How much noise can we tolerate in horizontal gradiometer data?

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Summary

The effect of varying amounts of noise in horizontal magnetic gradiometer data is investigated, in particular when the gradient data are used as an enhancement to gridding total field data. Synthetic line data with different amounts of noise are created to model anomalies of various sizes, which are gridded using two variations of a minimum curvature gridding algorithm; first using only total field values and then using total field values along with calculated horizontal gradients to enhance the interpolation. Profiles are sampled from the resultant grids perpendicular to the survey lines, showing the interpolation between survey lines. Examples are presented which illustrate each of the following results: the addition of the horizontal gradient data adds no benefit to the interpolation, the addition of the horizontal gradient is very beneficial, the benefit of the horizontal gradient data depends on the noise level present in the data, and finally when the synthetic anomaly totally eludes the interpolation algorithm. The conclusion is that the success of using the horizontal gradients to enhance grid interpolation depends on the quality of the horizontal gradient data, and the expected magnetic responses in the survey area.

Introduction

An enormous number of line kilometers of airborne magnetic gradiometer surveying have been flown in the past three years, with an equally large number currently being flown. The advantages of a gradiometer survey over a total field magnetic survey are generally considered to be a reduction in the effects of high geomagnetic activity, better definition of near surface features and the provision of extra information that can be used to better interpolate between survey lines (Donovan, 1984; Marcotte, 1992). It has also been suggested that measured horizontal gradients can be used to level total field data instead of using control lines (Nelson, 1994).

One of the recent projects involved as many as eight different aircraft, all outfitted with magnetic gradiometer systems. Comparative tests have shown that the different aircraft displayed a very large variation in the noise levels in the acquired magnetic data. We investigate the effect of different noise levels on the usefulness of horizontal gradient data. In particular, we focus on the ability of a gradient enhanced interpolation algorithm to model anomalies between lines.

Figure 1: A Cessna 208B Grand Caravan with gradiometer system

Sources of noise in horizontal gradiometry

Some total field measurement errors are inherent in an airborne magnetometer system, such as noise caused by motion induced magnetic interference, the limitations of the compensation process, and total field frequency counting errors (Hardwick, 1984). In addition, noise can be due to factors that are very much under control of the operator – the quality of the sensors being used, the quality of the compensation test performed, and the thoroughness of the de-magnetization process of the airplane. Cesium magnetometer sensors tend to drift at different rates while warming up immediately after being turned on, thus gradients calculated before a proper warm-up period will contain offset errors.

A very important factor in the gradient noise level is the physical design of the horizontal gradient system. It is important to try to maximize the distance between the sensors and sources of the aircraft generated noise. This can be achieved by attaching the sensor pods to stinger-like extensions on the wings, rather than directly to the wings (Figure 1). The extensions also have the added benefit of increasing the baseline of the measured horizontal gradient, proportionally decreasing the gradient noise.

It is much more difficult to design a quiet wingtip sensor installation than a tail stinger installation. This is due to the proximity of the sensors to the aircraft engine and moving parts in the wing, the flexing of the wings, and greater flexibility of the wingtip stingers due to the smaller diameter of the wingtip stinger tube. Obviously, the engine related noise in the wingtip sensors is much greater for an aircraft with an engine attached to each wing than for a single engine aircraft with the engine in the front.

Note that noise that may appear insignificant in total field measurements will become significant in gradiometer data (Hardwick, 1984). This is due to the fact that the magnitude of the gradient over the baseline of the horizontal gradiometer may not be much larger than the magnitude of the sum of all the noise in the total field measurements. Note also that the gradient is measured over a relatively short distance, the baseline of the gradiometer system which, in the best case, is only slightly larger than the wingspan of the aircraft, but is extrapolated over a much longer distance, based on the line spacing.

Method

A dipole anomaly was modeled and sampled at 500 m line spacing. The theoretical horizontal gradient was calculated, based on a horizontal separation of 20 m. The line data was gridded using a minimum curvature gridding algorithm in two modes; with and without the horizontal gradient enhancement. The resultant grids were re-sampled along the theoretical flight lines and compared to the original anomaly. Varying amounts of noise, simulating both high frequency noise in the total field data and an offset error, simulating a combination of all other noise sources in the gradient data were generated and applied randomly.

Noise levels for the test data were chosen using typical industry survey noise envelope specification, .1 nT peak to peak, as well as the results from the comparative test line data from a recent tri-axial gradiometer survey involving different types of survey aircraft operated by more than one survey company. Noise levels for data from the tail stingers on the different aircraft varied by a factor of 2.5, measured by standard deviation of the fourth difference. All wingtip sensors were slightly noisier than the tail sensors for the corresponding airplane, with the increase in noise varying from a factor of 1.1 to 3.

In order to generate the examples, the following noise limits were defined:

	Tail sensor noise (nT)	Wingtip sensor noise (nT)	Offset error in wingtip sensors (nT)	Resultant gradient noise (nT/m)
Ideal	0	0	0	0
Quiet	.1	.1	.12	.011
Noisy	.15	.5	1.0	.075

Sensor noise limits are specified as full envelope amplitude, for example, .1 nT refers to +/- .05 nT noise.

Results

The profiles illustrated in the following figures are sampled from the test grids perpendicular to the primary survey line direction. In all examples, the original data profile is a thin black line, the profile of the data gridded using only the total field data is a thick blue line, and profile of the data gridded using the horizontal gradient and the total field data is a medium red line. The points that fall on the survey lines, every 500 m, are marked with small triangles. These are the points that are input to the gridding algorithm. Any other points are interpolated values, representing the ability of the gridding algorithm to model the data that falls between the survey lines.

