Aliasing estimation for TMI and FTMG survey design

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SUMMARY

Aliasing of TMI and full tensor magnetic gradient (FTMG) data has a major impact on the quality of grids, images and derivative products from aeromagnetic surveys. Optimum parameters are defined by a trade-off between cost and line spacing for the target geology. How do you determine the optimum survey parameters? Line spacing, flying height, sensor type, terrain, geology, geological noise and gridding method all play a role in degrading the quality of the final grids. We demonstrate a method for evaluating the impact of these parameters with the goal of reducing survey costs and improving final grid quality.

Key words: Aliasing, magnetic, gradient, tensor, gridding.

INTRODUCTION

The influence of aliasing is evident in the gridding of detailed line data where the magnitude increases with wider line spacing, lower flying height and distance from the flight lines. Additional factors include sensor type, gridding and shallow geological noise sources such as laterites. Magnetic sensors in common use include total magnetic intensity (TMI), horizontal TMI gradients and full tensor magnetic gradients (FTMG) where aliasing is different for TMI and gradient measurements. Deterministic gridding algorithms are designed to convert the detailed line data into a regular grid for advanced processing and imaging. Because TMI grids are used to produce shorter wavelength derivative products such as first vertical derivative, total gradient, tilt angle and tensor gradients, it is important to evaluate aliasing in the derivative products.

The concept of aliasing in magnetic surveys is well understood from magnetic survey experience and the theory documented by Reid (1980) and Clark (2014) for magnetic dipoles. The magnetic dipole is often representative of near surface magnetic noise associated with shallow magnetic sources but is occasionally used for targets such as compact ore bodies and UXO where all dimensions are less than the depth to the magnetic source. Clark and Reid's work was designed to provide a theoretical basis for optimising aeromagnetic survey line spacing and magnetic sensor height.

The introduction of the FTMG sensor has increased the resolution of magnetic data collected along the flight lines and the need for improved gridding algorithms. The magnetic gradient sensor records six tensor channels that cannot be gridded independently without sacrificing the closely coupled potential field relationships that are inherent in the recorded data. Fitzgerald et al. (2009) created a deterministic, tensor-consistent interpolation algorithm that is capable of gridding at approximately half the cell size of conventional gridding algorithms.

Our study investigates a new method for estimating the precision of gridding and derivative processing results by creating a simulation of a full magnetic survey with multiple sensor types and variable target styles. The geological model is used to compute the magnetic response of any desired field, field component or derivative across a grid covering the same area as the survey. The flight line data is then gridded at a resolution that matches the theoretical grid so that the results can be compared at any desired location relative to the flight lines and target model positions. The differences between the gridded and theoretical data are examined over small areas relative to the line spacing and varying distances from the flight line.

Results from this investigation provide interesting insights into commonly used derivative products and the importance of survey design specifications that reduce aliasing in the derivatives, not just the TMI data. All commonly used gridding procedures are deterministic and attempt to improve visual coherence, but do they strictly comply with the physics of potential fields?

ANALYTICAL METHOD

Clark (2014) extended the theory of the dipole to cover monopole sources that approximate magnetic pipes. His work includes the behaviour of total magnetic intensity data (TMI) and FTMG measurements over magnetic pipes and dipolar noise sources. Clark's results have been expanded in Figure 1 to show clearly the difference in aliasing for a $\mathbf{B_z}$ component (≈TMI) or $\mathbf{B_{zz}}$ component gradient (≈FTMG, ≈1VD) surveys.

