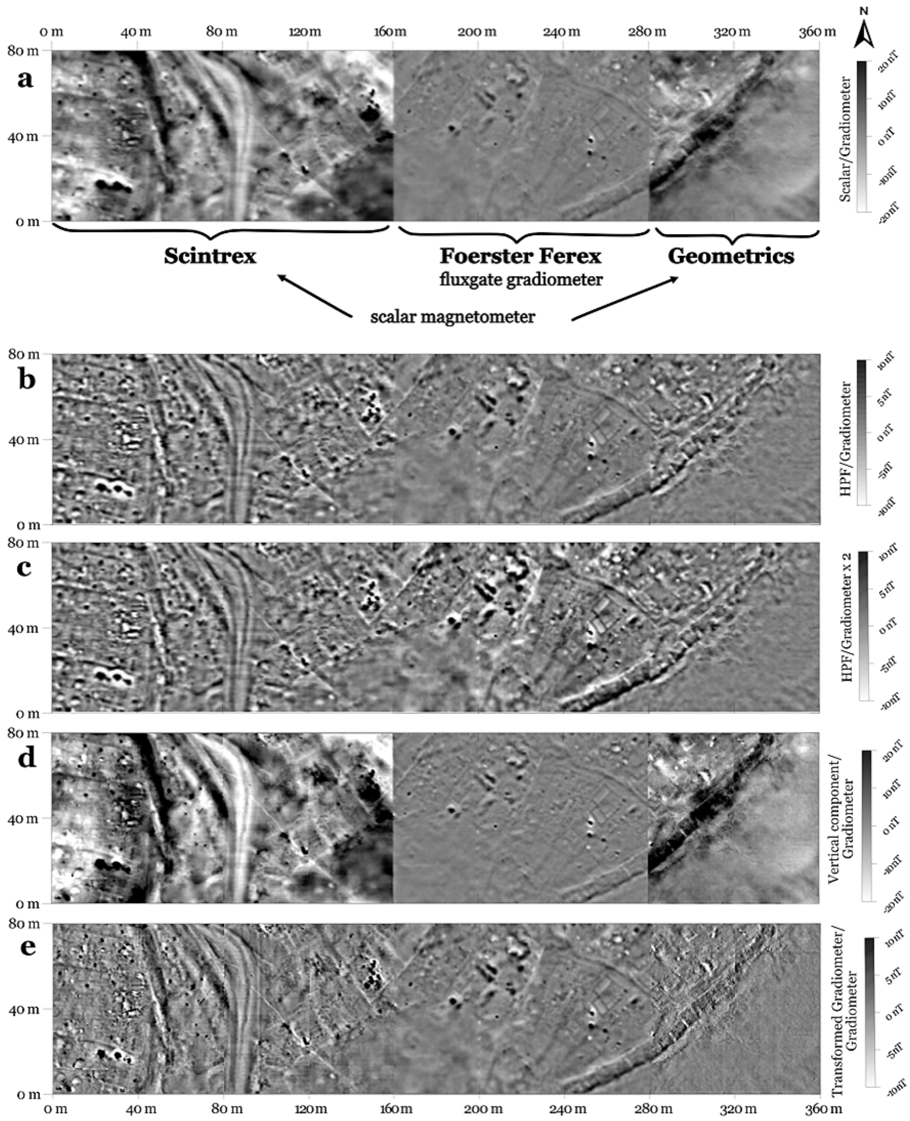

Fig. 1: a) Combination of the scalar magnetometer and the vertical gradiometer data sets. b) … of the high-pass filtered scalar magnetometer and the fluxgate gradiometer data sets. c) … of the high-pass filtered scalar magnetometer data sets and the gradiometer data sets multiplied by 2. d) … of the vertical component computed from the scalar magnetometer data sets and gradiometer data sets. e) … of vertical upwards continuation (0.65 m) of the vertical component of the scalar magnetometer data set minus the original data set (transformed gradiometer data) and fluxgate gradiometer data sets.

Results

Combining the segments measured by the two scalar magnetometers and the fluxgate gradiometer directly after data processing (Fig. 1a) the difference is distinct. Through trial-and-error, a visual match works best when an image HPF (Gaussian) with a radius of 10 is applied to the scalar magnetometer data. This visual result is shown in Figure 1b. Comparing the standard deviation for all three magnetometer data sets, the high-pass filtered scalar magnetometers' data sets have the same value, while the fluxgate gradiometer data sets show only half of the high-pass filtered scalar magnetometers' data sets for all magnetograms of this case study. Therefore, we multiplied the gradiometer data set by factor of two to achieve a better match of the data sets in terms of their data values as well as their optical output. The resultant magnetogram (Fig. 1c) appears visually uniform.

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Discussion

Scalar magnetometers and fluxgate gradiometers measure different components of the magnetic flux density. If these different components are now displayed in a combined magnetogram, these physical differences also become visually apparent. The application of a HPF on the segments of scalar data, corrected for diurnal variations, effectively filters out larger spatial wavelengths as illustrated by Scollar (1969). Theoretically, this, together with the correction for diurnal variations, is akin to the idea of gradiometer measurements. As Figures 1b and 1c show, this strongly resembles the visual appearance of the gradiometer data set of the adjacent segments. By multiplying the data set of the gradiometer by a factor of two, the lack of signal strength in comparison to the scalar magnetometer data can be compensated for (Fig. 1c). The lack of signal strength results from measuring only one component of the magnetic flux density and the subtraction of the two readings of the upper and lower fluxgate sensor. This factor is expected to be dependent on the inclination of Earth's magnetic field in the survey area (higher for lower inclinations) and the distance between the two fluxgate sensors of the gradiometer (higher for shorter distances). Exactly how they affect the multiplication factor and whether the inclination affects the settings of the image HPF still needs to be investigated.

To compare our method with the physical correct approach, we transformed the total-field anomaly data with a self-written MATLAB script based on Gerovska and Araúzo-Bravo (2006), Figure 1d, and used the „MagPick" program (Geometrics) to obtain the upward continuation (Blakely 1996) for a second sensor at height of 0.65 m and subtracted these values from each other. The result can be seen in Fig. 1e. The high-pass filtered and the transformed gradiometer data of the scalar magnetometer data show good visual agreement (see Fig. 1c and d).

Conclusion

Our method of applying an image HPF (Gaussian, R = 10) on the total field data sets and multiplying the gradiometer data sets by a factor of two can provide a combined magnetogram of all three survey segments which appears uniform regardless of the instruments used and the boundaries of the survey segments. The findings in the case study of Fara highlight the benefit of combing both data sets into one magnetogram. Our method enabled faster visual interpretation of the magnetograms and made it easier to trace and compare features across the different segments. In our inplementation, the use of a high-pass filter is quicker and more convenient, since all visual data processing is then carried out by one software.

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