Figure 2 illustrates a 5 km, 50 nT anomaly modeled using the noisy system noise parameters as a worst case scenario. In this case, the three profiles are very similar. The anomaly is well modeled by the number of lines it passes through and the minimum curvature gridding algorithm is able to properly interpolate between the lines even with no gradient information. The horizontal gradient information adds little value to this mode. In fact, in the quiet area to the either side of the anomaly, the inclusion of the noisy gradient data results in an unacceptable interpolation.

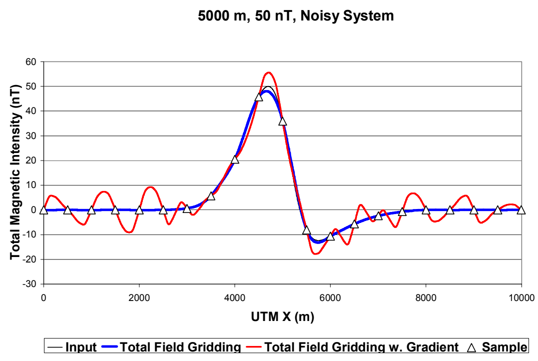

Figure 2: The anomaly is well modelled by the total field data

Figure 3 illustrates an example where the anomalies are under sampled by the 500 m line spacing. In this case, the data gridded with no horizontal gradient data totally conceals the anomaly, but the inclusion of the horizontal gradient data to the gridding algorithm results in a profile which adequately models the anomaly, even with noise included. It should be noted that this particular example is a sine wave sampled theoretically, a situation which would be unlikely to occur in the real world.

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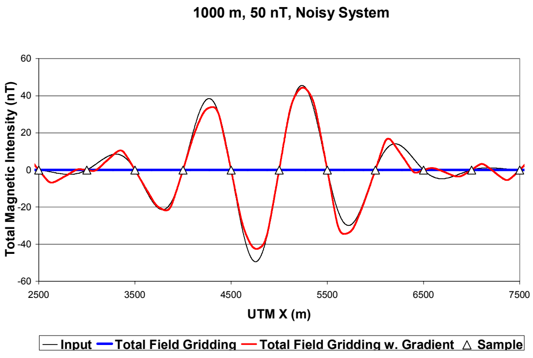

Figure 3: The anomalies are well modelled using the gradient enhanced gridding algorithm, but are lost when only total field data are used

Figures 4a and 4b illustrate a 10 nT anomaly that is undersampled by the 500 m line spacing. In the case of the "quiet" gradiometer system, the addition of the horizontal gradient data to the interpolation has helped to model the anomaly. Figure 4b illustrates the noisy system, in which case, the true anomaly is lost among the false anomalies generated by the noisy gradient data.

Figure 5 illustrates an anomaly that is not well modeled even when using the ideal gradiometer system. Note that it is a very high amplitude anomaly, but the survey lines have totally missed sampling the anomaly. The gradients measured at the edges of the anomaly are so small that they do not add much information to the interpolation algorithm.

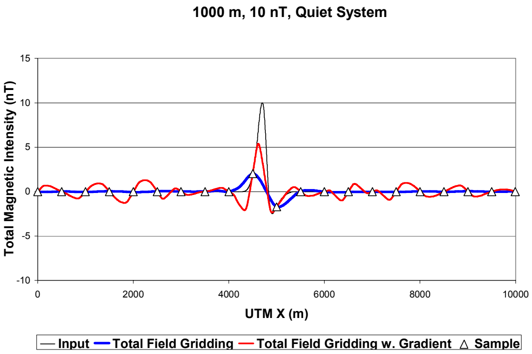

Figure 4a: The anomaly is possible to find using a "quiet" system

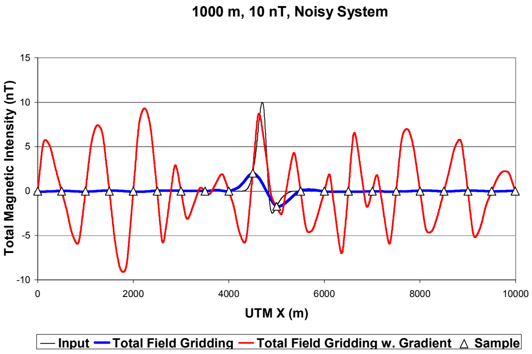

Figure 4b: The anomaly is lost using a "noisy" system

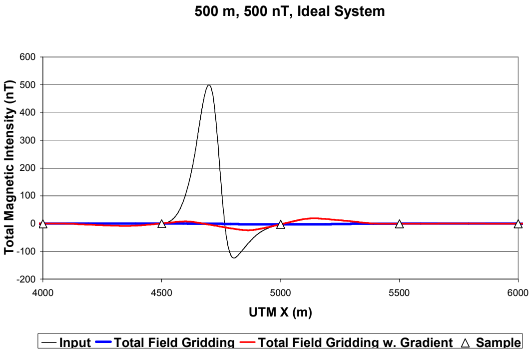

Figure 5: The anomaly eludes us even using gradient enhancement

Conclusions

Anomalies that are broad enough to cross several survey lines are well modeled using total field data only. Anomalies that fall completely between the lines may not be modeled even using the extra information provided by the horizontal gradient data. An example was presented where the horizontal gradient data, even from the “noisy” system was invaluable to modeling the magnetic field. Finally an example was presented where the gradient data from the “quiet” horizontal gradient system was able to well define the anomaly, but it would be difficult to find using the “noisy” system.

It is important to carefully evaluate the capabilities of the specific horizontal gradiometer system and airplane that will be used to fly an airborne survey and to model the expected magnetic responses in the survey area in order to determine if horizontal gradient data will add benefit to the interpolation algorithm for the total field data.

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