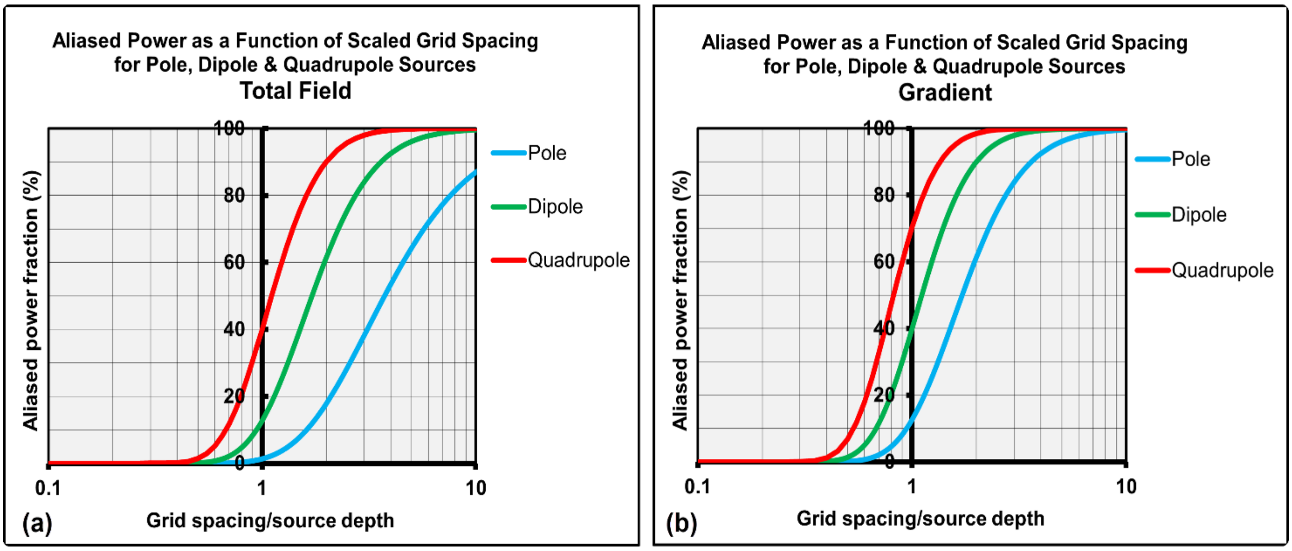

Figure 1: Aliased power estimation for TMI (a) and gradient (b) measurements for pole, dipole and quadrupole magnetic sources. The quadrupole moment of shallow noise sources can significantly contribute to ground magnetic signatures.

For diamond exploration we focus on exploration for kimberlite pipes and the pole field is used as a first order approximation to the pipe. In mature terrains, the weathering profile often contains laterite which is closer to dipole magnetic sources because they have limited depth extent. Here there is an increase in aliasing requiring a reduction in line spacing of approximately 40% to maintain a 10% level of aliasing from a TMI survey and 30% for a gradient survey. This assertion also assumes that the anomaly range is similar for both the dipole and pole magnetic sources and located at the same depth below the sensor.

The aliased power from the laterite can be reduced by flying higher, because the dipole field decreases by an order of magnitude faster than a pole field. The same rule also applies to the rate of decrease between the gradient and TMI sensors. Determining optimum line spacing, flying height and sensor type is now a complex problem.

To add to this complexity, the process of creating a regular grid from the finely sampled line data also adds to the aliasing. Grids derived from aeromagnetic surveys dominate geological interpretation procedures and this is where aliasing is most apparent. We strive to see the finest geological detail that can be inferred from each segment of our images where coherence of the detail is fundamental to accurate geological interpretation. The analysis of aliasing has moved from deciding on the line spacing and flying height to a five dimensional problem:

- line spacing
- height above target geology
- gradient or TMI sensor
- gridding algorithm
- height above near surface noise sources.

We can eliminate the sensor question by assuming that all surveys are flown to produce gradient grids in addition to the primary field because the creation of gradient-related grids has become standard industry practice. This leaves four dimensions. While we can study the impact of near surface noise with our new method, we cannot predict the relative noise amplitudes of the noise sources and targets. Upward continuation of historical low level or ground surveys can provide guidance for optimum survey height.

GRID METHOD

When it comes to the interpretation of magnetic data, the aliased power is an abstract concept that is difficult to apply to specific geological investigations. What does it look like over the target and how does it change with different survey specifications?

To answer this question, we have developed a method that compares segments of a grid derived from the original flight line data over a target model with the theoretical grid computed directly from the same model. For each grid analysis segment we use four radial lines in the shape of a star, centred on the analysis point (Fig. 2a) and then interpolate the grid onto the radial lines using a bicubic surface interpolator. The process is applied to both the theoretical grid and the deterministic grid and the difference data collated for different target styles, line spacing, survey height and sensor type. The most useful result for general survey planning is the standard deviation of the differences normalised by the full anomaly range which eliminates the magnetic property variability.

We have chosen one specific target example to illustrate the method using a 50 metre wide pipe, located at a distance 50 metres from a flight line (Fig. 2b) using a line spacing of 200 metres and grid mesh size of 50 metres. The results are shown in Figure 2(b) for the model and minimum curvature grids of the cross-line $\mathbf{B_{xx}}$ tensor component. Note that the deterministic grid honours the measured data along the flight line, but the aliased difference increases rapidly towards the 50 metre offset pipe. We use the END for the XYZ tensor convention.

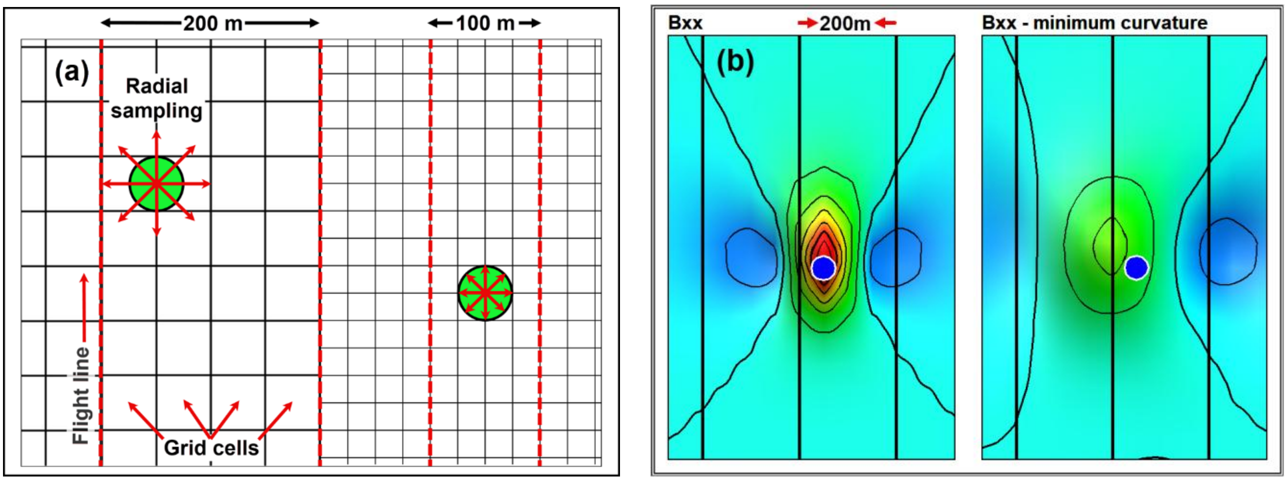

Figure 2: (a) Schematic illustration of the grid sampling method that is used to compare the results of a theoretical grid with a grid generated using minimum curvature gridding of the flight line data. Grid values are located at the corners of each grid cell. (b) A 200 m line spacing example with 50 m cell size images and contours of B_{xx} from the computed model and minimum curvature gridding of the model line data. The model is a 50 m wide pipe positioned 50 m from a flight line for a survey 100 m above the target pipe. The contour intervals are the same in both grids and the mesh size is 50 m.

Do we achieve better grids and images from a FTMG survey than a conventional survey at the same line spacing? Figure 2(b) suggests that there is no advantage when only conventional minimum curvature gridding is applied one component at a time.

We computed full tensor model surveys for the pipe model at sensor heights of 50, 100, 150 and 200 metres for survey line spacings of 150 and 200 metres. The results for each of the eight surveys were gridded using minimum curvature and full tensor gridding (Fitzgerald et al., 2009). The statistics for both gridding methods are reproduced for the $\mathbf{B_{zz}}$ and $\mathbf{B_{xx}}$ tensor components in Figures 3(a) and 3(b). The results show a large reduction in aliasing when using full tensor gridding of all components when compared with conventional minimum curvature gridding of a single tensor component. The reduction in aliasing noise by using tensor gridding is in the order of 50% for a sensor height of 100 metres which is significantly better than the 5% improvement achieved by decreasing the line spacing from 200 to 150 metres with minimum curvature gridding. While this is only one target example, it demonstrates the inherent information that exists in the measurement of the magnetic tensor, but it cannot be realised without full tensor gridding or multi-channel inversion of the tensor line data.

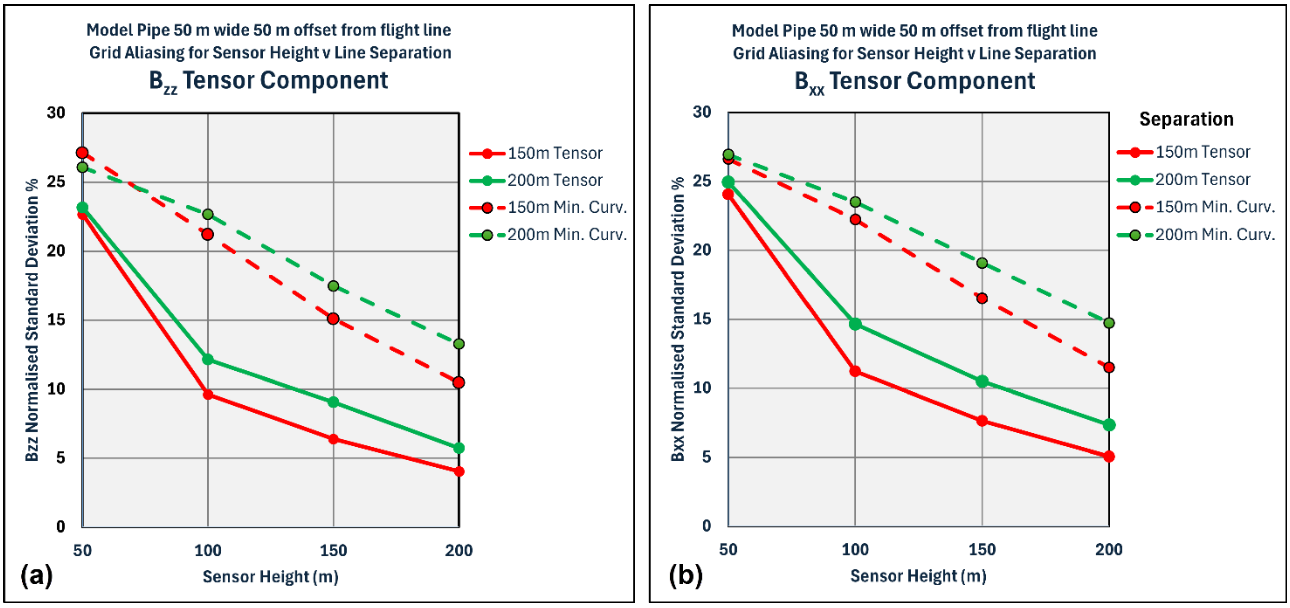

Figure 3: Comparison of grid alias estimates for different sensor heights and line separations for the B_{zz} tensor component (a) and B_{xx} component (b) using minimum curvature gridding (dashed lines) and full tensor gridding (solid lines).

CONCLUSIONS AND RECOMMENDATIONS

We have provided new charts of analytical estimates of aliasing for field components (TMI) and gradient components (tensor) that include the magnetic pole as well as the dipole. A new grid-based aliasing estimation method was applied to simulated airborne surveys to investigate aliasing for specific geological models and demonstrate the value of full tensor interpolation.

The inversion of multi-channel full tensor line data automatically uses the additional information inherent in the magnetic gradient tensor, but conventional single tensor channel gridding techniques provide no advantage for image interpretation. Full tensor gridding is required to extract the inherent additional information for improved resolution and coherence with our experiments suggesting improvements up to 40 to 50 percent. The tensor gridding results used here were derived using deterministic processes and further gains are possible if a physics-based approach is used for full magnetic tensor interpolation or multi-channel inversion.

We recommend that all surveys should be planned for gradient sensors since the TMI surveys are routinely used to produce gradient products for interpretation. For FTMG surveys, we recommend the use of full tensor gridding to achieve optimal value from the survey data. All commonly used gridding procedures are deterministic and attempt to improve visual coherence, but do they strictly comply with the physics of potential fields? We suggest that there are opportunities to improve the quality of all potential field gridding by using the physics of potential fields to reduce aliasing, reduce short wavelength platform noise, improve geological continuity and replace grid transformations such as RTP and FTMG with direct computation.

ACKNOWLEDGMENTS

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REFERENCES

Clark, D.A. 2014. Integrated magnetics: Contributions to improved processing and interpretation of magnetic gradient tensor data. New methods for source location and estimation of magnetisation, and predictive exploration models. Ph.D. Thesis, Macquarie University, NSW Australia, 344 p.

Fitzgerald, D., Argast, D., Paterson, & Holstein, H., 2009 Full tensor magnetic gradiometry processing and interpretation developments. 11th SAGA Biennial Technical Meeting and Exhibition, Swaziland, 8p.

Reid, A. B., 1980, Aeromagnetic survey design: Geophysics, 45, 973–976. doi:10.1190/1.